QUANTA COMPUTER INC.

OPENFLOW QUICK START GUIDE

By

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Document History

Revision	Date	Editor	Remark
0.1	2012/12/20	Evan, George	Initial Release.
0.2	2012/12/25	Evan, George	Update commands and display information.
0.3	2012/12/26	Moore C. J. Lee	Reorganized the chapters
0/4	2013/2/27	Moore C. J. Lee	- Update Supported features - Support to configure the OpenFlow fail mode of connection interruption - Support to configure the OpenFlow variant of switch
0.5	2013/4/3	Evan, George	- Update debug commands. - Update Supported Features.
0.6	2013/9/23	Evan, George	- Support OpenFlow 1.3 - Supported Features - OF 1.3: Meter

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1. Overview

OpenFlow Overview

In a classical router or switch, the fast packet forwarding (data path) and the high level routing decisions (control path) occur on the same device. An OpenFlow Switch separates these two functions. The data path portion still resides on the switch, while high-level routing decisions are moved to a separate controller, typically a standard server. The OpenFlow Switch and Controller communicate via the OpenFlow protocol, which defines messages, such as packet-received, send-packet-out, modify-forwarding-table, and get-stats.

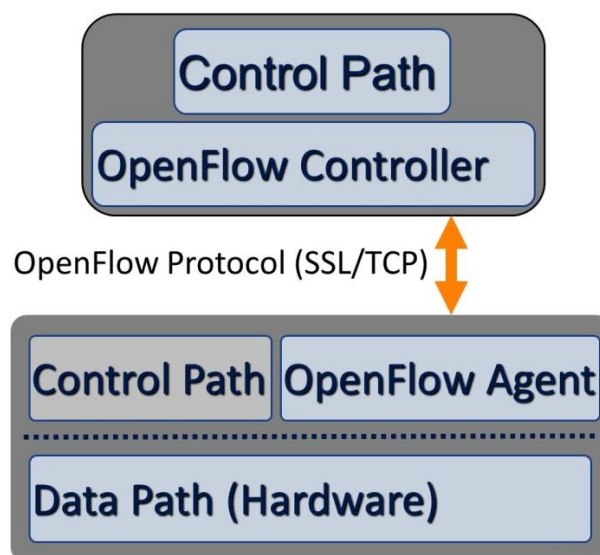Figure 1 control path and data path on classical switch

Figure 2 OpenFlow

The data path of an OpenFlow Switch presents a clean flow table abstraction; each flow table entry contains a set of packet fields to match, and an action (such as send-out-port, modify-field, or drop). When an

OpenFlow Switch receives a packet it has never seen before, for which it has no matching flow entries, it sends this packet to the controller. The controller then makes a decision on how to handle this packet. It can drop the packet, or it can add a flow entry directing the switch on how to forward similar packets in the future.

Quanta OpenFlow agent is implemented with Open vSwitch 1.10.0. (OpenFlow v1.0/1.1/1.2/1.3 is supported in current version.) In Quanta OpenFlow Switch, it provides hybrid mode, per VLAN-based mode and per PORT-based mode and one mode per OpenFlow Instance.

- Per VLAN-based mode

  A VLAN can map to one OpenFlow switch instance only.

  An OpenFlow instance can consist of multiple VLANs.

- Per PORT-based mode

  A PORT can map to one OpenFlow switch instance only.

  An OpenFlow instance can consist of multiple PORTs.

Enabling OpenFlow

The OpenFlow feature can be enabled or disabled by the network administrator. Although this feature is administratively enabled, it is not operational until the switch has an IP address. A separate operational state indicates whether the OpenFlow feature is operational. If the feature is not operational, then another state indicates the reason for the feature to be disabled.

After administratively disabling the feature, the network administrator must wait until the OpenFlow Feature is operationally disabled before re-enabling the feature. The OpenFlow feature can be administratively disabled at any time.

In this document, the supported CLI commands are listed and some examples are demonstrated for setup your environment.

2. Supported Features

NOTE:

O	Supported
X	Not Supported
	Not Defined in Spec.

Features	Items	Sub Items	OF1.0	OF1.1	OF1.2	OF1.3
Match Fields	IN_PORT		O	O	O	O
	IN_PHY_PORT				X	X
	METADATA				X	X
	ETH_DST		O	O	O	O
	ETH_DST_MASK			O	O	O
	ETH_SRC		O	O	O	O
	ETH_SRC_MASK			O	O	O
	ETH_TYPE		O	O	O	O
	VLAN_VID		O	O	O	O
	VLAN_PCP		O	O	O	O
	IP_DSCP(IPv4 ToS Bits)		O	O	O	O
	IP_ECN				X	X
	IP_PROTO		O	O	O	O
	IPV4_SRC		O	O	O	O
	IPV4_SRC_MASK			O	O	O
	IPV4_DST		O	O	O	O
	IPV4_DST_MASK			O	O	O
	TCP_SRC		O	O	O	O
	TCP_DST		O	O	O	O
	UDP_SRC		O	O	O	O
	UDP_DST		O	O	O	O
	SCTP_SRC			O	O	O
	SCTP_DST			O	O	O
	ICMPV4_TYPE			X	X	X
	ICMPV4_CODE			X	X	X
	ARP_OP			X	X	X

	ARP_SPA				X	X
	ARP_TPA				X	X
	ARP_SHA				X	X
	ARP_THA				X	X
	IPV6_SRC				O	O
	IPV6_SRC_MASK				O	O
	IPV6_DST				O	O
	IPV6_DST_MASK				O	O
	IPV6_FLABEL				O	O
	ICMPV6_TYPE				X	X
	ICMPV6_CODE				X	X
	IPV6_ND_TARGET				X	X
	IPV6_ND_SLL				X	X
	IPV6_ND_TLL				X	X
	MPLS_LABEL			X	X	X
	MPLS_TC			X	X	X
	MPLS_BOS				X	X
	PBB_ISID				X	X
	TUNNEL_ID				X	X
	IPV6_EXTHDR				X	X
Instruction	OFPIT_GOTO_TABLE			X	X	X
	OFPIT_WRITE_METADATA			X	X	X
	OFPIT_WRITE_ACTIONS			X	X	X
	OFPIT_APPLY_ACTIONS			O	O	O
	OFPIT_CLEAR_ACTIONS			O	O	O
	OFPIT_METER					O
Action	OUTPUT	OutPut Port – Physical Port	O	O	O	O
		OutPut Port – Logical Port	O	O	O	O
		Controller	O	O	O	O
		Normal	O	O	O	O
		All	O	O	O	O
		Flood	O	O	O	O
		InPort	O	O	O	O
		Local	X	X	X	X
		Table	X	X	X	X

		Drop	O	O	O	O
	COPY_TTL_OUT			X	X	X
	COPY_TTL_IN			X	X	X
	SET_MPLS_TTL			X	X	X
	DEC_MPLS_TTL			X	X	X
	PUSH_VLAN			O	O	O
	POP_VLAN			O	O	O
	PUSH_MPLS			X	X	X
	POP_MPLS			X	X	X
	SET_QUEUE			X	X	X
	GROUP			X	X	X
	SET_NW_TTL			X	X	X
	DEC_NW_TTL			X	X	X
	SET_FIELD	IN_PORT			X	X
		IN_PHY_PORT			X	X
		METADATA			X	X
		ETH_DST	O	O	O	O
		ETH_SRC	O	O	O	O
		ETH_TYPE			X	X
		VLAN_ID	O	O	O	O
		VLAN_PCP	O	O	O	O
		IP_DSCP(IPv4 ToS Bits)	O	O	O	O
		IP_ECN		X	X	X
		IP_PROTO			X	X
		IPV4_SRC	X	X	X	X
		IPV4_DST	X	X	X	X
		TCP_SRC		X	X	X
		TCP_DST		X	X	X
		UDP_SRC		X	X	X
		UDP_DST		X	X	X
		SCTP_SRC		X	X	X
		SCTP_DST		X	X	X
		ICMPV4_TYPE			X	X
		ICMPV4_CODE			X	X
		ARP_OP			X	X

		ARP_SPA			X	X
		ARP_TPA			X	X
		ARP_SHA			X	X
		ARP_THA			X	X
		IPV6_SRC			X	X
		IPV6_DST			X	X
		IPV6_FLABEL			X	X
		ICMPV6_TYPE			X	X
		ICMPV6_CODE			X	X
		IPV6_ND_TARGET			X	X
		IPV6_ND_SLL			X	X
		IPV6_ND_TLL			X	X
		MPLS_LABEL		X	X	X
		MPLS_TC		X	X	X
		MPLS_BOS			X	X
		PBB_ISID			X	X
		TUNNEL_ID			X	X
		IPV6_EXTHDR			X	X
	PUSH_PBB					X
	POP_PBB					X
	EXPERIMENTER					X
Counter	Per Table	Active Entries	O	O	O	O
		Packet Lookups	O	O	O	O
		Packet Matches	O	O	O	O
	Per Flow	Received Packets	O	O	O	O
		Received Bytes	O	O	O	O
		Duration (seconds)	O	O	O	O
		Duration (nanoseconds) (nanoseconds)	O	O	O	O
	Per Port	Received Packets	O	O	O	O
		Transmitted Packets	O	O	O	O
		Received Bytes	O	O	O	O
		Transmitted Bytes	O	O	O	O
		Receive Drops	O	O	O	O
		Transmit Drops	O	O	O	O
		Receive Errors	O	O	O	O

		Transmit Errors	O	O	O	O
		Receive Frame Alignment Errors	O	O	O	O
		Receive Overrun Errors	O	O	O	O
		Receive CRC Errors	O	O	O	O
		Collisions	O	O	O	O
		Duration (seconds)				O
		Duration (nanoseconds) (nanoseconds)				O
	Per Queue	Transmit Packets	O	O	O	O
		Transmit Bytes	O	O	O	O
		Transmit Overrun Errors	O	O	O	O
		Duration (seconds)				O
		Duration (nanoseconds) (nanoseconds)				O
	Per Group	Reference Count (flow entries)			X	X
		Packet Count			X	X
		Byte Count			X	X
		Duration (seconds)				X
		Duration (nanoseconds) (nanoseconds)				X
	Per Group Bucket	Packet Count			X	X
		Byte Count			X	X
	Per Meter	Flow Count				O
		Input Packet Count				O
		Input Byte Count				O
		Duration (seconds)				O
		Duration (nanoseconds) (nanoseconds)				O
	Per Meter Band	In Band Packet Count				O
		In Band Byte Count				O
Protocol	HELLO		O	O	O	O
	ERROR		O	O	O	O
	ECHO		O	O	O	O
	VENDOR/EXPERIMENTER		X	X	X	X
	FEATURES	Link Status(Up/Down)	O	O	O	O
		Current Feature	O	O	O	O
		Advertised Feature	O	O	O	O
		Supported Feature	O	O	O	O
		Peer Feature	X	X	X	X

		Current Speed		O	O	O
		Max Speed		O	O	O
	GET_CONFIG		O	O	O	O
	SET_CONFIG	Miss_send_len	O	O	O	O
		IP fragments flags	X	X	X	X
	PACKET_IN		O	O	O	O
	FLOW_REMOVED		O	O	O	O
	PORT_STATUS		O	O	O	O
	PACKET_OUT	OFPAT_OUTPUT	O	O	O	O
		OFPP_IN_PORT	O	O	O	O
		OFPP_FLOOD	O	O	O	O
		OFPP_ALL	O	O	O	O
		OFPP_TABLE	X	X	X	X
		OFPP_LOCAL	X	X	X	X
	FLOW_MOD	OFPFC_ADD	O	O	O	O
		OFPFC_MODIFY	O	O	O	O
		OFPFC_MODIFY_STRICT	O	O	O	O
		OFPFC_DELETE	O	O	O	O
		OFPFC_DELETE_STRICT	O	O	O	O
		OFPFF_SEND_FLOW_REM	O	O	O	O
		OFPFF_CHECK_OVERLAP	O	O	O	O
		OFPFF_EMERG	X			
		OFPFF_RESET_COUNTS			O	O
		OFPFF_NO_PKT_COUNTS				O
		OFPFF_NO_BYT_COUNTS				O
	GROUP_MOD			X	X	X
	PORT_MOD	OFPPC_PORT_DOWN	O	O	O	O
		OFPPC_NO_PACKET_IN	O	O	O	O
		OFPPC_NO_RECV	X	X	X	X
		OFPPC_NO_FWD	X	X	X	X
	TABLE_MOD	OFPTC_TABLE_MISS_CONTROLLER		O	O	
		OFPTC_TABLE_MISS_CONTINUE		X	X	
		OFPTC_TABLE_MISS_DROP		O	O	
		OFPTC_DEPRECATED_MASK				O
	STATS	OFPST_DESC	O	O	O	

		OFPST_FLOW	O	O	O	
		OFPST_AGGREGATE	O	O	O	
		OFPST_TABLE	O	O	O	
		OFPST_PORT	O	O	O	
		OFPST_QUEUE	O	O	O	
		OFPST_GROUP		X	X	
		OFPST_GROUP_DESC		X	X	
		OFPST_GROUP_FEATURES		X	X	
		OFPST_VENDOR	X	X	X	
	MULTIPART	OFPMP_DESC				O
		OFPMP_FLOW				O
		OFPMP_AGGREGATE				O
		OFPMP_TABLE				O
		OFPMP_PORT_STATS				O
		OFPMP_QUEUE				O
		OFPMP_GROUP				X
		OFPMP_GROUP_DESC				X
		OFPMP_GROUP_FEATURES				X
		OFPMP_METER				O
		OFPMP_METER_CONFIG				O
		OFPMP_METER_FEATURES				O
		OFPMP_TABLE_FEATURES - Get				O
		OFPMP_TABLE_FEATURES - Set				X
		OFPMP_PORT_DESC				O
		OFPMP_EXPERIMENTER				X
	BARRIER		O	O	O	O
	QUEUE_GET_CONFIG			X	X	X
	ROLE				O	O
	GET_ASYNC					O
	SET_ASYNC					O
	METER_MOD					O
	Table-Miss	Default action: Controller	O	O	O	
		Default action: Drop				O
		Table-Miss flow entry				O
	Multi-Controllers	Role Request/Reply			O	O

		Asynchronous Configuration Message				O
	Auxiliary Connections					X
	Cookie in Packet-In					O

3. Command Line Interface

3.1 Command Summary

Command	Function
openflow instance	This command enters an OpenFlow instance.
enable	To enable or disable OpenFlow feature.
controller	To specify up to five IP addresses to which the switch should establish an OpenFlow Controllers connection.
hybridmode	To configure the hybrid OpenFlow.
variant	To configure the OpenFlow variant of switch.
failmode	To configure the OpenFlow fail mode of connection interruption.
debug openflow	To configure the OpenFlow debug information.
show openflow < instance-id >	To displays the OpenFlow instance configuration information.
show openflow configured controller	This command displays the OpenFlow controller configuration information.
show openflow installed flows	This command displays the installed flows information from OpenFlow controller.
show openflow installed meters	This command displays the installed meters information from OpenFlow controller.
show openflow table status	This command displays the table information of OpenFlow switch.

3.2 Functional Components

3.2.1 OpenFlow Instance

This command enters OpenFlow instance.

Syntax
openflow instance <instance-id>

Command Mode: Global Configuration

3.2.2 OpenFlow Enable/Disable

To configure admin mode of OpenFlow instance.

Syntax
enable
no enable

Default Setting: Disable

Command Mode: OpenFlow Instance Mode

3.2.3   OpenFlow Controller

Specify up to five IP addresses to which the switch should establish an OpenFlow Controllers connection. Each command invocation specifies one IP address and connection mode (TCP or TLS). If the IP Port is omitted then the default IP port number 6633 is used. The default connection mode is TLS.

Syntax
controller <ipaddr> [<portid>] [ssl | tcp]
no controller {<ipaddr> [<portid>] | all }

Default Setting: ssl

Command Mode: OpenFlow Instance Mode

3.2.4   OpenFlow Hybrid Mode

To configure the hybrid OpenFlow.

Syntax
hybridmode {per-vlan | per-port}
no hybridmode

Default Setting: None

Command Mode: OpenFlow Instance Mode

3.2.5   OpenFlow VLAN in Per-VLAN mode instance

To add/remove VLAN to OpenFlow per-VLAN instance.

Syntax
vlan <vlan-list>
no vlan <vlan-list>

Default Setting: None

Command Mode: OpenFlow Instance per-VLAN Mode

3.2.6   OpenFlow PORT in Per-PORT mode instance

To add/remove PORT to OpenFlow per-PORT instance.

Syntax
port {<port-list>	port-channel <ChId-List> }
no port {<port-list>	port-channel <ChId-List> }

Default Setting: None

Command Mode: OpenFlow Instance per-PORT Mode

3.2.7 OpenFlow Variant

To configure the OpenFlow variant of switch. It can choose the OpenFlow 1.0 or OpenFlow 1.1 or OpenFlow 1.2 or OpenFlow 1.3 protocol to connect with Controller.

Syntax
variant { openflow10	openflow11	openflow12	openflow13 }

Default Setting: openflow13

Command Mode: OpenFlow Instance Mode

3.2.8 OpenFlow Fail Mode

To configure the OpenFlow fail mode of connection interruption. It can choose the Fail-Secure or Fail-Standalone mode.

In the case that a switch loses contact with all controllers, the switch should immediately enter either "fail secure mode" or "fail standalone mode". In "fail secure mode", the only change to switch behavior is that packets and messages destined to the controllers are dropped. Flows should continue to expire according to their timeouts in "fail secure mode". In "fail standalone mode", the switch processes all packets using the OFPP_NORMAL port; in other words, the switch acts as a legacy Ethernet switch or router.

Syntax
failmode { secure	standalone }

Default Setting: secure

Command Mode: OpenFlow Instance Mode

3.2.9 Debug OpenFlow Event

To configure the OpenFlow event debug information. It will display the general or flow-mod, packet-in or packet-out event log.

Syntax
debug openflow event [flowmod	packetin	packetout] no debug openflow event [flowmod	packetin	packetout]

Default Setting: disable

Command Mode: Privileged EXEC

3.2.10 Debug OpenFlow Packet

To configure the OpenFlow packet debug information. It will display the flow-mod, packet-in or packet-out packets information.

Syntax
debug openflow packet { flowmod	packetin	packetout } no debug openflow packet { flowmod	packetin	packetout }

Default Setting: disable

Command Mode: Privileged EXEC

3.2.11 show openflow instance

This command displays the OpenFlow instance status and configuration information.

Syntax
show openflow < instance-id >

Command Mode: Privileged EXEC

Examples:

(Quanta) #show openflow 1

Administrative Mode............................ Enable

Operational Status............................. Enabled

Disable Reason................................. None

IP Address..................................... 192.168.2.117

OpenFlow Variant............................... OpenFlow 1.1

Fail Mode...................................... Fail-Secure

Hybrid Mode.................................... Per-Port

Port List:

0/1-0/3,0/5,0/7-0/8,ch1-ch2,ch4,ch6-ch7

3.2.12 show openflow controller

This command displays the OpenFlow controller configuration information.

Syntax
show openflow <instance-id> configured controller

Command Mode: Privileged EXEC

Examples:

(Quanta) #show openflow 1 configured controller

```
IP Address       IP Port      Connection Mode      Connection Status

---------------  ----------   -----------------    ------------------

192.168.2.5        6633           tcp                  ACTIVE
```

3.2.13 show openflow installed flows

This command displays the installed flows information from OpenFlow Controller.

Syntax
show openflow < instance-id > installed flows

Command Mode: Privileged EXEC

Examples:

(Quanta) #show openflow 1 installed flows

Flow 0000000B type "1DOT0"

Match criteria:

Flow table   24 : Priority   65535

Ingress port   0/1 : Src MAC   00:00:00:00:00:01 : Dst MAC   00:00:00:00:00:02

VLAN   5 : VLAN prio   3 : Ether type   800

IP proto   6 : Src IP   1.1.1.1 : Dst IP   2.2.2.2

Src IP port   12345 : Dst IP port   80 : TOS   16

Actions:

Egress port   0/3

Status:

Duration   131 : Idle   125 : installed in hardware   1

3.2.14 show openflow installed meters

This command displays the installed meters information from OpenFlow Controller.

Syntax
show openflow < instance-id > installed meters

Command Mode: Privileged EXEC

Examples:

(Quanta) #do show openflow 1 installed meters

Meter ID...................................... 6

Number of bands................................ 1

Band type...................................... Drop

Rate for dropping packets...................... 8000

Size of bursts................................. 4000

Number of flows bound to meter................. 1

Number of packets in input..................... 3134691

Number of bytes in input....................... 200620288

Duration....................................... 274

Band ID.. 1

Number of packets in band...................... 650555

Number of bytes in band........................ 41635520

Number of packets out band..................... 2484136

Number of bytes out band....................... 158984768

3.2.15 show openflow table status

This command displays the table information of OpenFlow switch.

Syntax
show openflow <instance-id> table-status

Command Mode: Privileged EXEC

Examples:

(Quanta) #show openflow 1 table-status

Flow Table Name................................ Openflow

Maximum Size................................... 896

Number of   Entries............................ 3

Hardware Entries............................... 3

Software-Only Entries.......................... 0

Waiting for Space Entries...................... 0

Flow Insertion Count........................... 3

Flow Deletion Count............................ 0

Insertion Failure Count......................... 0

Flow Table Description......................... The Openflow table matches on the packet layer-2 header, including DA-MAC, SA-MAC, VLAN, Vlan priority ether type; layer-3 header, including SRC-IP, DST-IP, IP protocol, IP-TOS; layer-4 header, including UDP/TCP source and dest port, ICMP type, and code; and input port including physical port, LAG port.

4. OpenFlow Network Example

In OpenFlow, the traffic should follow the Controller installed flow to forward the packet, but the normal L2 switch operation.

In this example,

- The Controller tells the Switch1 to forward the red traffic from port 0/1 to port-channel ch1, and tells the Switch2 to forward the red traffic from port-channel ch1 to port 0/1.
- The Controller tells the Switch2 to forward the orange traffic from port 0/1 to port-channel ch1, and tells the Switch1 to forward the orange traffic from port-channel ch1 to port 0/1.

Without the flow from Controller, the two traffics would not be forwarded to the other end well.

4.1 Environment
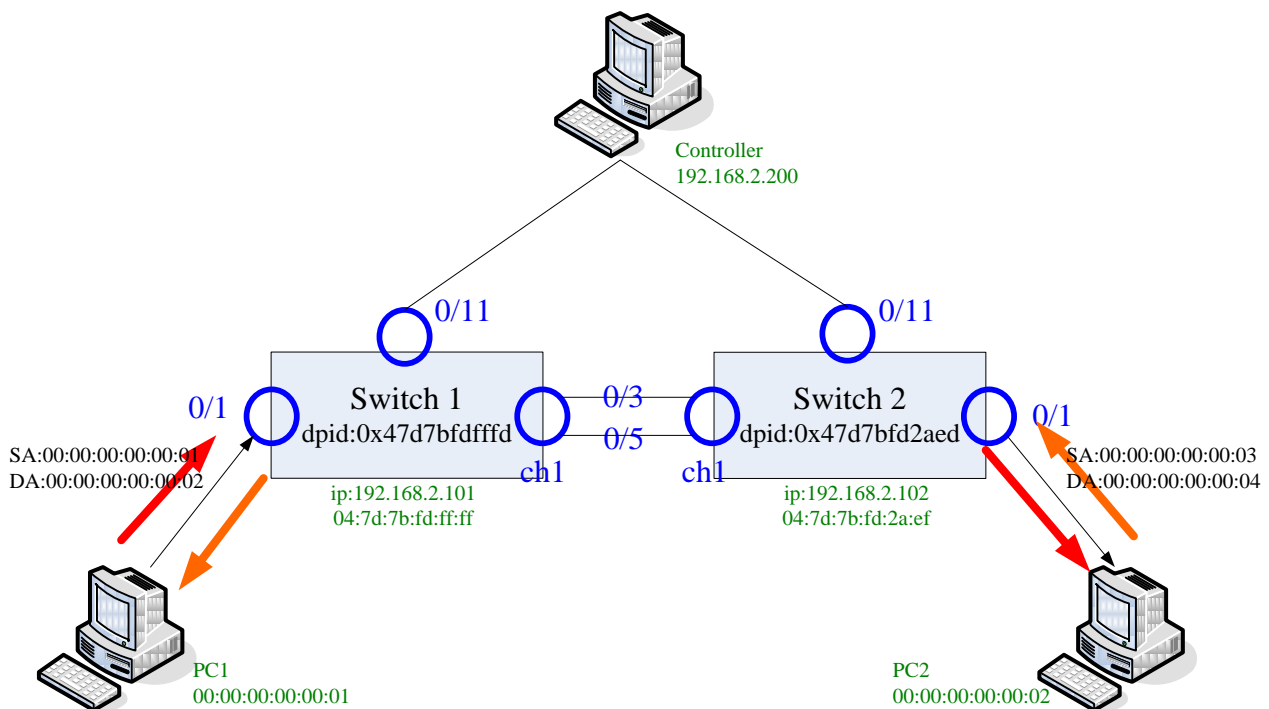
4.2 Configuration

4.2.1   POX Controller Configuration

- POX Script

```
def send_FLOW1(self, event):


    #Flow to Switch1
    #Flow 1
        msg = of.ofp_flow_mod()
        msg.match.in_port = 1
        msg.match.dl_vlan=2
        msg.match.dl_src=EthAddr("00:00:00:00:00:01")
        msg.match.dl_dst=EthAddr("00:00:00:00:00:02")
        msg.flags = 1
        msg.actions.append(of.ofp_action_output(port = 50))
        self.connection.send(msg)


    #Flow 2
        msg = of.ofp_flow_mod()
        msg.match.in_port = 50
        msg.match.dl_vlan=2
        msg.match.dl_src=EthAddr("00:00:00:00:00:03")
        msg.match.dl_dst=EthAddr("00:00:00:00:00:04")
        msg.flags = 1
        msg.actions.append(of.ofp_action_output(port = 1))
        self.connection.send(msg)
```

```python
def send_FLOW2(self, event):

#Flow to Switch2
#Flow1
    msg = of.ofp_flow_mod()
    msg.match.in_port = 50
    msg.match.dl_vlan=2
    msg.match.dl_src=EthAddr("00:00:00:00:00:01")
    msg.match.dl_dst=EthAddr("00:00:00:00:00:02")
    msg.flags = 1
    msg.actions.append(of.ofp_action_output(port = 1))
    self.connection.send(msg)

#Flow2
    msg = of.ofp_flow_mod()
    msg.match.in_port = 1
    msg.match.dl_vlan=2
    msg.match.dl_src=EthAddr("00:00:00:00:00:03")
    msg.match.dl_dst=EthAddr("00:00:00:00:00:04")
    msg.flags = 1
    msg.actions.append(of.ofp_action_output(port = 50))
    self.connection.send(msg)
```

● Start Up Packets

No.	Time	Source	Destination	Protocol	Info .
21	4.503200	192.168.2.102	192.168.2.200	OFP	Hello (SM) (8B)
23	4.504687	192.168.2.200	192.168.2.102	OFP	Hello (SM) (8B)
25	4.506787	192.168.2.200	192.168.2.102	OFP	Features Request (CSM) (8B)
28	4.507951	192.168.2.102	192.168.2.200	OFP	Features Reply (CSM) (2384B)[Dissector bu
30	4.512900	192.168.2.200	192.168.2.102	OFP	Set Config (CSM) (12B)
33	4.550611	192.168.2.200	192.168.2.102	OFP	Barrier Request (CSM) (8B)
34	4.551885	192.168.2.102	192.168.2.200	OFP	Flow Removed (AM) (88B)
35	4.552119	192.168.2.102	192.168.2.200	OFP	Flow Removed (AM) (88B)
36	4.554910	192.168.2.102	192.168.2.200	OFP	Barrier Reply (CSM) (8B)
38	4.583128	192.168.2.200	192.168.2.102	OFP	Flow Mod (CSM) (80B)
40	4.622942	192.168.2.200	192.168.2.102	OFP	Flow Mod (CSM) (80B)
45	4.765324	192.168.2.101	192.168.2.200	OFP	Hello (SM) (8B)
47	4.805846	192.168.2.200	192.168.2.101	OFP	Hello (SM) (8B)
49	4.807242	192.168.2.200	192.168.2.101	OFP	Features Request (CSM) (8B)
53	4.808638	192.168.2.101	192.168.2.200	OFP	Features Reply (CSM) (2384B)[Dissector bu
55	4.812408	192.168.2.200	192.168.2.101	OFP	Set Config (CSM) (12B)
57	4.850316	192.168.2.200	192.168.2.101	OFP	Barrier Request (CSM) (8B)
58	4.852324	192.168.2.101	192.168.2.200	OFP	Flow Removed (AM) (88B)
59	4.852771	192.168.2.101	192.168.2.200	OFP	Flow Removed (AM) (88B)
60	4.853315	192.168.2.101	192.168.2.200	OFP	Flow Removed (AM) (88B)
61	4.857397	192.168.2.101	192.168.2.200	OFP	Flow Removed (AM) (88B)
62	4.857406	192.168.2.101	192.168.2.200	OFP	Barrier Reply (CSM) (8B)
64	4.880054	192.168.2.200	192.168.2.102	OFP	Flow Mod (CSM) (80B)
65	4.880711	192.168.2.200	192.168.2.101	OFP	Flow Mod (CSM) (80B)
67	4.880822	192.168.2.200	192.168.2.102	OFP	Flow Mod (CSM) (80B)
70	4.918102	192.168.2.200	192.168.2.101	OFP	Flow Mod (CSM) (80B)

⊞ Frame 21 (74 bytes on wire, 74 bytes captured)
⊟ Ethernet II, Src: 04:7d:7b:fd:2a:ef (04:7d:7b:fd:2a:ef), Dst: CadmusCo_9e:af:a4 (08:00:27:9e:af:a4)
　⊟ Destination: CadmusCo_9e:af:a4 (08:00:27:9e:af:a4)
　　　Address: CadmusCo_9e:af:a4 (08:00:27:9e:af:a4)
　　　.... ...0 .... = IG bit: Individual address (unicast)
　　　.... ..0. .... = LG bit: Globally unique address (factory default)
　⊟ Source: 04:7d:7b:fd:2a:ef (04:7d:7b:fd:2a:ef)

```
0000  08 00 27 9e af a4 04 7d  7b fd 2a ef 08 00 45 00   ..'....} {.*...E.
0010  00 3c fb 7a 40 00 40 06  b8 c2 c0 a8 02 66 c0 a8   .<.z@.@. .....f..
0020  02 c8 99 20 19 e9 84 b2  13 ad 55 f3 d6 66 80 18   ... .... ..U..f..
0030  00 5c ac 80 00 00 01 01  08 0a 00 12 e8 d4 41 f1   .\...... ......A.
```

4.2.2   Switch1 Configuration

(Switch1) #configure

(Switch1) (Config)#interface vlan 1

Interface Vlan1 created for VLAN ID 1

(Switch1) (if-vlan1)# ip address 192.168.2.101 255.255.255.0

(Switch1) (if-vlan1)# exit

(Switch1) (Config)#interface port-channel 1

Interface ch1 created for port-channel ID 1

(Switch1) (if-port-channel ch1)#exit

(Switch1) (Config)#interface range 0/3 , 0/5

(Switch1) (if-range)#channel-group 1

(Switch1) (if-range)#exit

(Switch1) (Config)#openflow instance 1

(Switch1) (openflow-1)#controller 192.168.2.200 6633 tcp

(Switch1) (openflow-1)# hybridmode per-port

(Switch1) (openflow-1-port-hybrid)#port 1

(Switch1) (openflow-1-port-hybrid)#port port-channel 1

(Switch1) (openflow-1-port-hybrid)#exit

(Switch1) (openflow-1)#exit

(Switch1) (Config)#exit

(Switch1) #show openflow 1

Administrative Mode............................ Enable

Operational Status............................. Enabled

Disable Reason................................. None

IP Address..................................... 192.168.2.101

OpenFlow Variant............................... OpenFlow 1.0

Hybrid Mode.................................... Per-Port

    Port List:

0/1,ch1

```
(Switch1) #show openflow 1 configured controller


IP Address        IP Port      Connection Mode     Connection Status
---------------   ----------   -----------------   ------------------
192.168.2.200     6633            tcp                 ACTIVE


(Switch1) #
```

4.2.3 Switch2 Configuration

(Switch2) #configure

(Switch2) (Config)#interface vlan 1

Interface Vlan1 created for VLAN ID 1

(Switch2) (if-vlan1)# ip address 192.168.2.102 255.255.255.0

(Switch2) (if-vlan1)# exit

(Switch2) (Config)#interface port-channel 1

Interface ch1 created for port-channel ID 1

(Switch2) (if-port-channel ch1)#exit

(Switch2) (Config)#interface range 0/3 , 0/5

(Switch2) (if-range)#channel-group 1

(Switch2) (if-range)#exit

(Switch2) (Config)#openflow instance 1

(Switch2) (openflow-1)#controller 192.168.2.200 6633 tcp

(Switch2) (openflow-1)# hybridmode per-port

(Switch2) (openflow-1-port-hybrid)#port 1

(Switch2) (openflow-1-port-hybrid)#port port-channel 1

(Switch2) (openflow-1-port-hybrid)#exit

(Switch2) (openflow-1)#exit

(Switch2) (Config)#exit

(Switch2) #show openflow 1

Administrative Mode............................ Enable

Operational Status............................. Enabled

Disable Reason................................. None

IP Address..................................... 192.168.2.102

OpenFlow Variant............................... OpenFlow 1.0

Hybrid Mode.................................... Per-Port

```
   Port List:
-------------------------------------
0/1,ch1
```

(Switch2) #show openflow 1 configured controller

```
IP Address          IP Port       Connection Mode     Connection Status
---------------   ----------   -----------------   ------------------
192.168.2.200     6633             tcp                 ACTIVE
```

(Switch2) #

4.2.4　Switch1 Installed Flow by Controller

```
(Switch1) #show openflow 1 installed flows

Flow 0000000B type "1DOT0"

Match criteria:
Flow table              24 : Priority              32768
Ingress port           0/1 : Src MAC  00:00:00:00:00:01 : Dst MAC  00:00:00:00:00:02
VLAN                     2
Actions:
Egress port            1/1
Status:
Duration                 4 : Idle                    0 : installed in hardware    1

Flow 0000000D type "1DOT0"

Match criteria:
Flow table              24 : Priority              32768
Ingress port           1/1 : Src MAC  00:00:00:00:00:03 : Dst MAC  00:00:00:00:00:04
VLAN                     2
Actions:
Egress port            0/1
Status:
Duration                 4 : Idle                    0 : installed in hardware    1


--More-- or (q)uit

(Switch1) #
```

4.2.5　Switch2 Installed Flow by Controller

```
(Switch2) #do show openflow 1 installed flows

Flow 00000053 type "1DOT0"

Match criteria:
Flow table              24 : Priority              32768
Ingress port           0/1 : Src MAC  00:00:00:00:00:01 : Dst MAC  00:00:00:00:00:02
VLAN                     2
Actions:
Egress port            1/1
Status:
Duration                92 : Idle                   90 : installed in hardware    1

Flow 00000033 type "1DOT0"

Match criteria:
Flow table              24 : Priority              32768
Ingress port           0/1 : Src MAC  00:00:00:00:00:03 : Dst MAC  00:00:00:00:00:04
VLAN                     2
Actions:
Egress port            1/1
Status:
Duration               448 : Idle                  376 : installed in hardware    1
```

4.3 Result

Switch1 receive packets from Switch2

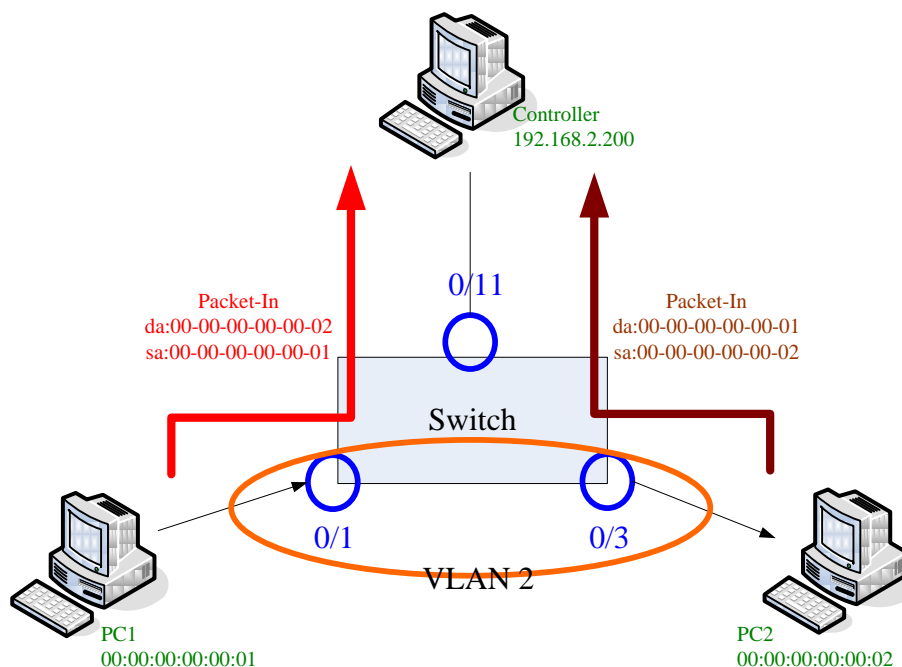| No. ▼	Time	Source	Destination	Protocol	Info
7 1.919333		169.254.43.163	255.255.255.255	UDP	Source port: 17
8 1.920465		169.254.43.163	169.254.255.255	UDP	Source port: 17
9 1.920495		169.254.43.163	255.255.255.255	UDP	Source port: 17
10 2.966947		00:00:00_00:00:03	00:00:00_00:00:04	IP	Bogus IP header
11 3.131263		00:00:00_00:00:03	00:00:00_00:00:04	IP	Bogus IP header
12 3.136357		06.7d.7b.ff.f4.01	Spanning-tree-(for-br	STP	MST. Root = 327
13 3.273605		00:00:00_00:00:03	00:00:00_00:00:04	IP	Bogus IP header
14 3.441313		00:00:00_00:00:03	00:00:00_00:00:04	IP	Bogus IP header
15 3.609509		00:00:00_00:00:03	00:00:00_00:00:04	IP	Bogus IP header
16 3.788131		00:00:00_00:00:03	00:00:00_00:00:04	IP	Bogus IP header
17 3.958228		00:00:00_00:00:03	00:00:00_00:00:04	IP	Bogus IP header
18 4.126243		00:00:00_00:00:03	00:00:00_00:00:04	IP	Bogus IP header

⊞ Frame 11 (56 bytes on wire, 56 bytes captured)
⊟ Ethernet II, Src: 00:00:00_00:00:03 (00:00:00:00:00:03), Dst: 00:00:00_00:00:04 (00:00
  ⊞ Destination: 00:00:00_00:00:04 (00:00:00:00:00:04)
  ⊞ Source: 00:00:00_00:00:03 (00:00:00:00:00:03)
    Type: IP (0x0800)
⊟ Internet Protocol
    Version: 0
    Header length: 0 bytes (bogus, must be at least 20)

Switch2 receive packets from Switch1

5. OpenFlow L2 Forward Example – Per VLAN

In this example, the Controller is a simulated simple L2 switch for learning and forwarding.

The Switch in OpenFlow Per-VLAN mode would "Packet-In" the OpenFlow VLAN unknown packet and sent to Controller. Controller would learn the source MAC of the received "Packet-In" packet. Then Controller will base on its logical and set a flow to Switch. In this case, after Controller learned the destination MAC later, it will set a flow to switch. Finally, the matched packets could be forwarded by the installed flow.

5.1 Environment

5.2 Configuration

5.2.1 POX Controller Configuration

- POX Script:

  noxrepo-pox-8e3743d# **./pox.py forwarding.l2_learning**

- Start Up Packets

No.	Time	Source	Destination	Protocol	Info .
9	4.971218	192.168.2.102	192.168.2.200	OFP	Hello (SM) (8B)
11	5.008513	192.168.2.200	192.168.2.102	OFP	Hello (SM) (8B)
13	5.026614	192.168.2.200	192.168.2.102	OFP	Features Request (CSM) (8B)
16	5.027907	192.168.2.102	192.168.2.200	OFP	Features Reply (CSM) (2384B)[Dissector bu
18	5.029763	192.168.2.200	192.168.2.102	OFP	Set Config (CSM) (12B)
20	5.068416	192.168.2.200	192.168.2.102	OFP	Barrier Request (CSM) (8B)
22	5.078083	192.168.2.102	192.168.2.200	OFP	Barrier Reply (CSM) (8B)
29	9.991297	192.168.2.102	192.168.2.200	OFP	Echo Request (SM) (8B)
31	10.031091	192.168.2.200	192.168.2.102	OFP	Echo Reply (SM) (8B)
37	14.992552	192.168.2.102	192.168.2.200	OFP	Echo Request (SM) (8B)
39	15.007479	192.168.2.200	192.168.2.102	OFP	Echo Reply (SM) (8B)
47	17.272209	192.168.2.101	192.168.2.200	OFP	Hello (SM) (8B)

```
+ Frame 9 (74 bytes on wire, 74 bytes captured)
- Ethernet II, Src: 04:7d:7b:fd:2a:ef (04:7d:7b:fd:2a:ef), Dst: CadmusCo_9e:af:a4 (08:00:27:9e:af:a4)
  - Destination: CadmusCo_9e:af:a4 (08:00:27:9e:af:a4)
      Address: CadmusCo_9e:af:a4 (08:00:27:9e:af:a4)
      .... ...0 .... .... .... .... = IG bit: Individual address (unicast)
      .... ..0. .... .... .... .... = LG bit: Globally unique address (factory default)
  - Source: 04:7d:7b:fd:2a:ef (04:7d:7b:fd:2a:ef)
      Address: 04:7d:7b:fd:2a:ef (04:7d:7b:fd:2a:ef)
      .... ...0 .... .... .... .... = IG bit: Individual address (unicast)
      .... ..0. .... .... .... .... = LG bit: Globally unique address (factory default)
      Type: IP (0x0800)
+ Internet Protocol, Src: 192.168.2.102 (192.168.2.102), Dst: 192.168.2.200 (192.168.2.200)
- Transmission Control Protocol, Src Port: 49210 (49210), Dst Port: 6633 (6633), Seq: 1, Ack: 1, Len: 8
      Source port: 49210 (49210)
```

5.2.2 Switch Configuration

(Switch1) #configure

(Switch1) (Config)#interface vlan 1

Interface Vlan1 created for VLAN ID 1

(Switch1) (if-vlan1)# ip address 192.168.2.101 255.255.255.0

(Switch1) (if-vlan1)# exit

(Switch1) (Config)#interface vlan 2

Interface Vlan2 created for VLAN ID 2

(Switch1) (if-vlan2)#exit

(Switch1) (Config)#interface range 0/1 , 0/3

(Switch1) (if-range)#switchport allowed vlan add 2

(Switch1) (if-range)#exit

(Switch1) (Config)#openflow instance 1

(Switch1) (openflow-1)#controller 192.168.2.200 6633 tcp

(Switch1) (openflow-1)# hybridmode per-vlan

(Switch1) (openflow-1-vlan-hybrid)#vlan 2

(Switch1) (openflow-1-vlan-hybrid)#exit

(Switch1) (openflow-1)#exit

(Switch1) (Config)#exit

(Switch1) #show openflow 1

Administrative Mode........................... Enable

Operational Status............................ Enabled

Disable Reason................................ None

IP Address.................................... 192.168.2.101

OpenFlow Variant.............................. OpenFlow 1.0

Hybrid Mode................................... Per-Vlan

   Vlan List:

2

(Switch1) #

(Switch1) #show openflow 1 configured controller

IP Address   IP Port   Connection Mode   Connection Status

---------------   ----------   -----------------   ------------------

192.168.2.200   6633   tcp   ACTIVE

(Switch1) #show vlan

VLAN ID VLAN Name   VLAN Type   Interface(s)

------- -------------------------------- ---------- ------------------------

1   default   Default   0/1,0/2,0/3,0/4,0/5,0/6,

                                                     0/7,0/8,0/9,0/10,0/11,

                                                     0/12,0/13,0/14,0/15,0/16,

                                                     0/17,0/18,0/19,0/20,0/21,

                                                     0/22,0/23,0/24,0/25,0/26,

                                                     0/27,0/28,0/29,0/30,0/31,

                                                     0/32,0/33,0/34,0/35,0/36,

                                                     0/37,0/38,0/39,0/40,0/41,

                                                     0/42,0/43,0/44,0/45,0/46,

                                                     0/47,0/48

2   VLAN0002   Static   0/1,0/3

(Switch1) #

5.2.3 Packet-In from Switch to Controller

Packet-In From VLAN 2 Member Port 1

Ethernet II, Src: 00:00:00_00:00:01 (00:00:00:00:00:01), Dst: 00:00:00_00:00:02 (00:00:00:00:00:02)

No.	Time	Source	Destination	Protocol	Info
311	120.457629	192.168.2.200	192.168.2.102	OFP	Echo Reply (SM) (8B)
314	121.050269	00:00:00_00:00:01	00:00:00_00:00:02	OFP+IP	Packet In (AM) (BufID=257) (78B) => Bogus
315	121.083633	192.168.2.200	192.168.2.101	OFP	Packet Out (CSM) (BufID=257) (24B)
317	121.272925	00:00:00_00:00:01	00:00:00_00:00:02	OFP+IP	Packet In (AM) (BufID=258) (78B) => Bogus
318	121.302156	192.168.2.200	192.168.2.101	OFP	Packet Out (CSM) (BufID=258) (24B)

```
+ Internet Protocol, Src: 192.168.2.101 (192.168.2.101), Dst: 192.168.2.200 (192.168.2.200)
+ Transmission Control Protocol, Src Port: 41435 (41435), Dst Port: 6633 (6633), Seq: 2639, Ack: 293, Len: 78
- OpenFlow Protocol
   + Header
   - Packet In
       Buffer ID: 257
       Frame Total Length: 60
       Frame Recv Port: 1
       Reason Sent: No matching flow (0)
     - Frame Data: 00000000000200000000000181000002080000000000000000...
        - Ethernet II, Src: 00:00:00_00:00:01 (00:00:00:00:00:01), Dst: 00:00:00_00:00:02 (00:00:00:00:00:02)
           - Destination: 00:00:00_00:00:02 (00:00:00:00:00:02)
              Address: 00:00:00_00:00:02 (00:00:00:00:00:02)
              .... ...0 .... .... .... .... = IG bit: Individual address (unicast)
              .... ..0. .... .... .... .... = LG bit: Globally unique address (factory default)
           - Source: 00:00:00_00:00:01 (00:00:00:00:00:01)
              Address: 00:00:00_00:00:01 (00:00:00:00:00:01)
              .... ...0 .... .... .... .... = IG bit: Individual address (unicast)
              .... ..0. .... .... .... .... = LG bit: Globally unique address (factory default)
           Type: 802.1Q Virtual LAN (0x8100)
        - 802.1Q Virtual LAN, PRI: 0, CFI: 0, ID: 2
           000. .... .... .... = Priority: 0
           ...0 .... .... .... = CFI: 0
           .... 0000 0000 0010 = ID: 2
           Type: IP (0x0800)
        + Internet Protocol
```

```
0040  ec 3a 01 0a 00 4e 00 00  00 00 00 00 01 01 00 3c    .:...N.. ..|.....<
0050  00 01 00 00 00 00 00 00  00 02 00 00 00 00 00 01    ........ ........
0060  81 00 00 02 08 00 00 00  00 00 00 00 00 00 00 00    ........ ........
0070  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00    ........ ........
```

Packet-In From VLAN 2 Member Port 3

Ethernet II, Src: 00:00:00_00:00:02 (00:00:00:00:00:02), Dst: 00:00:00_00:00:01 (00:00:00:00:00:01)

No.	Time	Source	Destination	Protocol	Info .
4	2.977657	192.168.2.200	192.168.2.102	OFP	Echo Reply (SM) (8B)
6	3.082456	00:00:00_00:00:02	00:00:00_00:00:01	OFP+IP	Packet In (AM) (BufID=259) (78B) => Bogus
7	3.093139	192.168.2.200	192.168.2.101	OFP	Flow Mod (CSM) (80B)
11	7.237006	192.168.2.101	192.168.2.200	OFP	Echo Request (SM) (8B)

```
+ Frame 6 (144 bytes on wire, 144 bytes captured)
+ Ethernet II, Src: 04:7d:7b:fd:ff:ff (04:7d:7b:fd:ff:ff), Dst: CadmusCo_9e:af:a4 (08:00:27:9e:af:a4)
+ Internet Protocol, Src: 192.168.2.101 (192.168.2.101), Dst: 192.168.2.200 (192.168.2.200)
+ Transmission Control Protocol, Src Port: 41435 (41435), Dst Port: 6633 (6633), Seq: 1, Ack: 1, Len: 78
- OpenFlow Protocol
  + Header
  - Packet In
      Buffer ID: 259
      Frame Total Length: 60
      Frame Recv Port: 3
      Reason Sent: No matching flow (0)
    - Frame Data: 00000000000100000000000281000002080000000000000000...
      - Ethernet II, Src: 00:00:00_00:00:02 (00:00:00:00:00:02), Dst: 00:00:00_00:00:01 (00:00:00:00:00:01)
        + Destination: 00:00:00_00:00:01 (00:00:00:00:00:01)
        + Source: 00:00:00_00:00:02 (00:00:00:00:00:02)
          Type: 802.1Q Virtual LAN (0x8100)
      - 802.1Q Virtual LAN, PRI: 0, CFI: 0, ID: 2
          000. .... .... .... = Priority: 0
          ...0 .... .... .... = CFI: 0
          .... 0000 0000 0010 = ID: 2
          Type: IP (0x0800)
      - Internet Protocol
          Version: 0
          Header length: 0 bytes (bogus, must be at least 20)
```

```
0000  08 00 27 9e af a4 04 7d  7b fd ff ff 08 00 45 00   ..'....} {.....E.
0010  00 82 f1 e7 40 00 40 06  c2 10 c0 a8 02 65 c0 a8   ....@.@. .....e..
0020  02 c8 a1 db 19 e9 49 2a  2b 68 e7 ae e8 76 80 18   ......I* +h...v..
0030  00 5c b7 83 00 00 01 01  08 0a 00 23 6a 45 41 fa   .\...... ...#jEA.
0040  ff 8a 01 0a 00 4e 00 00  00 00 00 00 01 03 00 3c   .....N.. .......<
0050  00 03 00 00 00 00 00 00  00 01 00 00 00 00 00 02   ........ ........
0060  81 00 00 02 08 00 00 00  00 00 00 00 00 00 00 00   ........ ........
0070  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ........ ........
```

5.2.4 Flow Mod from Controller to Switch

(POX) DEBUG:forwarding.l2_learning:installing flow for 00:00:00:00:00:02.3 -> 00:00:00:00:00:01.1

No.	Time	Source	Destination	Protocol	Info .
6	3.082456	00:00:00_00:00:02	00:00:00_00:00:01	OFP+IP	Packet In (AM) (BufID=259) (78B) => Bogus
7	3.093139	192.168.2.200	192.168.2.101	OFP	Flow Mod (CSM) (80B)
11	7.237006	192.168.2.101	192.168.2.200	OFP	Echo Request (SM) (8B)

```
OpenFlow Protocol
  + Header
  - Flow Modification
    - Match
      + Match Types
        Ethernet Src Addr: 00:00:00_00:00:02 (00:00:00:00:00:02)
        Ethernet Dst Addr: 00:00:00_00:00:01 (00:00:00:00:00:01)
        Input VLAN ID: 2
        Input VLAN priority: 0
        Ethernet Type: IP (0x0800)
        IPv4 DSCP: 0
        Protocol: IPv6 hop-by-hop option (0x00)
        IP Src Addr: 0.0.0.0 (0.0.0.0)
        IP Dst Addr: 0.0.0.0 (0.0.0.0)
      Cookie: 0x0000000000000000
      Command: New flow (0)
      Idle Time (sec) Before Discarding: 10
      Max Time (sec) Before Discarding: 30
      Priority: 32768
      Buffer ID: 259
      Out Port (delete* only): None  (not associated with a physical port)
    + Flags
    - Output Action(s)
      - Action
          Type: Output to switch port (0)
          Len: 8
          Output port: 1
          Max Bytes to Send: 0
        # of Actions: 1
```

```
0000  04 7d 7b fd ff ff 08 00  27 9e af a4 08 00 45 00   .}{..... '.....E.
0010  00 84 6d 9f 40 00 40 06  46 57 c0 a8 02 c8 c0 a8   ..m.@.@. FW......
0020  02 65 19 e9 a1 db e7 ae  e8 76 49 2a 2b b6 80 18   .e...... .vI*+...
0030  00 b5 86 f4 00 00 01 01  08 0a 41 fb 04 50 00 23   ........ ..A..P.#
```

○ Frame (frame), 146 bytes   ≡ Packets: 507 Displayed: 164 Marked: 0   ≡ Profile: Default

(POX) DEBUG:forwarding.l2_learning:installing flow for 00:00:00:00:00:01.1 -> 00:00:00:00:00:02.3

No.	Time	Source	Destination	Protocol	Info .
10	3.085833	00:00:00_00:00:01	00:00:00_00:00:02	OFP+IP	Packet In (AM) (BufID=260) (78B) => Bogus
12	3.126793	192.168.2.200	192.168.2.101	OFP	Flow Mod (CSM) (80B)

```
- OpenFlow Protocol
  + Header
  - Flow Modification
    - Match
      + Match Types
        Ethernet Src Addr: 00:00:00_00:00:01 (00:00:00:00:00:01)
        Ethernet Dst Addr: 00:00:00_00:00:02 (00:00:00:00:00:02)
        Input VLAN ID: 2
        Input VLAN priority: 0
        Ethernet Type: IP (0x0800)
        IPv4 DSCP: 0
        Protocol: IPv6 hop-by-hop option (0x00)
        IP Src Addr: 0.0.0.0 (0.0.0.0)
        IP Dst Addr: 0.0.0.0 (0.0.0.0)
      Cookie: 0x0000000000000000
      Command: New flow (0)
      Idle Time (sec) Before Discarding: 10
      Max Time (sec) Before Discarding: 30
      Priority: 32768
      Buffer ID: 260
      Out Port (delete* only): None  (not associated with a physical port)
    + Flags
    - Output Action(s)
      - Action
          Type: Output to switch port (0)
          Len: 8
          Output port: 3
          Max Bytes to Send: 0
        # of Actions: 1
```

```
0000  04 7d 7b fd ff ff 08 00  27 9e af a4 08 00 45 00   .}{..... '.....E.
0010  00 84 6e 2e 40 00 40 06  45 c8 c0 a8 02 c8 c0 a8   ..n.@.@. E.......
0020  02 65 19 e9 a1 db e7 ae  eb c6 49 2a 2f 04 80 18   .e...... ..I*/...
0030  00 b5 86 f4 00 00 01 01  08 0a 41 fc dc 9e 00 25   ........ ..A....%
```

5.2.5   Switch Installed Flow by Controller

```
(Switch1) #show openflow 1 installed flows


(Switch1) #show openflow 1 installed flows

Flow 00000023 type "1DOT0"

Match criteria:
Flow table              24 : Priority               32768
Src MAC  00:00:00:00:00:01 : Dst MAC  00:00:00:00:00:02 : VLAN                    2
VLAN prio                0 : Ether type              800 : IP proto                0
Src IP            0.0.0.0 : Dst IP            0.0.0.0 : TOS                     0
Actions:
Egress port            0/3
Status:
Duration                 4 : Idle                      0 : installed in hardware   1

Flow 00000021 type "1DOT0"

Match criteria:
Flow table              24 : Priority               32768
Src MAC  00:00:00:00:00:02 : Dst MAC  00:00:00:00:00:01 : VLAN                    2
VLAN prio                0 : Ether type              800 : IP proto                0
Src IP            0.0.0.0 : Dst IP            0.0.0.0 : TOS                     0
Actions:
Egress port            0/1
Status:

--More-- or (q)uit
Duration                 5 : Idle                      0 : installed in hardware   1


(Switch1) #
```

5.3 Result
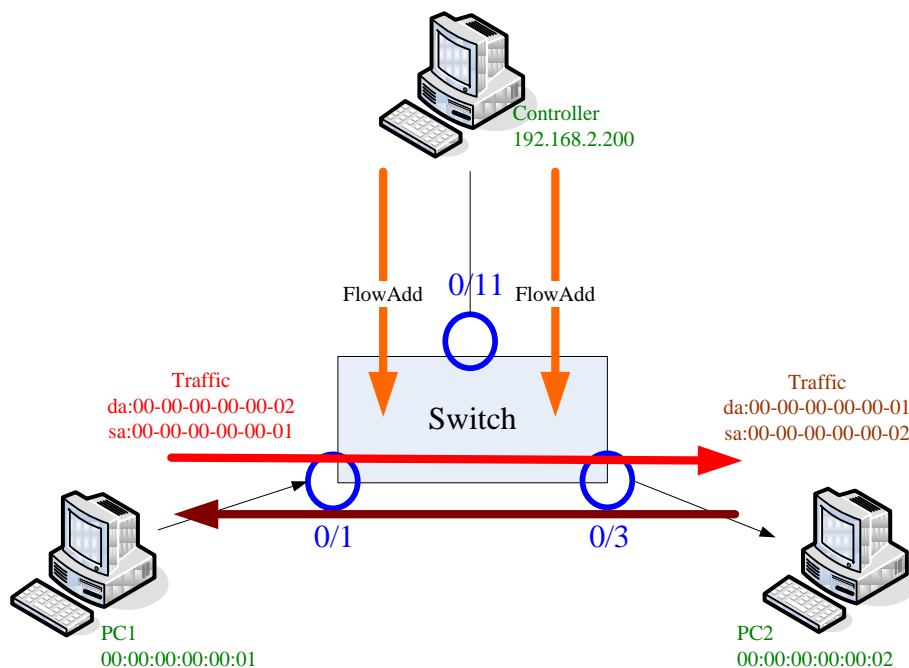
No. ▾	Time	Source	Destination	Protocol	Info
1203	1098.912413	00:00:00_00:00:01	00:00:00_00:00:02	IP	Bogus IP header length
1204	1098.961036	00:00:00_00:00:02	00:00:00_00:00:01	IP	Bogus IP header length
1205	1099.056610	00:00:00_00:00:01	00:00:00_00:00:02	IP	Bogus IP header length
1206	1099.154464	00:00:00_00:00:02	00:00:00_00:00:01	IP	Bogus IP header length
1207	1099.208856	00:00:00_00:00:01	00:00:00_00:00:02	IP	Bogus IP header length
1208	1099.357210	00:00:00_00:00:02	00:00:00_00:00:01	IP	Bogus IP header length
1209	1099.361481	00:00:00_00:00:01	00:00:00_00:00:02	IP	Bogus IP header length
1210	1099.529135	00:00:00_00:00:01	00:00:00_00:00:02	IP	Bogus IP header length
1211	1099.565391	00:00:00_00:00:02	00:00:00_00:00:01	IP	Bogus IP header length
1212	1099.720556	00:00:00_00:00:01	00:00:00_00:00:02	IP	Bogus IP header length
1213	1099.769643	00:00:00_00:00:02	00:00:00_00:00:01	IP	Bogus IP header length
1214	1099.880172	00:00:00_00:00:01	00:00:00_00:00:02	IP	Bogus IP header length

⊞ Frame 945 (60 bytes on wire, 60 bytes captured)
⊟ Ethernet II, Src: 00:00:00_00:00:01 (00:00:00:00:00:01), Dst: 00:00:00_00:00:02 (00:00:00:00:0
  ⊞ Destination: 00:00:00_00:00:02 (00:00:00:00:00:02)
  ⊞ Source: 00:00:00_00:00:01 (00:00:00:00:00:01)
    Type: 802.1Q Virtual LAN (0x8100)
⊞ 802.1Q Virtual LAN, PRI: 0, CFI: 0, ID: 2
⊟ Internet Protocol
    Version: 0
    Header length: 0 bytes (bogus, must be at least 20)

```
0000   00 00 00 00 00 02 00 00   00 00 00 01 81 00 00 02    ........ ........
0010   08 00 00 00 00 00 00 00   00 00 00 00 00 00 00 00    ........ ........
0020   00 00 00 00 00 00 00 00   00 00 00 00 00 00 00 00    ........ ........
0030   00 00 00 00 00 00 00 00   00 00 00 00                ........ ....
```

6. OpenFlow L2 Forward Example – Per PORT

In this example, the Controller is a simulated simple L2 switch for learning and forwarding.

The Switch in OpenFlow Per-PORT mode would "Packet-In" the unknown packet which received on the OpenFlow ports and sent it to Controller. Controller would learn the source MAC of the received "Packet-In" packet. When Controller learned the destination MAC later, it would set a flow to Switch. Finally, the matched packets could be forwarded by the installed flow.

6.1 Environment
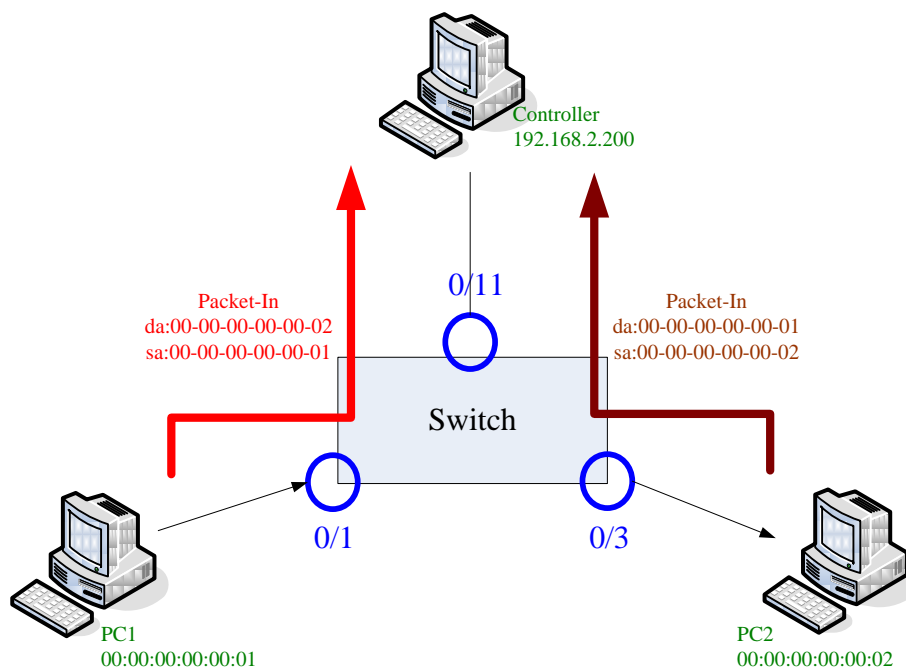
6.2 Configuration

6.2.1   POX Controller Configuration

- POX Script:

  noxrepo-pox-8e3743d# **./pox.py forwarding.l2_learning**

- Start Up Packets

No.	Time	Source	Destination	Protocol	Info .
9	4.971218	192.168.2.102	192.168.2.200	OFP	Hello (SM) (8B)
11	5.008513	192.168.2.200	192.168.2.102	OFP	Hello (SM) (8B)
13	5.026614	192.168.2.200	192.168.2.102	OFP	Features Request (CSM) (8B)
16	5.027907	192.168.2.102	192.168.2.200	OFP	Features Reply (CSM) (2384B)[Dissector bu
18	5.029763	192.168.2.200	192.168.2.102	OFP	Set Config (CSM) (12B)
20	5.068416	192.168.2.200	192.168.2.102	OFP	Barrier Request (CSM) (8B)
22	5.078083	192.168.2.102	192.168.2.200	OFP	Barrier Reply (CSM) (8B)
29	9.991297	192.168.2.102	192.168.2.200	OFP	Echo Request (SM) (8B)
31	10.031091	192.168.2.200	192.168.2.102	OFP	Echo Reply (SM) (8B)
37	14.992552	192.168.2.102	192.168.2.200	OFP	Echo Request (SM) (8B)
39	15.007479	192.168.2.200	192.168.2.102	OFP	Echo Reply (SM) (8B)
47	17.272209	192.168.2.101	192.168.2.200	OFP	Hello (SM) (8B)

```
+ Frame 9 (74 bytes on wire, 74 bytes captured)
- Ethernet II, Src: 04:7d:7b:fd:2a:ef (04:7d:7b:fd:2a:ef), Dst: CadmusCo_9e:af:a4 (08:00:27:9e:af:a4)
  - Destination: CadmusCo_9e:af:a4 (08:00:27:9e:af:a4)
      Address: CadmusCo_9e:af:a4 (08:00:27:9e:af:a4)
      .... ...0 .... .... .... .... = IG bit: Individual address (unicast)
      .... ..0. .... .... .... .... = LG bit: Globally unique address (factory default)
  - Source: 04:7d:7b:fd:2a:ef (04:7d:7b:fd:2a:ef)
      Address: 04:7d:7b:fd:2a:ef (04:7d:7b:fd:2a:ef)
      .... ...0 .... .... .... .... = IG bit: Individual address (unicast)
      .... ..0. .... .... .... .... = LG bit: Globally unique address (factory default)
    Type: IP (0x0800)
+ Internet Protocol, Src: 192.168.2.102 (192.168.2.102), Dst: 192.168.2.200 (192.168.2.200)
- Transmission Control Protocol, Src Port: 49210 (49210), Dst Port: 6633 (6633), Seq: 1, Ack: 1, Len: 8
    Source port: 49210 (49210)
```

6.2.2 Switch Configuration

(Switch1) #configure

(Switch1) (Config)#interface vlan 1

Interface Vlan1 created for VLAN ID 1

(Switch1) (if-vlan1)# ip address 192.168.2.101 255.255.255.0

(Switch1) (if-vlan1)# exit

 (Switch1) (Config)#openflow instance 1

(Switch1) (openflow-1)#controller 192.168.2.200 6633 tcp

(Switch1) (openflow-1)# hybridmode per-port

(Switch1) (openflow-1-port-hybrid)#port 1,3

(Switch1) (openflow-1-port-hybrid)#exit

(Switch1) (openflow-1)#exit

(Switch1) (Config)#exit

(Switch1) #show openflow 1

Administrative Mode........................... Enable

Operational Status............................ Enabled

Disable Reason................................ None

IP Address.................................... 192.168.2.101

OpenFlow Variant.............................. OpenFlow 1.0

Hybrid Mode................................... Per-Port

   Port List:

0/1,0/3

 (Switch1) #show openflow 1 configured controller

IP Address   IP Port   Connection Mode   Connection Status

--------------   ----------   ----------------   ------------------

	192.168.2.200	6633	tcp	ACTIVE

6.2.3 Packet-In from Switch to Controller

Packet-In From Port 1

Ethernet II, Src: 00:00:00_00:00:01 (00:00:00:00:00:01), Dst: 00:00:00_00:00:02 (00:00:00:00:00:02)

No.	Time	Source	Destination	Protocol	Info
3	0.949366	192.168.2.200	192.168.2.102	OFP	Echo Reply (SM) (8B)
6	2.773938	00:00:00_00:00:01	00:00:00_00:00:02	OFP+IP	Packet In (AM) (BufID=283) (78B) => B
7	2.782515	192.168.2.200	192.168.2.101	OFP	Packet Out (CSM) (BufID=283) (24B)
10	5.750611	00:00:00_00:00:01	00:00:00_00:00:02	OFP+IP	Packet In (AM) (BufID=284) (78B) => B

```
+ Frame 6 (144 bytes on wire, 144 bytes captured)
+ Ethernet II, Src: 04:7d:7b:fd:ff:ff (04:7d:7b:fd:ff:ff), Dst: CadmusCo_9e:af:a4 (08:00:27:9e:af:a4)
+ Internet Protocol, Src: 192.168.2.101 (192.168.2.101), Dst: 192.168.2.200 (192.168.2.200)
+ Transmission Control Protocol, Src Port: 35701 (35701), Dst Port: 6633 (6633), Seq: 1, Ack: 1, Len: 78
- OpenFlow Protocol
  + Header
  - Packet In
      Buffer ID: 283
      Frame Total Length: 60
      Frame Recv Port: 1
      Reason Sent: No matching flow (0)
    - Frame Data: 00000000000200000000000108000000000000000000000000...
      - Ethernet II, Src: 00:00:00_00:00:01 (00:00:00:00:00:01), Dst: 00:00:00_00:00:02 (00:00:00:00:00:02)
        + Destination: 00:00:00_00:00:02 (00:00:00:00:00:02)
        + Source: 00:00:00_00:00:01 (00:00:00:00:00:01)
          Type: IP (0x0800)
      + Internet Protocol
```

```
0000  08 00 27 9e af a4 04 7d  7b fd ff ff 08 00 45 00   ..'....} {.....E.
0010  00 82 90 f0 40 00 40 06  23 08 c0 a8 02 65 c0 a8   ....@.@. #....e..
0020  02 c8 8b 75 19 e9 6f 22  e4 5c 11 ea 25 99 80 18   ...u..o" .\..%...
0030  00 5c 52 09 00 00 01 01  08 0a 00 28 c3 21 42 00   .\R..... ...(.!B.
0040  5d 26 01 0a 00 4e 00 00  00 00 00 00 01 1b 00 3c   ]&...N.. .......<
0050  00 01 00 00 00 00 00 00  00 02 00 00 00 00 00 01   ........ ........
0060  08 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ........ ........
0070  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ........ ........
0080  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ........ ........
```

Packet-In From Port 3

Ethernet II, Src: 00:00:00_00:00:02 (00:00:00:00:00:02), Dst: 00:00:00_00:00:01 (00:00:00:00:00:01)

No.	Time	Source	Destination	Protocol	Info .
7	1.044315	192.168.2.200	192.168.2.101	OFP	Packet Out (CSM) (BufID=316) (24B)
9	1.549629	00:00:00_00:00:02	00:00:00_00:00:01	OFP+IP	Packet In (AM) (BufID=317) (78B) => Bogu
11	1.563010	192.168.2.200	192.168.2.101	OFP	Flow Mod (CSM) (80B)
13	1.745050	169.254.43.163	169.254.255.255	OFP+NBNS	Packet In (AM) (BufID=318) (110B) => Nam

```
+ Frame 9 (144 bytes on wire, 144 bytes captured)
+ Ethernet II, Src: 04:7d:7b:fd:ff:ff (04:7d:7b:fd:ff:ff), Dst: CadmusCo_9e:af:a4 (08:00:27:9e:af:a4)
+ Internet Protocol, Src: 192.168.2.101 (192.168.2.101), Dst: 192.168.2.200 (192.168.2.200)
+ Transmission Control Protocol, Src Port: 35701 (35701), Dst Port: 6633 (6633), Seq: 221, Ack: 49, Len: 78
- OpenFlow Protocol
  + Header
  - Packet In
      Buffer ID: 317
      Frame Total Length: 60
      Frame Recv Port: 3
      Reason Sent: No matching flow (0)
    - Frame Data: 00000000000100000000000208000000000000000000000...
      - Ethernet II, Src: 00:00:00_00:00:02 (00:00:00:00:00:02), Dst: 00:00:00_00:00:01 (00:00:00:00:00:01)
        - Destination: 00:00:00_00:00:01 (00:00:00:00:00:01)
            Address: 00:00:00_00:00:01 (00:00:00:00:00:01)
            .... ...0 .... .... .... .... = IG bit: Individual address (unicast)
            .... ..0. .... .... .... .... = LG bit: Globally unique address (factory default)
        - Source: 00:00:00_00:00:02 (00:00:00:00:00:02)
            Address: 00:00:00_00:00:02 (00:00:00:00:00:02)
            .... ...0 .... .... .... .... = IG bit: Individual address (unicast)
            .... ..0. .... .... .... .... = LG bit: Globally unique address (factory default)
          Type: IP (0x0800)
      + Internet Protocol
```

```
0000  08 00 27 9e af a4 04 7d  7b fd ff ff 08 00 45 00   ..'....} {.....E.
0010  00 82 91 5a 40 00 40 06  22 9e c0 a8 02 65 c0 a8   ...Z@.@. "....e..
0020  02 c8 8b 75 19 e9 6f 22  f6 74 11 ea 29 61 80 18   ...u..o" .t..)a..
0030  00 5c 3f fa 00 00 01 01  08 0a 00 29 3e ef 42 00   .\?..... ...)>.B.
0040  dd 62 01 0a 00 4e 00 00  00 00 00 00 01 3d 00 3c   .b...N.. .....=.<
0050  00 03 00 00 00 00 00 00  00 01 00 00 00 00 00 02   ........ ........
0060  08 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ........ ........
0070  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ........ ........
0080  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00   ........ ........
```

6.2.4 Flow Mod from Controller to Switch

(POX) DEBUG:forwarding.l2_learning:installing flow for 00:00:00:00:00:01.1 -> 00:00:00:00:00:02.3

No.	Time	Source	Destination	Protocol	Info
2	0.429336	00:00:00_00:00:01	00:00:00_00:00:02	OFP+IP	Packet In (AM) (BufID=383) (78B) => Bogus
3	0.455166	192.168.2.200	192.168.2.101	OFP	Flow Mod (CSM) (80B)
5	0.937517	192.168.2.102	192.168.2.200	OFP	Echo Request (SM) (8B)

```
- OpenFlow Protocol
  + Header
  - Flow Modification
    - Match
      + Match Types
        Ethernet Src Addr: 00:00:00_00:00:01 (00:00:00:00:00:01)
        Ethernet Dst Addr: 00:00:00_00:00:02 (00:00:00:00:00:02)
        Input VLAN ID: 65535
        Input VLAN priority: 0
        Ethernet Type: IP (0x0800)
        IPv4 DSCP: 0
        Protocol: IPv6 hop-by-hop option (0x00)
        IP Src Addr: 0.0.0.0 (0.0.0.0)
        IP Dst Addr: 0.0.0.0 (0.0.0.0)
      Cookie: 0x0000000000000000
      Command: New flow (0)
      Idle Time (sec) Before Discarding: 10
      Max Time (sec) Before Discarding: 30
      Priority: 32768
      Buffer ID: 383
      Out Port (delete* only): None  (not associated with a physical port)
    + Flags
    - Output Action(s)
      - Action
          Type: Output to switch port (0)
          Len: 8
          Output port: 3
          Max Bytes to Send: 0
        # of Actions: 1
```

```
0000  04 7d 7b fd ff ff 08 00  27 9e af a4 08 00 45 00   .}{..... '.....E.
0010  00 84 d9 7a 40 00 40 06  da 7b c0 a8 02 c8 c0 a8   ...z@.@. .{......
0020  02 65 19 e9 8b 75 11 ea  31 59 6f 23 19 7e 80 18   .e...u.. 1Yo#.~..
0030  03 ea 86 f4 00 00 01 01  08 0a 42 01 c0 30 00 2a   ........ ..B..0.*
```

(POX) DEBUG:forwarding.l2_learning:installing flow for 00:00:00:00:00:02.3 -> 00:00:00:00:00:01.1

No.	Time	Source	Destination	Protocol	Info .
7	1.044315	192.168.2.200	192.168.2.101	OFP	Packet Out (CSM) (BufID=316) (24B)
9	1.549629	00:00:00_00:00:02	00:00:00_00:00:01	OFP+IP	Packet In (AM) (BufID=317) (78B) => Bogus
11	1.563010	192.168.2.200	192.168.2.101	OFP	Flow Mod (CSM) (80B)
13	1.745050	169.254.43.163	169.254.255.255	OFP+NBNS	Packet In (AM) (BufID=318) (110B) => Name

```
+ Transmission Control Protocol, Src Port: 6633 (6633), Dst Port: 35701 (35701), Seq: 49, ACK: 299, Len: 80
- OpenFlow Protocol
   + Header
   - Flow Modification
      - Match
         + Match Types
           Ethernet Src Addr: 00:00:00_00:00:02 (00:00:00:00:00:02)
           Ethernet Dst Addr: 00:00:00_00:00:01 (00:00:00:00:00:01)
           Input VLAN ID: 65535
           Input VLAN priority: 0
           Ethernet Type: IP (0x0800)
           IPv4 DSCP: 0
           Protocol: IPv6 hop-by-hop option (0x00)
           IP Src Addr: 0.0.0.0 (0.0.0.0)
           IP Dst Addr: 0.0.0.0 (0.0.0.0)
        Cookie: 0x0000000000000000
        Command: New flow (0)
        Idle Time (sec) Before Discarding: 10
        Max Time (sec) Before Discarding: 30
        Priority: 32768
        Buffer ID: 317
        Out Port (delete* only): None  (not associated with a physical port)
      + Flags
      - Output Action(s)
         - Action
             Type: Output to switch port (0)
             Len: 8
             Output port: 1
```

```
0000  04 7d 7b fd ff ff 08 00  27 9e af a4 08 00 45 00   .}{..... '.....E.
0010  00 84 d8 e5 40 00 40 06  db 10 c0 a8 02 c8 c0 a8   ....@.@. ........
0020  02 65 19 e9 8b 75 11 ea  29 61 6f 22 f6 c2 80 18   .e...u.. )ao"....
0030  03 ea 86 f4 00 00 01 01  08 0a 42 00 dd e4 00 29   ........ ..B....)
```

6.2.5 Switch Installed Flow by Controller

```
(Switch1) #show openflow 1 installed flows

Flow 0000014F type "1DOT0"

Match criteria:
Flow table              24 : Priority             32768
Src MAC  00:00:00:00:00:01 : Dst MAC  00:00:00:00:00:02 : VLAN                65535
VLAN prio                0 : Ether type            800 : IP proto               0
Src IP            0.0.0.0 : Dst IP            0.0.0.0 : TOS                    0
Actions:
Egress port            0/3
Status:
Duration                 8 : Idle                   0 : installed in hardware   1

Flow 00000151 type "1DOT0"

Match criteria:
Flow table              24 : Priority             32768
Src MAC  00:00:00:00:00:02 : Dst MAC  00:00:00:00:00:01 : VLAN                65535
VLAN prio                0 : Ether type            800 : IP proto               0
Src IP            0.0.0.0 : Dst IP            0.0.0.0 : TOS                    0
Actions:
Egress port            0/1
Status:

--More-- or (q)uit
Duration                 7 : Idle                   0 : installed in hardware   1


(Switch1) #
```

6.3 Result