FlowVisor Overview

Network Virtualization

- Network Operators “Delegate” control of subsets of network hardware and/or traffic to other Network Operators or Users
- Multiple Controllers can talk to same set of switches
- Imagine a Hypervisor for network equipment
- Allows experiments to be run on the network in isolation of each other and production traffic

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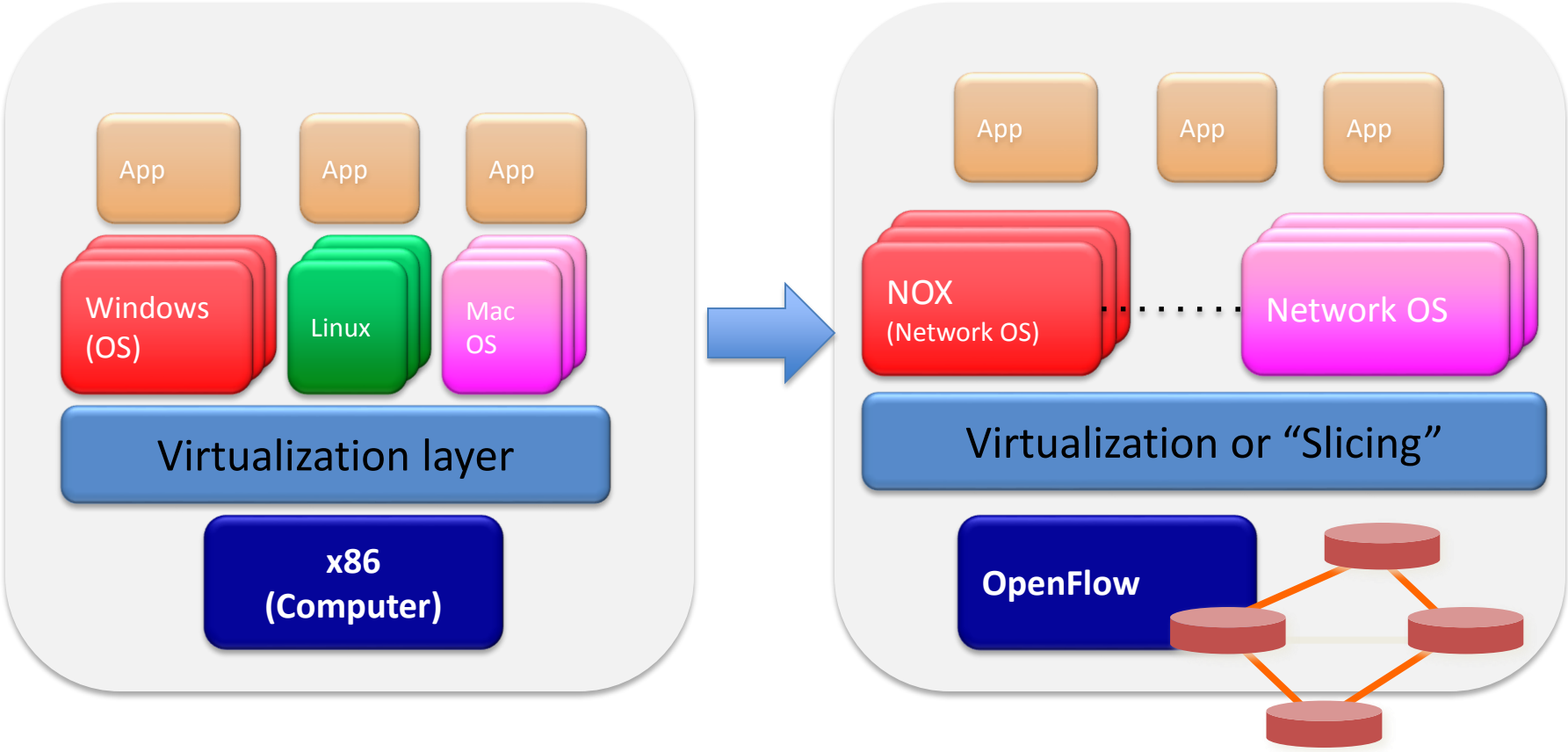
Trend



Computer Industry

Network Industry

FlowVisor

- Network Hypervisor developed by Stanford
- A software proxy between the forwarding and control planes of network devices
- > /usr/sbin/flowvisor /usr/etc/flowvisor/config.xml &
- > man flowvisor
- > man fvconfig
- > man fvctl

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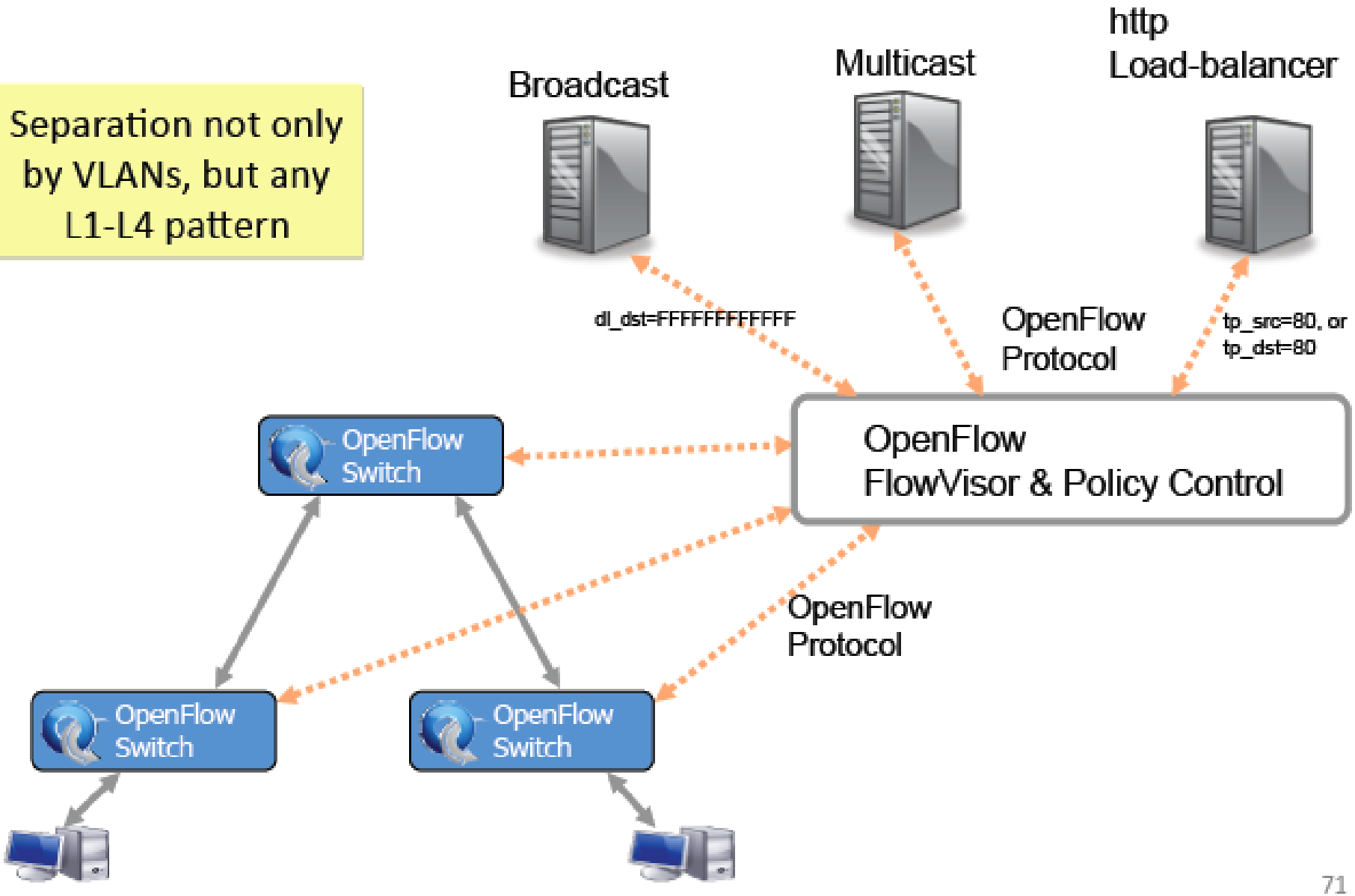
FlowVisor-based Virtualization

Separation not only by VLANs, but any L1-L4 pattern



FlowVisor Slicing

- Slices are defined using a slice definition policy
  - The policy language specifies the slice's resource limits, flowspace, and controller's location in terms of IP and TCP port-pair
  - FlowVisor enforces transparency and isolation between slices by inspecting, rewriting, and policing OpenFlow messages as they pass

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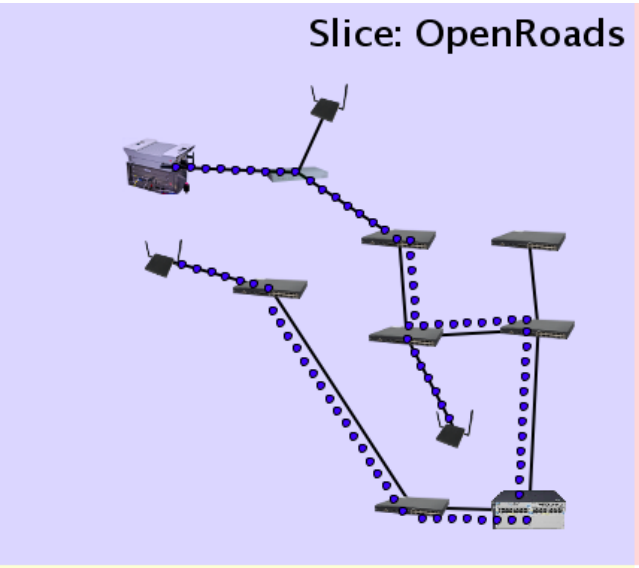
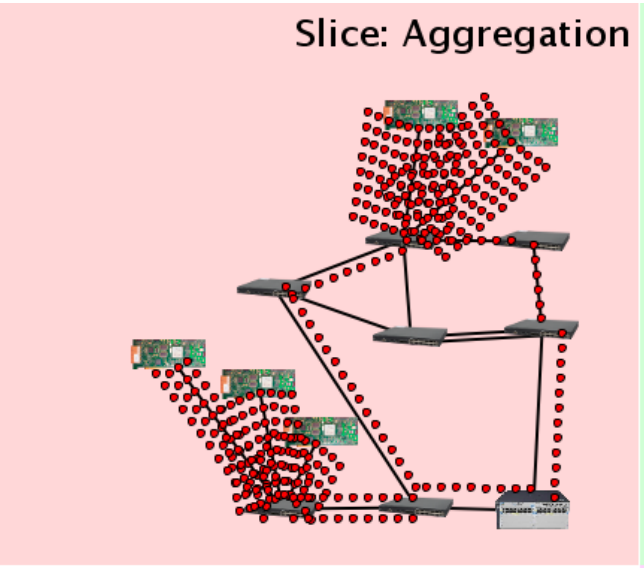
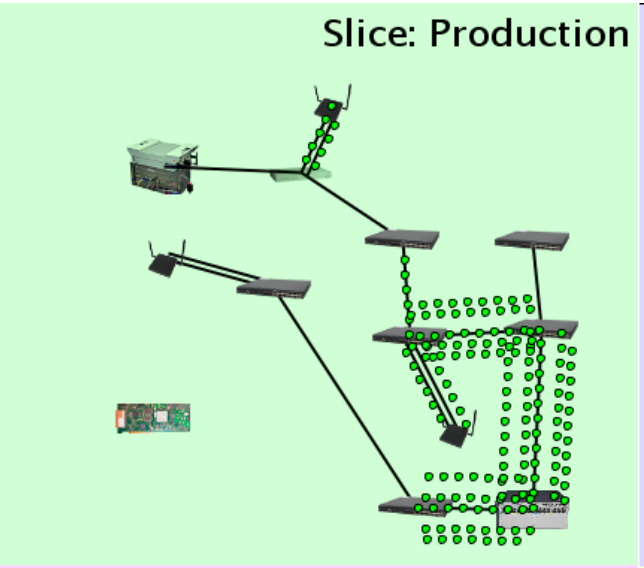
FlowVisor Resource Limits

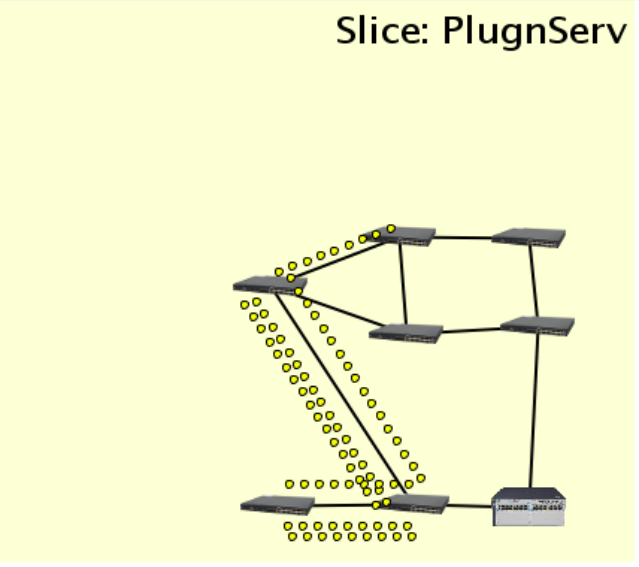
- FV assigns hardware resources to “Slices”
  - Topology
    - Network Device or Openflow Instance (DPID)
    - Physical Ports
  - Bandwidth
    - Each slice can be assigned a per port queue with a fraction of the total bandwidth
  - CPU
    - Employs Course Rate Limiting techniques to keep new flow events from one slice from overrunning the CPU
  - Forwarding Tables
    - Each slice has a finite quota of forwarding rules per device

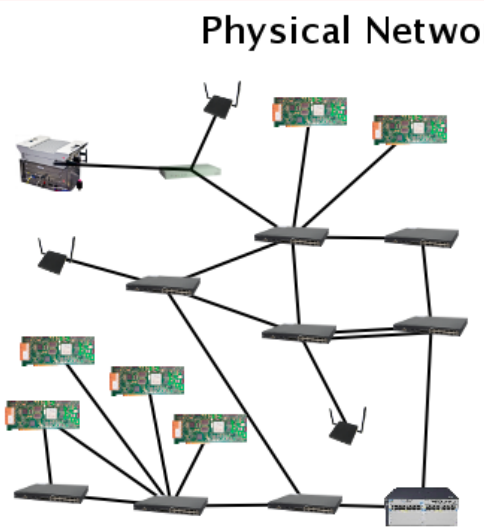
Slicing

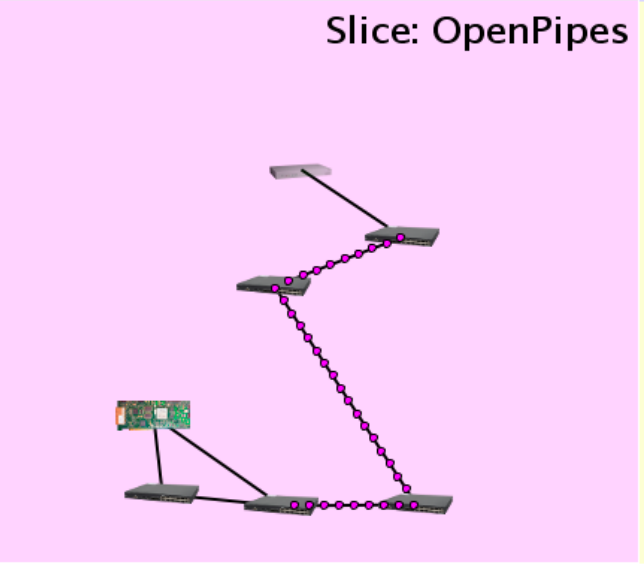

Slice: OpenRoads


Slice: Aggregation


Slice: Production


Slice: PlugnServ


Physical Network


Slice: OpenPipes

FlowVisor FlowSpace

- FlowSpace defined by a collection of packet headers and assigned to “Slices”
  - Src/Dst MAC Address
  - VLAN ID
  - Ethertype
  - IP Protocol
  - Src/Dst IP Address
  - ToS/DSCP
  - Src/Dst Port Number

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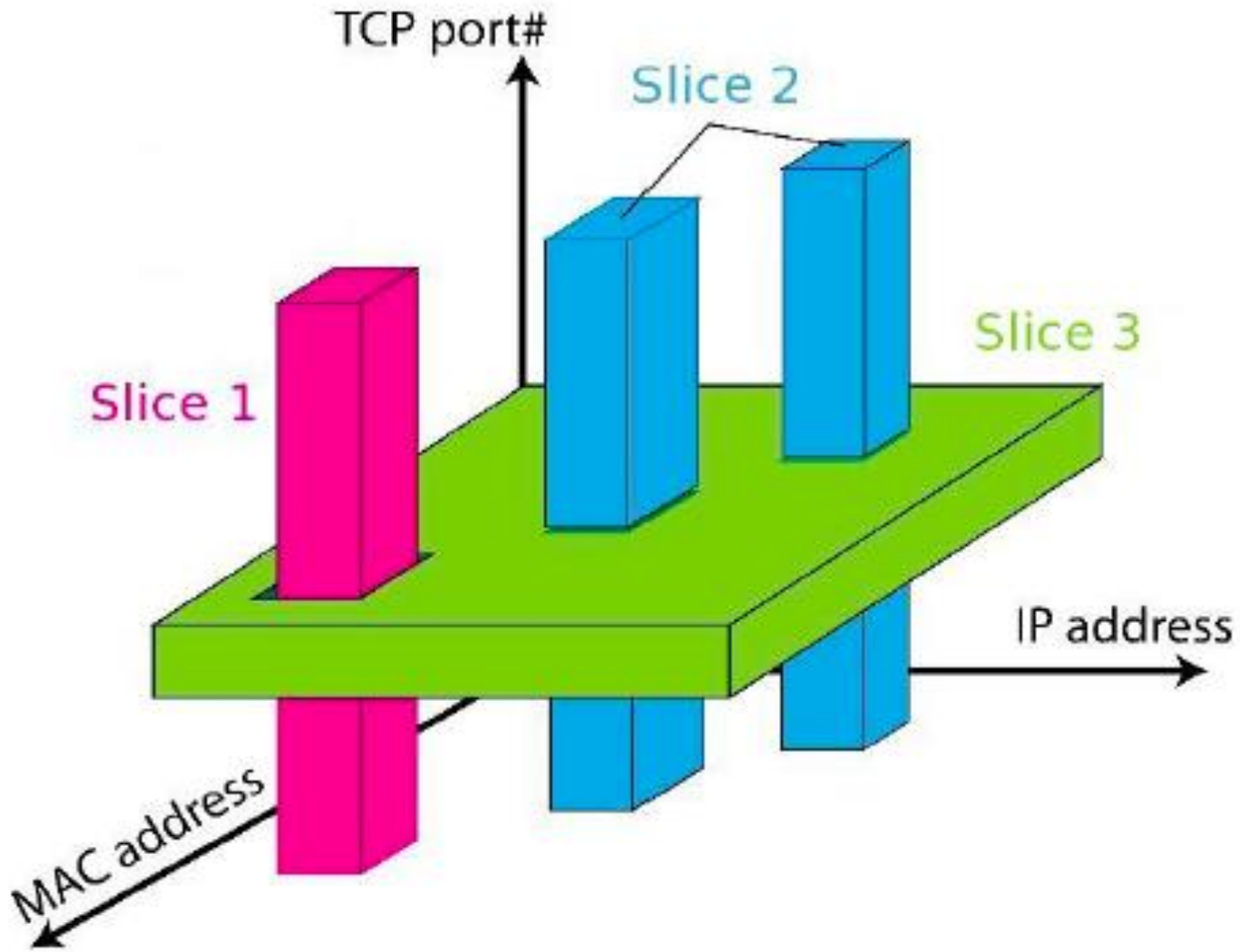
FlowSpace: Maps Packets to Slices



FlowSpace

Flowspaces

Add Flowspace

Write Slice	DPID	Equipment	Priority	In Port	VLAN	Src MAC	Dst MAC	Ethertype	Src IP	Dst IP	IP Protocol Number	IP TOS	Trans Src Port	Trans Dst Port
CPQD	c8:08:17:f4:4b:82:00	of-noc	500	17,18,19,30					172.31.0.0/16		None	None	None	None
CPQD	c8:08:17:f4:4b:82:00	of-noc	500	17,18,19,30					10.0.0.0/24		None	None	None	None
CPQD	c8:08:17:f4:4b:82:00	of-noc	500	17,18,19,30					20.0.0.0/24		None	None	None	None
CPQD	c8:08:17:f4:4b:82:00	of-noc	500	17,18,19,30					30.0.0.0/24		None	None	None	None
CPQD	c8:08:17:f4:4b:82:00	of-noc	500	17,18,19,30					40.0.0.0./24		None	None	None	None
CPQD	c8:08:17:f4:4b:82:00	of-noc	500	17,18,19,30					50.0.0.0/24		None	None	None	None
CPQD	00:00:00:00:00:00:00:11	of-dnoc-227	500	51,52					172.31.0.0/16		None	None	None	None
CPQD	00:00:00:00:00:00:00:11	of-dnoc-227	500	51,52					10.0.0.0/24		None	None	None	None
CPQD	00:00:00:00:00:00:00:11	of-dnoc-227	500	51,52					20.0.0.0/24		None	None	None	None
CPQD	00:00:00:00:00:00:00:11	of-dnoc-227	500	51,52					30.0.0.0/24		None	None	None	None
CPQD	00:00:00:00:00:00:00:11	of-dnoc-227	500	51,52					40.0.0.0./24		None	None	None	None
CPQD	00:00:00:00:00:00:00:11	of-dnoc-227	500	51,52					50.0.0.0/24		None	None	None	None
CPQD	00:00:00:00:00:00:00:12	of-dnoc-1214	500	49,50,51					172.31.0.0/16		None	None	None	None
CPQD	00:00:00:00:00:00:00:12	of-dnoc-1214	500	49,50,51					10.0.0.0/24		None	None	None	None
CPQD	00:00:00:00:00:00:00:12	of-dnoc-1214	500	49,50,51					20.0.0.0/24		None	None	None	None
CPQD	00:00:00:00:00:00:00:12	of-dnoc-1214	500	49,50,51					30.0.0.0./24		None	None	None	None
CPQD	00:00:00:00:00:00:00:12	of-dnoc-1214	500	49,50,51					40.0.0.0./24		None	None	None	None
CPQD	00:00:00:00:00:00:00:12	of-dnoc-1214	500	49,50,51					50.0.0.0/24		None	None	None	None
CPQD	00:00:00:00:00:00:00:13	of-dnoc-2637	500	3,5,6,51,50					172.31.0.0/16		None	None	None	None
CPQD	00:00:00:00:00:00:00:13	of-dnoc-2637	500	3,5,6,51,50					10.0.0.0/24		None	None	None	None
CPQD	00:00:00:00:00:00:00:13	of-dnoc-2637	500	3,5,6,51,50					20.0.0.0/24		None	None	None	None
CPQD	00:00:00:00:00:00:00:13	of-dnoc-2637	500	3,5,6,51,50					40.0.0.0./24		None	None	None	None
CPQD	00:00:00:00:00:00:00:13	of-dnoc-2637	500	3,5,6,51,50					50.0.0.0/24		None	None	None	None
l2-NOX	c8:08:17:f4:4b:82:00	of-noc	400	18,19,29	1327,2908-2912						None	None	None	None
l2-NOX	c8:08:17:f4:4b:82:00	of-noc	400	43	1327						None	None	None	None
l2-NOX	00:00:00:00:00:00:00:13	of-dnoc-2637	400	2,51,50	1327,2908-2912						None	None	None	None
l2-NOX	00:00:00:00:00:00:00:12	of-dnoc-1214	400	2,49,51,52	1327,2908-2912						None	None	None	None

FlowSpace (Cont.)

Clemson	0e:83:00:23:47:4b:2f:80	of-dnoc-5507-vlan3715	2000					10144			None	None	None	None
Clemson	0e:84:00:23:47:4b:2f:80	of-dnoc-5507-vlan3716	2000					10144			None	None	None	None
Clemson	0e:84:00:23:47:4b:2f:80	of-dnoc-5507-vlan3716	2000						10.43.100.0/24		None	None	None	None
Clemson	00:e9:00:23:47:4b:2f:80	of-dnoc-5507-vlan233	2000						10.43.100.0/24		None	None	None	None
Clemson	0e:83:00:23:47:4b:2f:80	of-dnoc-5507-vlan3715	2000						10.43.100.0/24		None	None	None	None
Clemson	00:e9:00:23:47:4b:2f:80	of-dnoc-5507-vlan233	2000					10144			None	None	None	None
iCAIR	00:00:00:00:00:00:00:13	of-dnoc-2637	300	4,51					10.37.15.0/24		None	None	None	None
ESNet	c8:08:17:f4:4b:82:00	of-noc	100	17,42		00:02:C9:10:F1:AC					None	None	None	None
ESNet	c8:08:17:f4:4b:82:00	of-noc	100	17,42			00:02:C9:10:F1:AC				None	None	None	None
Clemson	c8:08:17:f4:4b:82:00	of-noc	2000	20,41				10144			None	None	None	None
iCAIR	c8:08:17:f4:4b:82:00	of-noc	300	19,41					10.37.15.0/24		None	None	None	None
ESNet	c8:08:17:f4:4b:82:00	of-noc	100	17,42					192.168.140.1/24		None	None	None	None
ESNet	c8:08:17:f4:4b:82:00	of-noc	100	17,42						192.168.140.1/24	None	None	None	None
SARA	c8:08:17:f4:4b:82:00	of-noc	800	17,31				35074			None	None	None	None
Clemson	c8:08:17:f4:4b:82:00	of-noc	2000	20,41					10.43.100.0/24		None	None	None	None
ESNet	00:00:00:00:00:00:00:11	of-dnoc-227	100	49,52		00:02:C9:10:F1:BE					None	None	None	None
ESNet	00:00:00:00:00:00:00:11	of-dnoc-227	100	49,52			00:02:C9:10:F1:BE				None	None	None	None
ESNet	00:00:00:00:00:00:00:11	of-dnoc-227	100	49,52					192.168.140.2/24		None	None	None	None
ESNet	00:00:00:00:00:00:00:11	of-dnoc-227	100	49,52						192.168.140.2/24	None	None	None	None
SARA	00:00:00:00:00:00:00:11	of-dnoc-227	800	3,50,52				35074			None	None	None	None
IU-100G	00:00:00:00:00:00:00:13	of-dnoc-2637	50	51,53		8C:7C:FF:0D:53:02					None	None	None	None
IU-100G	00:00:00:00:00:00:00:13	of-dnoc-2637	50	51,53		8C:7C:FF:10:0E:02					None	None	None	None
IU-100G	00:00:00:00:00:00:00:13	of-dnoc-2637	50	51,53		8c:7c:ff:0e:06:02					None	None	None	None
IU-100G	00:00:00:00:00:00:00:13	of-dnoc-2637	50	51,53		8c:7c:ff:0d:e7:02					None	None	None	None
IU-100G	c8:08:17:f4:4b:82:00	of-noc	50	19,44		8C:7C:FF:0D:53:02					None	None	None	None
IU-100G	c8:08:17:f4:4b:82:00	of-noc	50	19,44		8C:7C:FF:10:0E:02					None	None	None	None
IU-100G	c8:08:17:f4:4b:82:00	of-noc	50	19,44		8c:7c:ff:0e:06:02					None	None	None	None
IU-100G	c8:08:17:f4:4b:82:00	of-noc	50	19,44		8c:7c:ff:0d:e7:02					None	None	None	None
IU-LB_of-noc	c8:08:17:f4:4b:82:00	of-noc	700	41,63		00:26:b9:5e:2c:86					None	None	None	None

FlowVisor Slicing Policy

- FV intercepts OF messages from devices
  - FV only sends control plane messages to the Slice controller if the src device is in the Slice Topology.
  - Rewrites OF feature negotiation messages so the slice controller only sees the ports in it's slice
  - Port up/down messages are pruned and only forwarded to affected slices

FlowVisor Slicing Policy

- FV intercepts OF messages from controllers
  - Rewrites Flow Insertion, Deletion & Modifications so they don't violate the slice definition
    - Flow definition – ex. Limit Control to HTTP traffic only
    - Actions – ex. Limit forwarding to only ports in the slice
  - Expand Flow rules into multiple rules to fit policy
    - Flow definition – ex. If there is a policy for John's HTTP traffic and another for Uwe's HTTP traffic, FV would expand a single rule intended to control all HTTP traffic into 2 rules.
    - Actions – ex. Rule action is send out all ports. FV will create one rule for each port in the slice.
  - Returns "action is invalid" error if trying to control a port outside of the slice

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FVCTL

- fvctl is the cli used to control a running instance of flowvisor (over XMLRPC)
- fvctl --passwd-file=/etc/flowvisor/fvpasswd command [args…]
- fvctl command [args…]

> fvctl createSlice

- Specifies a controller/slice
  - fvctl createSlice <slicename> <controller_url> <email>
    - controller_url = tcp:<ip address>:<port #>
  - fvctl createSlice FinanceDept tcp:155.55.5.5:6633 bob@finance.example.edu

> fvctl getSliceInfo

- Dumps information about the slice
  - controller_port=6633
  - controller_hostname=140.221.223.153
  - creator=fvadmin
  - contact_email=bob@example.edu

> fvctl changeSlice

- Edit a slice attributes:
  - controller_port=6633
  - controller_hostname=140.221.223.153
  - creator=fvadmin
  - contact_email=you@example.edu
- Examples:
  - fvctl changeSlice <slicename> <key> <value>
  - fvctl changeSlice iCAIR controller_port 6644

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> fvctl listSlices

- lists the slices that have been created
  - Slice 0: iCAIR
  - Slice 1: CPQD
  - Slice 2: Clemson
  - Slice 3: I2-NOX
  - Slice 4: IU-100G
  - Slice 5: SARA
  - Slice 6: ESNet
  - Slice 7: fvadmin

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> fvctl deleteSlice

- Delete a slice, and the slice's corresponding flowspace
  - fvctl deleteSlice ESNet

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> fvctl listDevices

- List DPID of all connected OpenFlow devices

Device 0: 00:00:0e:83:40:39:18:58

Device 1: 00:00:0e:83:40:39:1a:57

Device 2: 00:00:0e:83:40:39:19:96

Device 3: 00:00:0e:83:40:39:1b:93

Device 4: 00:00:0e:83:40:39:18:1b

Device 5: 00:00:0e:84:40:39:19:96

Device 6: 00:00:0e:84:40:39:1a:57

Device 7: 00:00:0e:84:40:39:1b:93

Device 8: 00:00:0e:84:40:39:18:1b

Device 9: 00:00:0e:84:40:39:18:58

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> fvctl getLinks

- List port # and DPID of both ends of each link
- Link 0:
  Link[srcDPID=00:00:0e:83:40:39:1b:93,srcPort=2,dstDPID=00:00:0e:83:40:39:18:1b,dstPort=2]
- Link 1:
  Link[srcDPID=00:00:0e:84:40:39:18:1b,srcPort=2,dstDPID=00:00:0e:84:40:39:1b:93,dstPort=2]

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> fvctl addFlowSpace

- Insert a flowspace rule
  - fvctl addFlowSpace <dpid> <priority> <match> <actions>
  - fvctl addFlowSpace 00:c8:08:17:f4:4b:82:00 100 in_port=22 Slice:ESNet=4

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dpid

- Unique DPID
  - 00:00:00:23:10:35:ce:a5
  - HP VLAN:MAC-ADDRESS
    - VLAN 10 - 00:0a:2c:27:d7:76:ea:80
    - VLAN 20 - 00:14:2c:27:d7:76:ea:80
    - VLAN 30 - 00:1e:2c:27:d7:76:ea:80
    - VLAN 40 - 00:28:2c:27:d7:76:ea:80
- Wildcard DPID
  - ff:ff:ff:ff:ff:ff:ff or “any” or “all”

priority

- Flow entries are sorted by PRIORITY (high number is higher priority) and only the highest priority matched is considered.
- Priorities are any positive integer in the range [0:2^31]

match

- Flow packet match fields
  - **in_port**=port_no
  - **dl_vlan**=vlan
  - **dl_src/dl_dst**=mac
  - **nw_src/nw_dst**=ip[/netmask]
  - **nw_proto**=proto
  - **nw_tos**=tos/dscp
  - **tp_src/tp_dst**=port

actions

- Comma-separated list of slices with control permissions over matching flowspace
- Permissions
  - Delegate=1
  - Read=2
  - Write=4
- Ex. Slice:IU-LB=4,Monitor=2

> fvctl listFlowSpace

- Dumps a list of the FlowSpace rules, matching:
  - listFlowsSpace
    - rule #: <dpid>,<ruleMatch>,<actionList>,<id>,<priority>
      - dpid=[00:00:00:00:00:00:00:13]
      - ruleMatch=[OFMatch[in_port=53,dl_src=8c:7c:ff:0d:e7:02]]
      - actionsList=[Slice:IU-100G=4]
      - id=[62973]
      - priority=[50]

> fvctl changeFlowSpace

- Change an existing FlowSpace rule
  - fvctl changeFlowSpace <id><dpid> <priority> <match> <actions>

    fvctl changeFlowSpace 62973 00:00:00:00:00:00:00:13 50 in_port=53 Slice:IU-100G=4

> fvctl removeFlowSpace

- Remove an existing FlowSpace rule
  - fvctl removeFlowSpace <id>
    - fvctl removeFlowSpace 62973

> complete list of fvctl commands

- listSlices
- createSlice <slicename> <controller_url> <email>
- changeSlice <slicename> <key> <value>
- deleteSlice <slicename>
- changePasswd <slicename>
- getSliceInfo <slicename>
- getSliceStats <slicename>
- getSwitchStats <dpid>
- getSwitchFlowDB <dpid>
- getSliceRewriteDB <slicename> <dpid>
- listFlowSpace
- removeFlowSpace <id>
- addFlowSpace <dpid> <priority> <match> <actions>
- changeFlowSpace <id> <dpid> <priority> <match> <actions>
- listDevices
- getDeviceInfo <dpid>
- getLinks
- ping <msg>
- getConfig <configEntry>
- setConfig <configEntry> <value>
- registerCallback <URL> <methodName> <cookie>
- registerTopologyEventCallback <URL> <methodName> <eventType>
- deregisterTopologyEventCallback <method> <eventType>
- unregisterCallback

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FlowVisor

- git clone git://gitosis.stanford.edu/flowvisor.git
- https://openflow.stanford.edu/display/DOCS/Installation+Guide

Expedient / Opt-In manager

- Software to tie campus OpenFlow deployments to GENI.
- Allows Aggregate Providers (Campus) to make a “sliver” of a switch available to researchers
- Integrates with Flowvisor XMLRPC interface and GENI AAA infrastructure
  - http://www.openflowswitch.org/foswiki/bin/view/OpenFlow/Deployment/HOWTO/ProductionSetup/InstallingExpedientOIM

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FOAM

- FlowVisor OpenFlow Aggregate Manager
  - Replaces the AM and OIM parts of Expedient
  - GENI AM API interface for experimenters
  - JSON API interface for management
  - foamctl command-line interface to the JSON API

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FlowVisor Lab 1

Insert FlowVisor between Controller and Switch

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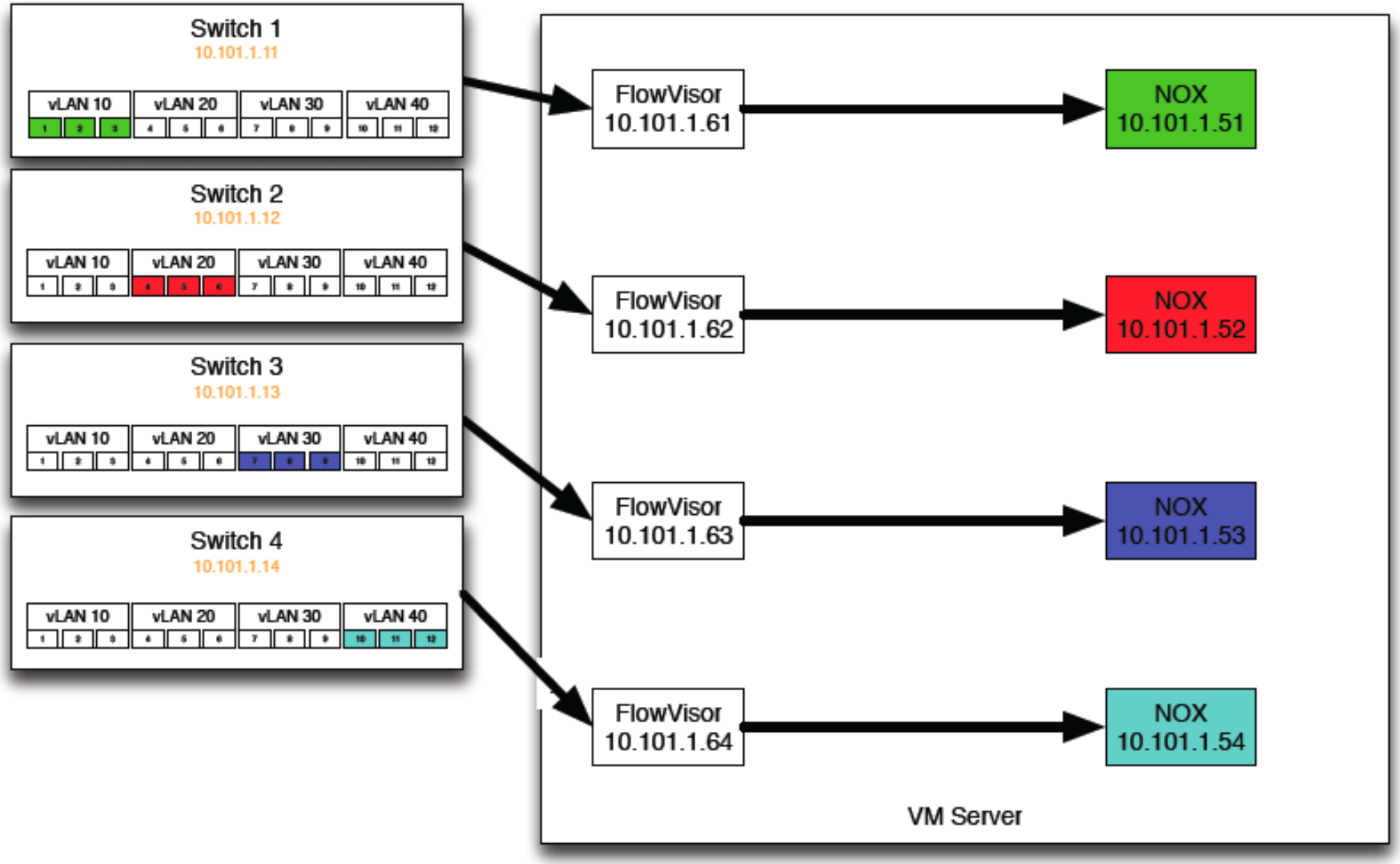
configure FlowVisor to connect to NOX



Start FlowVisor

- Login to FV VM
- Reset the Flowvisor config
  > sudo fvconfig generate /usr/etc/flowvisor/config.xml
  - set password as “flowvisor” (without quotes)
- Start Flowvisor

  > /usr/sbin/flowvisor /usr/etc/flowvisor/config.xml &

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Restart NOX (if necessary)

- Login to NOX-[group_num] VM
  # cd /home/openflow/nox/build/src
  # ./nox_core -v -i ptcp:6633 pyhub &

Reconfigure Switch

- Point OF VLAN at FV as its controller

  vlan <group vlan number>

  openflow disable

  no openflow controller tcp:<controller ip address>:6633
  openflow controller tcp:<flowvisor ip address>:6633
  openflow enable

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Create Slice & FlowSpace

- Create Slice (pick a slice name and email address
  - fvctl createSlice <slice name> tcp:<nox controller ip address>:6633 <email_address>
- Create Flowspace (replace x,y,z with assigned ports)
  - fvctl addFlowSpace <switch dpid> <priority> in_port=x Slice:<slice name>=4
  - fvctl addFlowSpace <switch dpid> <priority> in_port=y Slice:<slice name>=4
  - fvctl addFlowSpace <switch dpid> <priority> in_port=z Slice:<slice name>=4

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Verify

- List Existing Slices & Devices
  - fvctl listSlices
  - fvctl getSliceInfo <slicename>
  - fvctl getSliceInfo <slicename>
  - fvctl getSliceStats <slicename>
  - fvctl listDevices
  - fvctl getDeviceInfo <dpid>
  - fvctl getSwitchStats <dpid>
  - fvctl getSwitchFlowDB <dpid>
  - fvctl getLinks
  - fvctl listFlowSpace
- Verify NOX sees switch DPID
- Ping between hosts

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FlowVisor Lab 2

Expand each groups repeater across all four switches

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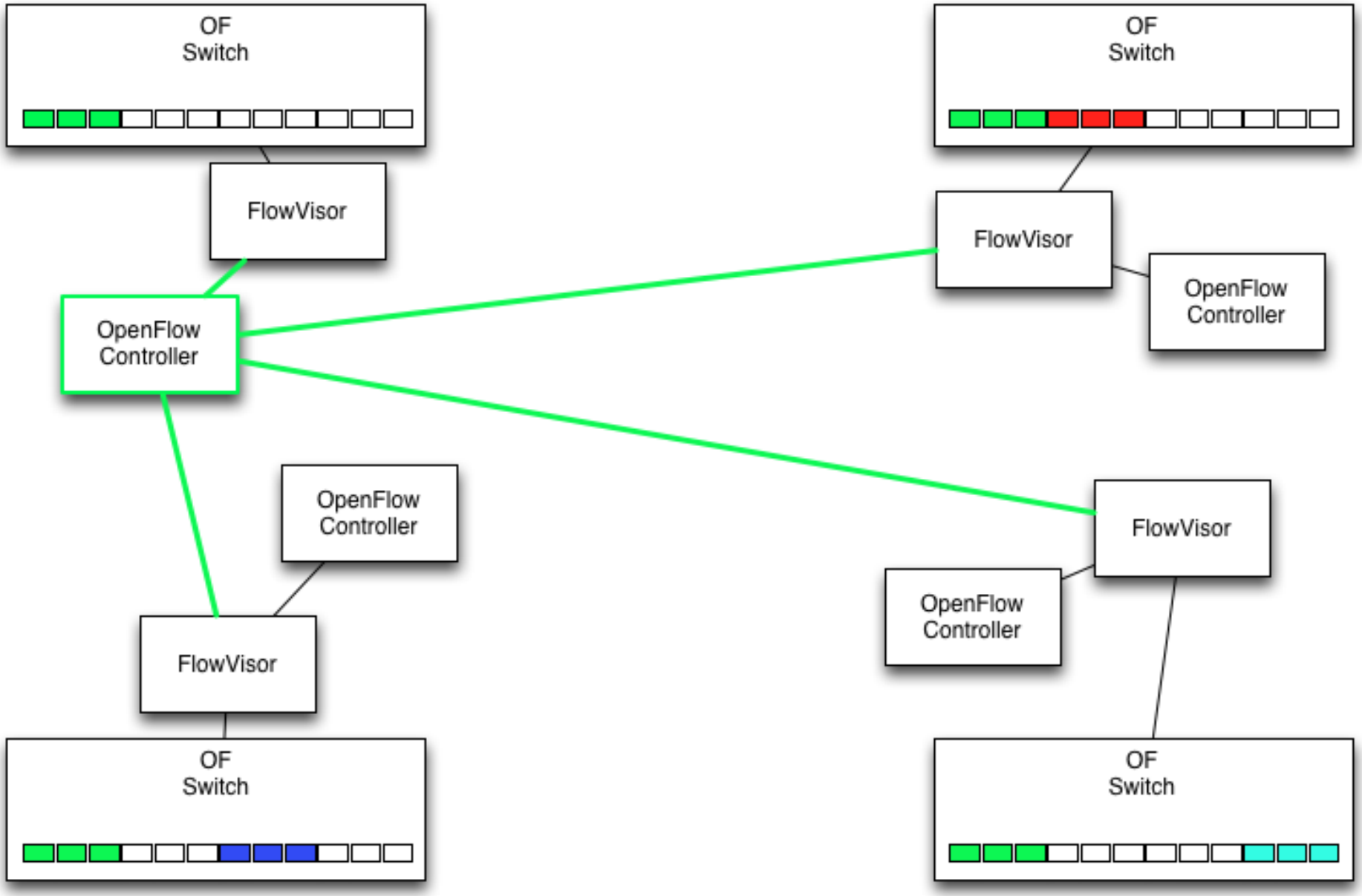
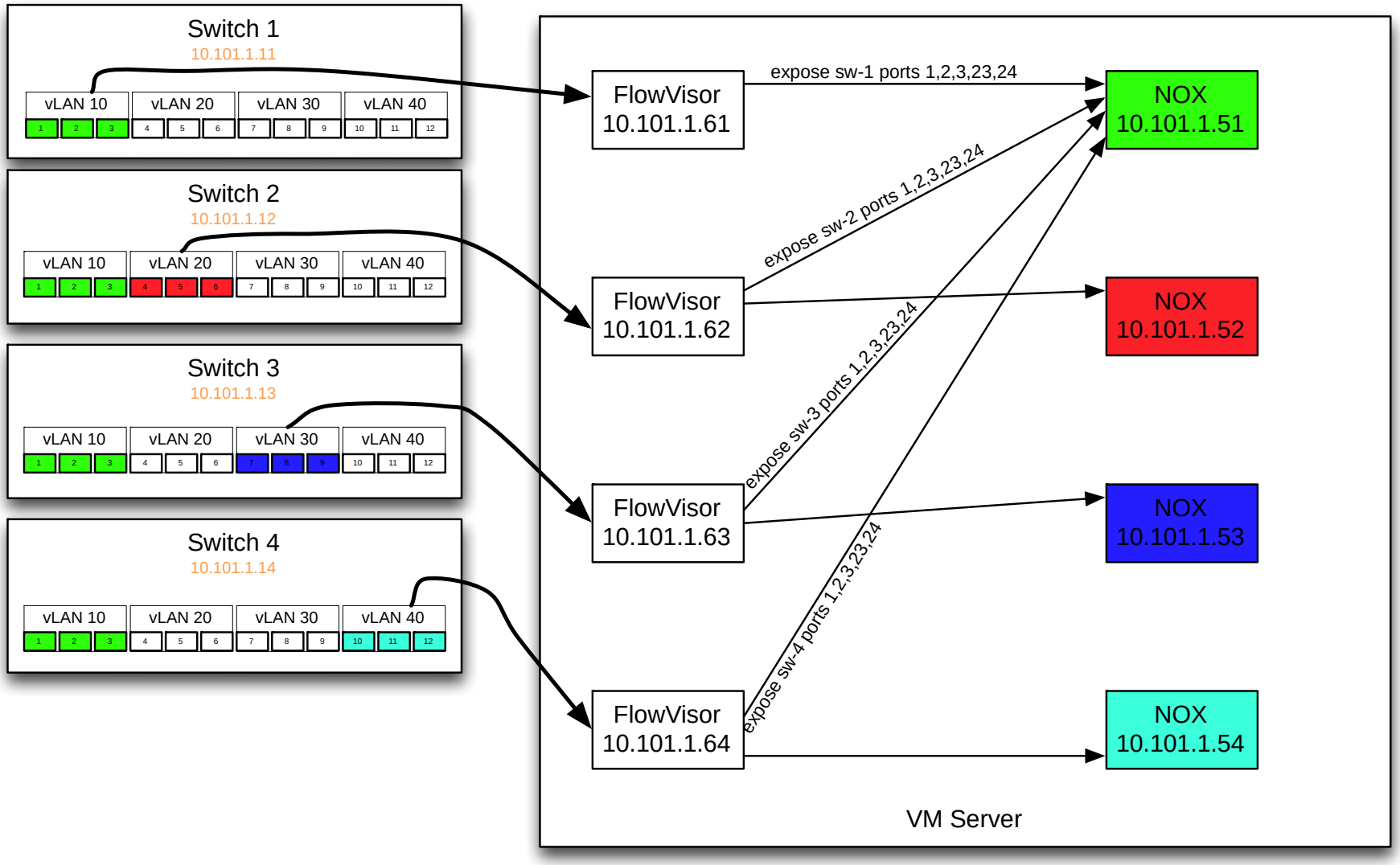
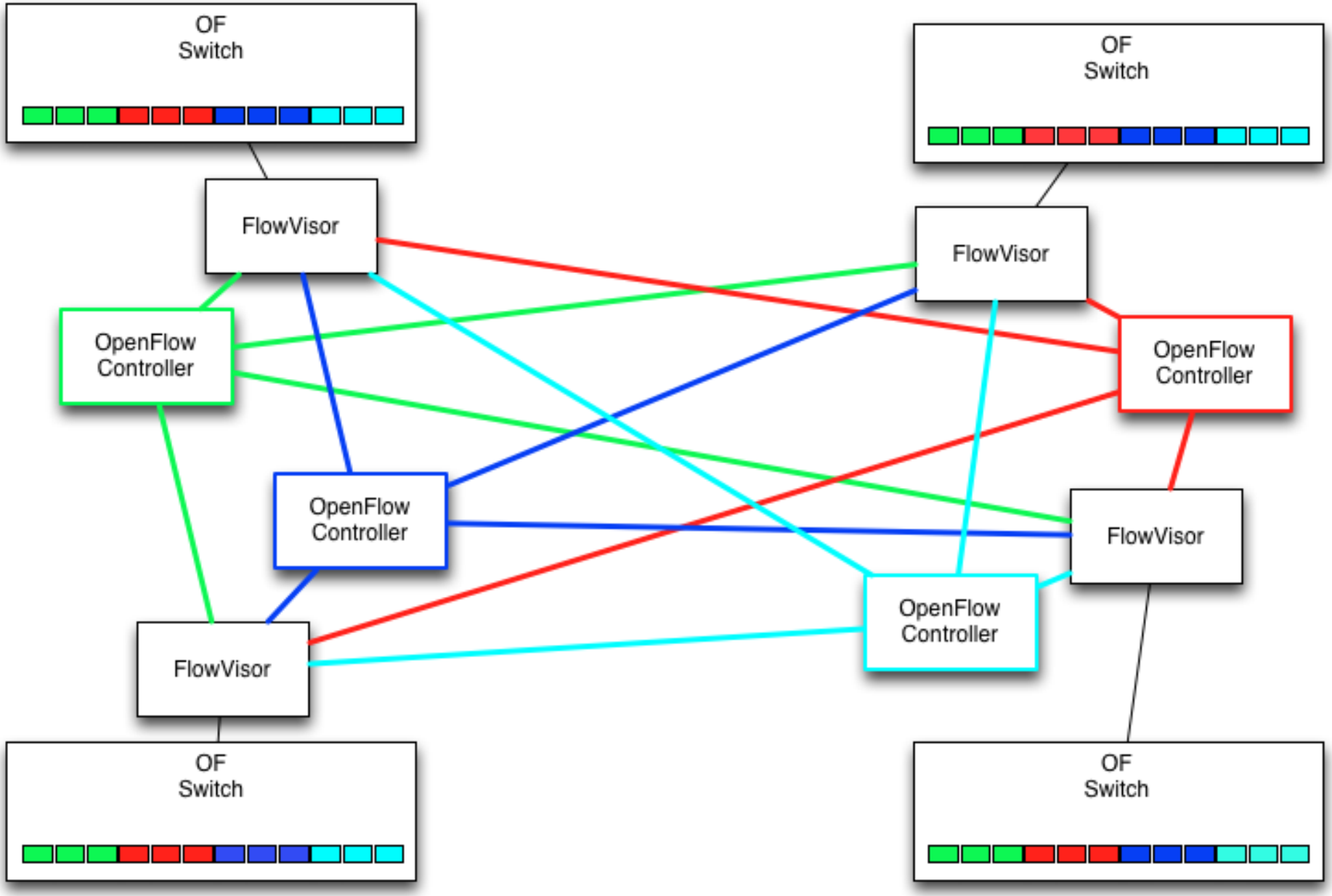
Extends each hub to each team's switch.



create a 12 port distributed hub using NOX



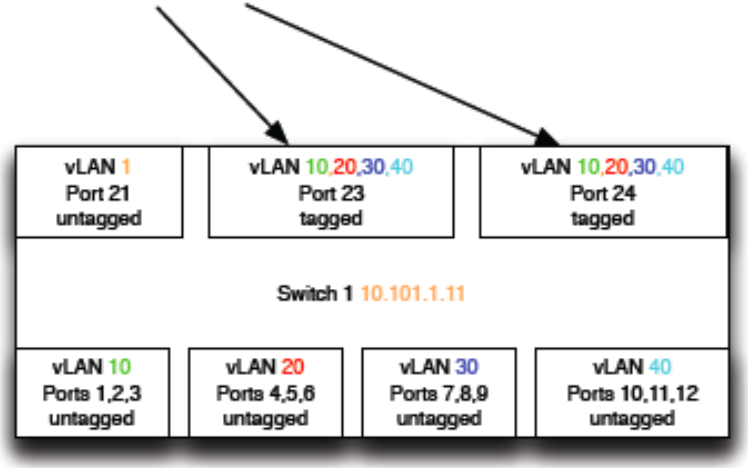
Extends each hub to each team's switch.



Flow Table for three port distributed repeater

Header Fields (to match packets against)	Actions (what to do with packets that match)
Ingress Port == 1?	Forward Port 2
	Forward Port 3
	Forward Port 23 *
	Forward Port 24 *
	End

* When forwarding packets via tagged interfaces, the HP automatically adds the appropriate vLAN tag.



Configure Switch

- On your own switch configure an openflow vlan for each of the other 3 groups and point them to your flowvisor

```
vlan <group vlan number>
 name “OpenFlow VLAN Group <group number>”
   untagged <group port range>
   tagged <trunk port list>
   openflow enable
   openflow controller tcp:<flowvisor ip address>:6633
```

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Configure FlowVisor

- On your flowvisor, create 3 additional slices pointing to each other groups NOX controller
  - fvctl createSlice <slice name> tcp:<nox controller ip address>:6633 <email_address>
- Create FlowSpace for each Slice
  - fvctl addFlowSpace <switch dpid> <priority> in_port=x Slice:<slice name>=4
  - fvctl addFlowSpace <switch dpid> <priority> in_port=y Slice:<slice name>=4
  - fvctl addFlowSpace <switch dpid> <priority> in_port=z Slice:<slice name>=4

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Restart NOX (if necessary)

- Login to NOX-[group_num] VM
  > cd /home/openflow/nox/build/src
  > ./nox_core -v -i ptcp:6633 pyhub &

Verify

- List Existing Slices & Devices
  - fvctl listSlices
  - fvctl getSliceInfo <slicename>
  - fvctl getSliceInfo <slicename>
  - fvctl getSliceStats <slicename>
  - fvctl listDevices
  - fvctl getDeviceInfo <dpid>
  - fvctl getSwitchStats <dpid>
  - fvctl getSwitchFlowDB <dpid>
  - fvctl getLinks
  - fvctl listFlowSpace
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