

# OpenFlow BoF

Internet2 Joint Techs – Clemson

Jan 31 2011



# Sections

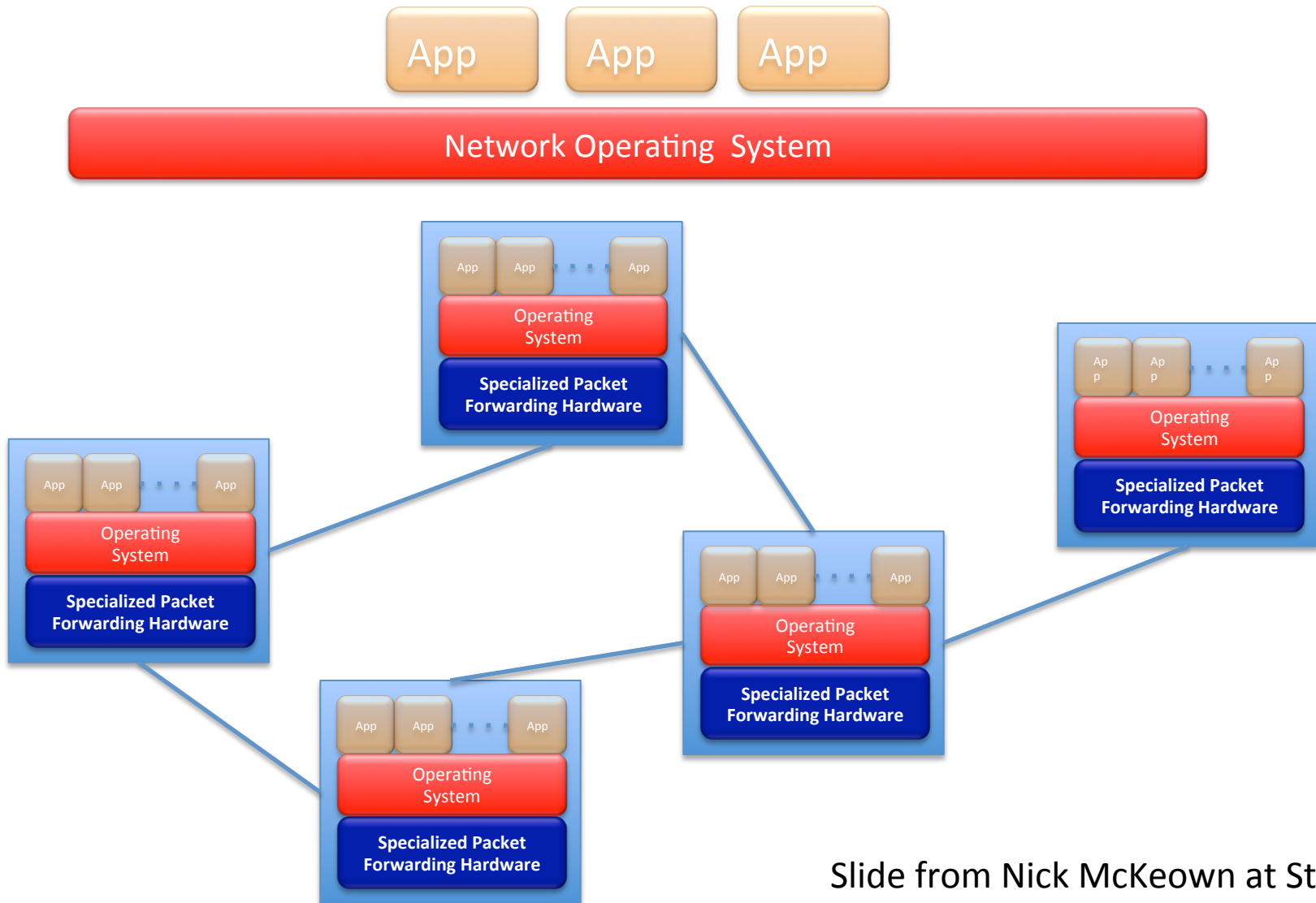
- OpenFlow introduction
- OpenFlow use cases
- Current and future deployments
- Software and hardware
- Demos
- Discussion



# Keys to Openflow/Software-Defined Networking

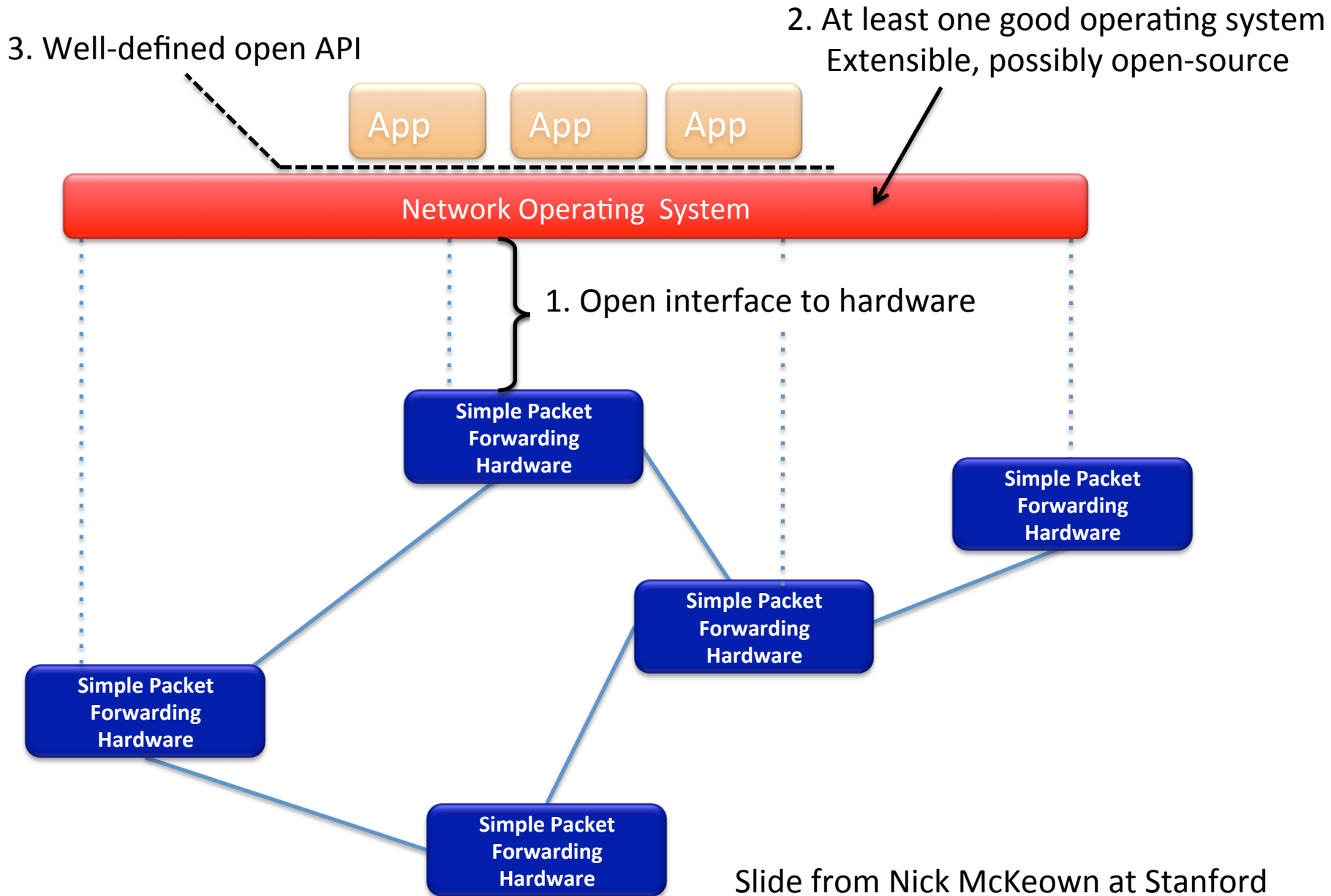
- Separation of Control Plane & Data Plane with Open API Between the Two
  - Logically Centralized Control-Plane with Open API to Applications
  - Network Slicing/Virtualization
- 
- Creates Open Interfaces between Hardware, OS and Applications Similar to Computer Industry
  - Increases Competition, Enables Innovation



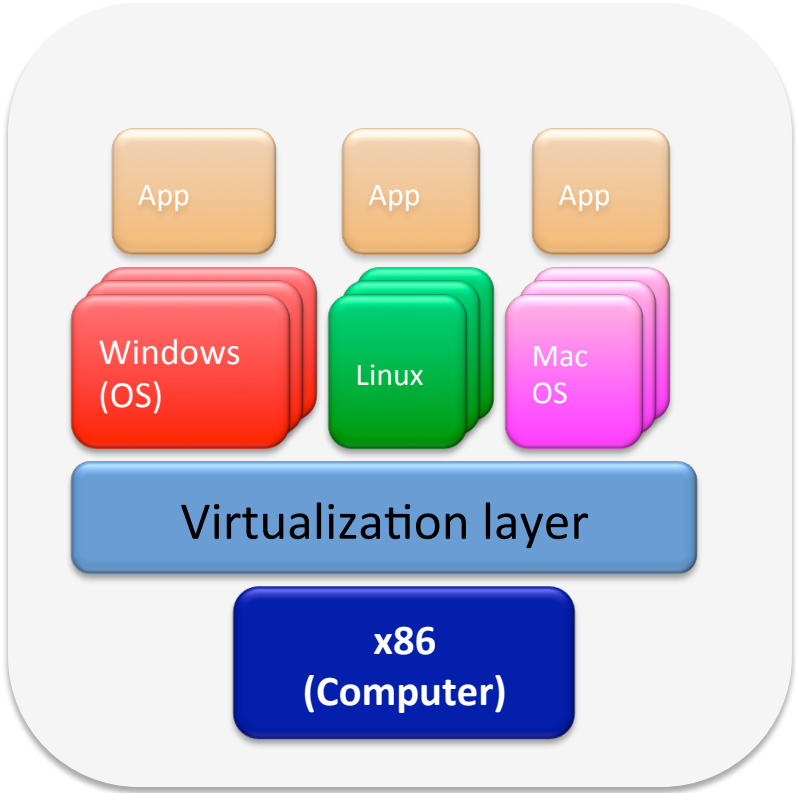


Slide from Nick McKeown at Stanford

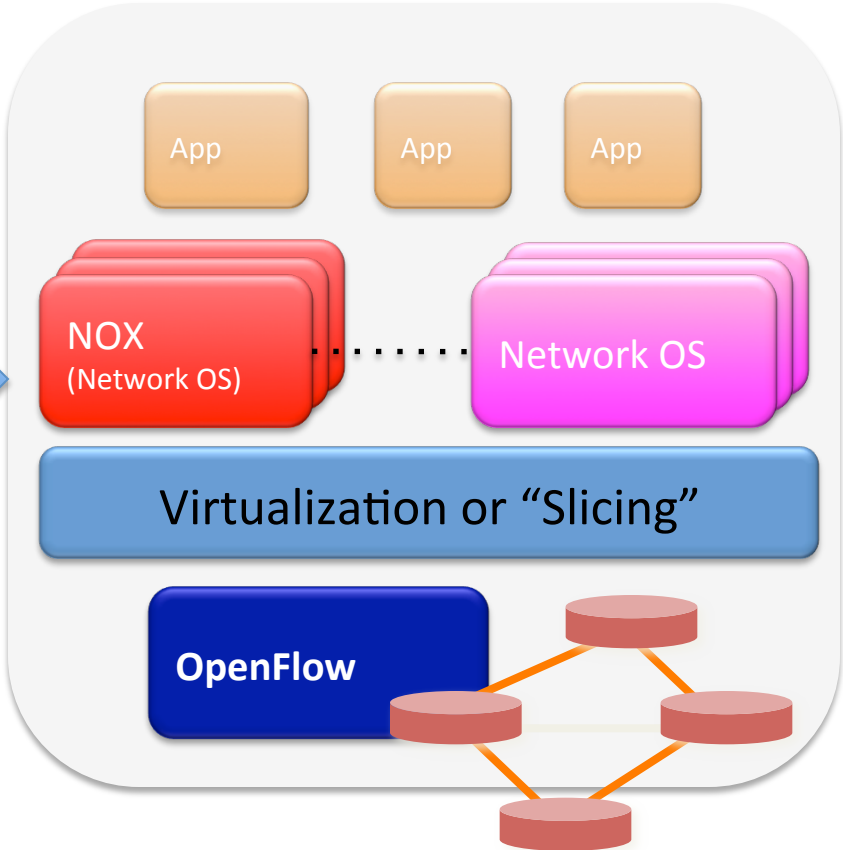
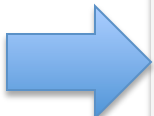
# The “Software-defined Network”



# Trend



Computer Industry

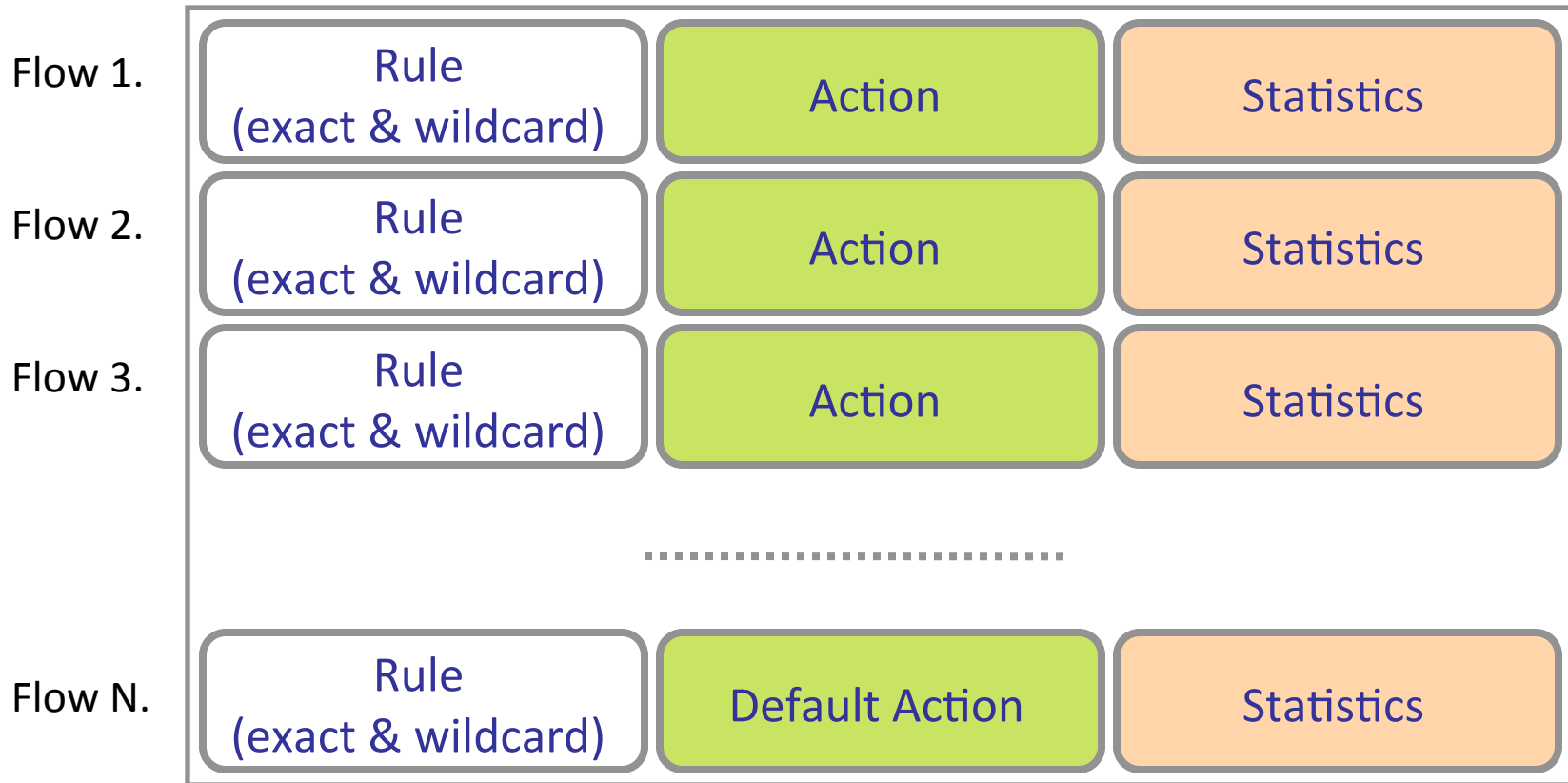


Network Industry

# OpenFlow Basics

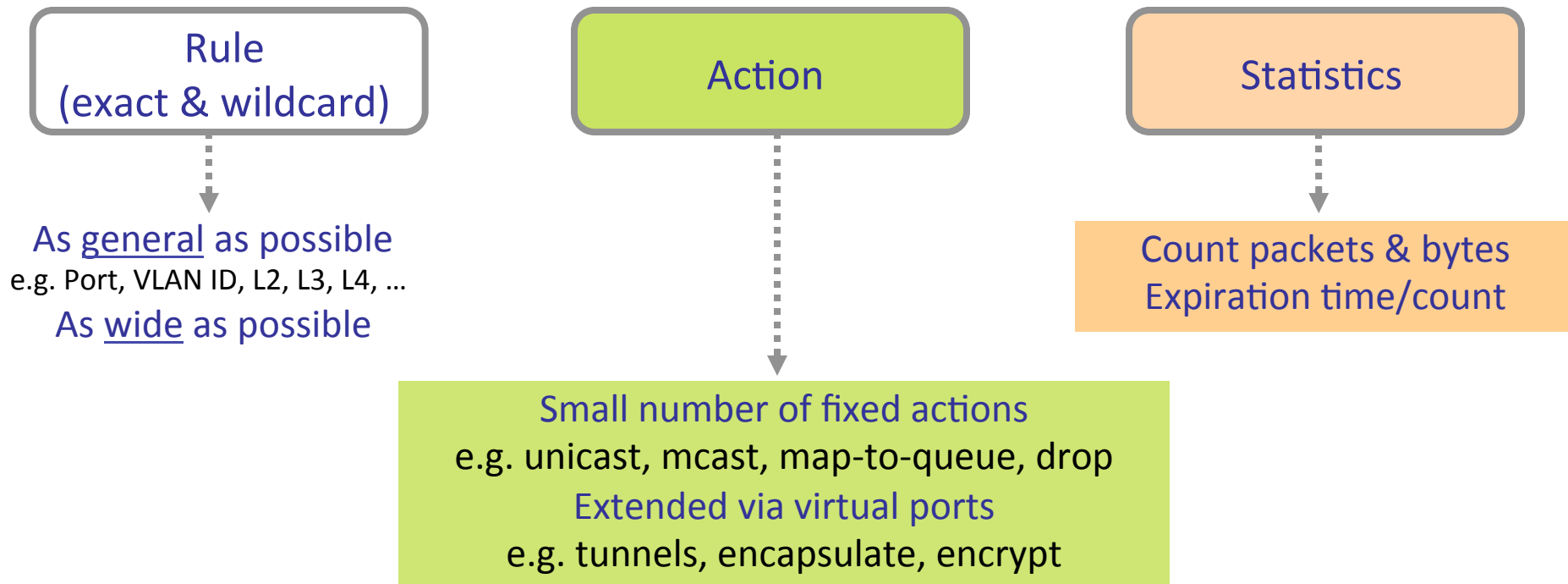
# OpenFlow Basics (1)

Exploit the flow table in switches, routers, and chipsets



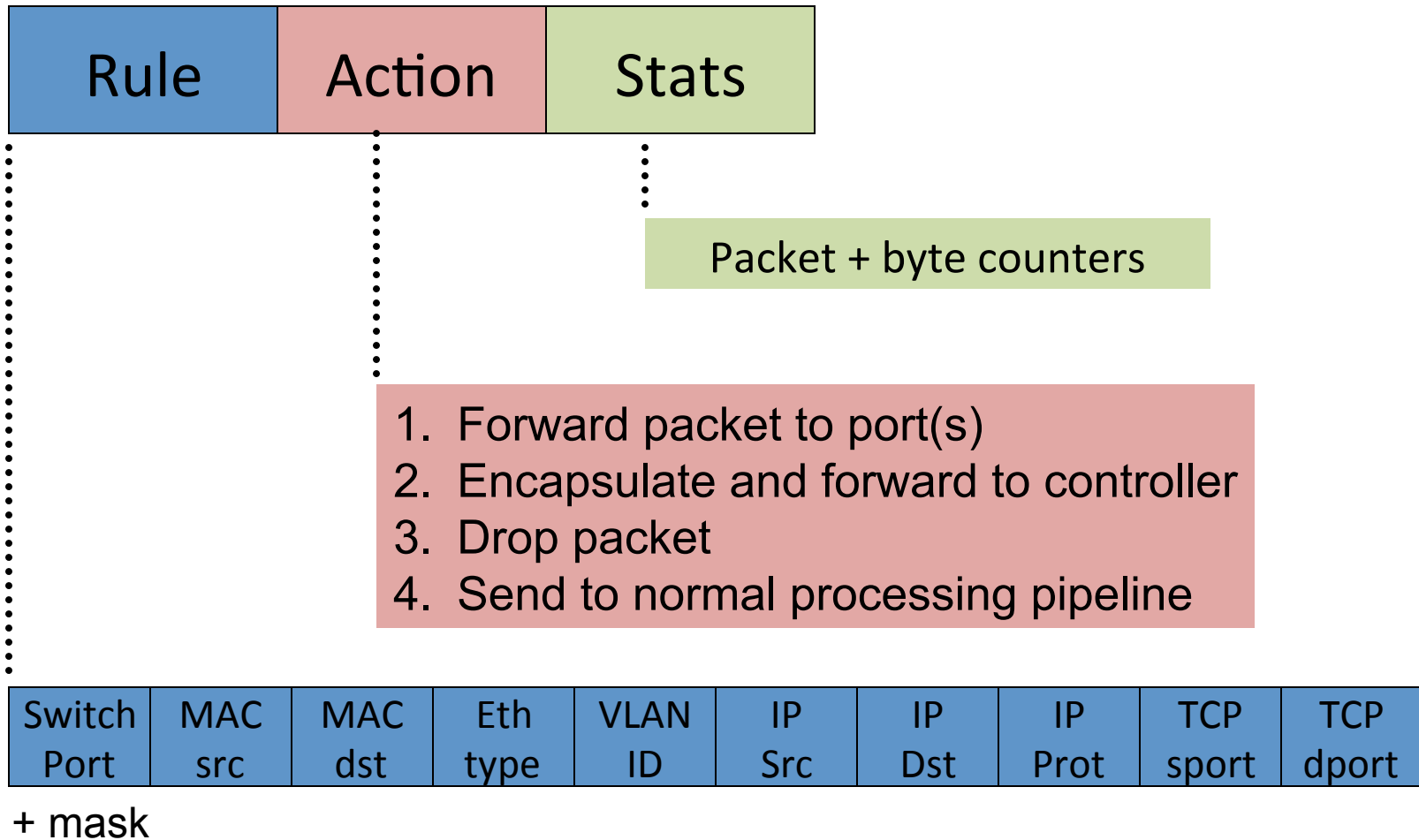


# OpenFlow Basics (2)

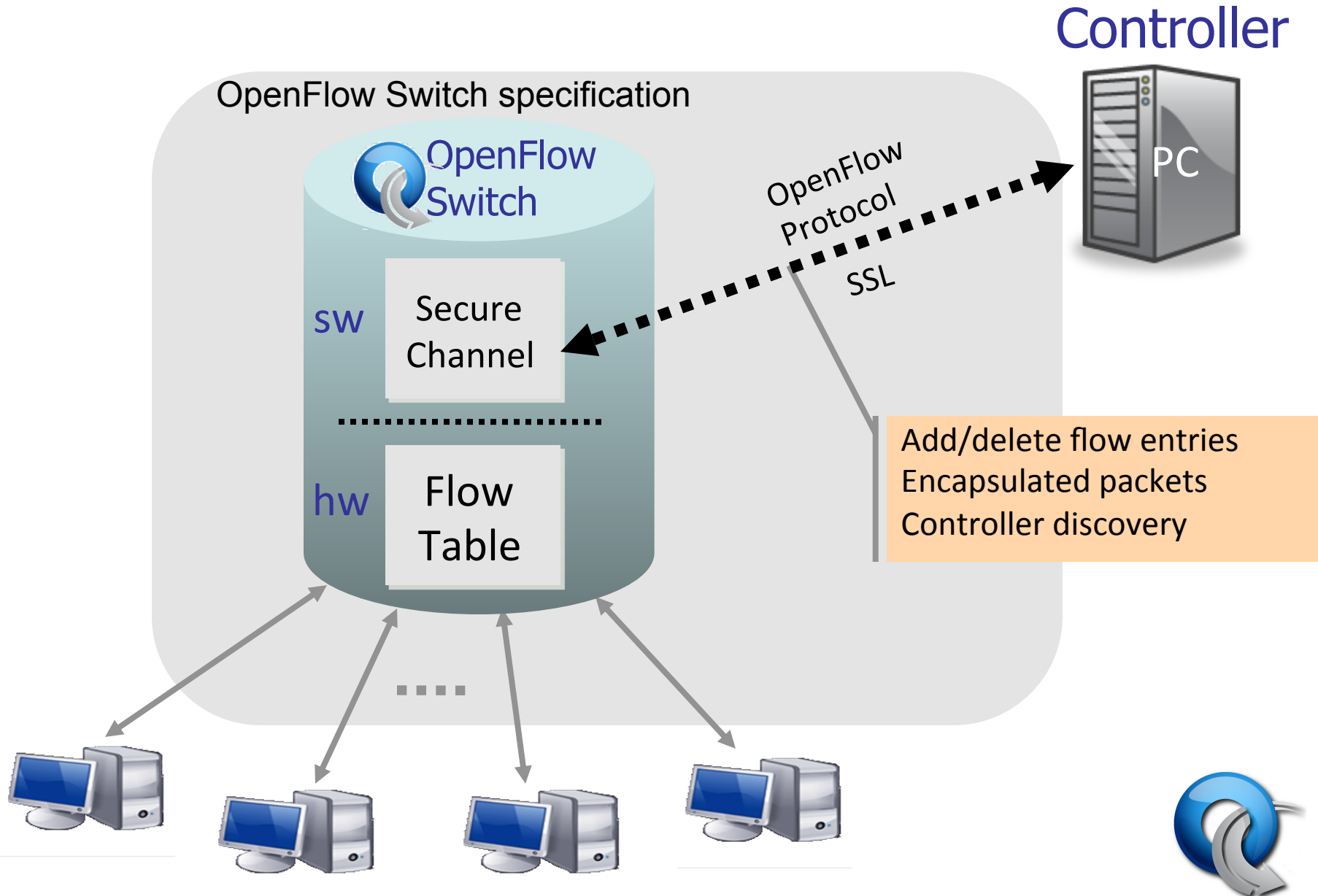


# Flow Table Entry

## OpenFlow 1.0 Switch



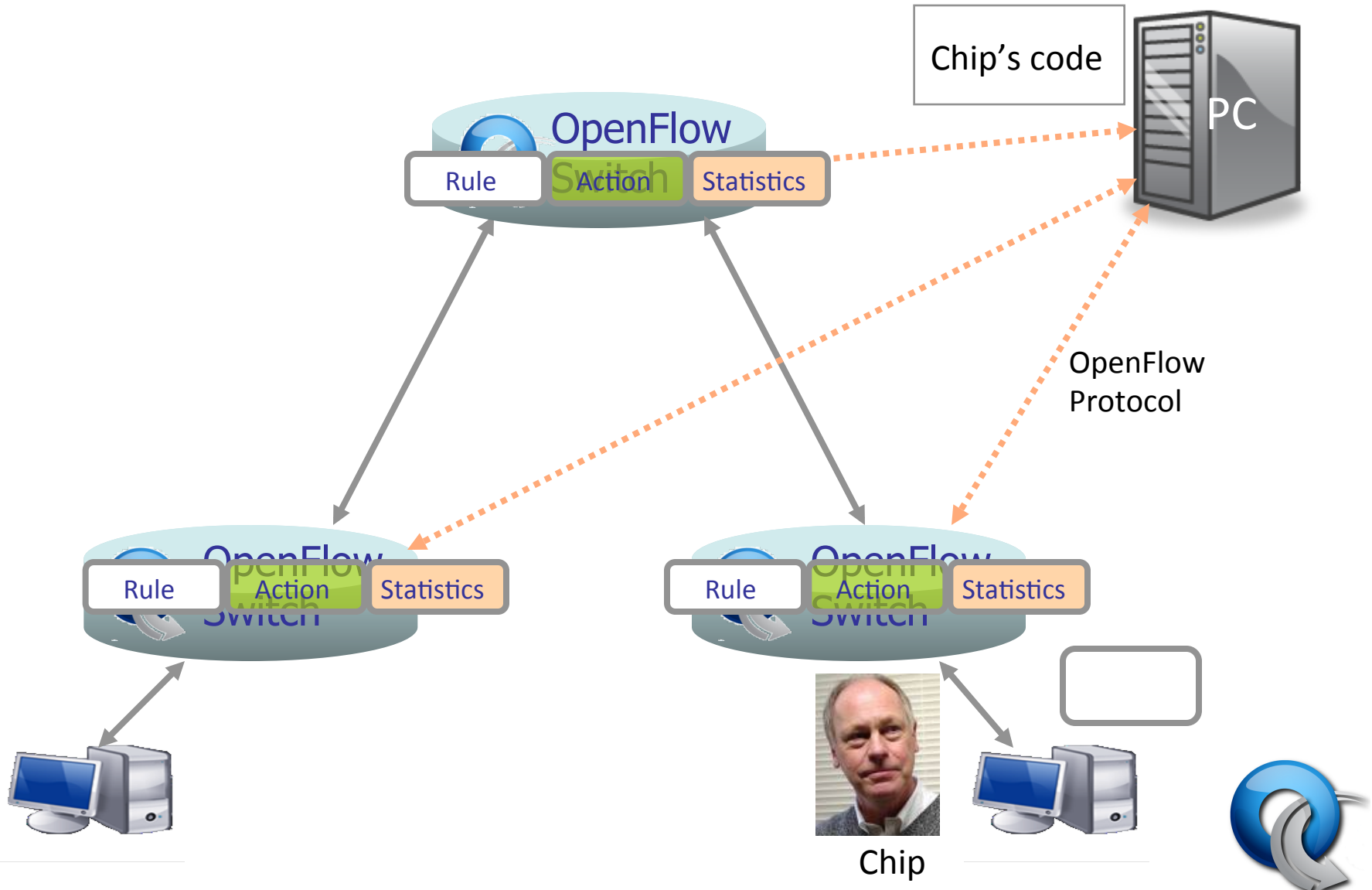
# OpenFlow Basics (3)



# OpenFlow Usage

## Dedicated OpenFlow Network

## Controller



# What will we do with OpenFlow ?

- 1k-3k TCAM Entries in Typical Edge Switch
- Difficult to take advantage of:
  - Manual Config, SNMP Writes, RADIUS
  - Limited Actions (allow/deny)
  - Vendor Specific
- But what if you could program these through a standard API ?



# Possible Uses of Openflow (Quick Wins)

- Security Applications
  - NAC
  - IDS/IPS
  - Remote Packet Capture & Injection
- VM Mobility
  - Redirect specific application traffic to remote site
  - Flow-based forwarding – no need to extend entire broadcast domain – no STP issues



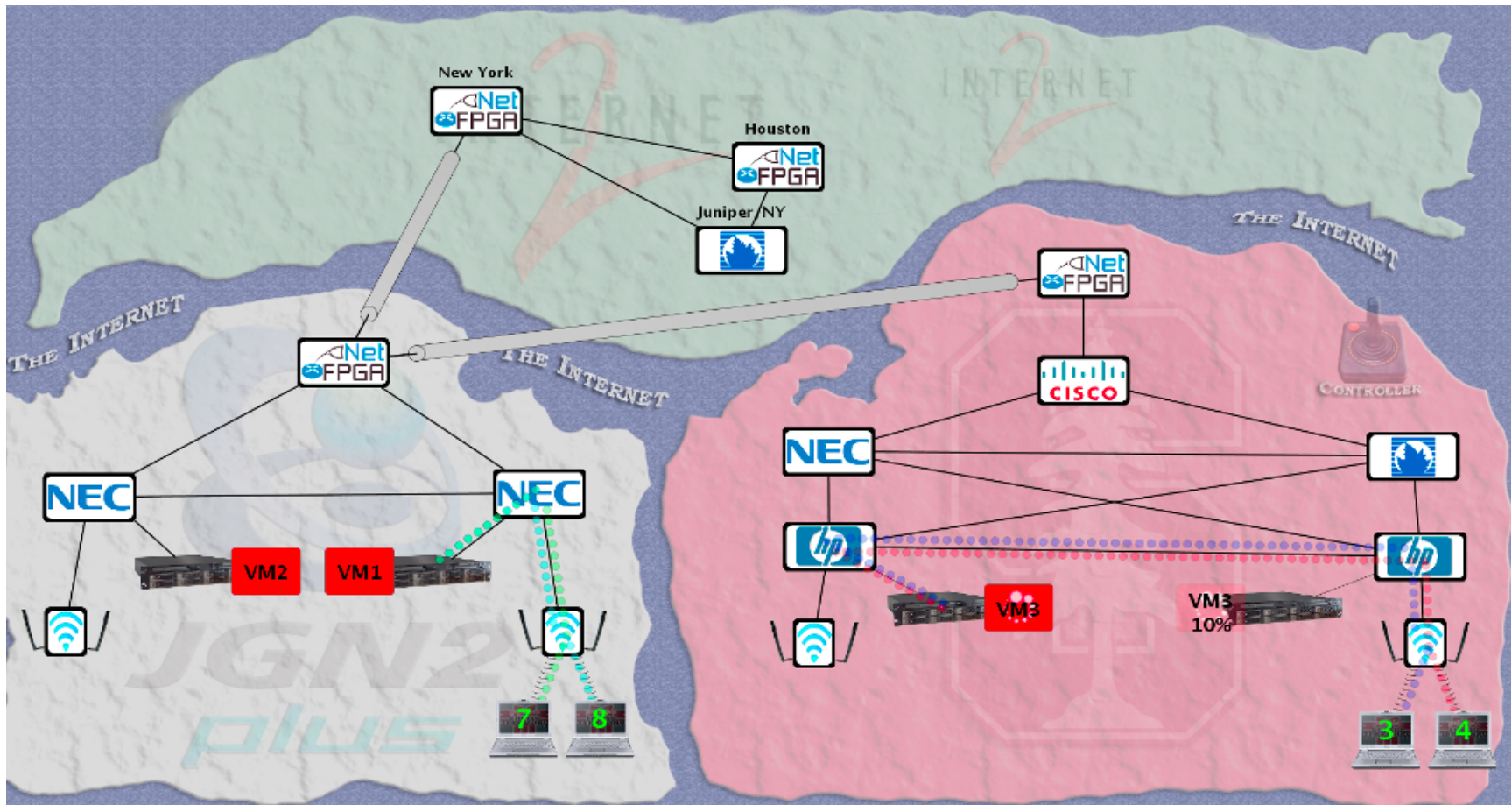
# Other Applications

- Load Balancing
- n-cast
  - multiple streams over lossy networks
- Load balancing
- Policy (Firewall)
- Flow based network provisioning



# Intercontinental VM Migration

Moved a VM from Stanford to Japan without changing its IP.  
VM hosted a video game server with active network connections.





# Possible Uses of Openflow (Quick Wins)

- Dynamic Circuit Provisioning
  - Don't need to extend layer-2 end-to-end
  - Simply direct specific flows down a engineered path with guaranteed priority
  - Don't have to rely on scripted SSH sessions, SNMP or other sub-optimal ways to programmatically configure switches/routers.



# Possible Uses of Openflow (Grand Challenges)

- Distributed Control-Plane Architecture Requires a Lot of State to be Synchronized Across Many Devices
- Many Protocols Needed for Synchronization Internally to Networks (OSPF, RSVP, STP, etc)
- Can these “internal” protocols eventually be removed entirely with only BGP for inter-domain route advertisements ?



# Deployments



# GENI

- GENI OpenFlow deployment on 8 campuses
- Internet2 and NLR backbones
- Integrated with Production hardware on campuses
- Backbone, Regionals (funded in GENI Solicitation 3) and Campuses interconnected
- Outreach to more campuses in future?



# OpenFlow and GENI



8 Universities, GPO/BBN, & 2 National Backbones

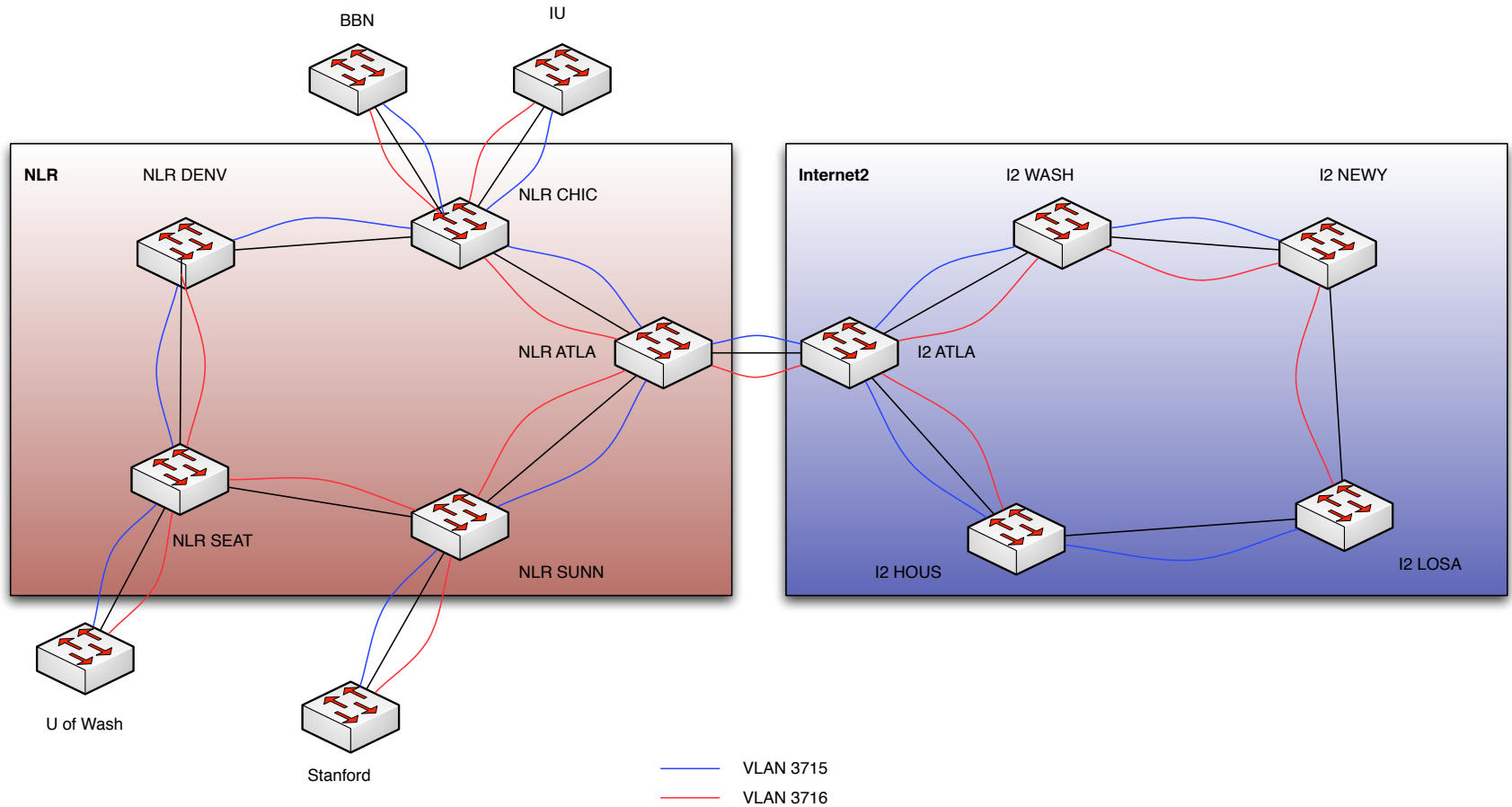
# Internet2 and NLR

- Internet2
  - Backbone of 5 NEC IP8800
  - Multiple 1G connections (in each direction)
  - L2circuits between sites
- NLR
  - Backbone of 5 HP 6600-24XG
  - 10 G wave between sites



# NLR – I2 OpenFlow Core

OpenFlow Core  
Connectivity v.1.0



# IU Campus Deployment

- Focused on Edge (Closet) Deployment
- Goals:
  - Stress-Test Current Implementations
  - Verify “Sandboxing” of Openflow
  - Develop Monitoring Tools
  - Prepare for Production Deployments





# IU Deployment

- HP switches in Testlab and Production
  - 4 6600s in Bloomington testlab
  - 1 5406in Testlab/Wireless
  - 2 5406 used by Engineering
  - 3500 in Gigapop
- Pronto switches (w/ Purdue Calumet)
- NetGear switches
- NetFPGA 10G and 1G?



# BLDC

## Production SNAC

snac-prod.grnoc.iu.edu

## Testlab SNAC

snac.grnoc.iu.edu

Non-OpenFlow  
Agg BLDC  
10.56.4.9

OF.Wireless  
10.56.4.11

CR.BLDC

VLAN 304  
305

VLAN 304,305

VLAN 304, 305

VLAN 304

VLAN 304

BSF42-19,20

VLAN 9

# WCC

WCC ENG  
10.129.9.10

VLAN 9

OF.WCC  
10.56.4.10

A21

304

9

OpenFlow  
WCC Wired  
Users

Vlan 9  
Syseng  
Wired

Wireless Switch  
10.100.1.6

304

HP WESM  
(Lindley Hall)  
Wireless

Wireless Switch  
10.13.0.34

304

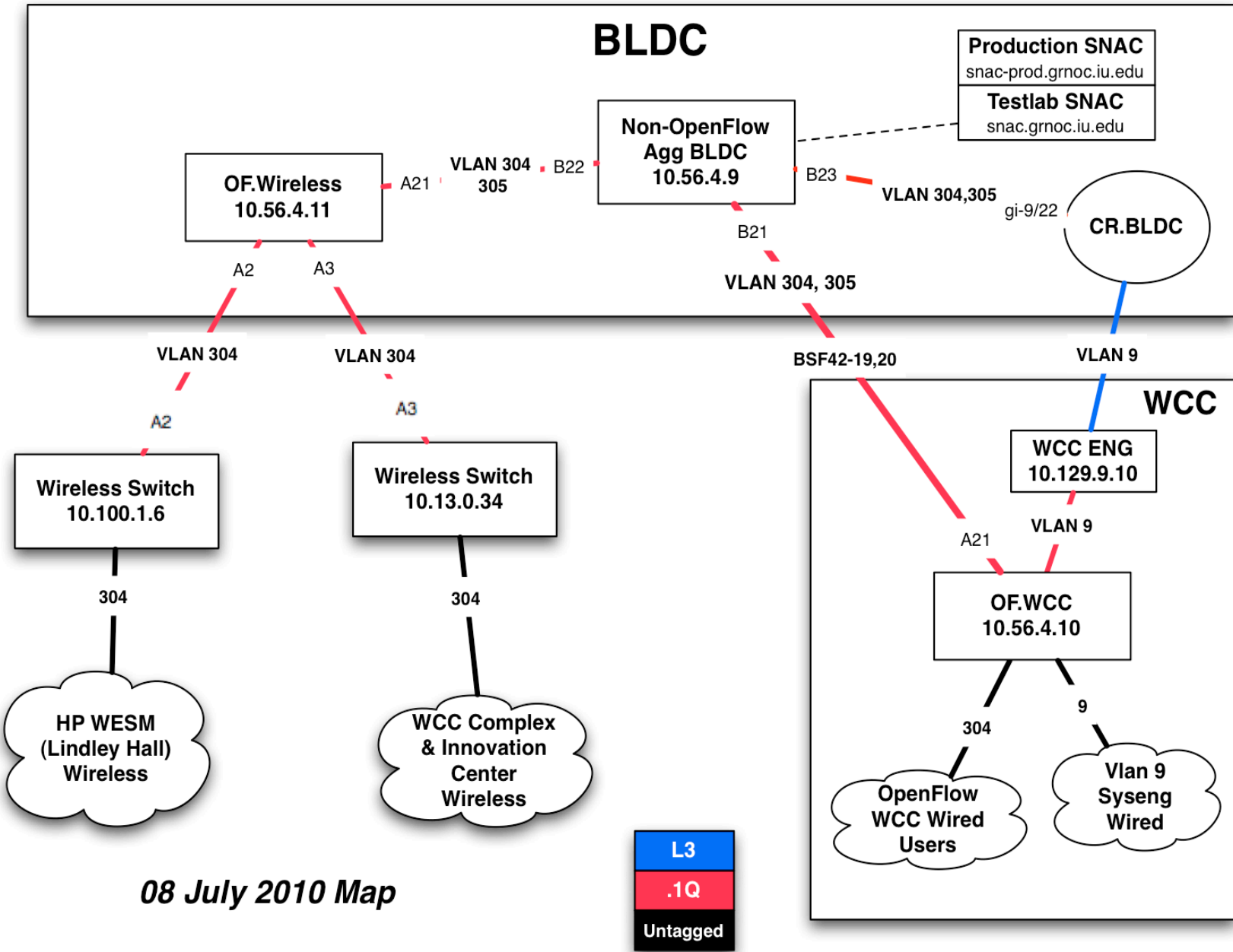
WCC Complex  
& Innovation  
Center  
Wireless

L3

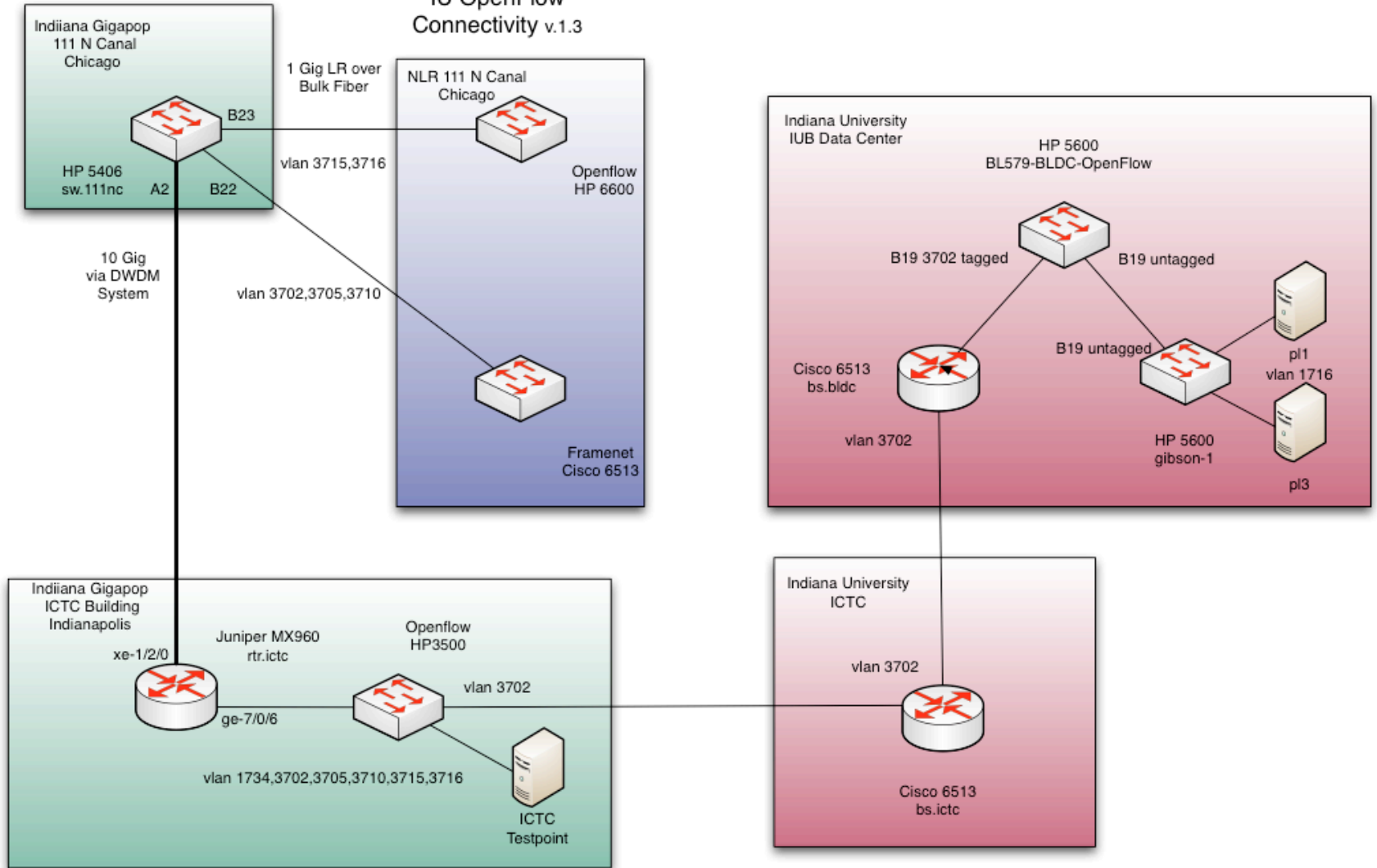
.1Q

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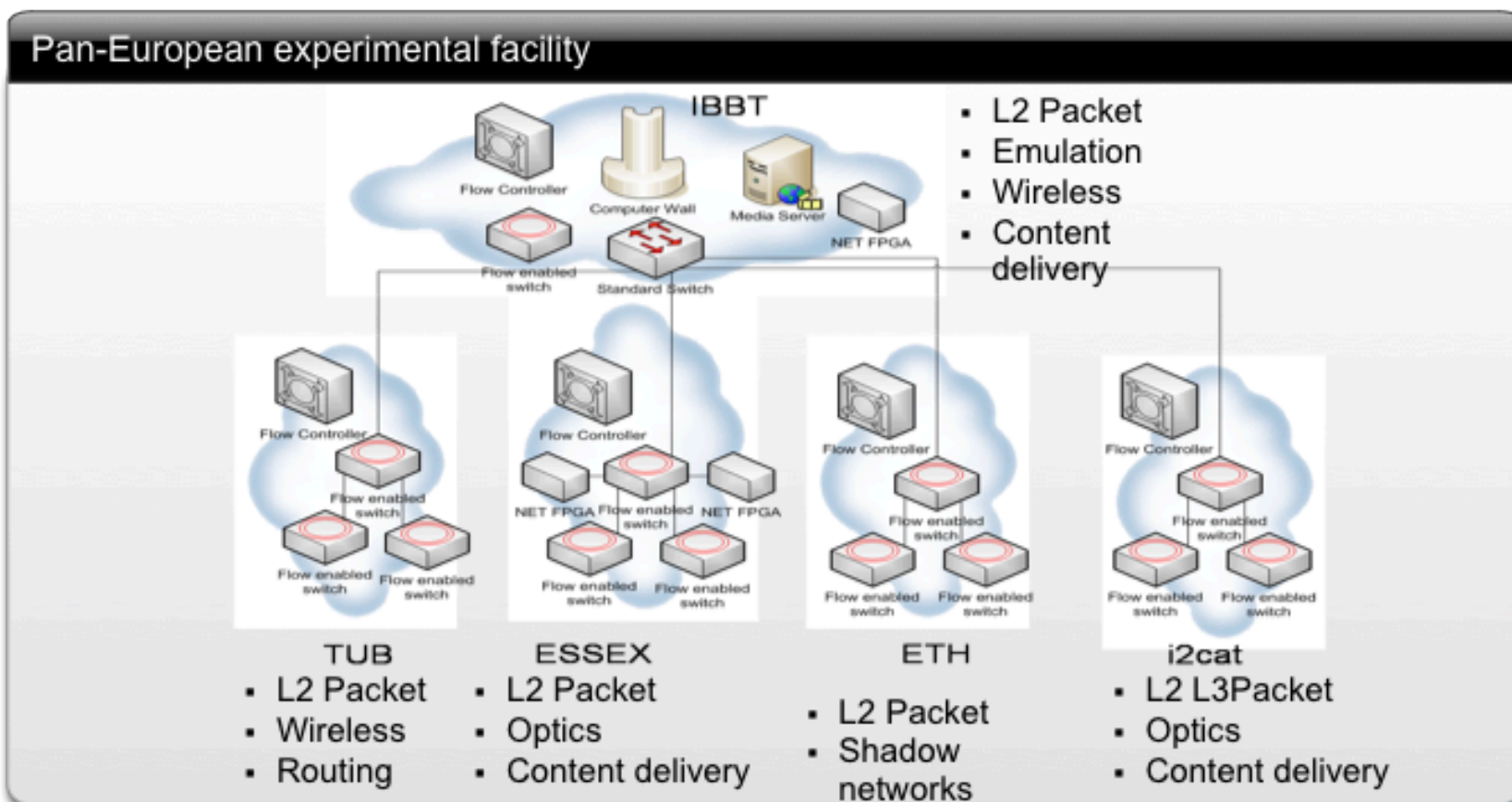
08 July 2010 Map



## IU OpenFlow Connectivity v.1.3



# 3 New EU Projects: OFELIA, SPARC, CHANGE



# EU Project Participants

- Germany
  - Deutsch Telekom Laboratories
  - Technische Universität Berlin
  - European Center for ICT
  - ADVA AG Optical Networking
  - NEC Europe Ltd.
  - Eurescom
- United Kingdom
  - University of Essex
  - Lancaster University
  - University College London
- Spain
  - i2CAT Foundation
  - University of the Basque Country, Bilbao
- Romania
  - Universitatea Politehnica Bucuresti
- Sweden
  - ACREO AB (Sweden)
  - Ericsson AB Sweden (Sweden)
- Hungary
  - Ericsson Magyarorszag Kommunikacios Rendszerek KFT
- Switzerland
  - Dreamlab Technologies
  - Eidgenossische Technische Hochschule Zurich
- Italy
  - Nextworks
  - Universita` di Pisa
- Belgium
  - Interdisciplinary Institute for Broadband Technology
  - Universite catholique de Louvain



# Global Interest



11,129 visits came from 1,252 cities

Detail Level: [City](#) | [Country/Territory](#) | [Sub-Continent Region](#) | [Continent](#) | Dimension: [None](#)

Site Usage **Goal Set 1** Views

	Visits	Pages/Visit	Avg. Time on Site	% New Visits	Bounce Rate
	<b>11,129</b> % of Site Total: 100.00%	<b>2.85</b> Site Avg: 2.85 (0.00%)	<b>00:05:33</b> Site Avg: 00:05:33 (0.00%)	<b>41.05%</b> Site Avg: 40.89% (+0.37%)	<b>49.09%</b> Site Avg: 49.09% (0.00%)
Detail Level: <a href="#">City</a>	Visits ↓	Pages/Visit	Avg. Time on Site	% New Visits	Bounce Rate
1. <a href="#">Shibuya</a>	530	2.85	00:02:47	36.79%	45.00%
2. <a href="#">Hanoi</a>	519	3.24	00:06:16	25.01%	46.85%
3. <a href="#">San Jose</a>	381	3.01	00:03:36	39.63%	46.19%
4. <a href="#">Stanford</a>	368	3.61	00:03:39	12.23%	41.85%
5. <a href="#">Tokyo</a>	290	2.78	00:03:53	45.17%	56.00%
6. <a href="#">Atlanta</a>	230	2.86	00:05:26	18.79%	43.04%
7. <a href="#">San-Os'Ang</a>	226	3.53	00:05:45	23.89%	31.85%
8. <a href="#">San Francisco</a>	185	2.63	00:02:58	39.46%	52.43%
9. <a href="#">Mountain View</a>	176	3.24	01:36:33	22.73%	49.43%
10. <a href="#">Bangalore</a>	167	2.37	00:05:11	39.52%	47.90%

# Current Trials and Deployments

## 68 Trials/Deployments - 13 Countries





# Current Trials and Deployments

## USA-Academia

Stanford University, CA  
University of Washington, WA  
Rutgers University, NJ  
Princeton University, NJ  
Clemson University, SC  
Georgia Tech, GA  
University of Wisconsin at Madison, WI  
Indiana University  
ICSI Berkeley, CA  
University of Massachusetts at Lowell  
Clarkston University  
Columbia University (course offered)  
University of Kentucky  
UC San Diego  
UC Davis  
iCAIR/Northwestern  
Rice University  
Purdue University  
Northern Arizona University

## USA-Industry

Internet2  
Cisco  
Juniper  
HP  
Ciena  
Deutsche Telekom R&D Lab  
Marvell  
Broadcom  
Google  
Unnamed Data Center Company  
Toroki  
Nicira  
Big switch networks  
Orange Labs

## USA-Government

BBN  
Unnamed Federal Agency

# Current Trials and Deployments

## **Brazil**

University of Campinas  
Federal University of Rio de Janeiro  
Federal University of Amazonas  
Foundation Center of R&D in Telecomm.

## **Canada**

University of Toronto

## **Germany**

T-Labs Berlin  
Leibniz Universität Hannover

## **France**

ENS Lyon/INRIA

## **India**

VNIT  
Mahindra Satyam

## **Italy**

Politecnico di Torino

## **United Kingdom**

University College London  
Lancaster University  
University of Essex

## **Taiwan**

National Center for High-Performance Computing  
Chunghwa Telecom Co

## **Japan**

NEC  
JGN Plus  
NICT  
University of Tokyo  
Tokyo Institute of Technology  
Kyushu Institute of Technology  
NTT Network Innovation Laboratories  
KDDI R&D Laboratories  
Unnamed University

## **South Korea**

KOREN  
Seoul National University  
Gwangju Institute of Science & Tech  
Pohang University of Science & Tech  
Korea Institute of Science & Tech  
ETRI  
Chungnam National University  
Kyung Hee University

## **Spain**

University of Granada

## **Switzerland**

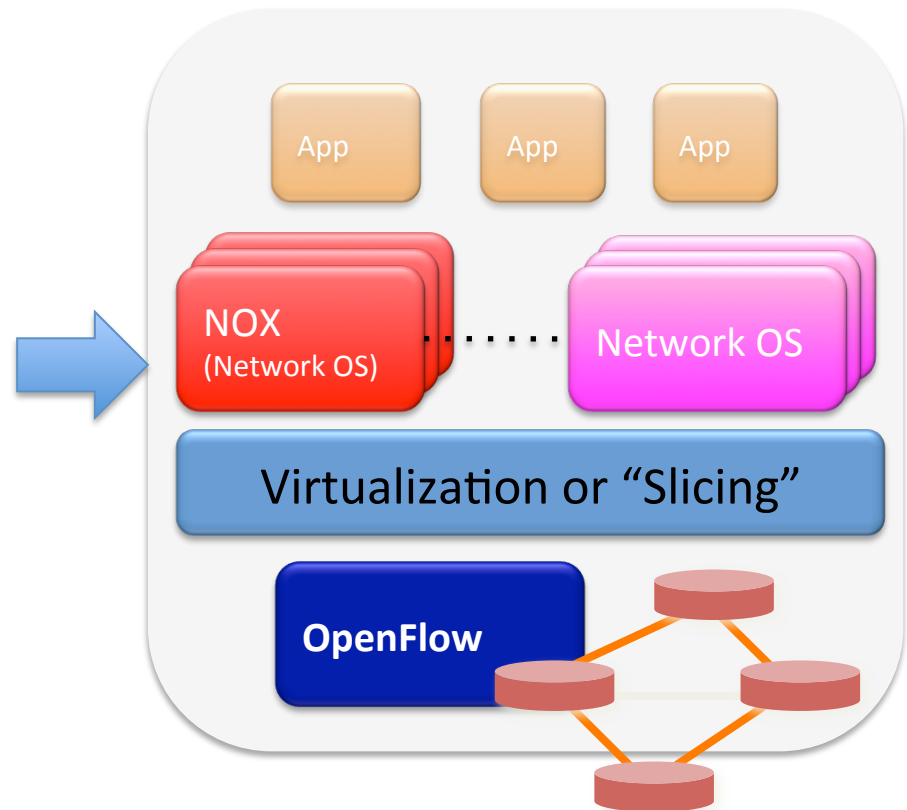
CERN

# Software and Hardware



# Controllers

- The Network “OS”
- Open Source
  - NOX
    - Nicira
    - C++/Python
  - Beacon
    - BigSwitch
    - Java
  - Maestro
    - Rice
    - Java



# Flowvisor

- Sends traffic from the same switch(es) to multiple controllers
- Acts like a Hypervisor for network equipment
- Rule set similar to OpenFlow rules that send traffic to multiple controllers
- Most GENI shared infrastructure will use Flowvisor to have multiple controllers control the same switches



# Fvctl

- Fvctl used to control flowvisor (over XMLRPC)
- Can create slice, direct traffic to “slices”, see
- FlowSpace is the set of mapping rules
- Devices Identified by DPID

```
chsmall@flowvisor:~$ fvctl listDevices
```

```
Device 0: 0e:83:00:23:47:c8:bc:00
```

```
Device 1: 0e:83:00:26:f1:40:a8:00
```

```
chsmall@flowvisor:~$ fvctl listFlowSpace
```

```
rule 0: FlowEntry[dpid=[all_dpids],ruleMatch=[OFMatch[]],actionsList=  
[Slice:meas_manager=4],id=[236],priority=[10],]
```



# 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>



# SNAC

- Simple Network Policy Controller
- Web-Based Policy manager
- IU production SNAC at [snac-prod.grnoc.iu.edu](http://snac-prod.grnoc.iu.edu)
- Can provide distributed firewall services
- Some statistics collected





# Overview



Network Overview ▶

Switches

Hosts

Users

Locations

Groups

Network Events Log

## Server Information

**Uptime:** 1 day 16 hours 52 minutes 53 seconds

**CPU Load:** 1%

**Flows/sec:** 7

## Entity Counts (Active/Total/Unregistered)

**Switches:** 3 / 3 / 0

**Locations:** 18 / 18 / 0

**Hosts:** 17 / 22 / 4

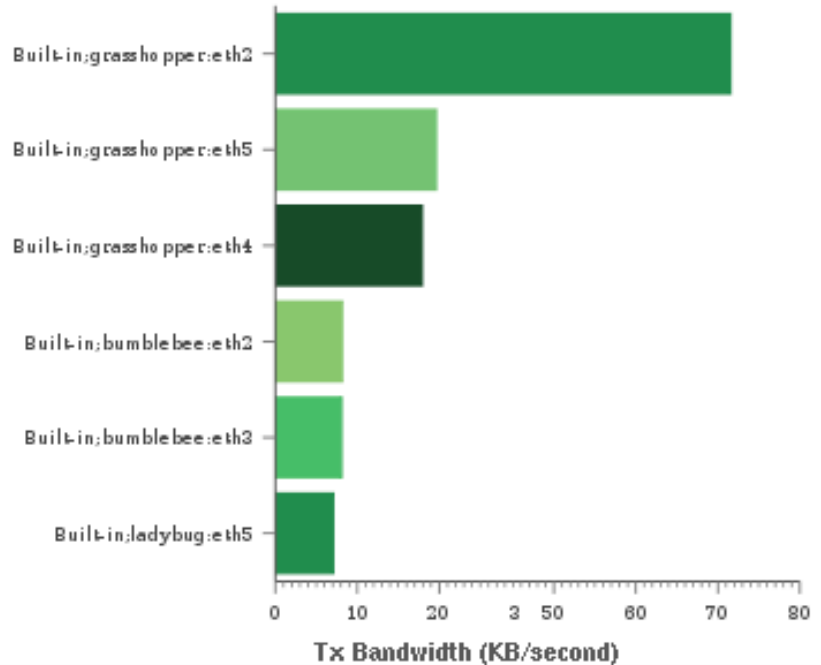
**Users:** 1 / 3 / 0

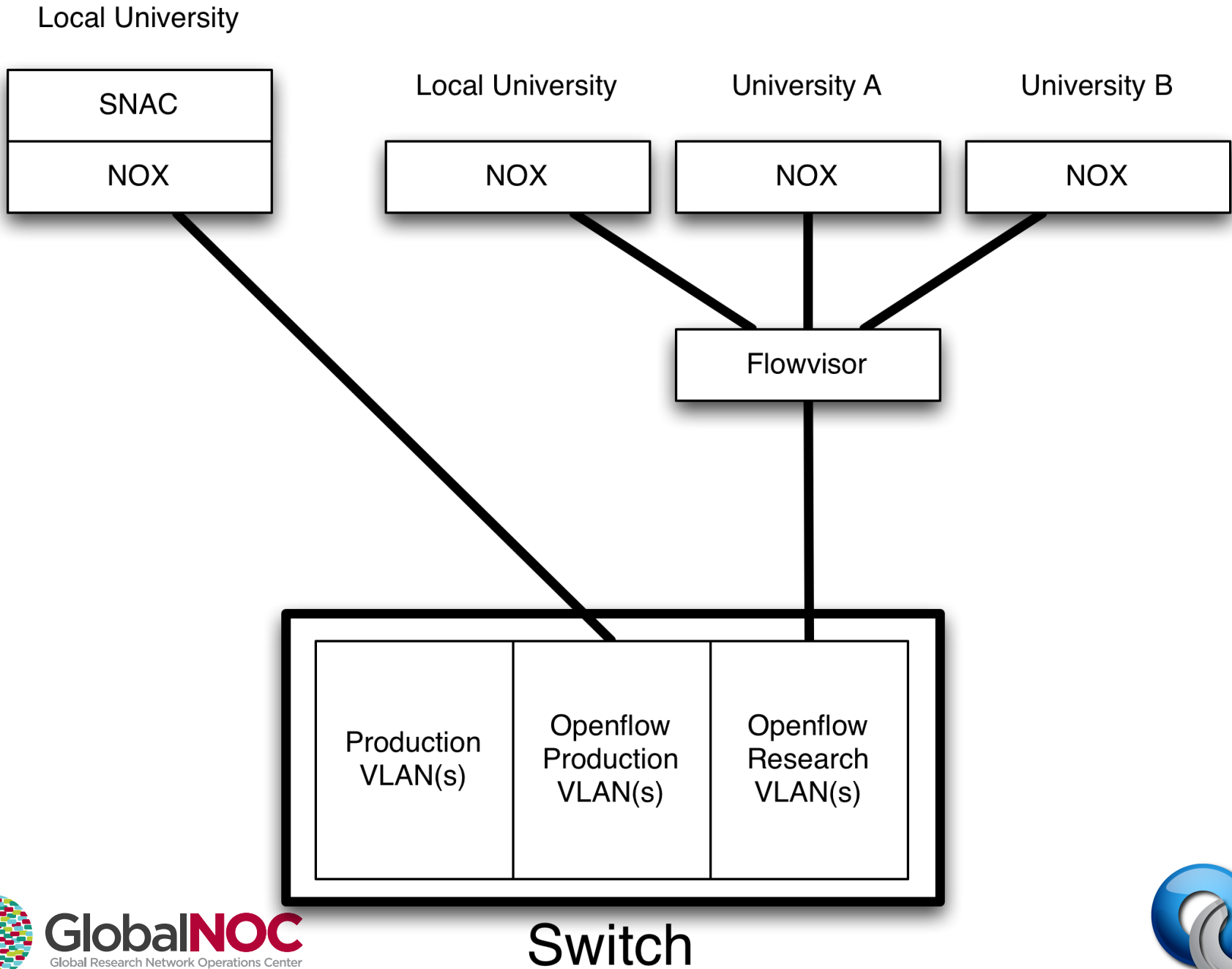
## Policy Statistics

**Total Drops:** 47698

**Total Rules:** 15

Top 5 Switch Ports by Tx Bandwidth





# OpenFlow Hardware



Juniper MX-series



NEC IP8800



WiMax (NEC)



HP Procurve 5400



Cisco Catalyst 6k



PC Engines



Quanta LB4G



Netgear

More Equipment Soon

# NetFPGA and Indigo

- NetFPGA
  - FPGA card to test protocols in hardware
  - 4 x 1G and 4 x 10G models
  - OpenFlow 1.0 implementation
  - Google used it for testing OpenFlow-MPLS code
    - [http://www.nanog.org/meetings/nanog50/presentations/Monday/NANOG50.Talk17.swhyte\\_Opensource\\_LSR\\_Presentation.pdf](http://www.nanog.org/meetings/nanog50/presentations/Monday/NANOG50.Talk17.swhyte_Opensource_LSR_Presentation.pdf)
- Indigo
  - Userspace Firmware Reference Release
  - Support for Broadcom chips used in Pronto/Quanta



# Switch Issues

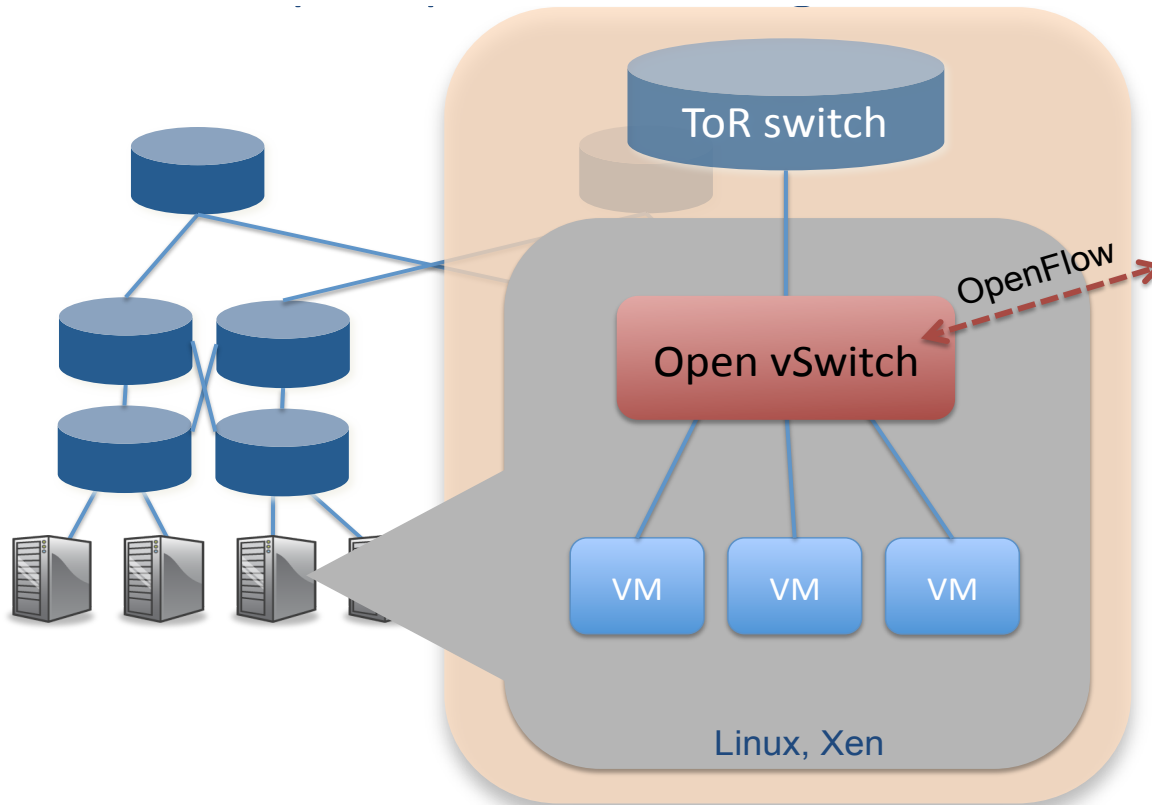
- Hw vs Sw rules
- Optional items in OF Spec
  - No one is really implementing rewrite right now
- Control Channel resource exhaustion
- CPU exhaustion and isolation
  - Preventing OF traffic affecting production vlans
- Security
- 48bit vs 64 bit DPIDs
- General strangeness
  - HPs built off live train, NEC uniqueness



# OpenVSwitch

<http://openvswitch.org>

VM-aware virtual switch, run distributed over hardware;



# OpenFlow Spec process

<http://openflow.org>

- V1.0: December 2009
- V1.1: November 2010
  - Open but ad-hoc process among 10-15 companies
- Future
  - Planning a more “standard” process from 2011



# Measurement Manager

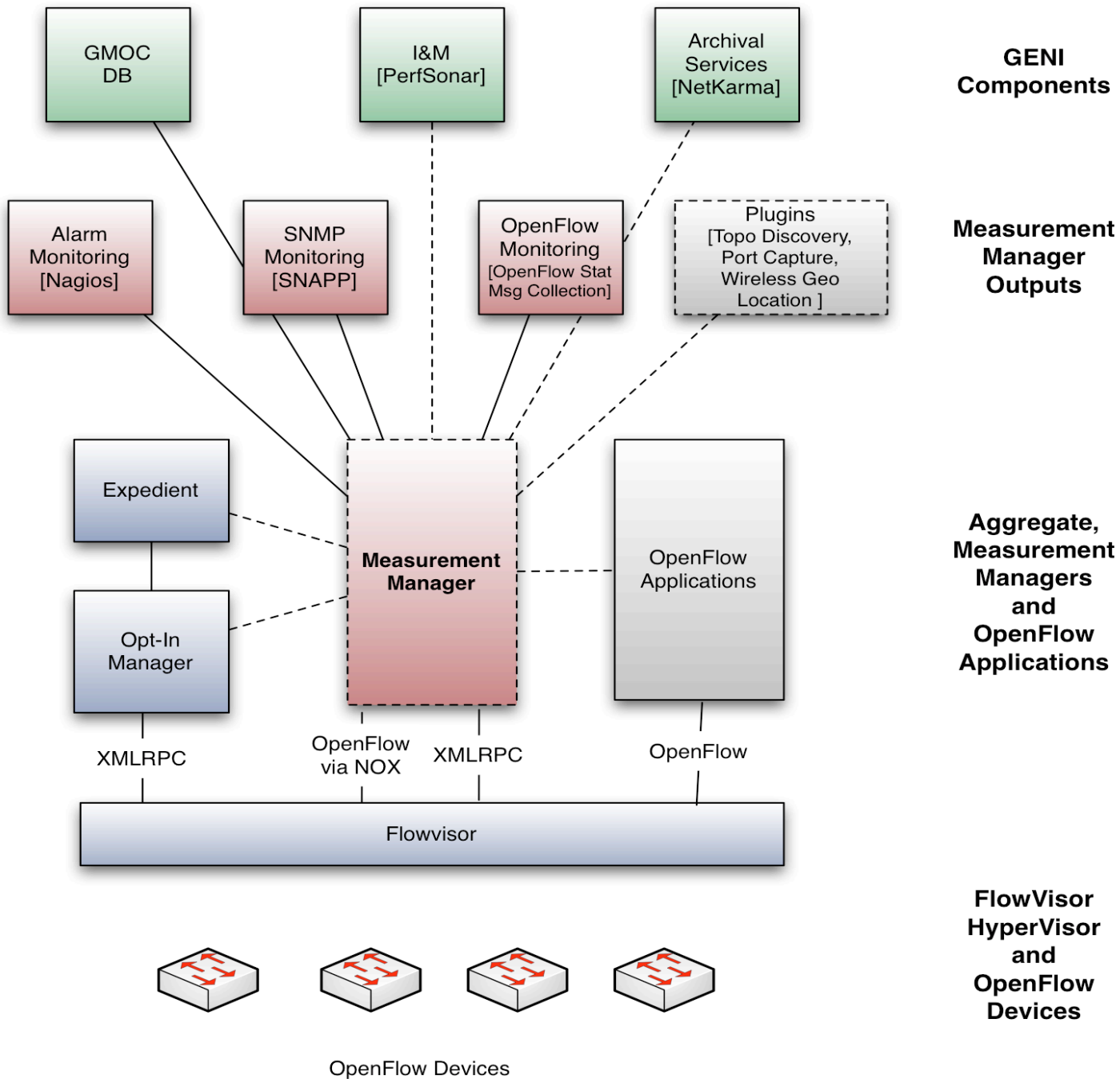




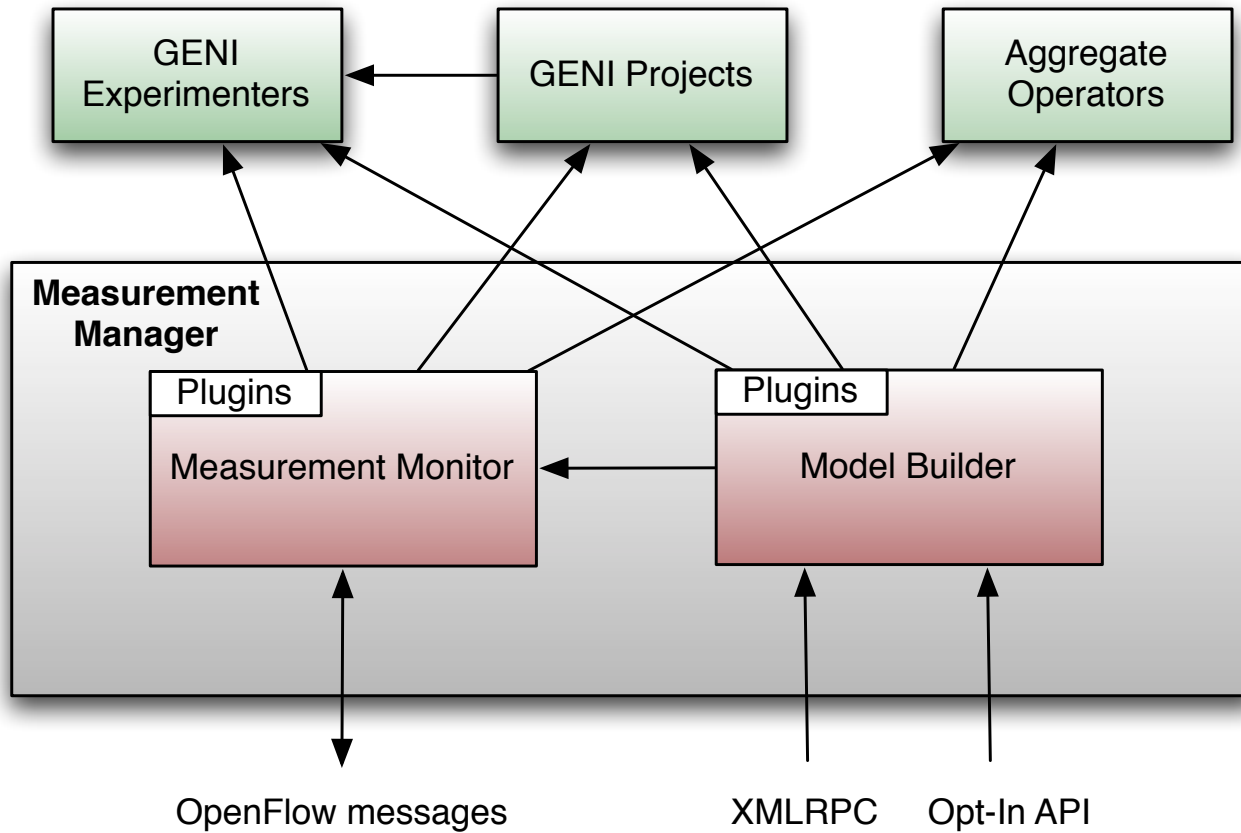
# Measurement Manager

- Software built by IU for monitoring OpenFlow networks
- Ties into Flowvisor to get list of devices and topology (using LLDP)
- Acts as OF Controller to gather statistics
- Outputs Nagios, GMOC, SNAPP formats





# Measurement Manager

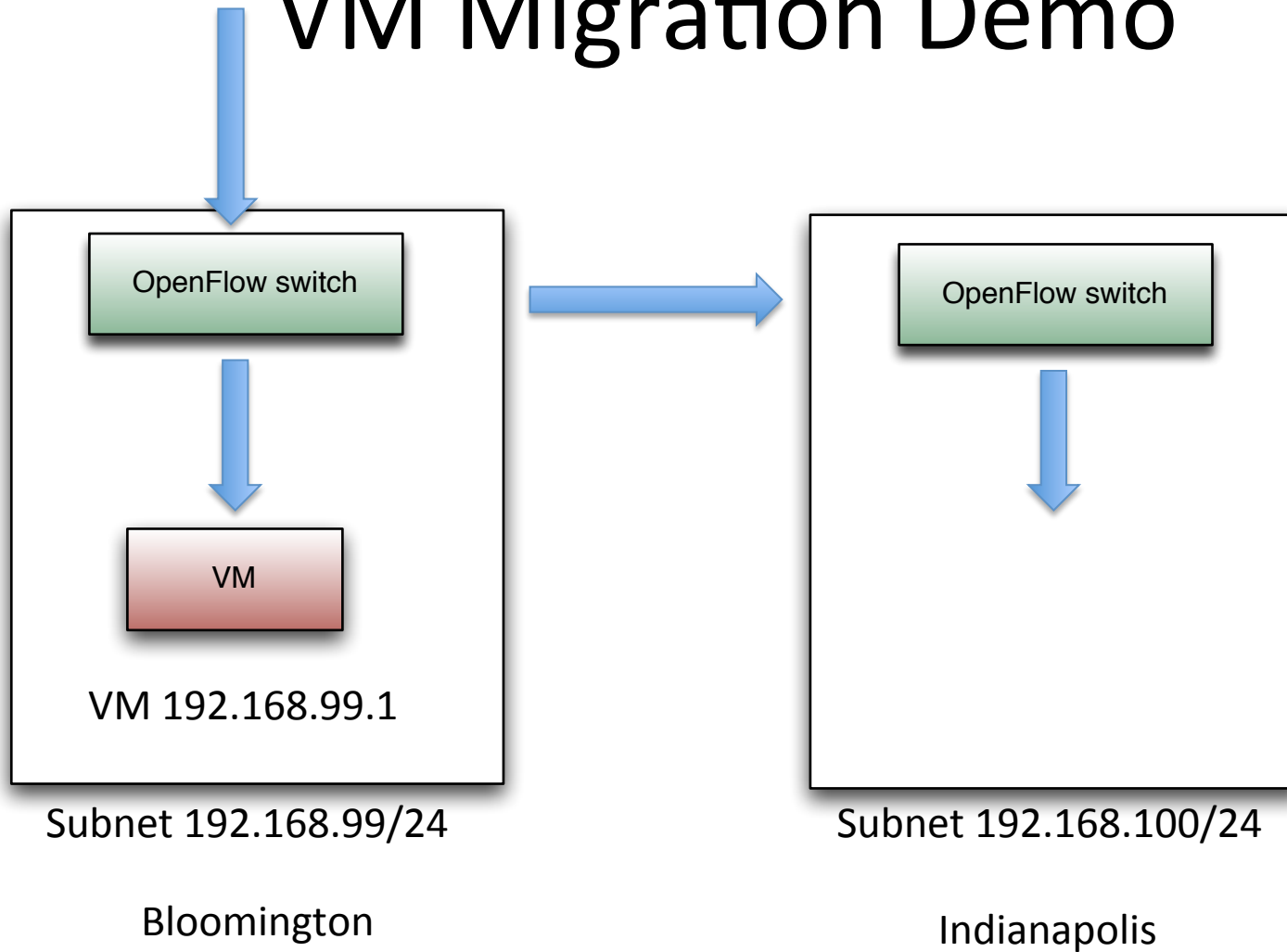


# Demos

- VM Migration Demo
  - Moving a VM between subnets
- Measurement Manager showing Backbone Deployments
  - Topology and Statistic collection in a controller based environment
- Hands-on Workshop
  - <http://www.openflowswitch.org/wk/index.php/HOTITutorial2010>



# VM Migration Demo



# How to get involved

- Experiment with Controllers
  - NOX: <http://noxrepo.org>
  - Beacon: <http://www.openflowhub.org/>
- Switches
  - Soft switches / Mininet
    - OpenFlow tutorial VM
  - Hardware switches you already may have

