Can the Production Network *Be* the Testbed?

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Problem:

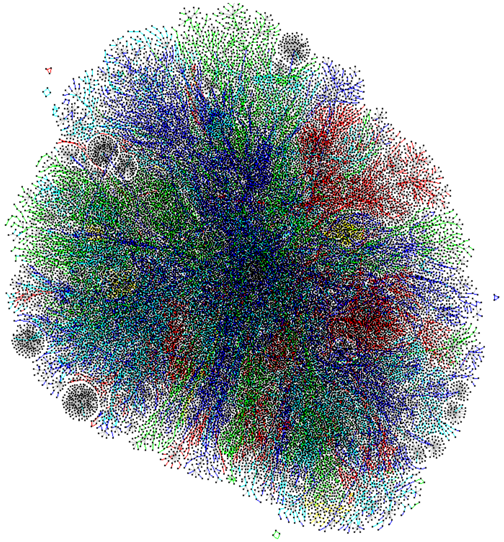
Realisticly evaluating new network services is *hard*

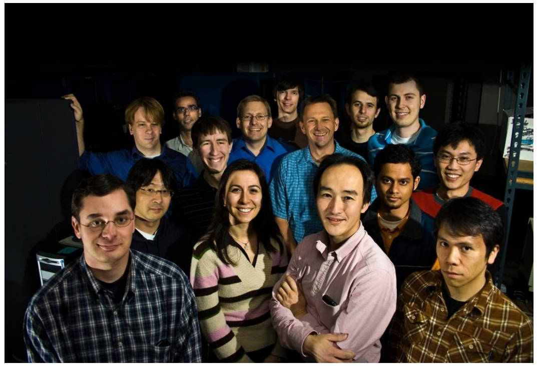
- services that require changes to switches and routers
- e.g.,
  - routing protocols
  - traffic monitoring services
  - IP mobility

Result: Many good ideas don't gets deployed;
Many deployed services still have bugs.

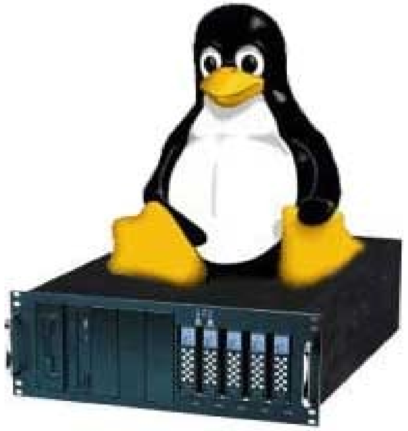
Why is Evaluation Hard?

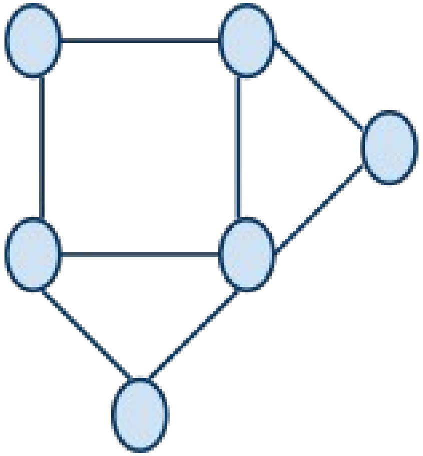
Real Networks

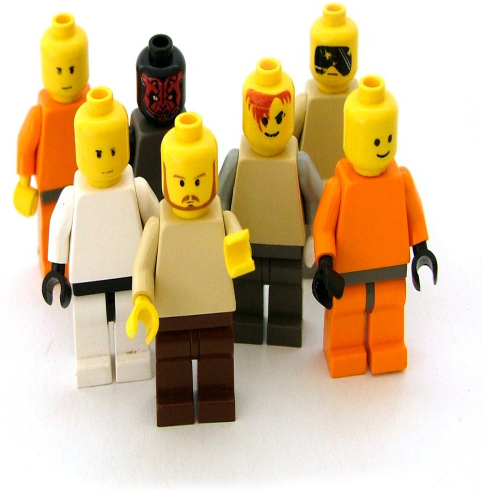




Testbeds







Not a New Problem

- Build open, programmable network hardware
  - NetFPGA, network processors
  - but: deployment is expensive, fan-out is small

- Build bigger software testbeds
  - VINI/PlanetLab, Emulab
  - but: performance is slower, realistic topologies?

- Convince users to try experimental services
  - personal incentive, SatelliteLab
  - but: getting *lots* of users is hard

Solution Overview: Network Slicing

- Divide the production network into logical *slices*
  - each slice/service controls its own packet forwarding
  - users pick which slice controls their traffic: opt-in
  - existing production services run in their own slice
    - e.g., Spanning tree, OSPF/BGP

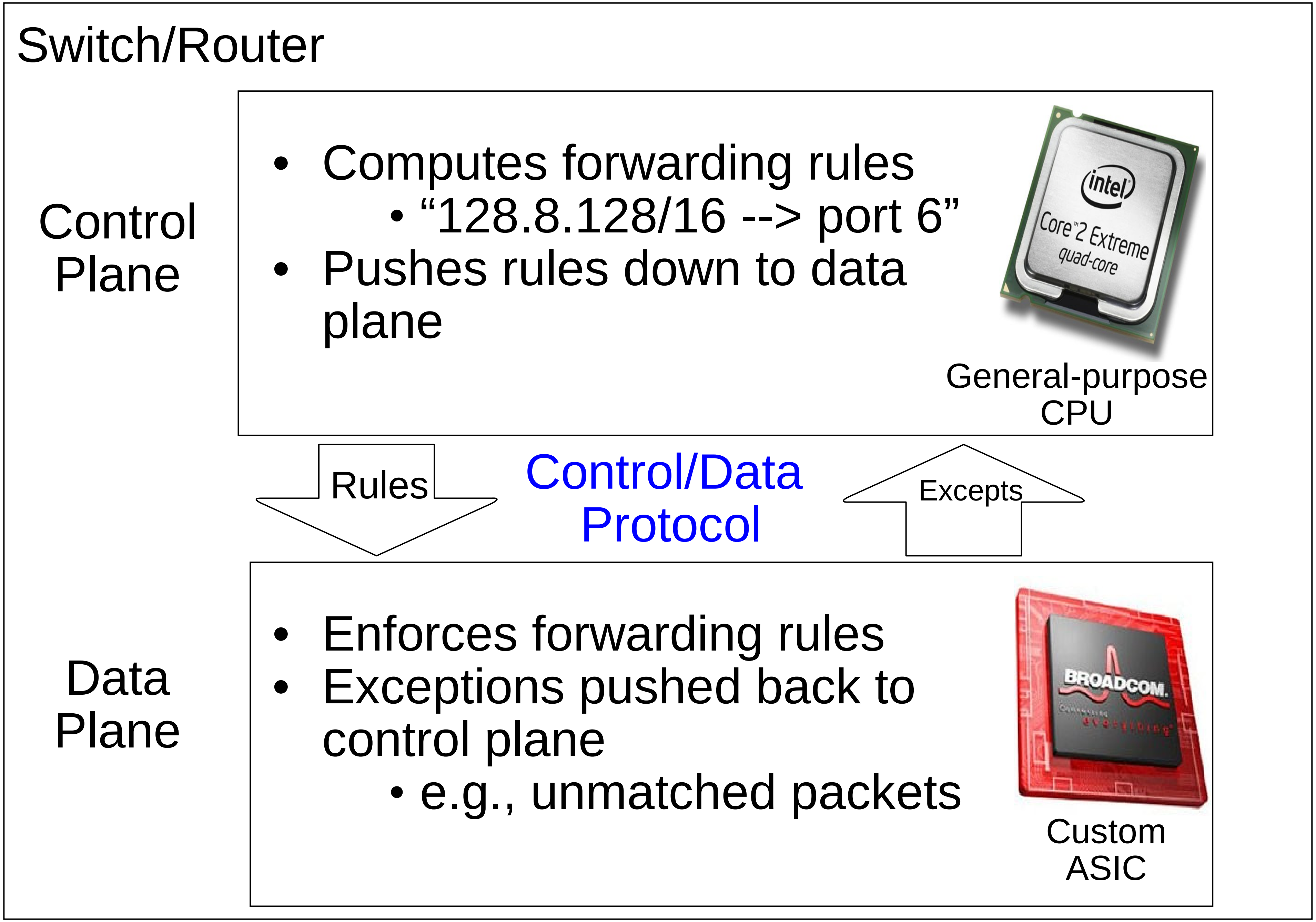
- Enforce strong isolation between slices
  - actions in one slice do not affect another

- Allows the (logical) testbed to mirror the production network
  - real hardware, performance, topologies, scale, users

Rest of Talk...

- How network slicing works: FlowSpace, Opt-In
- Our prototype implementation: FlowVisor
- Isolation and performance results
- Current deployments: 8+ campuses, 2+ ISPs
- Future directions and conclusion

Current Network Devices



Switch/Router

Control Plane

- Computes forwarding rules
    - “128.8.128/16 --> port 6”
- Pushes rules down to data plane

General-purpose CPU

Rules

Control/Data Protocol

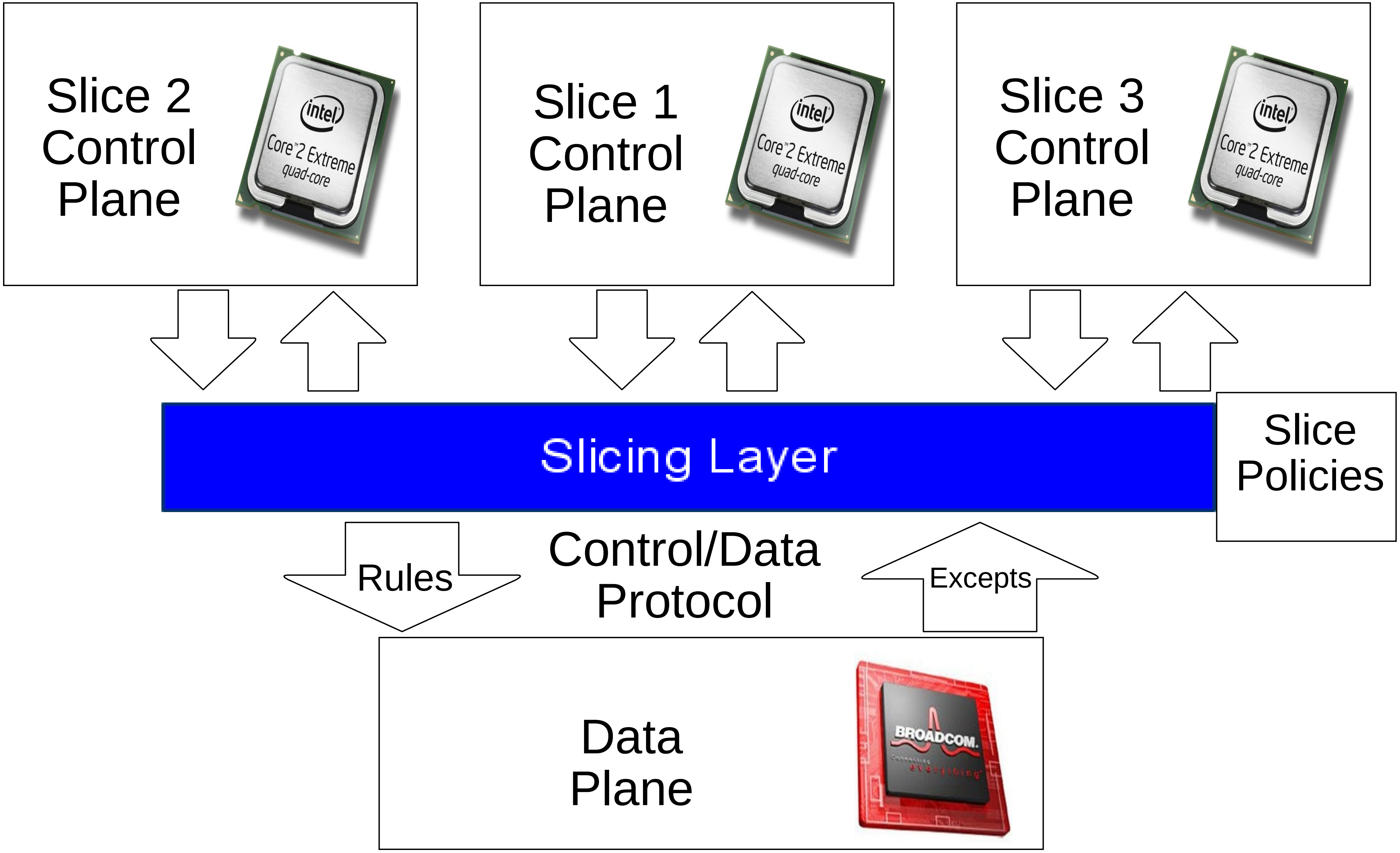
Excepts

Data Plane

- Enforces forwarding rules
- Exceptions pushed back to control plane
    - e.g., unmatched packets

Custom ASIC

Add a Slicing Layer Between Planes



Network Slicing Architecture

A network slice is a collection of sliced switches/routers

- Data plane is unmodified
  - – Packets forwarded with no performance penalty
  - – Slicing with existing ASIC

- Transparent slicing layer
  - – each slice believes it owns the data path
  - – enforces isolation between slices
    - i.e., rewrites, drops rules to adhere to slice police
  - – forwards exceptions to correct slice(s)

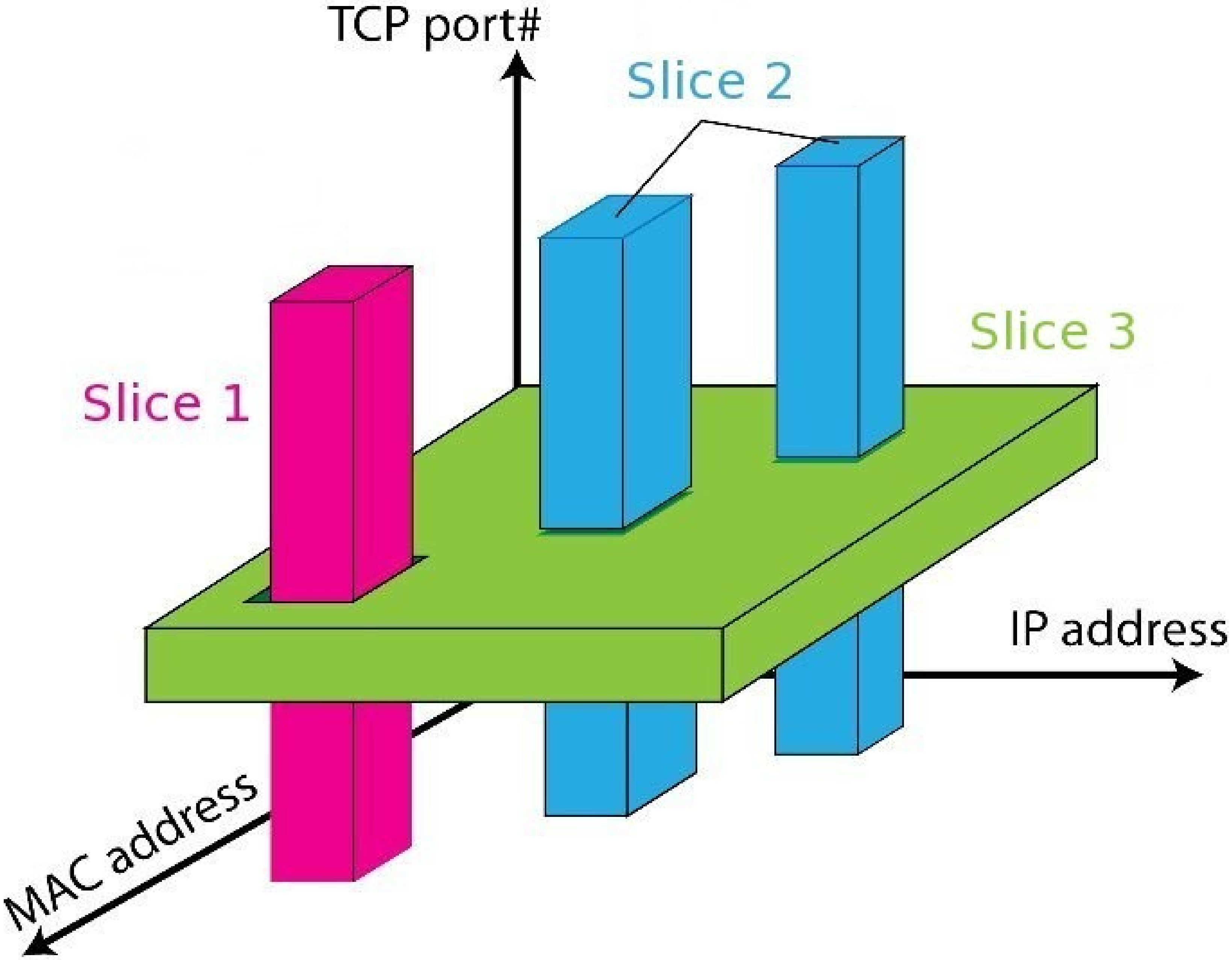
Slicing Policies

The policy specifies resource limits for each slice:

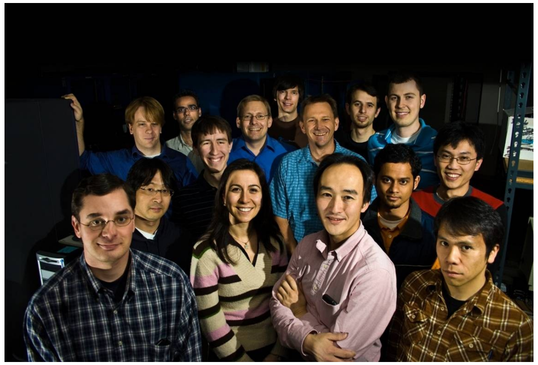
- Link bandwidth
- Maximum number of forwarding rules
- Topology
- Fraction of switch/router CPU

- *FlowSpace: which packets does the slice control?*

FlowSpace: Maps Packets to Slices



Real User Traffic: Opt-In



- Allow users to Opt-In to services in real-time
  - Users can delegate control of individual flows to Slices
  - Add new FlowSpace to each slice's policy

- Example:
  - *"Slice 1 will handle my HTTP traffic"*
  - *"Slice 2 will handle my VoIP traffic"*
  - *"Slice 3 will handle everything else"*

- Creates incentives for building high-quality services

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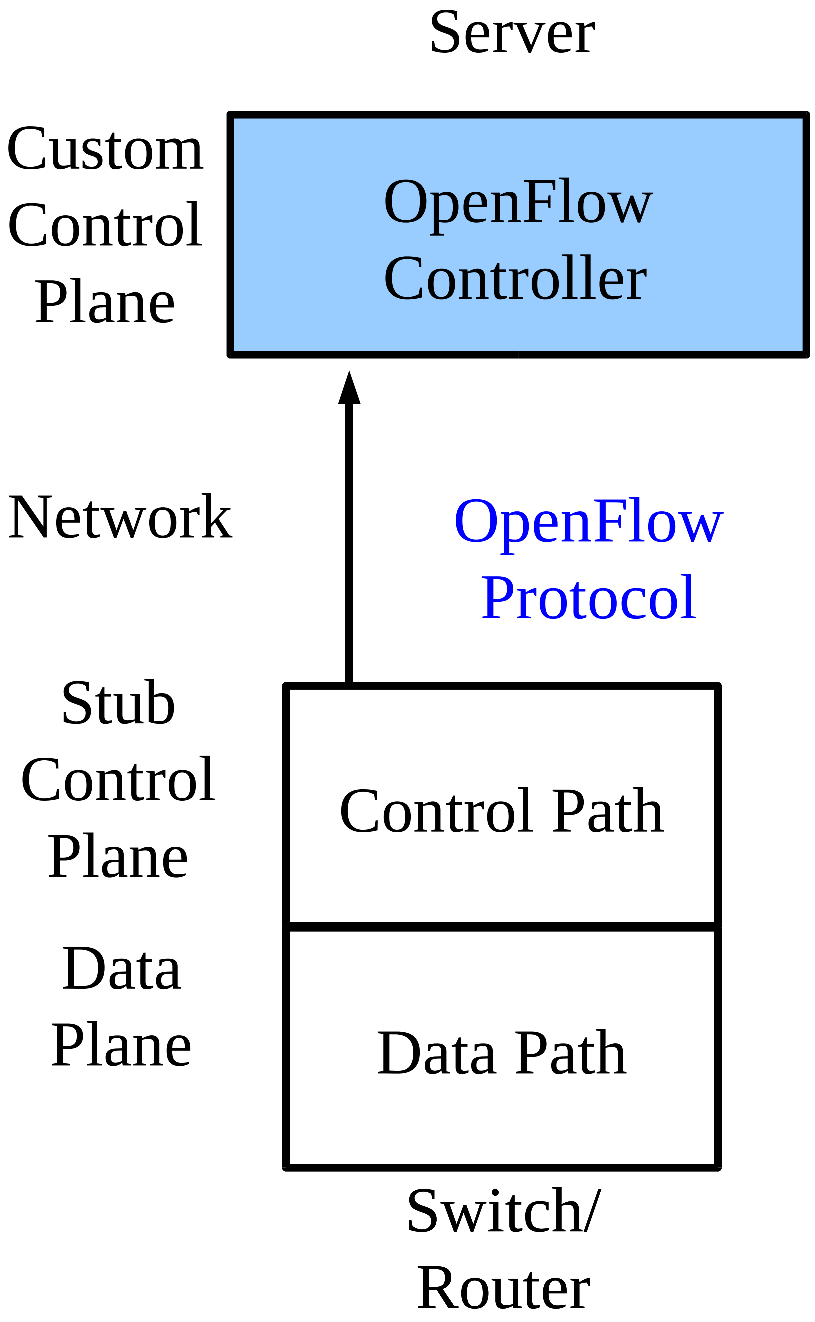
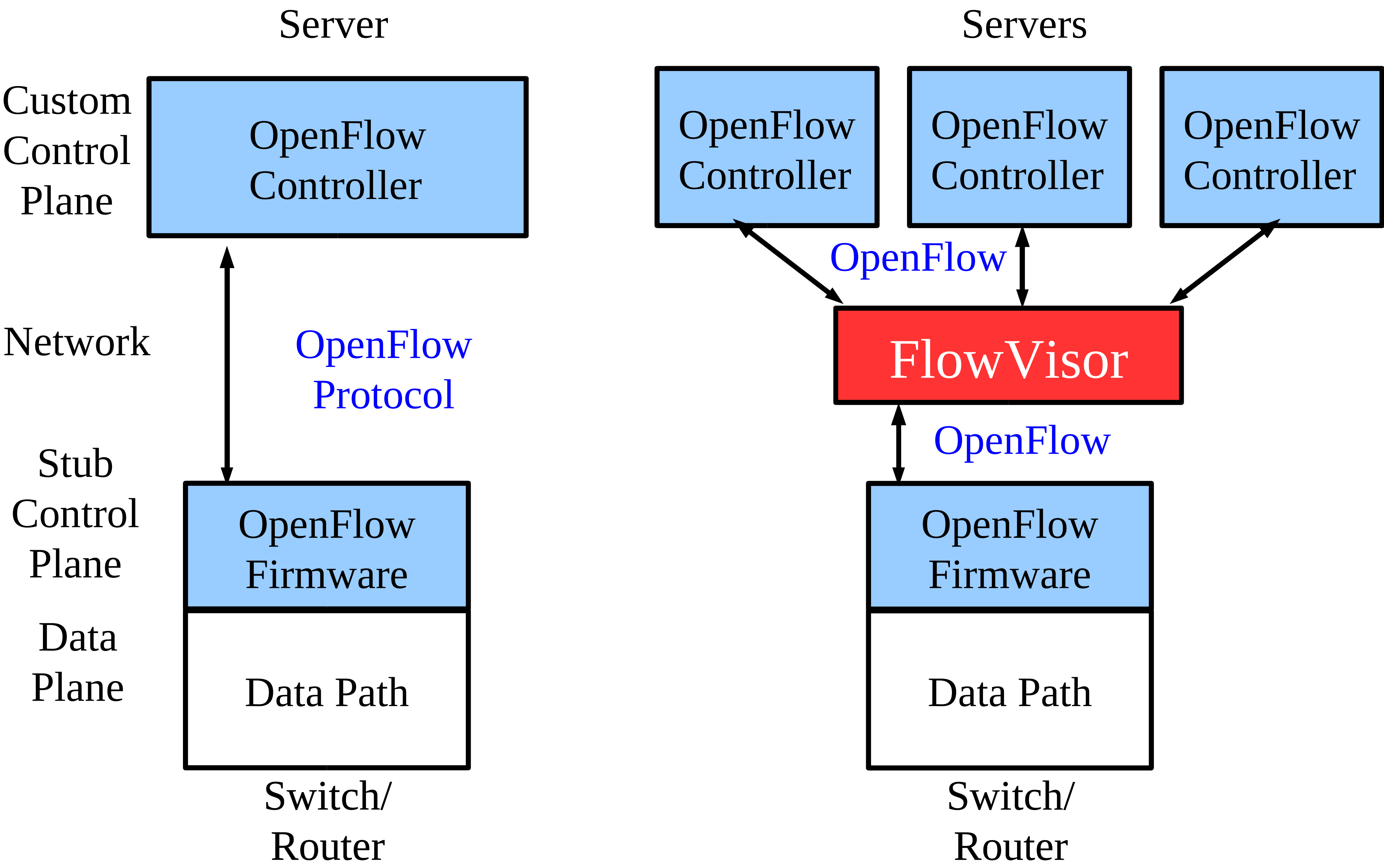
Implemented on OpenFlow

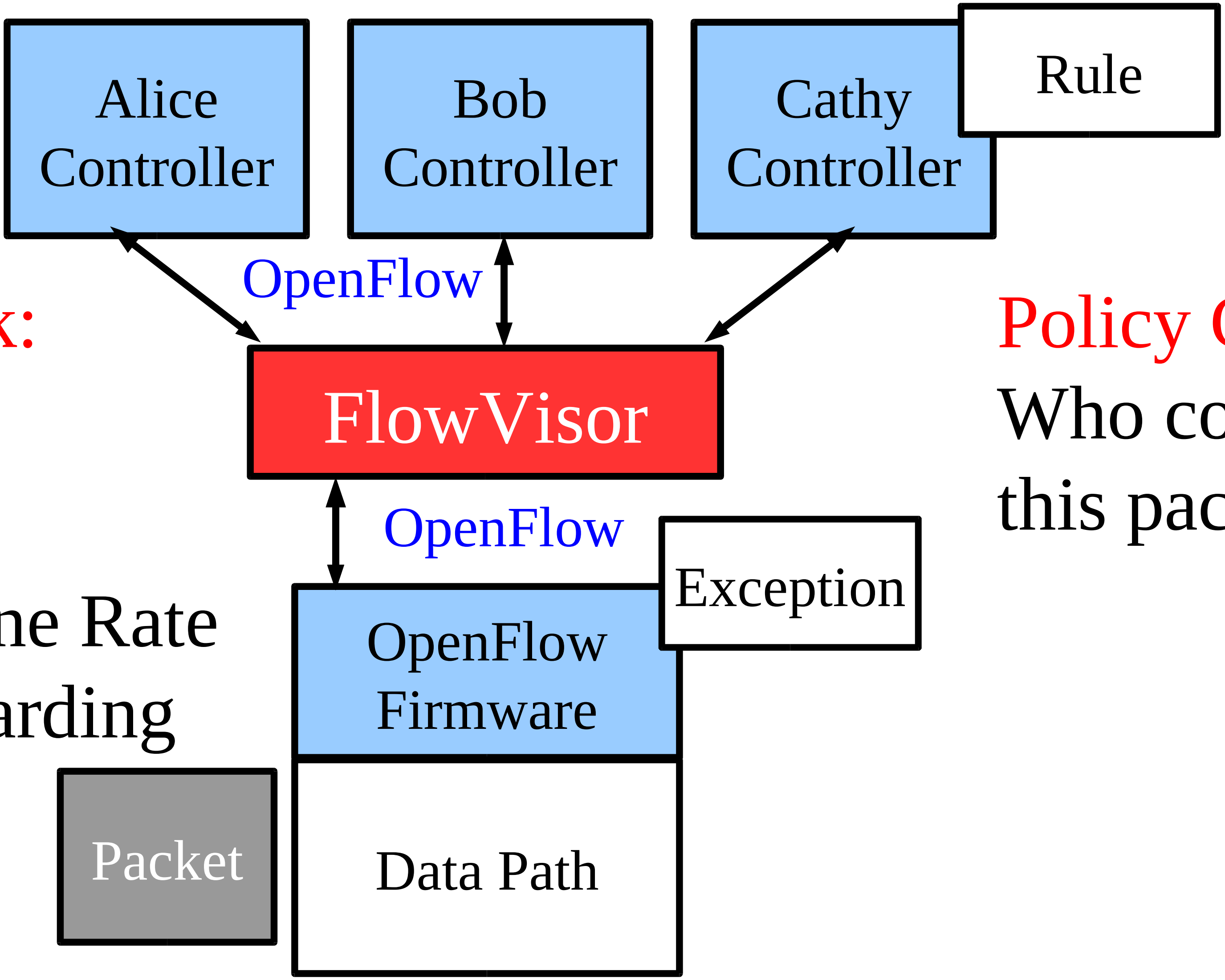


- API for controlling packet forwarding
- Abstraction of control plane/data plane protocol
- Works on commodity hardware
  - via firmware upgrade
  - www.openflow.org

FlowVisor Implemented on OpenFlow



FlowVisor Message Handling



Alice Controller

Bob Controller

Cathy Controller

Rule

OpenFlow

FlowVisor

OpenFlow

Exception

OpenFlow Firmware

Data Path

Packet

Policy Check:
Is this rule allowed?

Policy Check:
Who controls this packet?

Full Line Rate Forwarding

FlowVisor Implementation

- Custom handlers for each of OpenFlow's 20 message types
  - Transparent OpenFlow proxy
  - 8261 LOC in C
  - New version with extra API for GENI

- Could extend to non-OpenFlow (ForCES?)

- Code: `git clone git://openflow.org/flowvisor.git`

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Isolation Techniques

Isolation is critical for slicing

In talk:

- Device CPU

In paper:

- FlowSpace
- Link bandwidth
- Topology
- Forwarding rules

As well as performance and scaling numbers

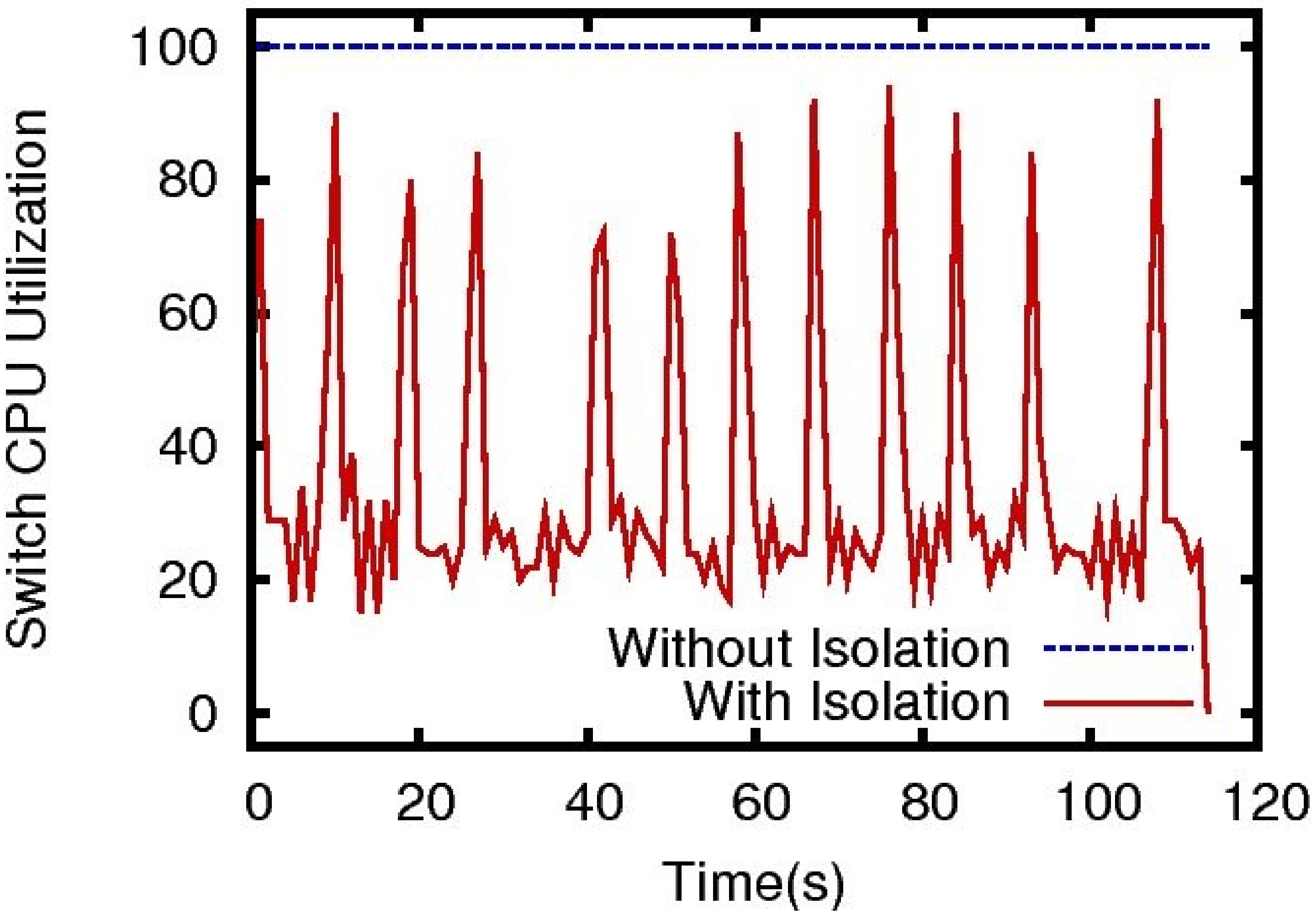
Device CPU Isolation

- Ensure that no slice monopolizes Device CPU

- CPU exhaustion
  - prevent rule updates
  - drop LLDPs ---> Causes link flapping

- Techniques
  - Limiting rule insertion rate
  - Use periodic drop-rules to throttle exceptions
  - Proper rate-limiting coming in OpenFlow 1.1

CPU Isolation: Malicious Slice



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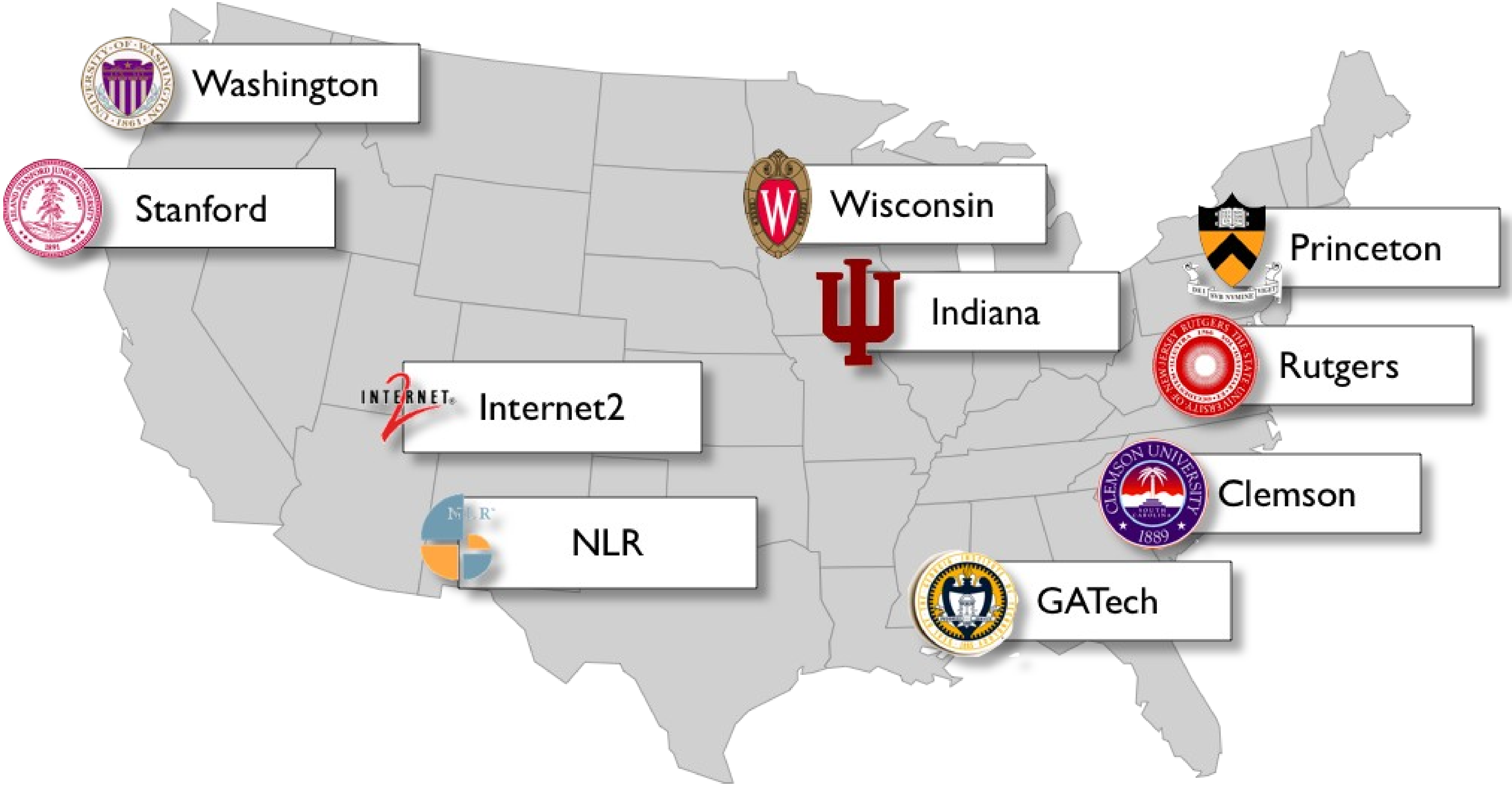
FlowVisor Deployment: Stanford

- Our real, production network
  - 15 switches, 35 APs
  - 25+ users
  - 1+ year of use
  - my personal email and web-traffic!
- Same physical network hosts Stanford demos
  - 7 different demos

FlowVisor Deployments: GENI



Future Directions

- Currently limited to subsets of actual topology
  - Add virtual links, nodes support
- Adaptive CPU isolation
  - Change rate-limits dynamically with load
  - ... message type
- More deployments, experience

Conclusion: Tentative Yes!

- Network slicing can help perform more realistic evaluations
- FlowVisor allows experiments to run concurrently but safely on the production network
    - CPU isolation needs OpenFlow 1.1 feature
- Over one year of deployment experience
- FlowVisor+GENI coming to a campus near you!

Questions?

git://openflow.org/flowvisor.git

Backup Slides

What about VLANs?

- Can't program packet forwarding
  - Stuck with learning switch and spanning tree
- OpenFlow per VLAN?
  - No obvious opt-in mechanism:
    - Who maps a packet to a vlan? By port?
  - Resource isolation more problematic
    - CPU Isolation problems in existing VLANs

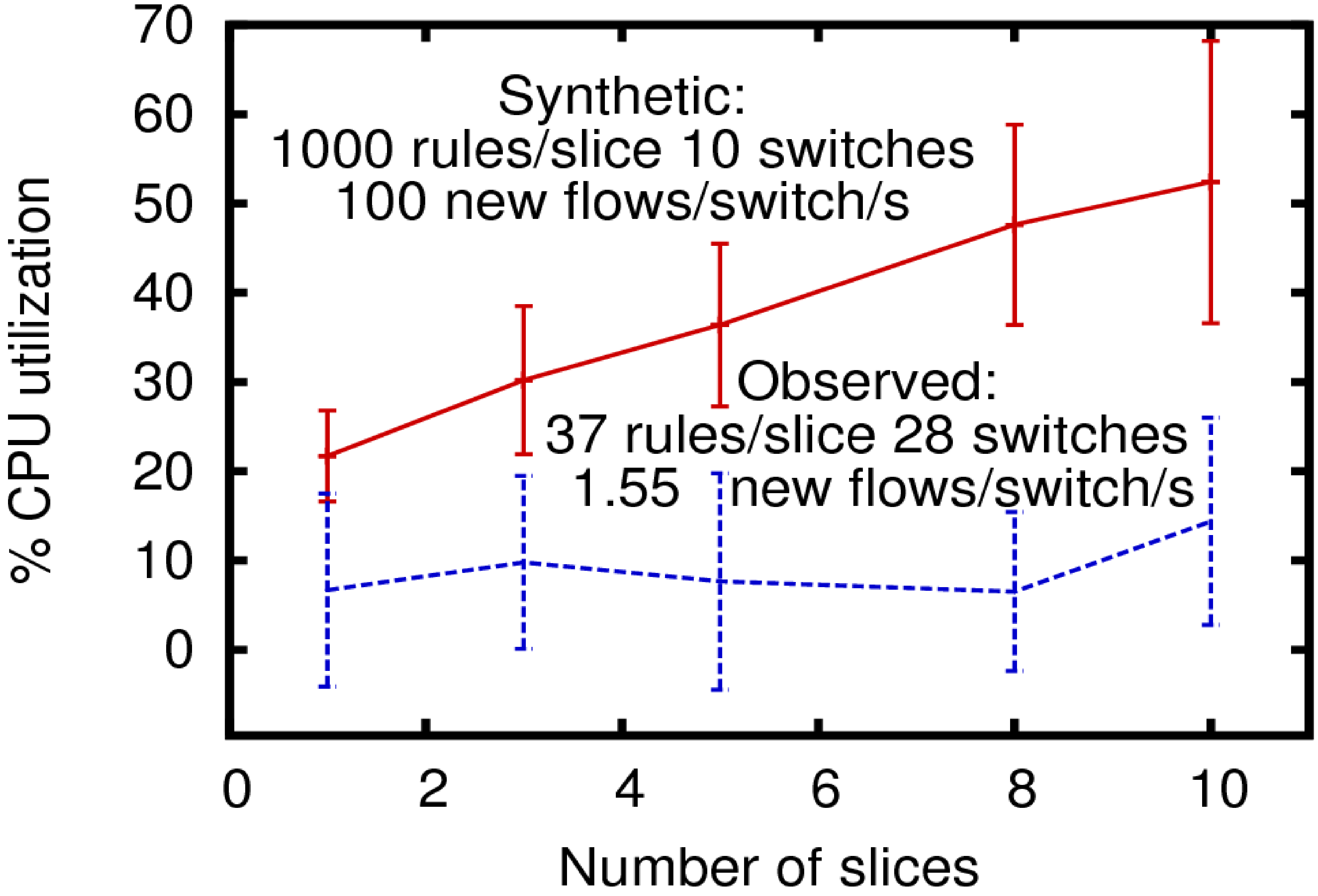
FlowSpace Isolation

Policy	Desired Rule	Result
HTTP	ALL	HTTP-only
HTTP	VoIP	Drop

- Discontinuous FlowSpace:
  - (HTTP or VoIP) & ALL == two rules

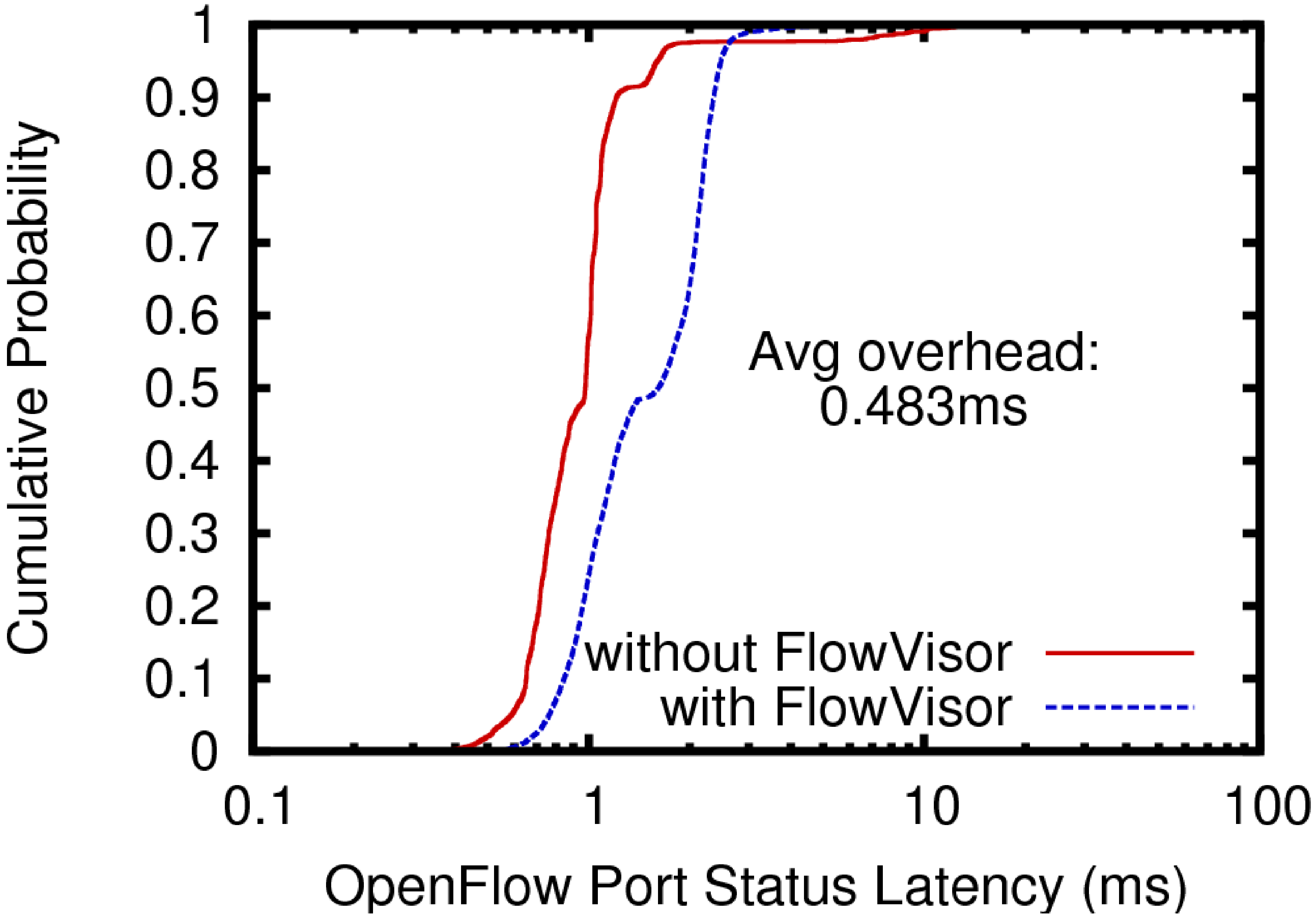
- Isolation by rule priority is hard
  - longest-prefix-match-like ordering issues
  - need to be careful about preserving rule ordering

Scaling



70
60
50
40
30
20
10
0
% CPU utilization
0
2
4
6
8
10
Number of slices
Synthetic:
1000 rules/slice 10 switches
100 new flows/switch/s
Observed:
37 rules/slice 28 switches
1.55 new flows/switch/s

Performance


Cumulative Probability
OpenFlow Port Status Latency (ms)
Avg overhead:
0.483ms
without FlowVisor
with FlowVisor