Software Defined Networks (SDN)

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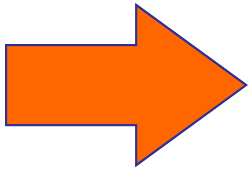
With: **Martín Casado**, Teemu Koponen, Scott Shenker
… and many others

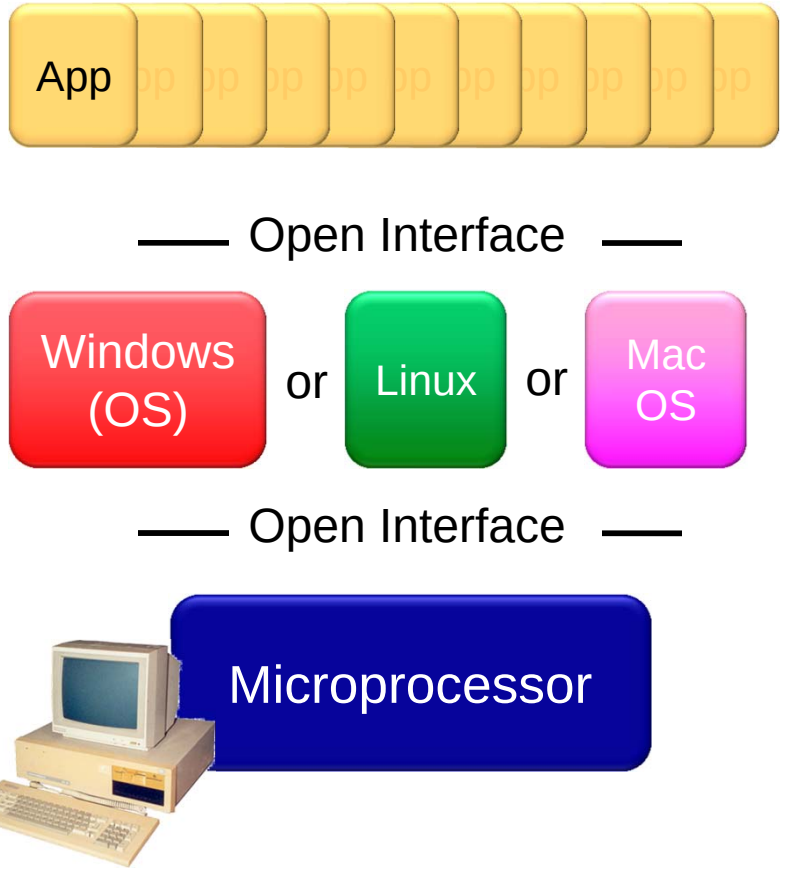
With thanks to: NSF, GPO, Stanford Clean Slate Program,
Cisco, DoCoMo, DT, Ericsson, Google, HP, Huawei, NEC, Xilinx

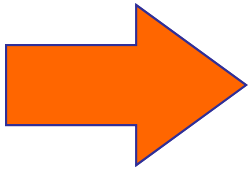
Outline

1. What are Software Defined Networks?
2. Why SDN?
3. The Consequences
   - For industry
   - For research
   - For standards and protocols

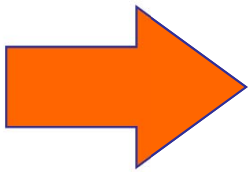
Vertically integrated
Closed, proprietary
Slow innovation
Small industry

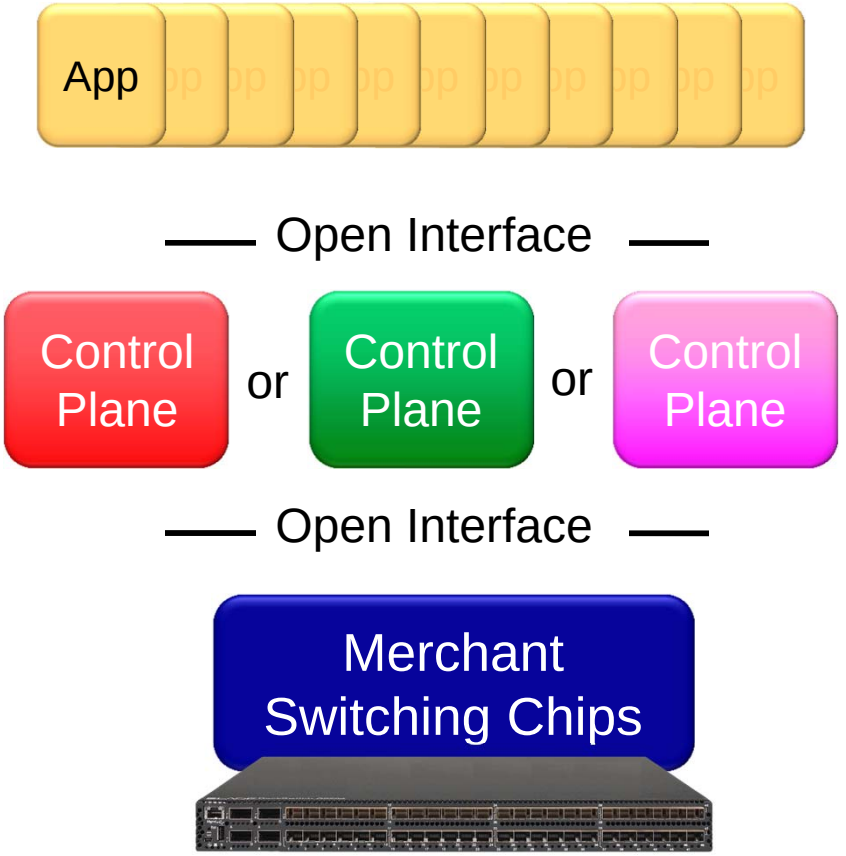




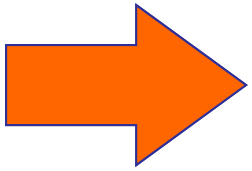


Horizontal
Open interfaces
Rapid innovation
Huge industry



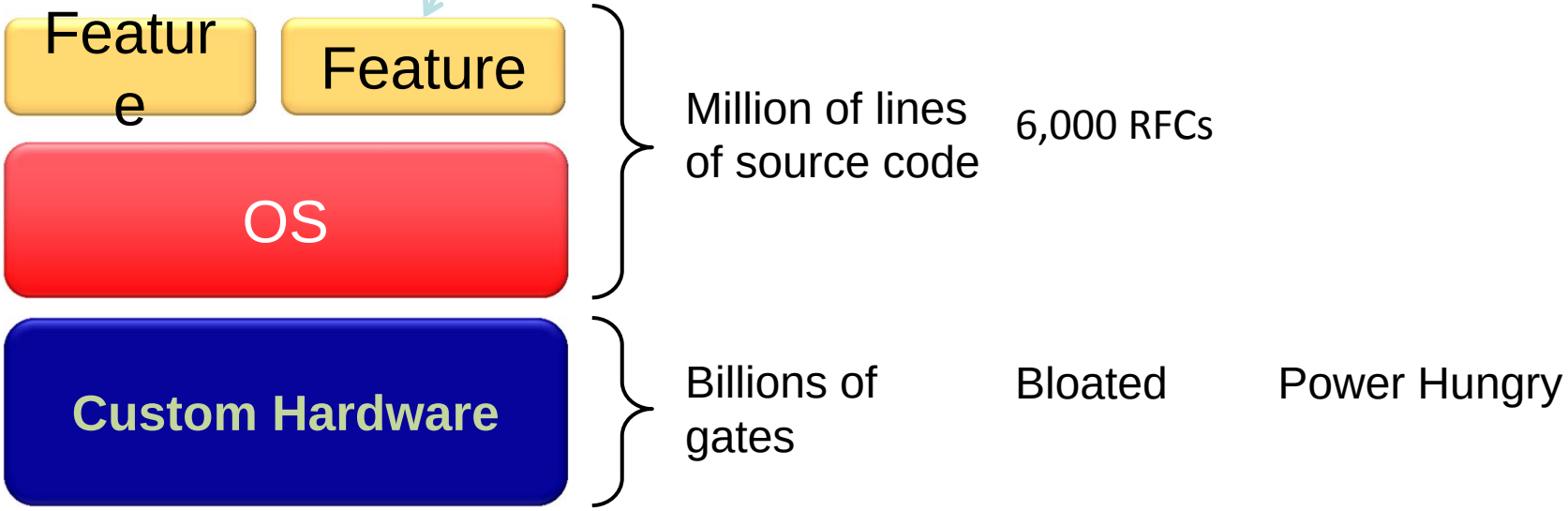


Vertically integrated
Closed, proprietary
Slow innovation



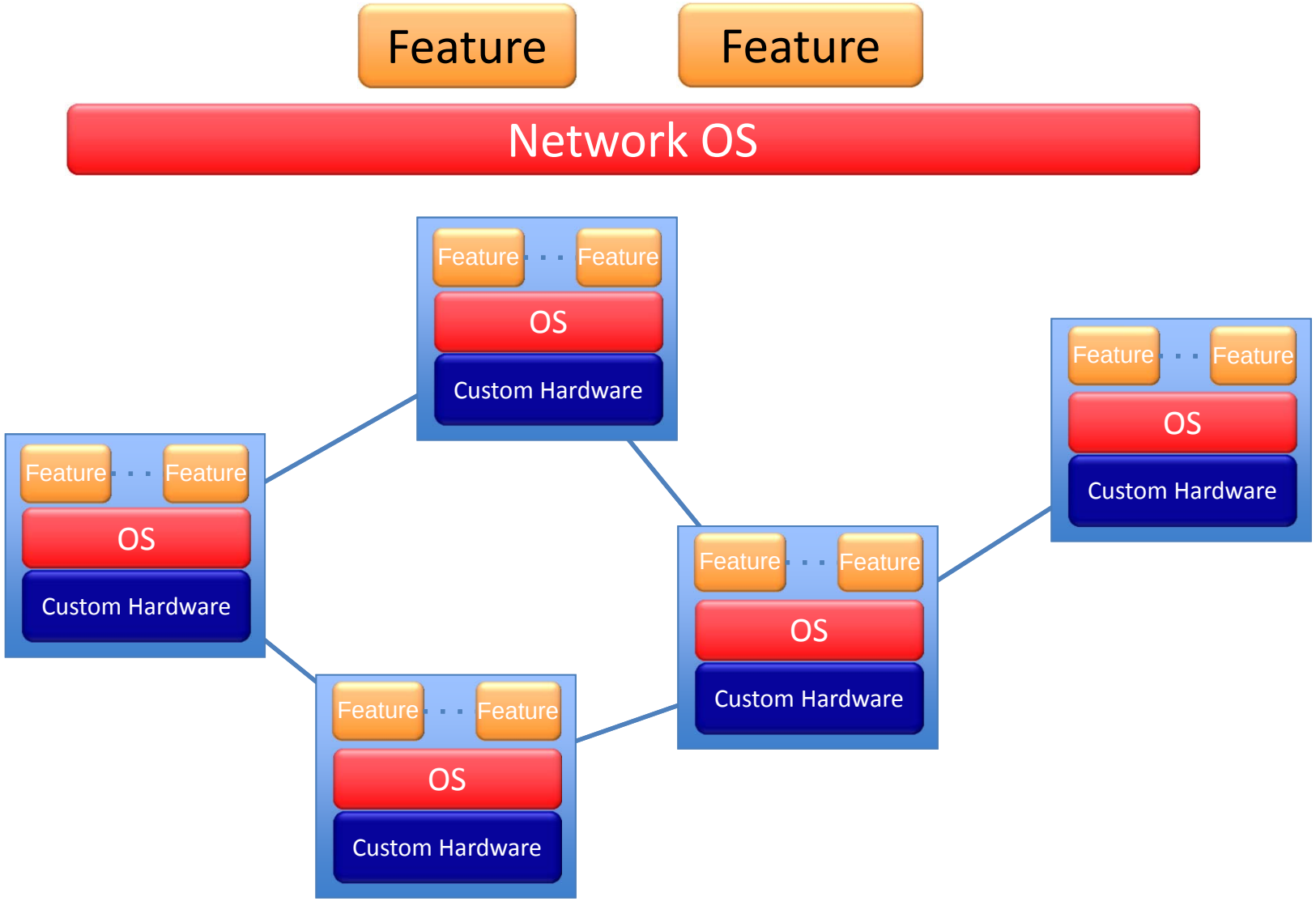
Horizontal
Open interfaces
Rapid innovation

Routing, management, mobility management, access control, VPNs, …

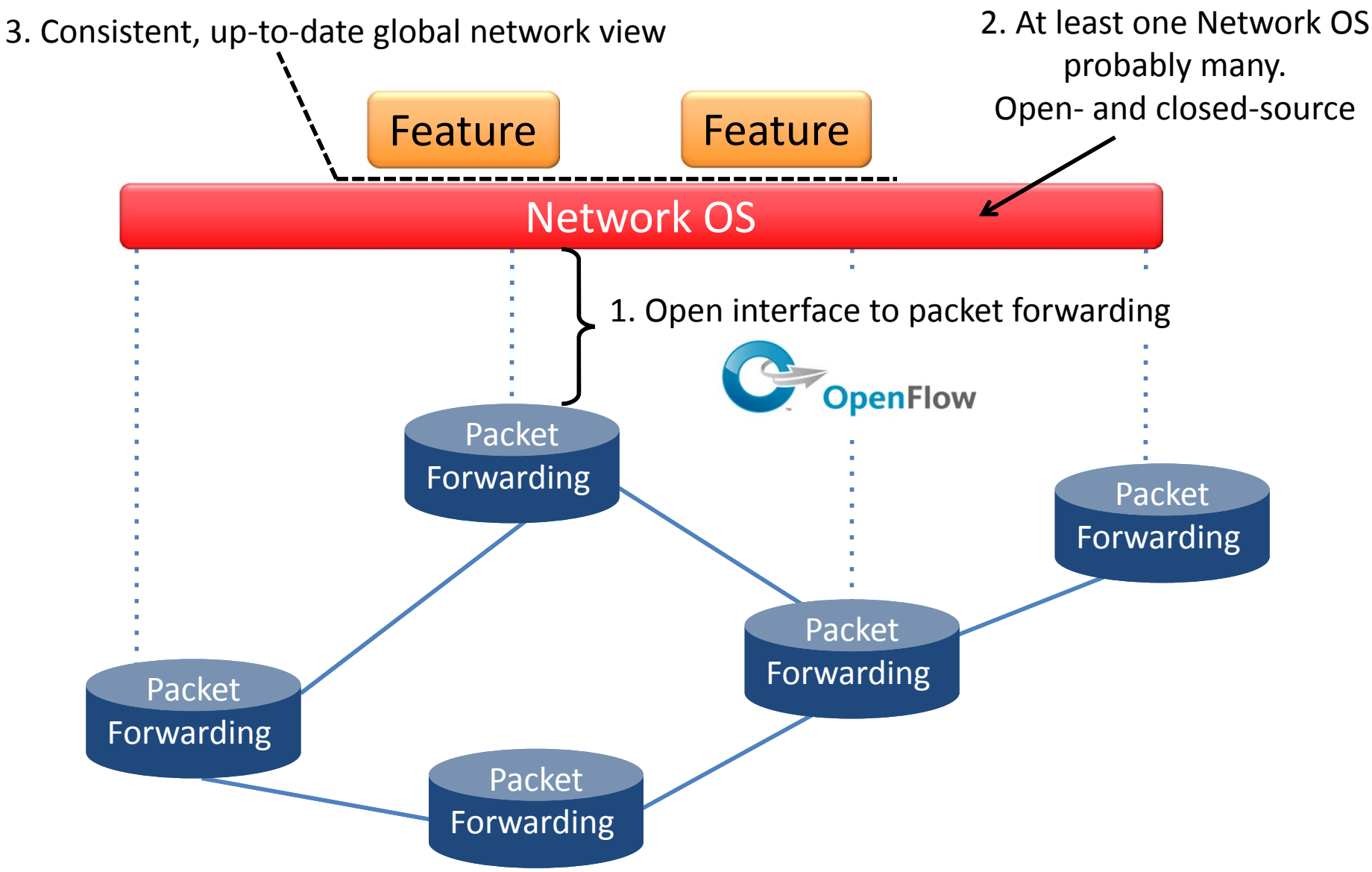


- Vertically integrated, complex, closed, proprietary
- Networking industry with “mainframe” mind-set

The network is changing



Software Defined Network (SDN)



Network OS

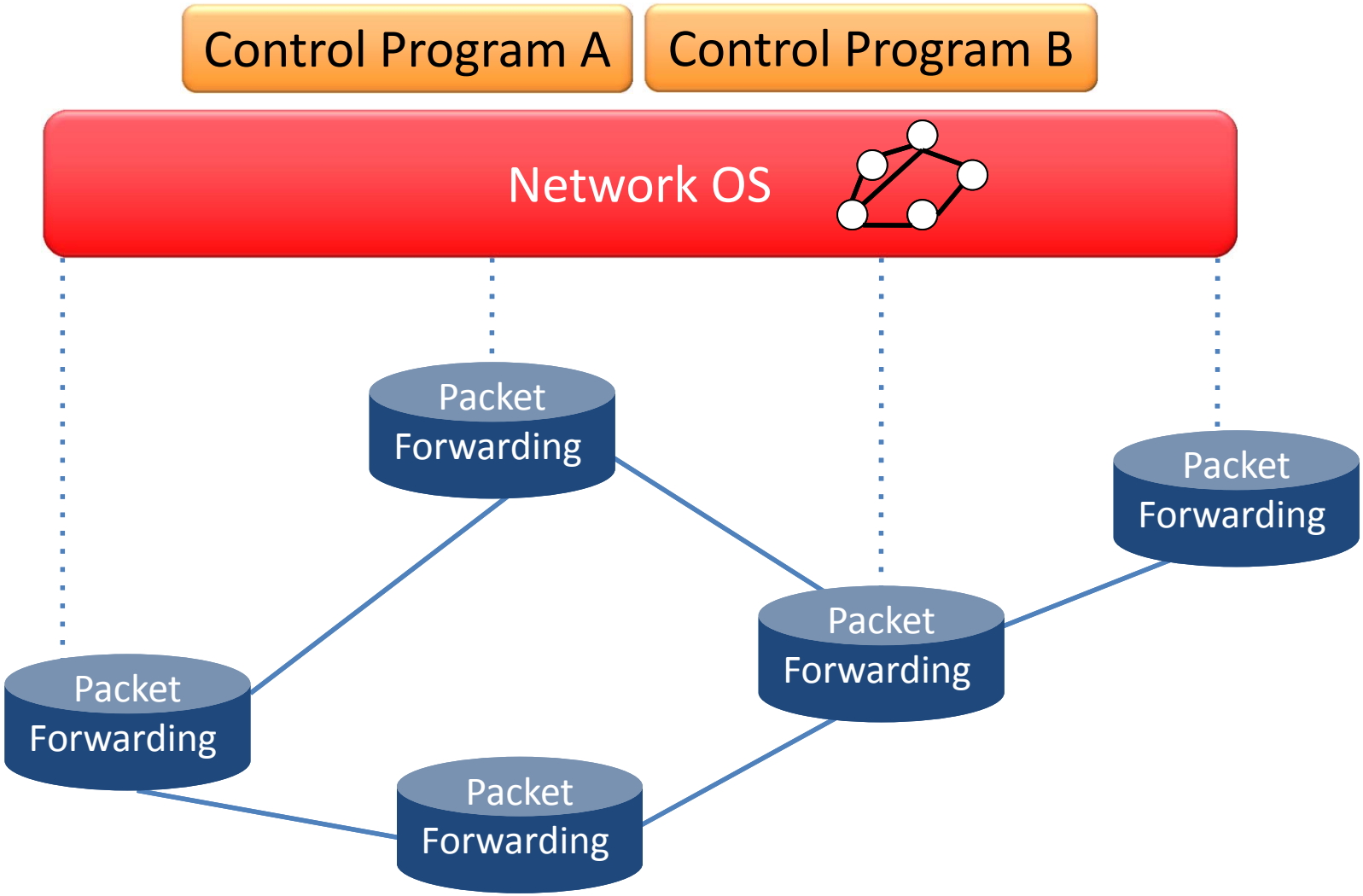
Network OS: distributed system that creates a consistent, up-to-date network view

- Runs on servers (controllers) in the network
- NOX, ONIX, Trema, Beacon, Maestro, … + more

Uses forwarding abstraction to:

- Get state information **from** forwarding elements
- Give control directives **to** forwarding elements

Software Defined Network (SDN)



Control Program

Control program operates on view of network

- **Input**: global network view (graph/database)
- **Output**: configuration of each network device

Control program is not a distributed system

- Abstraction hides details of distributed state

Forwarding Abstraction

Purpose: Abstract away forwarding hardware

Flexible

- Behavior specified by control plane
- Built from basic set of forwarding primitives

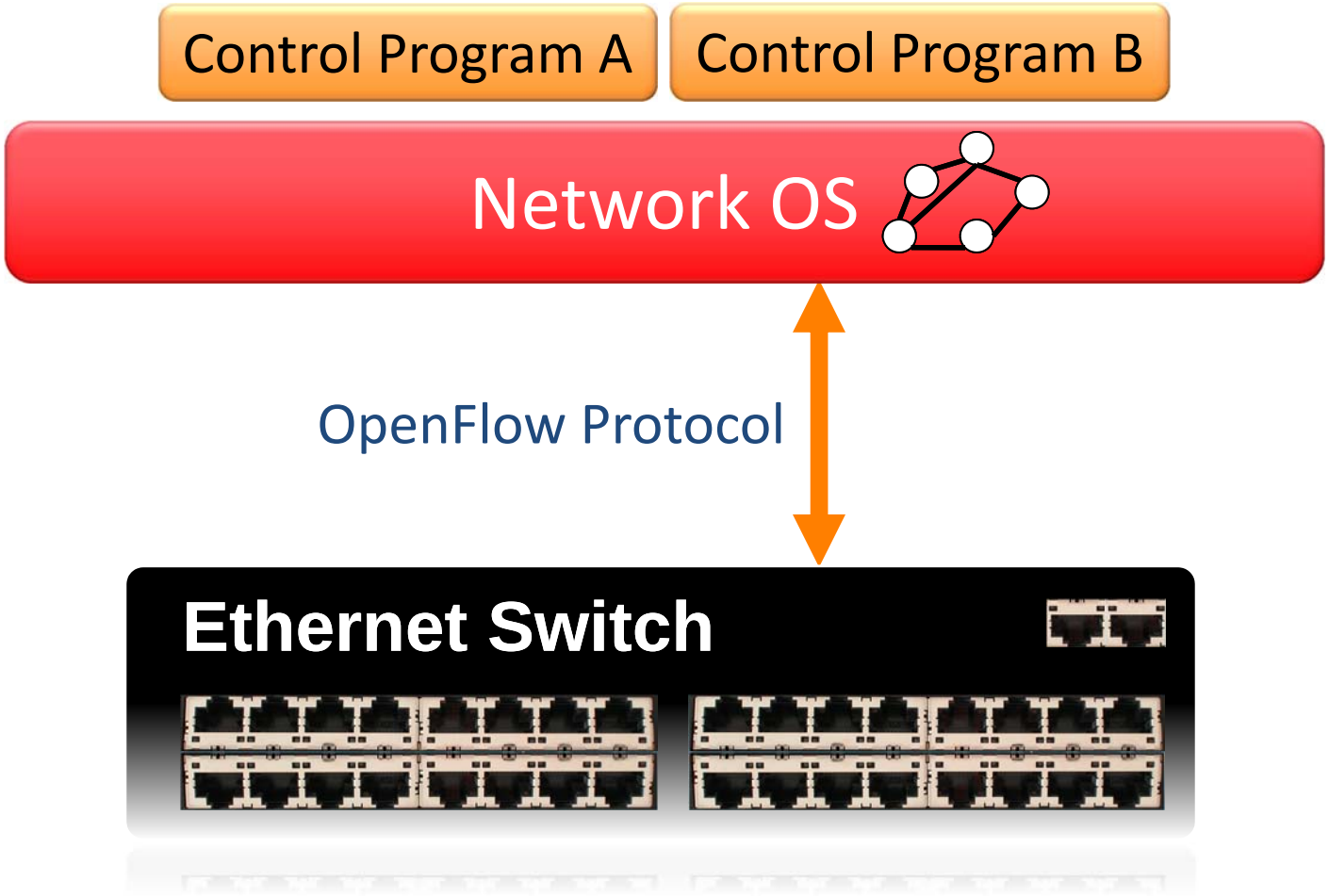
Minimal

- Streamlined for speed and low-power
- Control program not vendor-specific

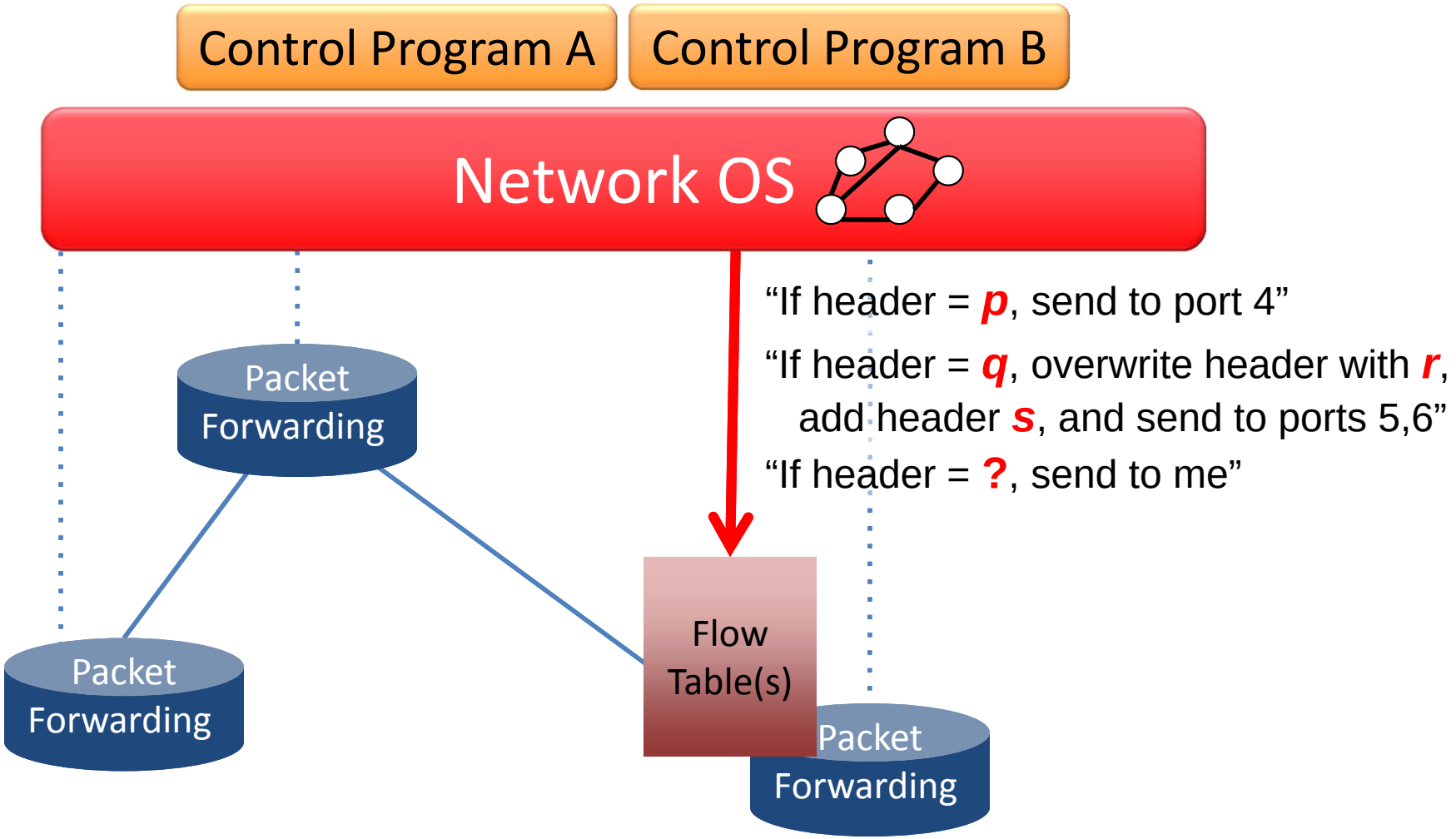
OpenFlow is an example of such an abstraction

OpenFlow Basics

OpenFlow Basics



OpenFlow Basics



Plumbing Primitives

<Match, Action>

Match arbitrary bits in headers:

Match: 1000x01xx0101001x

- Match on any header, or new header
- Allows any flow granularity

Action

- Forward to port(s), drop, send to controller
- Overwrite header with mask, push or pop
- Forward at specific bit-rate

General Forwarding Abstraction

Small set of primitives
"Forwarding instruction set"

Protocol independent
Backward compatible

Switches, routers, WiFi APs,
basestations, TDM/WDM

Three examples

Example 1.

OSPF and Dijkstra

OSPF

- RFC 2328: **245 pages**

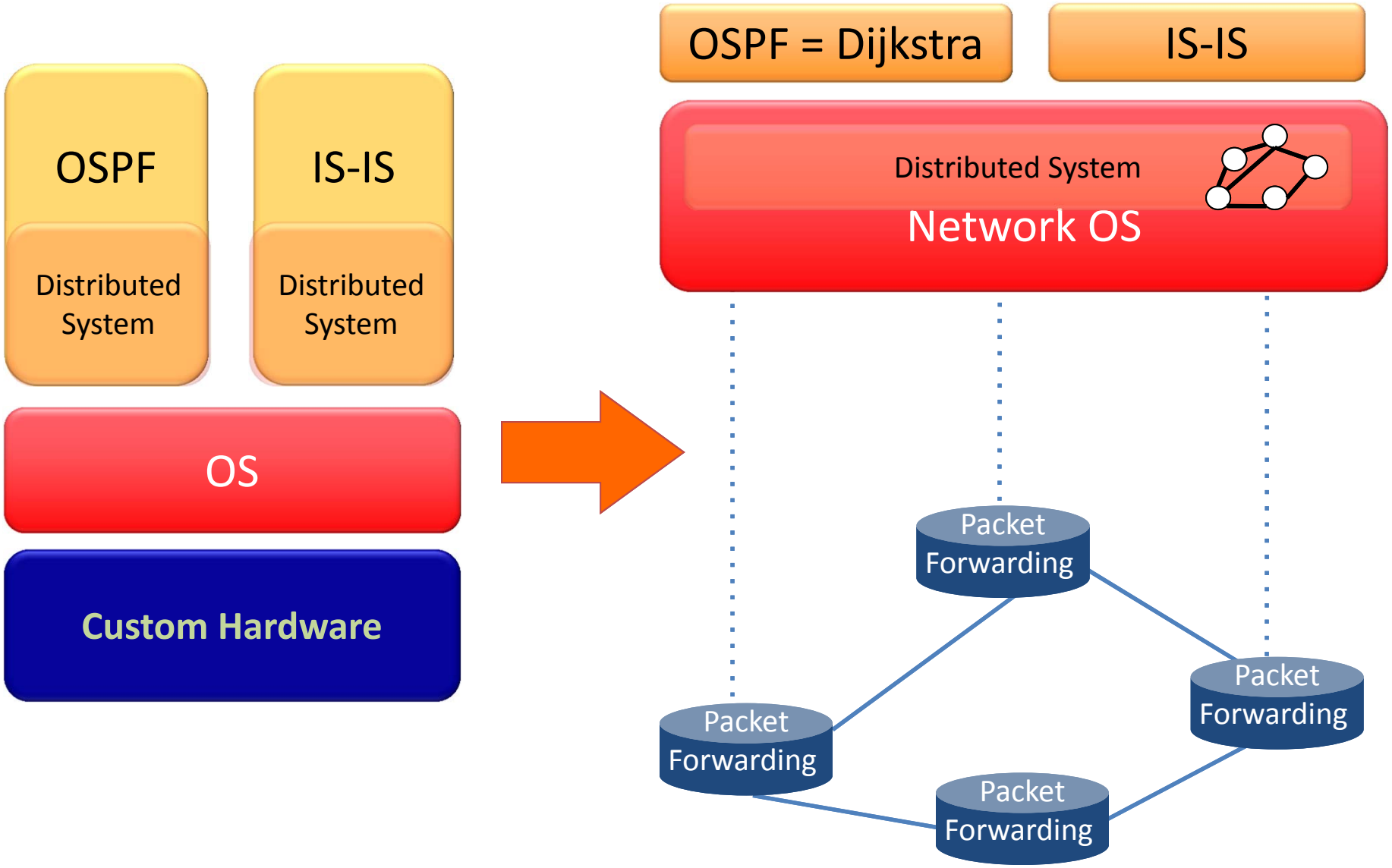
Distributed System

- Builds consistent, up-to-date map of the network: **101 pages**

Dijkstra's Algorithm

- Operates on map: **4 pages**

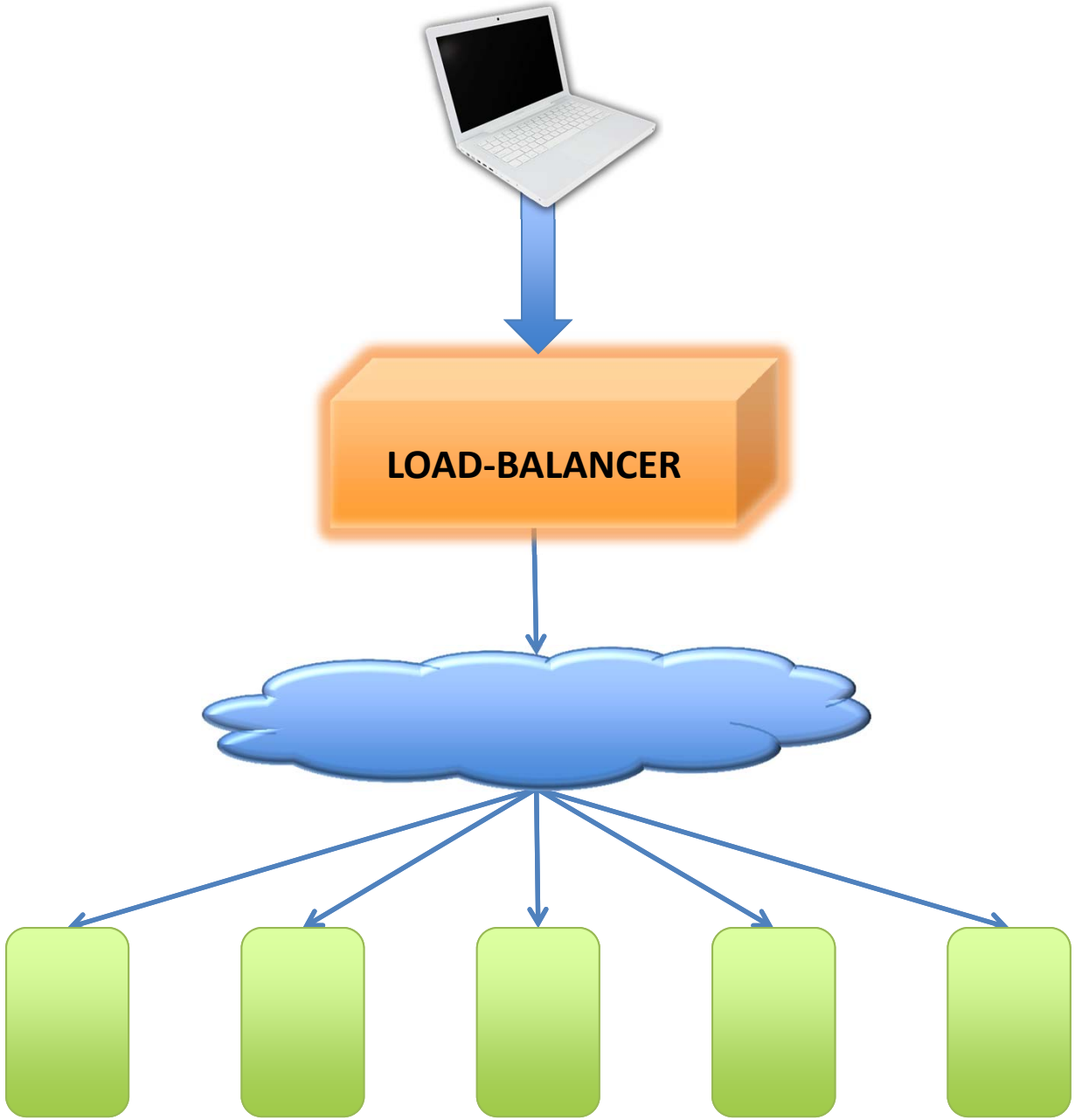
Example

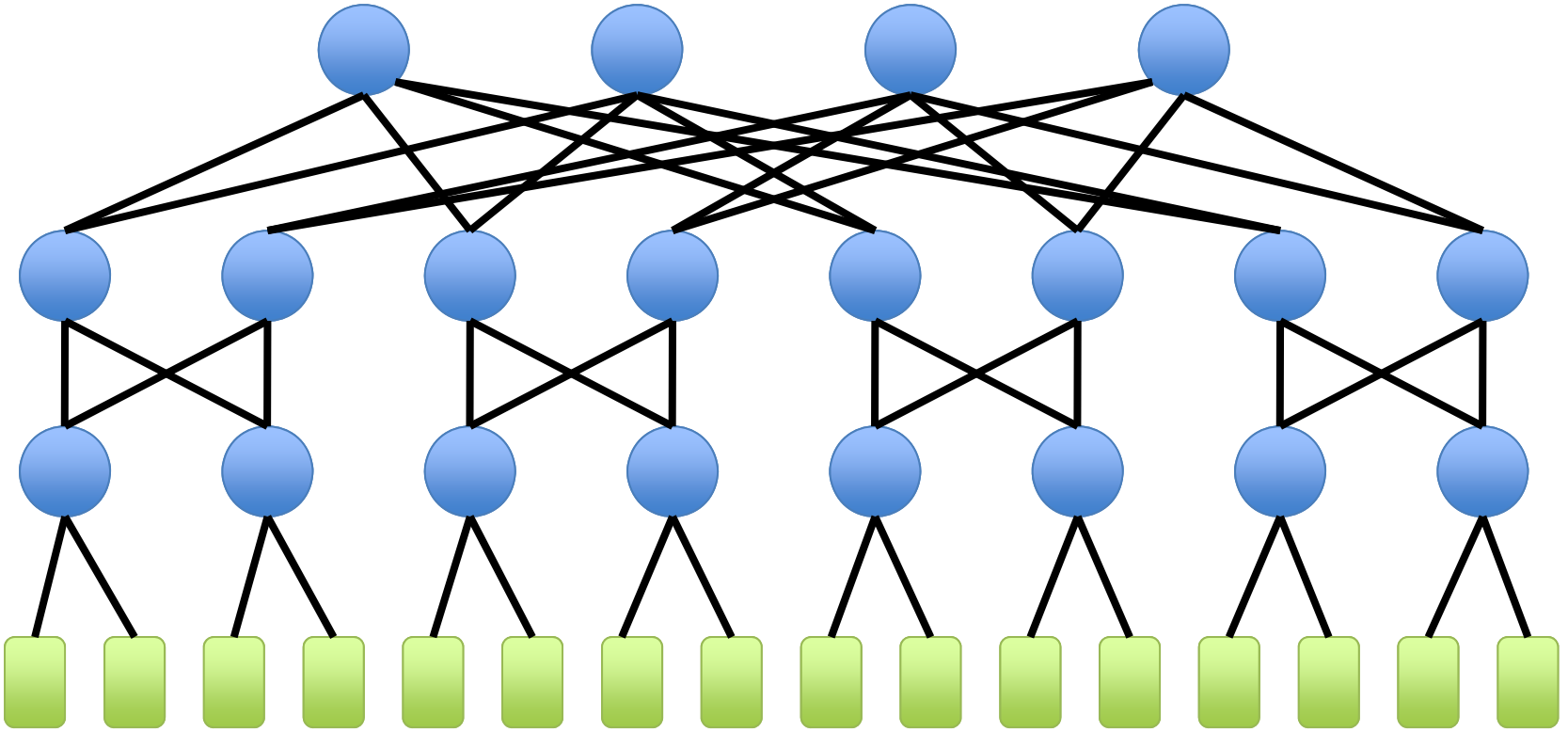

OSPF
IS-IS
Distributed System
Distributed System
OS
Custom Hardware
OSPF = Dijkstra
IS-IS
Distributed System
Network OS
Packet Forwarding
Packet Forwarding
Packet Forwarding
Packet Forwarding

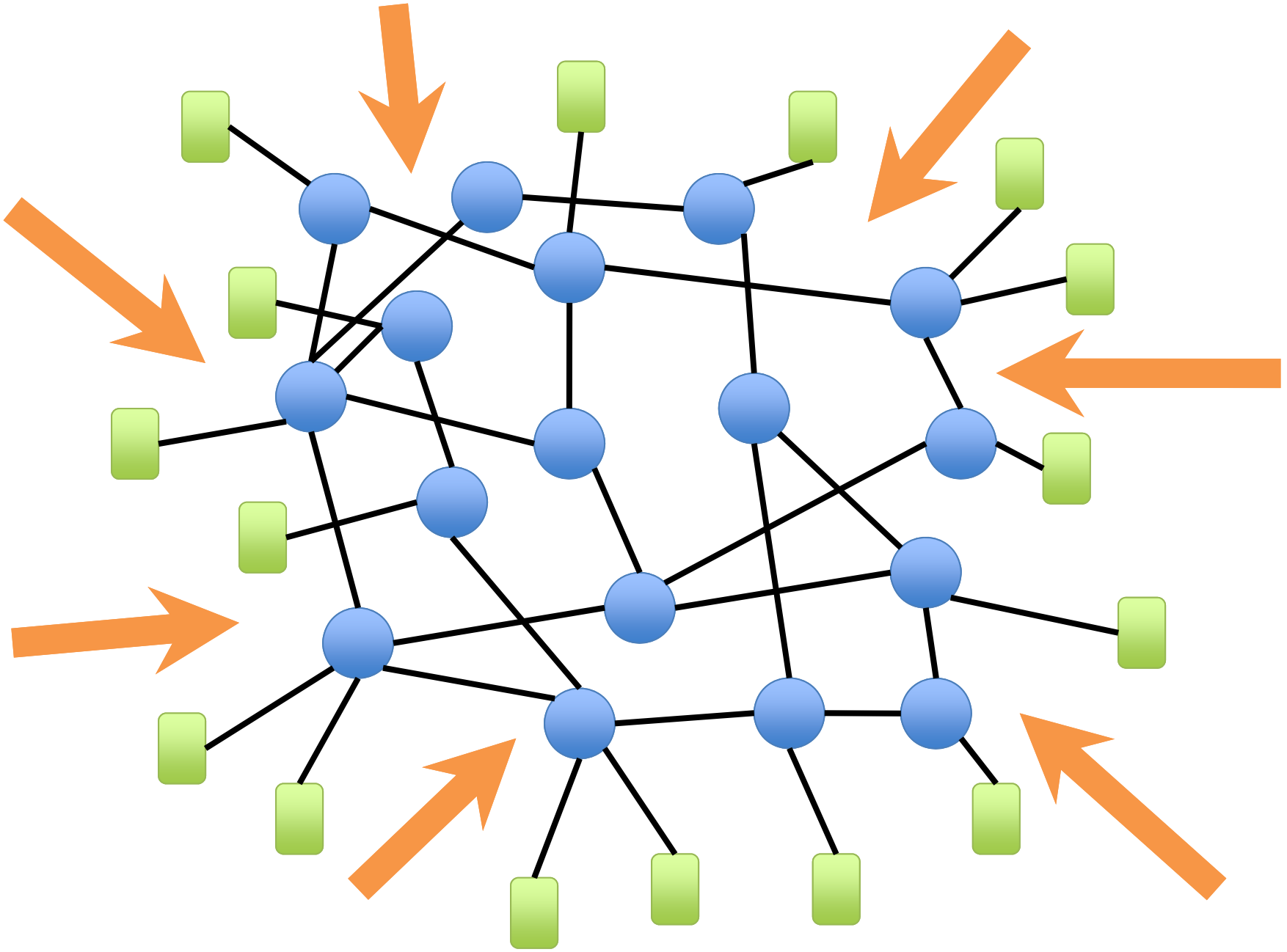
Example 2.

Load-balancing as a network primitive

Nikhil Handigol, Mario Flajslik, Srini Seetharaman


LOAD-BALANCER

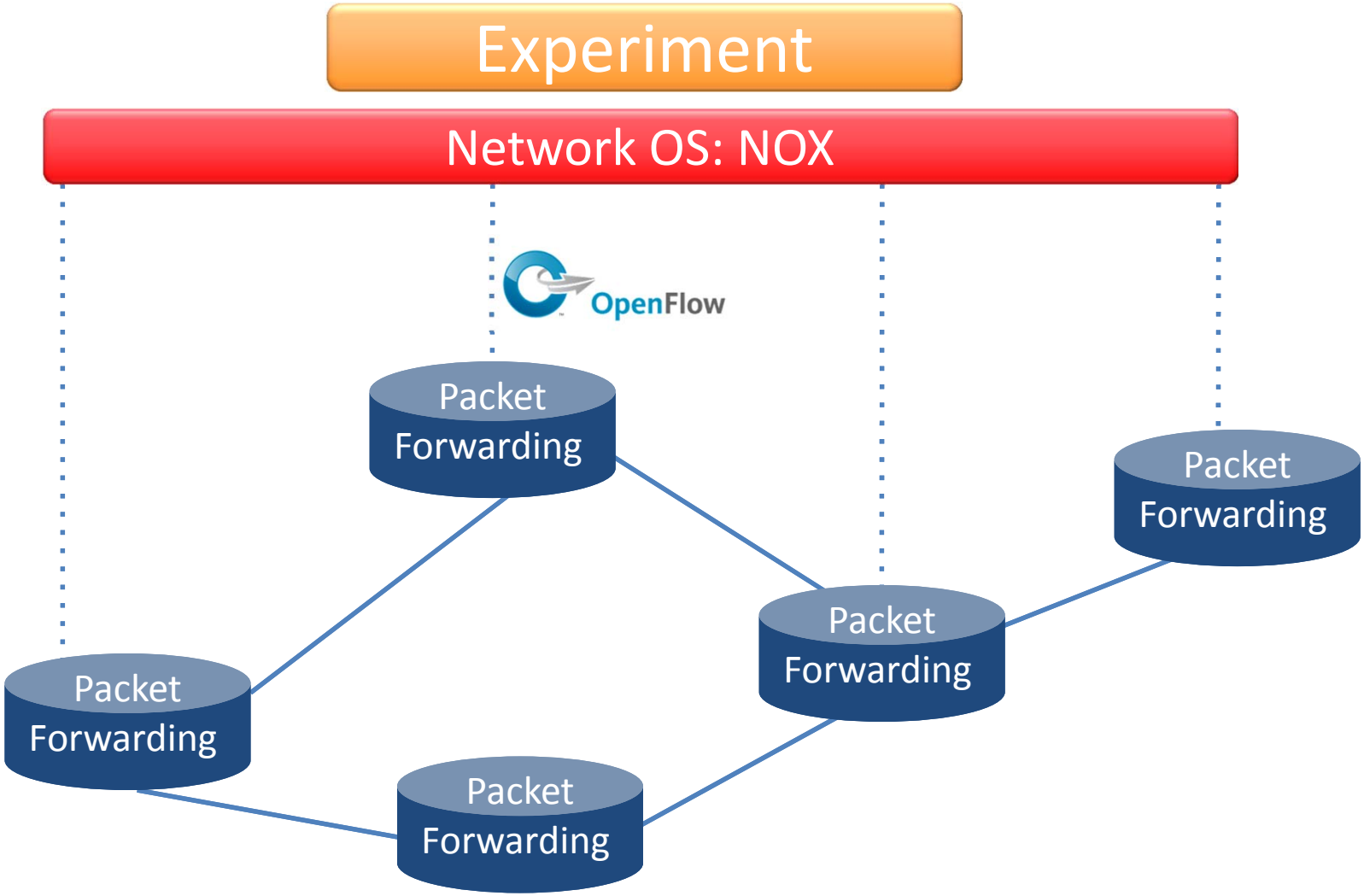




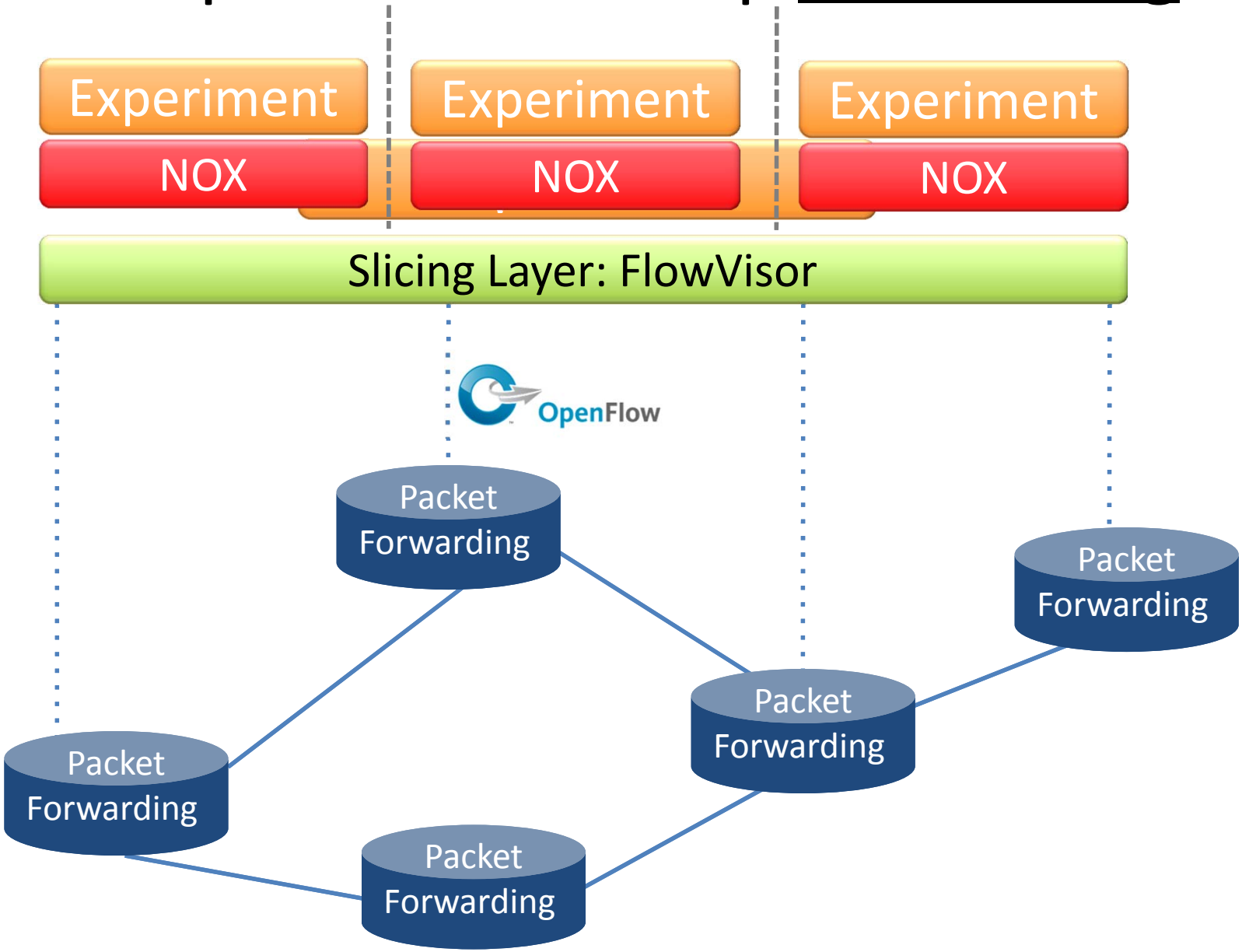
Load Balancing is just Smart Routing

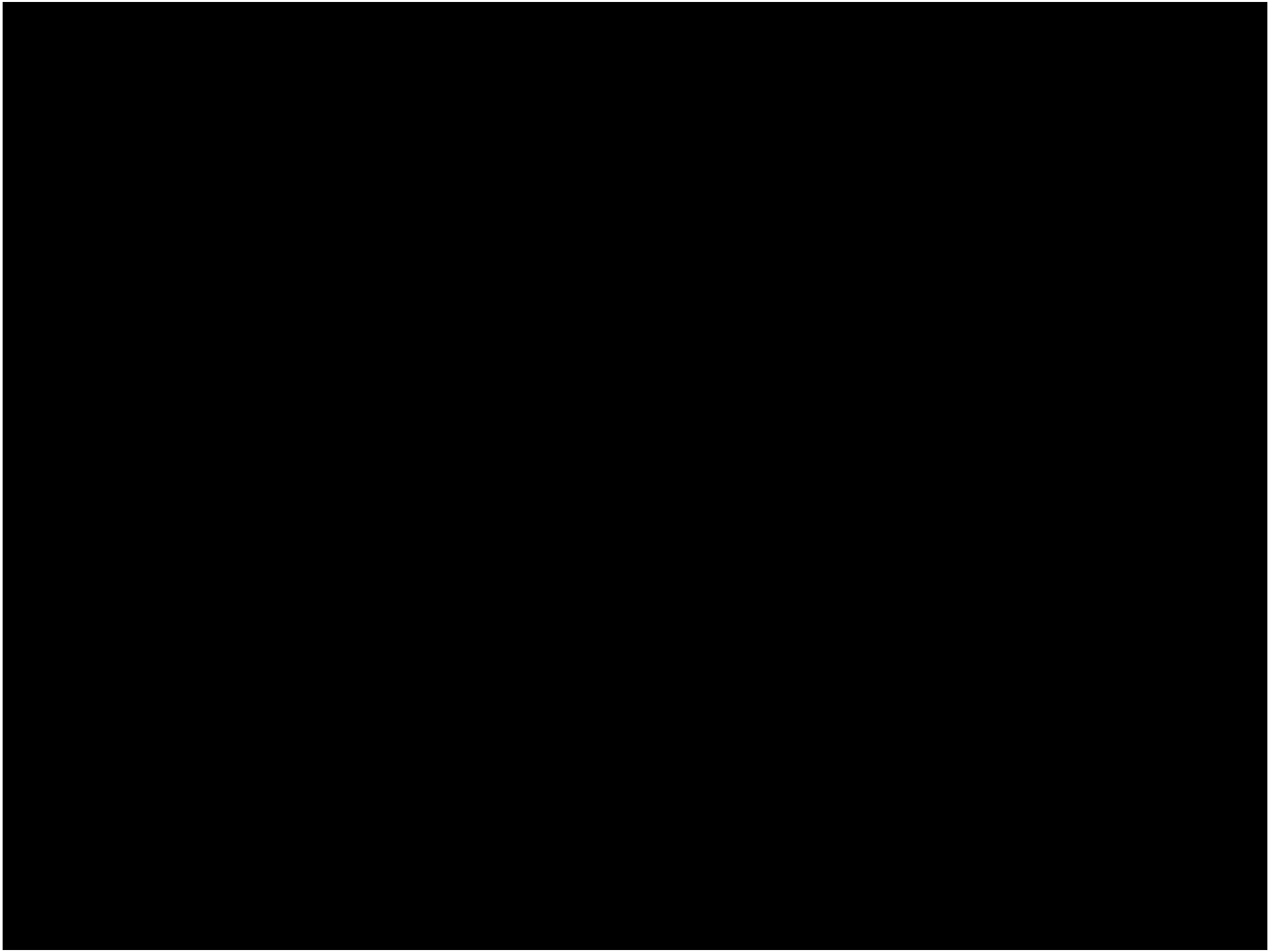

NLR

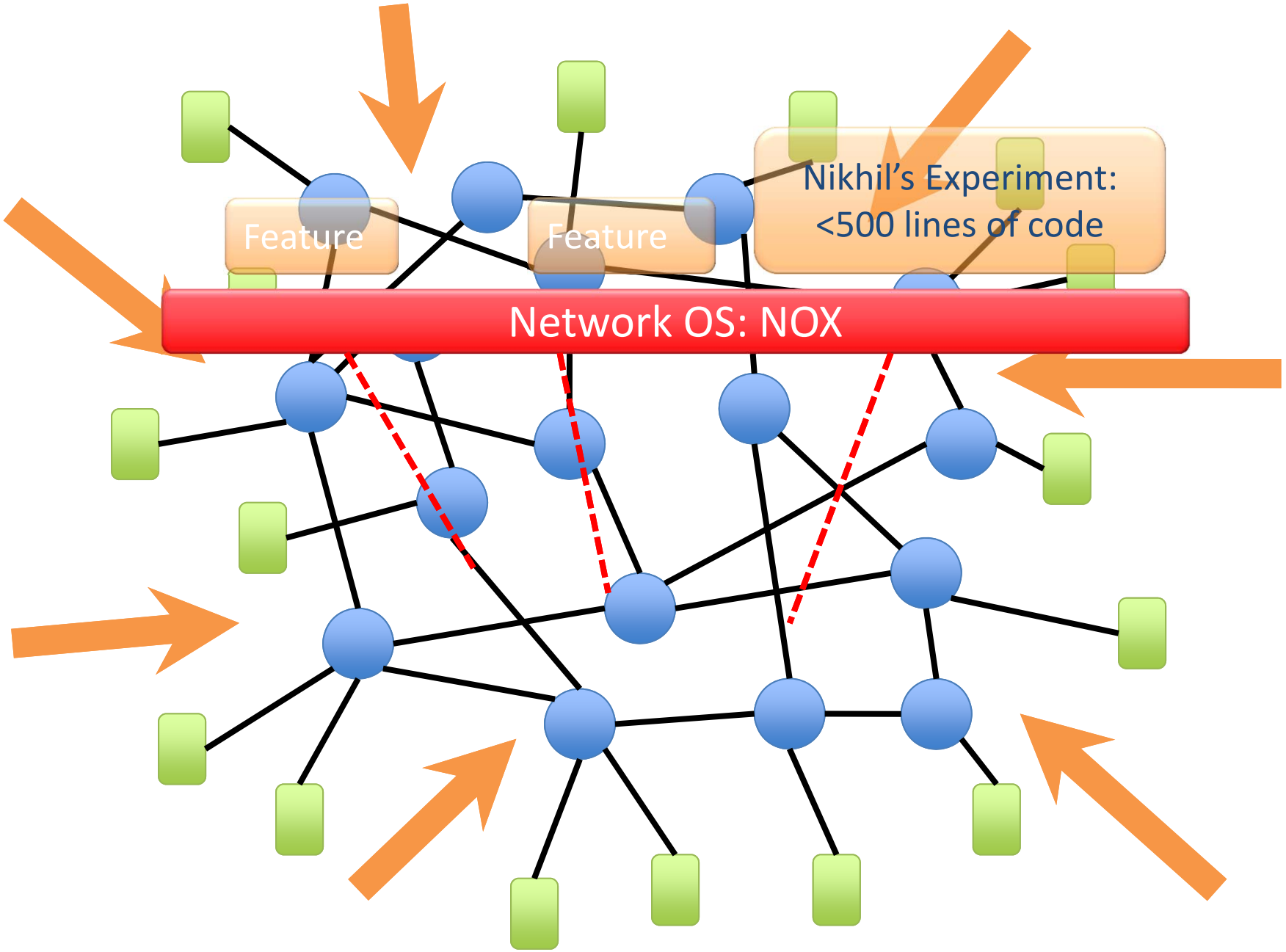
Experimental Setup



Experimental Setup with Slicing



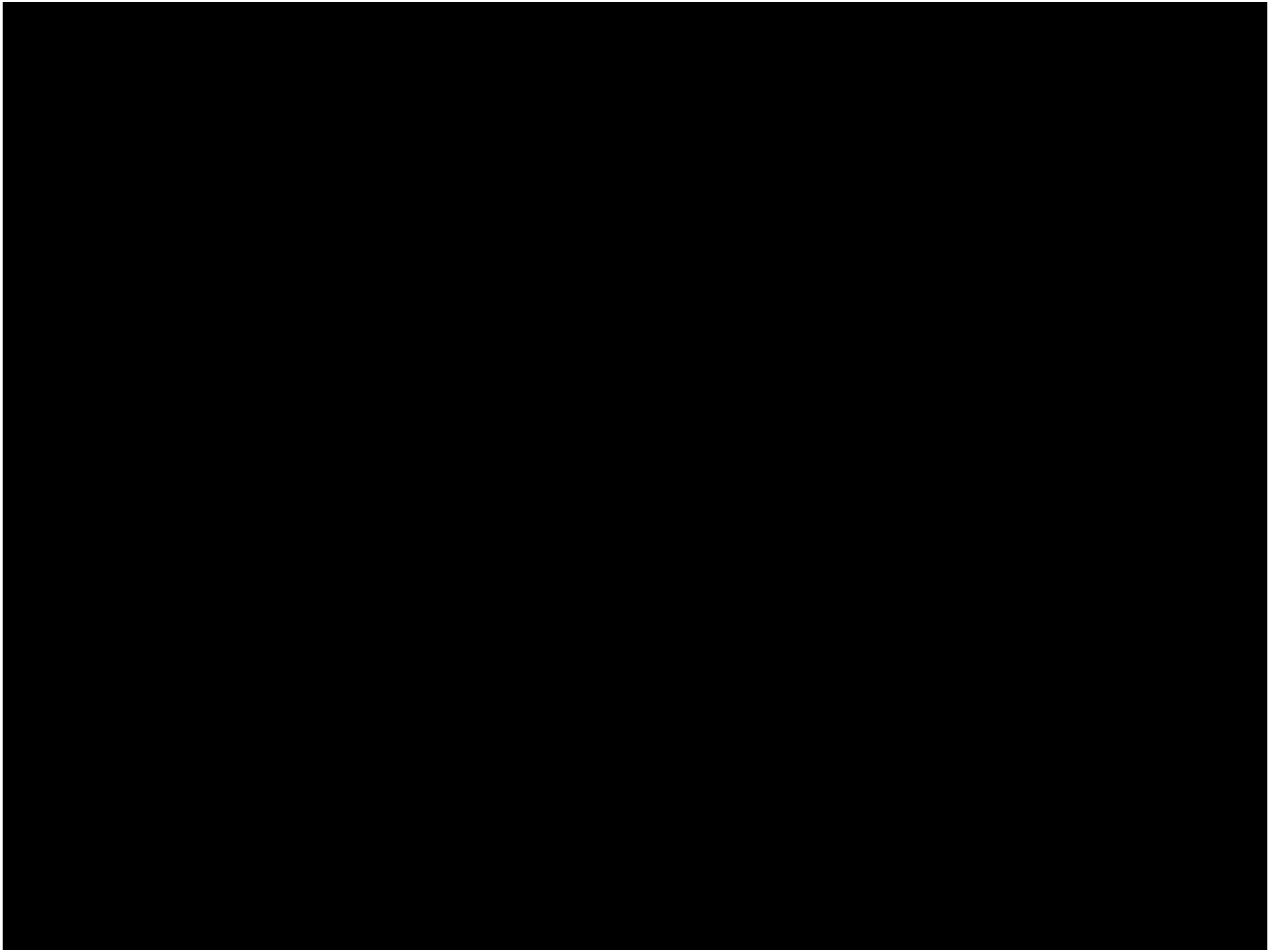


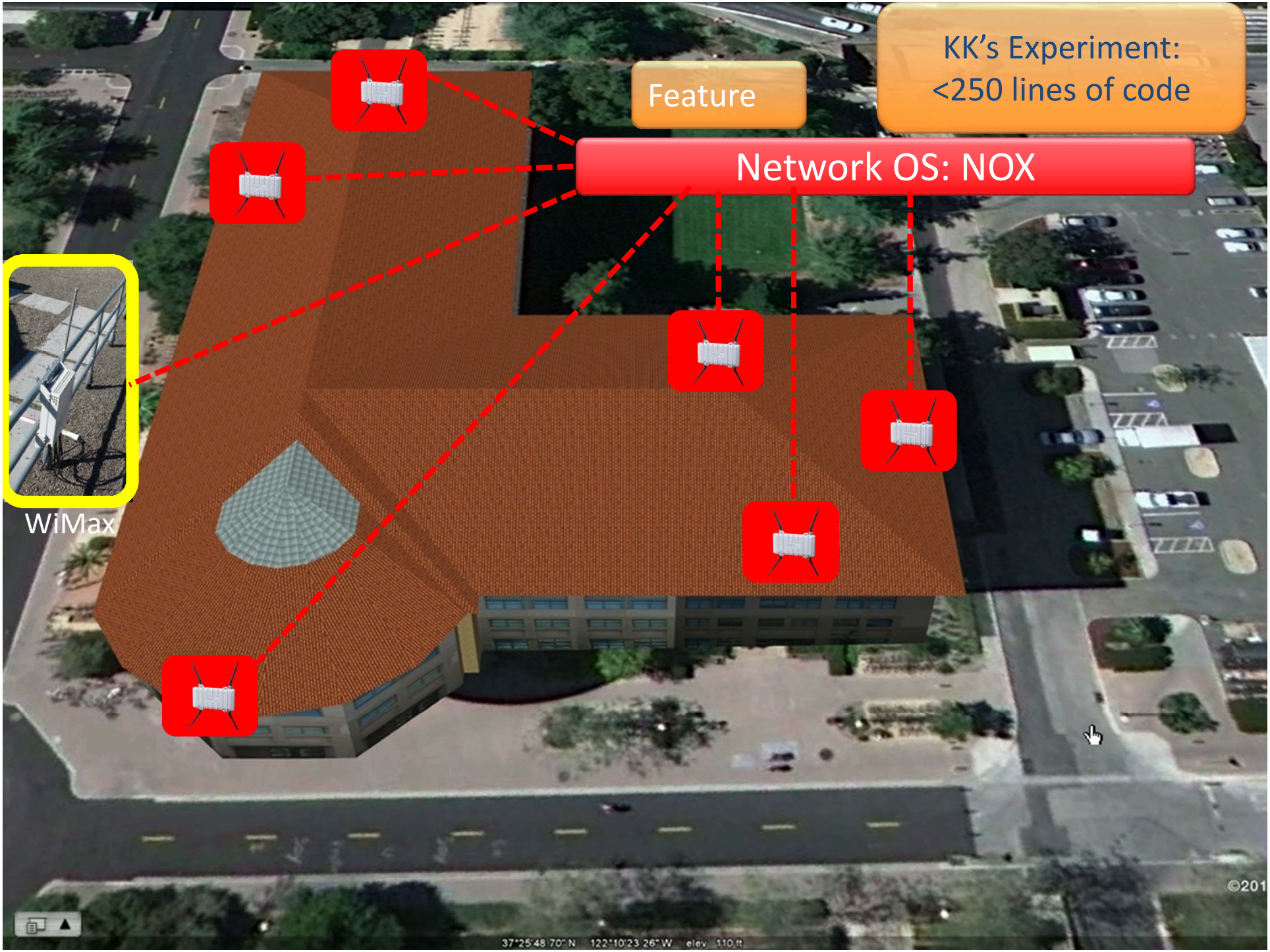

Feature
Feature
Nikhil's Experiment:
<500 lines of code
Network OS: NOX

Research Example #2

Using all the wireless capacity around us

KK Yap, Masayoshi Kobayashi, Yiannis Yiakoumis, TY Huang




Feature
KK's Experiment:
<250 lines of code
Network OS: NOX
WiMax

More videos

openflow.org/videos

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Great talk by Scott Shenker

http://www.youtube.com/watch?v=WVs7Pc99S7w

(Story summarized here)

Networking

Networking is “Intellectually Weak”

Networking is behind other fields

Networking is about the mastery of complexity

Good abstractions tame complexity

Interfaces are instances of those abstractions

No abstraction => increasing complexity

We are now at the complexity limit

By comparison: Programming

Machine languages: no abstractions

- Had to deal with low-level details

Higher-level languages: OS and other abstractions

- File system, virtual memory, abstract data types, …

Modern languages: even more abstractions

- Object orientation, garbage collection,…

Programming Analogy

What if programmers had to:

- Specify where each bit was stored
- Explicitly deal with internal communication errors
- Within a programming language with limited expressability

Programmers would redefine problem by:

- Defining higher level abstractions for memory
- Building on reliable communication primitives
- Using a more general language

Specification Abstraction

Network OS eases implementation

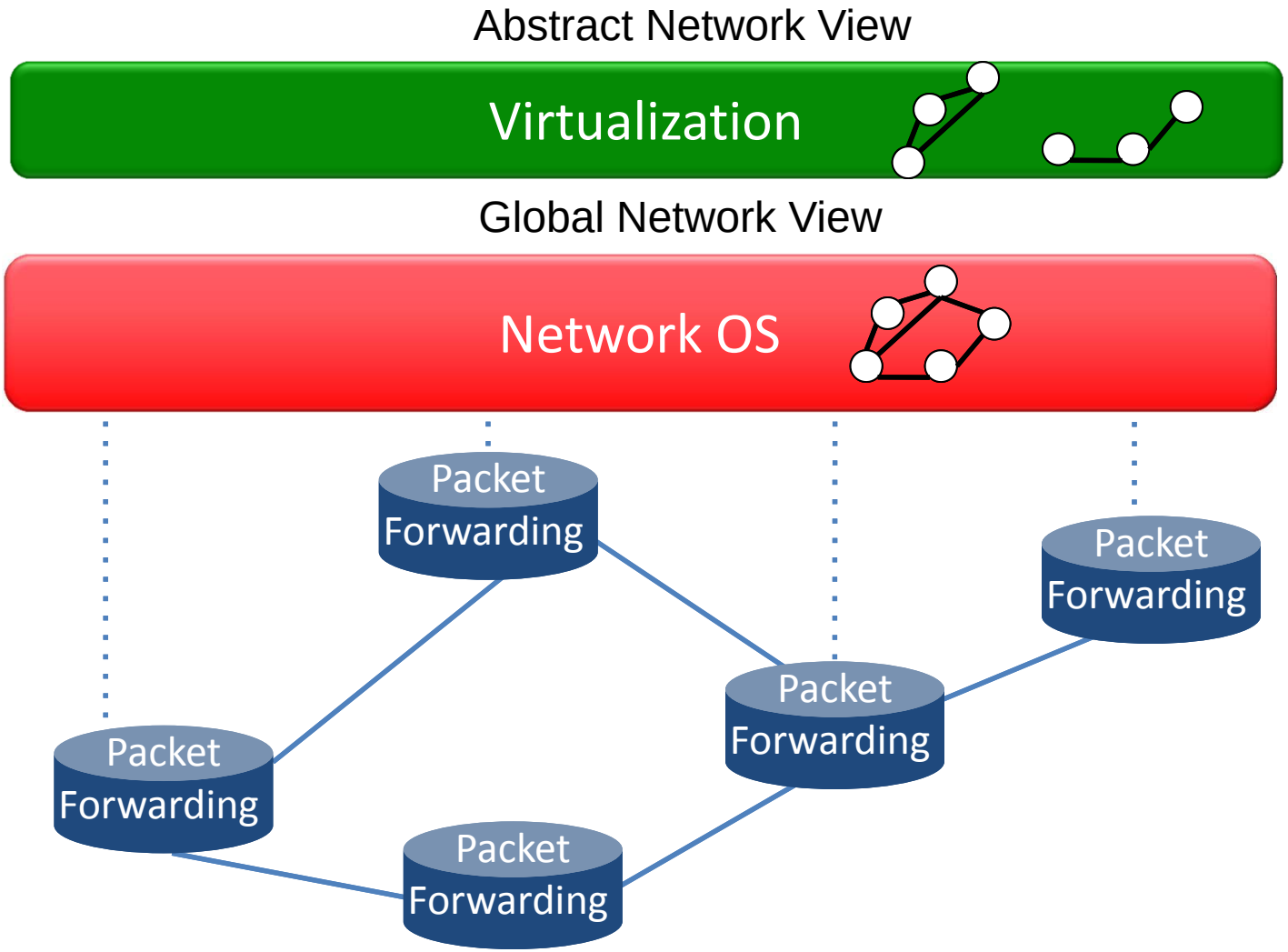
Next step is to ease specification

Provide abstract view of network map

Control program operates on abstract view

Develop means to simplify specification

Software Defined Network (SDN)



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SDN in development

Domains

- Data centers
- Enterprise/campus
- Cellular backhaul
- Enterprise WiFi
- WANs

Products

- Switches, routers: About 15 vendors
- Software: About 6 vendors and startups

New startups (6 so far). Lots of hiring in networking.

Interop, May 2011

Demos: 16 companies demonstrated OpenFlow

Best of show: NEC OpenFlow switch

"*Interop 2011 could have been called the OpenFlow Show.*" - Computerworld

Open Networking Foundation (ONF)

New non-profit standards organization (Mar 2011)

Defining standards for SDN, starting with OpenFlow

Board of Directors

Google, Facebook, Microsoft, Yahoo, DT, Verizon

39 Member Companies

Cisco, VMware, IBM, Juniper, HP, Broadcom, Citrix, NTT, Intel, Ericsson, Dell, Huawei, …

http://www.OpenNetworkingFoundation.org

Cellular industry

- Recently made transition to IP
- Billions of mobile users
- Need to securely extract payments and hold users accountable
- IP is bad at both, yet hard to change

SDN enables industry to customize their network

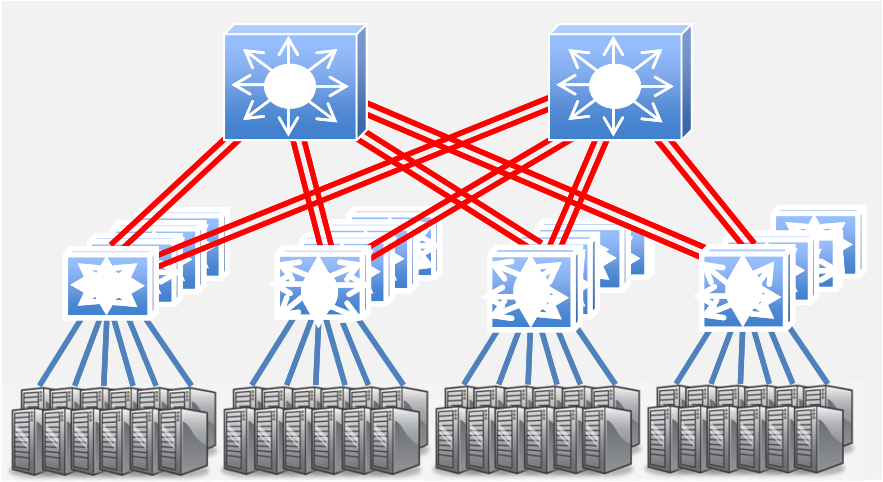
Telco Operators

- Global IP traffic growing 40-50% per year
- End-customer monthly bill remains unchanged
- Therefore, CAPEX and OPEX need to reduce 40-50% per Gb/s per year
- But in practice, reduces by ~20% per year

SDN enables industry to reduce OPEX and CAPEX

…and to create new differentiating services

Example: New Data Center



Cost

200,000 servers
Fanout of 20 ➔ 10,000 switches
$5k vendor switch = $50M
$1k commodity switch = $10M

Savings in 10 data centers = $400M

Control

More flexible control
Tailor network for services
Quickly improve and innovate

Consequences for research

Ease of trying new ideas

- Existing tools: NOX, Beacon, switches, Mininet
- More rapid technology transfer
- GENI, Ofelia and many more

A stronger foundation to build upon

- Provable properties of forwarding
- New languages and specification tools

Consequences for standards

Standards will define the interfaces

The role of standards will change:

- Network owners will define network behavior
- Features will be adopted without standards

Programming world

- Good software is adopted, not standardized

Summary

Networks becoming

- More programmatic
- Defined by owners and operators, not vendors
- Faster changing, to meet operator needs
- Lower opex, capex and power

Abstractions

- Will shield programmers from complexity
- Make behavior more provable
- Will take us places we can’t yet imagine