OpenFlow/Software Defined Networking:

Enable Innovations in Internet Infrastructure

Guru Parulkar
parulkar@stanford.edu
www.openflow.org

Funded in part by: NSF, Cisco, DoCoMo, DT, Ericsson, Google, Huawei, NEC, Xilinx
Nick McKeown, Guru Parulkar, Guido Appenzeller, Nick Bastin, David Erickson, Glen Gibb, Nikhil Handigol, Brandon Heller, TY Huang, Peyman Kazemian, Masayoshi Kobayashi, Jad Naous, Johan van Reijendam, Srinivasa Seetharaman, Rob Sherwood, Dan Talayco, Paul Weissman, Tatsuya Yabe, KK Yap, Yiannis Yiakoumis and many more.

With Scott Shenker and team at Berkeley and Martin Casado at Nicira
Internet has been wildly successful

Internet has many problems:
Well known for many years

Root cause: Internet has been closed for innovations
Why Is Internet Closed for Innovation?

Routing, management, mobility management, access control, VPNs, ...

- Million of lines of source code
- 6000+ RFCs
- Billions of gates
- Bloated
- Power Hungry
- Vertically integrated, complex, closed, proprietary
- Not suitable for experimental ideas

Not good for network owners & users; Not good for researchers.
From Vertically Integrated to

Network OS

Operating System
Specialized Packet Forwarding Hardware

Feature

Operating System
Specialized Packet Forwarding Hardware

Feature

Operating System
Specialized Packet Forwarding Hardware

Feature

Operating System
Specialized Packet Forwarding Hardware

Feature

Operating System
Specialized Packet Forwarding Hardware

Feature
Open Software Defined Networks

- Well-defined open API
- Constructs a logical map of the network

Network OS

Open vendor agnostic protocol

Simple Packet Forwarding Hardware

OpenFlow

Simple Packet Forwarding Hardware

Simple Packet Forwarding Hardware

Simple Packet Forwarding Hardware

Simple Packet Forwarding Hardware
OpenFlow Operation: Cache Forwarding Decisions

If header = \( x \), send to port 4
If header = \( y \), overwrite header with \( z \), send to ports 5, 6
If header = \(?\), send to me
Definitions

\(<\text{Match, Action}>\)

**Match** arbitrary bits in headers:

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

\[
\begin{array}{c|c}
\text{Header} & \text{Data} \\ \hline
\text{Match: 1000x01xx0101001x} & \\
\end{array}
\]

**Action**

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

Network OS
(Server Software)

OpenFlow Protocol

Ethernet Switch
OpenFlow Enabled “Switches”

Prototypes or products

Wireline switches
- HP, NEC, Juniper, Quanta, Netgear, …
- Extreme, Arista, …

Switching chips
- Reference designs: Broadcom, Marvell

Transport switches
- Ciena, Fujitsu

WiFi APs and WiMAX Base stations
Network OS

Research

- NOX (C++/Python)
  http://noxrepo.org
- Beacon (Java) coming soon.
- Others in development

Commercial

- ONIX [OSDI 2010, Google, Nicira, NEC]
- Expect others
Slicing and Virtualization

Network OS

Default: Production Traffic

New routing protocol

New mobility mgmt
Nation-wide OpenFlow Infrastructure
Part of NSF’s GENI
Example Research Enabled

- Data center: energy conservation, routing, and management
- Seamless use of diverse wireless networks
- Network based load balancing
- Packet/circuit convergence, traffic engineering
- Simpler control plane for converged packet/circuit MPLS networks
- Slicing and scalable remote control/management of home networks
- Distributed snap shot of VMs (by DOCOMO researchers)
- Inter-domain routing with pathlets (by UIUC)
- Redundant traffic elimination [for CDNs] (by Univ of Wisconsin)
- And many more …
An Example Experiment

Using all the wireless capacity around us

KK Yap, Masayoshi Kobayashi, Yiannis Yiakoumis, TY Huang
KK’s Experiment:

- <250 lines of code

Feature

Network OS (NOX)

WiMax
More Experiments and Videos

http://www.openflow.org/videos/
Early Ecosystem

Interest from providers/data center operators

Deployments in R&E Networks

Vendors

Commitment varies
Open Network Foundation to continue standardization of OpenFlow and other SDN interfaces/APIs

www.opennetworkingfoundation.org

Board of Directors
Deutsche Telekom, Facebook, Google, Microsoft, Verizon, Yahoo!

Members
Broadcom, Brocade Ciena, Cisco, Citrix, Dell, Ericsson, Force10, HP, IBM, Juniper Networks, Marvell, NEC, Netgear, NTT, Riverbed Technology, VMware
Why Providers Like OpenFlow/SDN

“OpenFlow really has the potential to be a very important shift in how people look at networks,” said Urs Hoelzle, Senior Vice President of Engineering at Google. “It can help make complicated networks simpler. Software-Defined Networking will allow networks to evolve and improve more quickly than they can today. Over time, we expect SDN will help networks become both more secure and more reliable.”

“We believe the ONF effort will accelerate the development of key network capabilities, which will help evolve our networks to be more responsive to our customers’ needs,” said Stu Elby, Vice President, Network Architecture & Technology at Verizon.

“With broad industry support from technology leaders and networking experts, the ONF brings new opportunities and flexibility to the future of networking,” added Jonathan Heiliger, ONF Founding Board Member and Vice President of Technical Operations at Facebook.
What is next?
Research and Development Agenda

- Continue to develop SDN
  - Scientific foundation
  - Technologies and systems
  Enable research community
- Explore various domains of use
  - Data center, enterprise, service provider, home, …
  - Showcase deployments
- Demonstrate new use cases on SDN
  - Enable research community
- Build partnerships to accomplish goals
  - We cannot do it all
How you can participate?

- **Researcher**
  - Deploy OpenFlow network & demonstrate interesting network capabilities
  - Design and build better building blocks: FlowVisor, Network OS, …
  - For different domains of use: home, enterprise, backbone, data center, and different network technologies: wired, wireless, optical

- **Vendor**
  - Add OpenFlow to a key product and have researchers build on it
  - Build and demonstrate interesting network capabilities for your customers
  - Design and build better building blocks: FlowVisor, Controller, …
  - For different domains of use and network technologies as above

- **Provider**
  - Ask your vendors to support OpenFlow
  - Deploy OpenFlow network & demonstrate interesting network
Final Takeaways

- OpenFlow/SDN enables innovation within
  - Enterprise, backbone, cellular, home & data center networks
  - Represents a promising architecture direction

- Providers like it for their own reasons
  - Enabling an ecosystem
  - OpenFlow being deployed in R&E networks around the world

Time to engage and help shape this important revolution in networking