Cloud e Datacenter Networking

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Software Defined Networking
Lesson outline

- Software Defined Networks (SDN)
- Credits for the material:
  - Jennifer Rexford
  - Nick McKeown
  - Scott Shenker
The Internet: A Remarkable Story

- Tremendous success
  - From research experiment to global infrastructure
- Brilliance of under-specifying
  - Network: best-effort packet delivery
  - Hosts: arbitrary applications
- Enables innovation in applications
  - Web, P2P, VoIP, social networks, virtual worlds
- But, change is easy only at the edge... 😞
Inside the network: a different story...

- Closed equipment
  - Software bundled with hardware
  - Vendor-specific interfaces
- Over specified
  - Slow protocol standardization
- Few people can innovate
  - Equipment vendors write the code
  - Long delays to introduce new features

Impacts performance, security, reliability, cost...
Networks are Hard to Manage

- Operating a network is expensive
  - More than half the cost of a network
  - Yet, operator error causes most outages
- Buggy software in the equipment
  - Routers with 20+ million lines of code
  - Cascading failures, vulnerabilities, etc.
- The network is “in the way”
  - Especially a problem in data centers
  - ... and home networks
Traditional networking

- Each networking device operates at three different planes
  - **Management plane**: configuration – responsible of general device behavior
    - Determines how the control plane should be configured
    - Slow time-scales (manual configuration by network administrators)
  - **Control Plane**: decision – responsible of establishing the state in routers
    - Determines how and where packets are forwarded
    - Routing, traffic engineering, firewall state, ...
    - Slow time-scales (per control event)
  - **Data Plane**: responsible of processing and forwarding of packets
    - Based on state in routers and endpoints
    - E.g., IP, TCP, Ethernet, etc.
    - Fast timescales (per-packet)
Traditional networking: a router’s view

- In an IP router, the control plane role is played by dynamic routing protocols and the associated state.
  - E.g. OSPF and the Link State Database.
### Traditional planes and time scales

<table>
<thead>
<tr>
<th>Data</th>
<th>Control</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time scales</td>
<td>Packets</td>
<td>Events</td>
</tr>
<tr>
<td>Task</td>
<td>Forwarding/buffering/filtering/scheduling</td>
<td>Routing, circuit set-up</td>
</tr>
<tr>
<td>Location</td>
<td>Hardware</td>
<td>Router software</td>
</tr>
<tr>
<td></td>
<td>• Specialized hardware</td>
<td>• Uses CPU</td>
</tr>
<tr>
<td></td>
<td>• Processes at line rate</td>
<td>• Can only process a small number of packets</td>
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<tr>
<td></td>
<td>• Every packet</td>
<td>• Very slow</td>
</tr>
<tr>
<td></td>
<td>• Very fast</td>
<td></td>
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</tbody>
</table>
Data plane:
Packet streaming

Forward, filter, buffer, mark, rate-limit, and measure packets
Control plane:

Distributed algorithms

Track topology changes, compute routes, install forwarding rules
Management plane:

Human time scale

Collect measurements and configure the equipment
SDN Concept

- Separate control plane and data plane entities
  - Network intelligence and state are logically centralized
  - The underlying network infrastructure is abstracted from the applications
- Remotely control network devices from a central entity
- Execute or run control plane software on general purpose hardware
  - Decouple from specific networking hardware
  - Use commodity servers
- An architecture to control
  - not just a networking device ...
  - but an entire network
- Expected advantages:
  - Ability to innovate through software
    - Overcome the “Internet ossification problem”
  - Cost reductions through increased competition, hardware commoditization and open-source software
A logically centralized “Controller” uses an open protocol (e.g., OpenFlow) to:

- Get state information from forwarding elements (i.e., switches)
- Give controls and directives to forwarding elements
SDN: controller programmability

Controller Application

Events from switches

Commands to switches
SDN allows to unify different kinds of boxes

- **Router**
  - Match: longest destination IP prefix
  - Action: decrement TTL, re-compute header checksum, forward out a link

- **Switch**
  - Match: destination MAC address
  - Action: forward or flood

- **Firewall**
  - Match: IP addresses and TCP/UDP port numbers
  - Action: permit or deny

- **NAT**
  - Match: IP address and port
  - Action: rewrite address and port

All the above boxes may be replaced by “generic” SDN switches whose behaviour is programmed in the controller

By decoupling the network function from the physical infrastructure, the SDN approach is also useful to second another emerging trend in the telecommunications industry: *Network Function Virtualization* (NFV)
A Short History of SDN

• ~2004: Research on new management paradigms
  • RCP, 4D [Princeton, CMU,....]
• 2006: Martin Casado, a PhD student at Stanford and team propose a clean-slate security architecture (SANE) which defines a centralized control of security (instead of at the edge as normally done)
• 2008: the idea of Software Defined Network is originated from OpenFlow project (ACM SIGCOMM 2008)
• 2009: Stanford publishes OpenFlow V1.0.0 specs
• June 2009: Martin Casado co-founds Nicira
• 2011: Open Networking Foundation (~69 members)
  • Board: Google, Yahoo, Verizon, DT, Msoft, F’book, NTT
  • Members: Cisco, Juniper, HP, Dell, Broadcom, IBM,....
• 2012: Latest Open Networking Summit
  • Almost 1000 attendees, Google: SDN used for their WAN
  • Commercialized, in production use (few places)
• July 2012: VMware buys Nicira for $1.26B
An OS for networks thanks to SDN

- The whole network as one big machine
- The key is to have a standardized control interface that speaks directly to hardware
The “Software-Defined Networking” (r)evolution
Computers evolution: from mainframes to microprocessors

Vertically integrated
Closed, proprietary
Slow innovation
Small industry

Horizontal
Open interfaces
Rapid innovation
Huge industry

From Nick McKeown’s talk “Making SDN Work” at the Open Networking Summit, April 2012
SND (r)evolution

Vertically integrated
Closed, proprietary
Slow innovation

Control Plane
Open Interface
or
Control Plane
or
Control Plane

Merchant Switching Chips

Horizontally integrated
Open interfaces
Rapid innovation
The “Software-Defined Network”

- **Network OS**
- **Control Program**
- **Abstract Network Model**
- **Network Virtualization**
- **Global Network View**

**Specifies behavior**

**Compiles to topology**

**Transmits to switches**

The software-defined network (SDN) architecture consists of the following components:

1. **Network OS**: Specifies the behavior.
2. **Control Program**: Compiles to topology.
3. **Global Network View**: Transmits to switches.

These components work together to provide a flexible and programmable networking infrastructure.
Write a simple program to configure a simple model
  - Configuration is merely a way to specify what you want

Examples
  - ACLs: who can talk to who
  - Isolation: who can hear my broadcasts
  - Routing: only specify routing to the degree you care
    - Some flows over satellite, others over landline
  - TE: specify in terms of quality of service, not routes

Virtualization layer “compiles” these requirements
  - Produces suitable configuration of actual network devices

NOS then transmits these settings to physical boxes
SDN: the role of the Network Operating System

Application Plane

Control Plane

Data Plane

Well-defined API

Network Virtualization

Network Map Abstraction

Separation of Data and Control Plane
Two examples uses

- **Scale-out router:**
  - Abstract view is single router
  - Physical network is collection of interconnected switches
  - Allows routers to “scale out, not up”
  - Use standard routing protocols on top

- **Multi-tenant networks:**
  - Each tenant has control over their “private” network
  - Network virtualization layer compiles all of these individual control requests into a single physical configuration

- Hard to do without SDN, easy (*in principle*) with SDN
Does SDN work?

- Is it scalable? Yes
- Is it less responsive? No
- Does it create a single point of failure? No
- Is it inherently less secure? No
- Is it incrementally deployable? Yes
SDN: clean separation of concerns

- **Control program**: specify behavior on abstract model
  - Driven by **Operator Requirements**

- **Network Virtualization**: map abstract model to global view
  - Driven by **Specification Abstraction**

- **NOS**: map global view to physical switches
  - API: driven by **Distributed State Abstraction**
  - Switch/fabric interface: driven by **Forwarding Abstraction**
Where SDN is and will be deployed

- Multi-tenant “virtualized” data centers
  - Public and private clouds

- WANs
  - Google WAN
  - Eventually, public WANs

- Enterprise networks
  - Greater control, fewer middleboxes
Where SDN is and will be deployed (2)

- Home networks
  - Outsourced management

- Cellular Networks
  - Separation of service from physical infrastructure

- Research and Education Networks
  - National backbones
  - College campus networks
Challenge: controller delay and overhead

- Controller is much slower than the switch
- Processing packets leads to delay and overhead
- Need to keep most packets in the “fast path”
SDNs with distributed controllers

Controller Application

For scalability and reliability

Partition and replicate state

Controller Application

Network OS

Network OS
Challenge: testing and debugging

- OpenFlow makes programming possible
  - Network-wide view at controller
  - Direct control over data plane
- Plenty of room for bugs
  - Still a complex, distributed system
- Need for testing techniques
  - Controller applications
  - Controller and switches
  - Rules installed in the switches
Challenge: programming abstractions

- Controller APIs are low-level
  - Thin layer on top of the underlying hardware
- Need better languages
  - Composition of modules
  - Managing concurrency
  - Querying network state
  - Network-wide abstractions
SDN use case: Dynamic Access Control

- Inspect first packet of a connection
- Consult the access control policy
- Install rules to block or route traffic
SDN use case: Seamless Mobility/Migration

- See host send traffic at new location
- Modify rules to reroute the traffic
SDN use case: Server Load Balancing

- Pre-install load-balancing policy
- Split traffic based on source IP
SDN use case: Network Virtualization

Partition the space of packet headers
The industries were skeptical whether SDN was possible

Google had big problems:

- **High financial cost** managing their datacenters: Hardware and software upgrade, over provisioning (fault tolerant), manage large backup traffic, time to manage individual switch, and a lot of men power to manage the infrastructure

- **Delay caused by rebuilding connections after link failure**
  - Slow to rebuild the routing tables after link failure
  - Difficult to predict what the new network may perform

Google went ahead and implemented SDN

- Built their hardware and wrote their own software for their internal datacenters
- Surprised the industries when Google announced SDN was possible in production

How did they do it?

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