Current Trends in Internet Evolution and a Framework for Application Delivery

RAJ JAIN

Washington University in Saint Louis
Saint Louis, MO 63130
Jain@wustl.edu

Hitachi Distinguished Lecture at
University of Oklahoma, Norman, OK, February 17, 2012

These slides and audio/video recordings of this talk are available on-line at:
http://www.cse.wustl.edu/~jain/talks/angi_ou.htm
Overview

1. Current trends in networking
2. Our research on next generation: open ADN
3. Software Defined Networks
Why to worry about Future Internet?

Billion dollar question!
2012: Where are we now?

- At the knee of Mobile Internet age (paradigm shift)
  - Computing (IBM 360) ⇒ Mini-computing (PDP11)
    ⇒ Personal Computing (Desktop, PC+MAC) ⇒ Laptops
    ⇒ Netbooks ⇒ Smart Phones + Tablets
- Most valued companies in the stock market are generally those that lead the paradigm shift
  - Automotive (General Motors) ⇒ Electrical (GE, Edison Electric) ⇒ Networking (Cisco + 3Com in 80’s) ⇒ Internet (Netscape + Yahoo in 90’s) ⇒ Mobile Internet (Apple +MS+ Google, 2010’s)
- Note: Apple ≠ PC (MAC) company (mobile device company)
  - Google ≠ search engine (mobile device company)
- Also Social Networking (Facebook), Internet Retail (Amazon)
5 Future Predictors

1. **Miniaturization**: Campus ⇒ Datacenter ⇒ Desktop ⇒ Laptop ⇒ Pocket ⇒ Multi-functional Pocket device
2. **Mobility**: Static ⇒ Mobile (1 km/hr) ⇒ Mobile (100 km/hr) ⇒ Mobile (600 km/hr)
3. **Distance**: PAN (5m) ⇒ LAN (500 m) ⇒ MAN (50 km) ⇒ WAN (500 km)
4. **Applications**: Defense ⇒ Industry ⇒ Personal
5. **Social Needs**: Energy, Environment, Health, Security
   - Broadening and Aggregation: Research ⇒ Many Solutions ⇒ One Standard ⇒ General Public adoption, e.g., Ethernet
   - Non-Linearity: Progress is not linear. It is exponential and bursty. Most predictions are linear ⇒ underestimates.

We are here
Trend: Moore’s Law

- Computing Hardware is cheap
- Memory is plenty

⇒ Storage and computing (Intelligence) in the net

- Energy
- Space
- Communication in Space

- Matter
- Time
- Communication in Time

- Link

- Storage (USB, Caching,…)

Next Gen nets will use storage in networks, e.g., DTN, CCN
Trend: Multihoming + Mobility

- Centralized storage of info
- Anytime Anywhere computing
- Dynamically changing Locator
- User/Data/Host/Site/AS Multihoming
- User/Data/Host/Site Mobility

⇒ ID/Locator Split

Mobile Telephony already distinguishes ID vs. Locator
We need to bring this technology to IP.
Trend: Profusion of Services

- Almost all top 50 Internet sites are services [Alexa]
- Smart Phones: iPhone, Android Apps
  ⇒ New globally distributed services, Games, …
  ⇒ More clouds, …

Networks need to support efficient service setup and delivery

Ref: Top 500 sites on the web, http://www.alexaworld.com/topsites
Washington University in St. Louis http://www.cse.wustl.edu/~jain/talks/ngi_ou.htm ©2012 Raj Jain
Private Smart WANs

- Services totally avoid the Internet core ⇒ Many private WANs
- Google WAN, Akamai ⇒ Rules about how to connect users

Opportunity for ISPs to offer these types of WAN services
OpenADN

- High-Speed WAN for Application Service Delivery.
- Allows ASPs to quickly setup services

![Diagram showing OpenADN architecture with services A1, B1, A2, and b2 connected through OpenADN, Internet, and access points to end user hosts via ISPs.](image-url)
Ten Key Features that Services Need

1. **Replication**: Multiple datacenters appear as one
2. **Fault Tolerance**: Connect to B if A is down
3. **Load Balancing**: 50% to A, 50% to B
4. **Traffic Engineering**: 80% on Path A, 20% on Path B
5. **Flow based forwarding**: Movies, Storage Backup, …
   - ATMoMPLS, TDMoMPLS, FRoMPLS, EoMPLS, …
   - Packets in Access, Flows in Core
6. **Security**: Provenance, Authentication, Privacy, …
7. **User Mobility**: Gaming/Video/… should not stop as the user moves
8. **Service composition**: Services using other services
9. **Customization**: Every service has different needs
10. **Dynamic Setup** ⇒ Networking as a Service
Five Arch Design Principles for Success

1. Evolution not replacement
2. Coexistence (Backward compatibility)
3. Incremental Deployment
4. Economic Incentive for first adopters
5. Customization without losing control
Networking: Failures vs Successes

- 1986: MAP/TOP (vs Ethernet)
- 1988: OSI (vs TCP/IP)
- 1991: DQDB
- 1994: CMIP (vs SNMP)
- 1995: FDDI (vs Ethernet)
- 1996: 100BASE-VG or AnyLan (vs Ethernet)
- 1997: ATM to Desktop (vs Ethernet)
- 1998: ATM Switches (vs IP routers)
- 1998: MPOA (vs MPLS)
- 1999: Token Rings (vs Ethernet)
- 2003: HomeRF (vs WiFi)
- 2007: Resilient Packet Ring (vs Carrier Ethernet)
- IntServ, DiffServ, …

Technology alone does not mean success.
Key Features of openADN

1. Edge devices only. Core network can be current TCP/IP based or future SDN based
2. Coexistence (Backward compatibility): Old on New. New on Old
3. Incremental Deployment
4. Economic Incentive for first adopters

Most versions of Ethernet followed these principles. Many versions of IP did not.
The Narrow Waist

- Everything as a service over service delivery narrow waist
- IP, HTTP, Content, Service delivery, …

Diagram:

- Applications
  - Transports
    - IP
    - HTTP
    - Content
    - Service Delivery
  - Link
  - Link/Phys
- IP
- Link
- Link/Phys
Trend: Separation of Control and Data Planes

- Control = Prepare forwarding table
- Data Plane: Forward using the table
- Forwarding table is prepared by a central controller
- Protocol between the controller and the forwarding element: OpenFlow
- Centralized control of policies
- Switches are simple. Controller can be complex. Can use powerful CPUs
- Lots of cheap switches = Good for large datacenters

OpenFlow (Cont)

- Three Components:
  - Flow table: How to identify and process a flow
  - Secure Channel: Between controller and the switch
  - Open Flow Protocol: Standard way for a controller to communicate with a switch

<table>
<thead>
<tr>
<th>Rule</th>
<th>Action</th>
<th>Stats</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forward to Port n</td>
<td>Packet + Byte Counters</td>
</tr>
<tr>
<td></td>
<td>Encapsulate and forward to controller</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drop</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Send to normal processing pipeline</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Modify fields</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In Port</th>
<th>VLAN ID</th>
<th>Ethernet</th>
<th>IP</th>
<th>TCP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SA</td>
<td>DA</td>
<td>Type</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SA</td>
<td>DA</td>
<td>Proto</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Src</td>
<td>Dst</td>
<td></td>
</tr>
</tbody>
</table>
OpenFlow (Cont)

- Controller forwards the packets correctly as the mobile clients move
- Reference designs for Linux, Access points (OpenWRT), and NetFPGA (hardware)
- Allows both proactive (flow tables loaded before hand) and reactive (Flow entries loaded on demand)
- Allows wild card entries for aggregated flows
- Multiple controllers to avoid single point of failure: Rule Partitioning, Authority Partitioning

Ref: [MCK08], OpenFlow.org, OpenNetworking.org
Trend: Software Defined Networks

- Problem: Multiple tenants in the datacenter
- Solution: Use multiple controllers. Each tenant can enforce its policies

Significant industry interest ⇒ Open Networking Foundation, [https://www.opennetworking.org/](https://www.opennetworking.org/)
Problem: Complex Routers

- The routers are expensive because there is no standard implementation.
- Every vendor has its own hardware, operating/management system, and proprietary protocol implementations.
- Similar to Mainframe era computers. No cross platform operating systems (e.g., Windows) or cross platform applications (Java programs).

<table>
<thead>
<tr>
<th>OSPF</th>
<th>BGP</th>
<th>DHCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Operating System</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proprietary fast forwarding hardware</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cisco IOS
Juniper JUNOS
Solution: Divide, Simplify and Standardize

- Computing became cheaper because of clear division of hardware, operating system, and application boundaries with well defined APIs between them.
- Virtualization ⇒ simple management + multi-tenant isolation

<table>
<thead>
<tr>
<th>Scientific</th>
<th>Business</th>
<th>Batch</th>
</tr>
</thead>
<tbody>
<tr>
<td>OS360 Operating System</td>
<td>IBM 360 HW, Storage, …</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MSOffice</th>
<th>OpenOffice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windows</td>
<td>OS X</td>
</tr>
<tr>
<td>Chrome</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intel</th>
<th>AMD</th>
<th>ARM</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>VM1</th>
<th>VM2</th>
<th>VM3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypervisor</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physical HW</th>
</tr>
</thead>
</table>
Multi-Tenant SDN Architecture

Enterprise 1
- Multicasting
- Network OS1

Enterprise 2
- Mobility
- Network OS2

Enterprise 3
- App1
- App2
- Network OS3

Applications
Network OS
Virtualization
Forwarding

Forwarding HW
Network Virtualization
### SDN Architecture Component Examples

<table>
<thead>
<tr>
<th>Monitoring/Debugging</th>
<th>Monitoring/Debugging</th>
</tr>
</thead>
<tbody>
<tr>
<td>OpenFlow</td>
<td>OpenFlow</td>
</tr>
<tr>
<td>OpenVSwitch</td>
<td>OpenVSwitch</td>
</tr>
<tr>
<td>Juniper</td>
<td>Juniper</td>
</tr>
<tr>
<td>Pronto</td>
<td>Pronto</td>
</tr>
<tr>
<td>Netgear</td>
<td>Netgear</td>
</tr>
<tr>
<td>NEC</td>
<td>NEC</td>
</tr>
<tr>
<td>Ciena</td>
<td>Ciena</td>
</tr>
<tr>
<td>Helios</td>
<td>Helios</td>
</tr>
<tr>
<td>NOX</td>
<td>NOX</td>
</tr>
<tr>
<td>Beacon</td>
<td>Beacon</td>
</tr>
<tr>
<td>Maestro</td>
<td>Maestro</td>
</tr>
<tr>
<td>Floodlight</td>
<td>Floodlight</td>
</tr>
<tr>
<td>FlowVisor</td>
<td>FlowVisor</td>
</tr>
<tr>
<td>Forwarding</td>
<td>Forwarding</td>
</tr>
<tr>
<td>Virtualization/Slicing</td>
<td>Virtualization/Slicing</td>
</tr>
<tr>
<td>Network OS/Controller</td>
<td>Network OS/Controller</td>
</tr>
<tr>
<td>Mobility</td>
<td>Mobility</td>
</tr>
<tr>
<td>Multicasting</td>
<td>Multicasting</td>
</tr>
</tbody>
</table>

Ref: [https://courses.soe.ucsc.edu/courses/cmpe259/Fall11/01/pages/lectures/srini-sdn.pdf](https://courses.soe.ucsc.edu/courses/cmpe259/Fall11/01/pages/lectures/srini-sdn.pdf)
SDN Impact

- Why so much industry interest?
  - Commodity hardware
    - Lots of cheap forwarding engines ⇒ Low cost
  - Programmability ⇒ Customization
  - Sharing with Isolation ⇒ Networking utility
  - Those who buy routers, e.g., Google, Amazon, Docomo, DT will benefit significantly

- Opens up ways for new innovations
  - Dynamic topology control: Turn switches on/off depending upon the load and traffic locality
    ⇒ “Energy proportional networking”
Life Cycles of Technologies

Potential

Time

Research Hype Disillusionment Success or Failure

SDN ATM

http://www.cse.wustl.edu/~jain/talks/ngi_ou.htm

©2012 Raj Jain
Industry Growth: Formula for Success

- Paradigm Shifts ⇒ Leadership Shift
- Old market leaders stick to old paradigm and loose
- Mini Computers → PC, Phone → Smart Phone, PC → Smart Phone

---

Washington University in St. Louis  
[http://www.cse.wustl.edu/~jain/talks/ngi_ou.htm](http://www.cse.wustl.edu/~jain/talks/ngi_ou.htm)  
©2012 Raj Jain
Summary

1. Peak of mobile internet paradigm shift
2. Miniaturization, Mobility, Distance, Applications, Social needs help predict the future
3. Profusion of multi cloud-based applications on the Internet. Application services need replication, fault tolerance, traffic engineering, security, …
4. OpenADN provides these features in a multi-cloud environment with backward compatibility, incremental deployment
5. Trend is towards simplifying and standardizing router interfaces ⇒ Software defined networking

Application Delivery: Opportunity for ISP’s