Current Topics for Networking Research

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Keynote Speech at International Conference on Advanced Computing,
Networking, and Security (ADCONS) 2011
Mangalore, India, December 17, 2011

These slides are available on-line at:

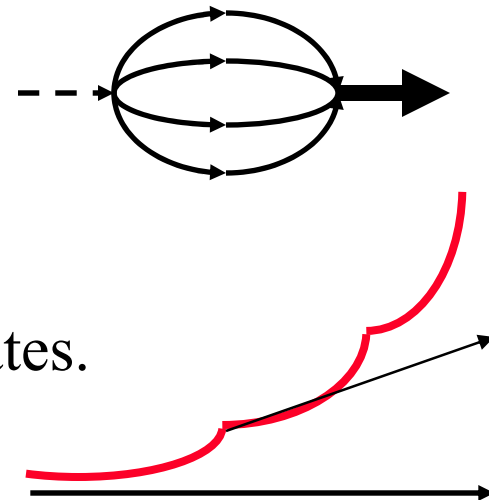http://www.cse.wustl.edu/~jain/talks/adcons.htm

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Overview

1. Security

2. Mobile Networking

3. Energy and Networking

4. Data Center Networking

5. Software defined Networking

6. Next Generation Internet

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 $\Rightarrow$ Datacenter $\Rightarrow$ Desktop $\Rightarrow$ Laptop $\Rightarrow$ Pocket $\Rightarrow$ Multi-functional Pocket device

2. **Mobility**: Static $\Rightarrow$ Mobile (1 km/hr) $\Rightarrow$ Mobile (100 km/hr) $\Rightarrow$ Mobile (600 km/hr)

3. **Distance**: PAN (5m) $\Rightarrow$ LAN (500 m) $\Rightarrow$ MAN (50 km) $\Rightarrow$ WAN (500 km)

4. **Applications:** Defense $\Rightarrow$ Industry $\Rightarrow$ Personal

5. **Social Needs**: Energy, Environment, Health, Security

❑ Broadening and Aggregation: Research
   $\Rightarrow$ Many Solutions $\Rightarrow$ One Standard
   $\Rightarrow$ General Public adoption, e.g., Ethernet

❑ Non-Linearity: Progress is not linear. It is exponential and bursty.
   Most predictions are linear $\Rightarrow$ underestimates.

Issues in Networking Research

List based on our interests and projects:

1. Security

2. Mobile Networking

3. Energy and Networking

4. Data Center Networking

5. Software defined Networking

6. Next Generation Internet

Short term + Medium Term + Long Term **Research Investment**

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1. Security

- Hackers: Individuals $\Rightarrow$ Organizations $\Rightarrow$ Countries

- Cyber Warfare: Nation States are penetrating other nations computers $\Rightarrow$ 5th domain of warfare (after land, sea, air, space)

- USA UK, China, Russia, Israel, North Korea have cyber command centers

- Cloud computing $\Rightarrow$ new cloud security issues: Application service providers (ASPs), Cloud Service Providers (CSPs), Internet Service Providers (ISPs), and Users **trust domains**.

- Mobile devices (Android) Trojans

In Nov 2010, hackers calling themselves "Indian Cyber Army" attacked Pakistani Websites. In Dec 2010, "Pakistan Cyber Army" attacked Indian Central Bureau of Intelligence.

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2. Wireless and Mobile Networking

- 700 MHz $\Rightarrow$ Long distance, rural areas
- Can partly handle device mobility
- Can't handle inter-device mobility
  $\Rightarrow$ Watching a movie on a mobile, continue it on a laptop
- Moving from 4" to 17" to 40" screen $\Rightarrow$ Translation
- Vehicular networking
 $\Rightarrow$ Mobile Ad-hoc networking
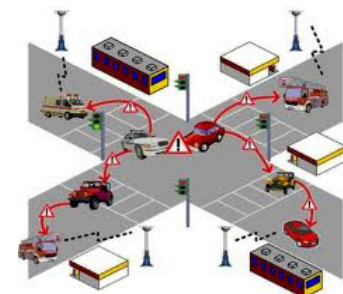
Aeronautical Datalinks (WUSTL)

- Unmanned Aircrafts: Border patrol, Drones
- Very long distances:
  - Wi-Fi covers 100m. WiMAX covers 5km
  - Aeronautical links need to cover 360 km
    - Limited Power $\Rightarrow$ High bit error rate
- Very High Mobility:
  - WiMAX/LTE is designed for 60-120 km/hr
  - Aeronautical links need to cover 600 nm/hr (1080 km/hr)

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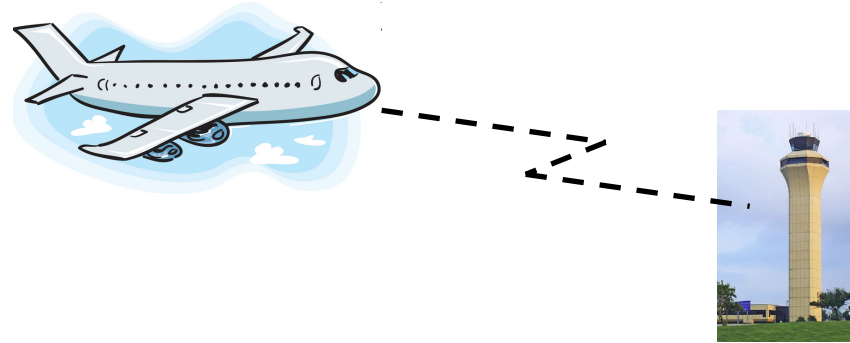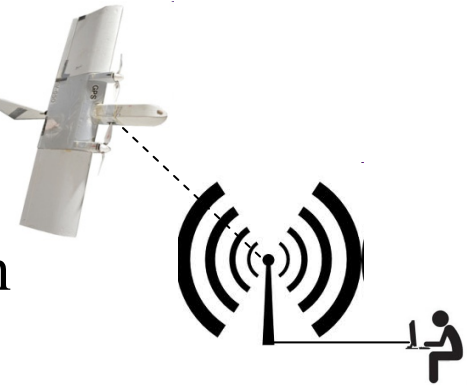
3. Energy Efficient Networking

- Original Internet design assumed all hosts are up all the time

- Computer Industry produces as much green house gases as the airlines industry

- Energy Efficient Ethernet

- Delay-Tolerant Networking:
  Routers store data if the next hop is down

- Mobile phones are already energy efficient
  $\Rightarrow$ Can benefit from energy efficient **backhaul**

- Smart mobile devices can help in savings energy by location sensing and control

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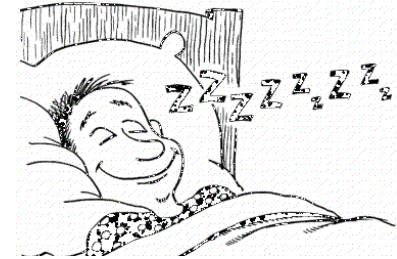
4. Datacenter Networking

- ❑ Cloud Computing:
  - ➢ Applications through Internet (Google Docs)
  - ➢ Computing through Internet (Amazon EC3)
  - ➢ Storage and backup through Internet
- ❑ Issues:
  - ➢ Policy, Security, QoS issues (Multi-organizational ownership)
- ❑ Solution: Separation of Control and Data Planes

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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
- Lots of cheap switches = Good for large datacenters

Switch { Control / Data

Forwarding Element

Forwarding Element

Forwarding Element

Forwarding Element
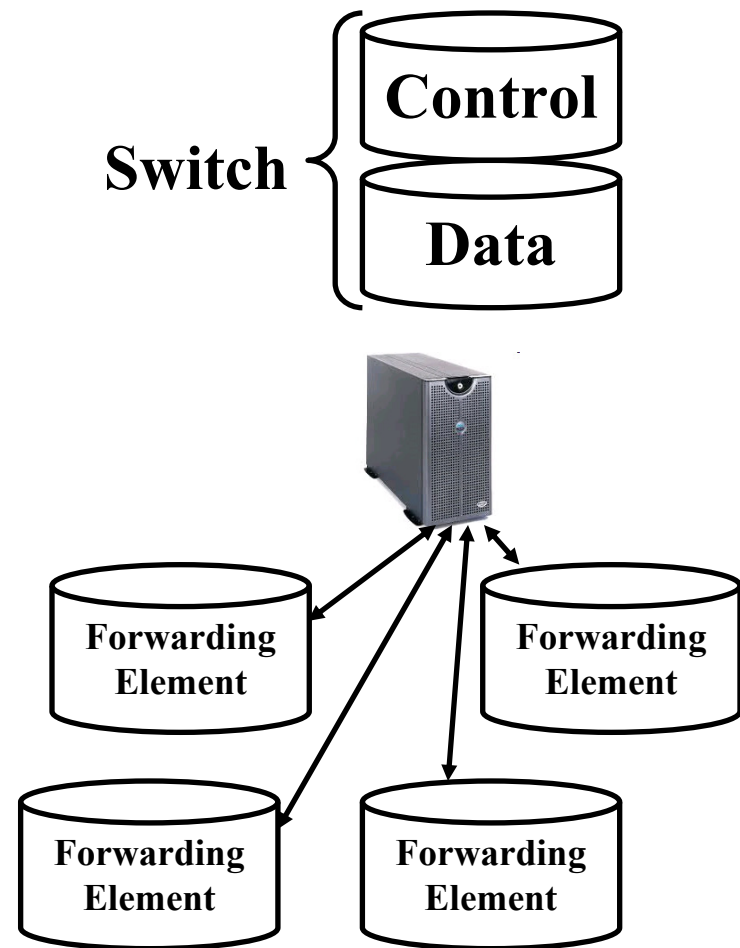
Ref: [MCK08] ``OpenFlow: Enabling Innovation in Campus Networks," OpenFlow Whitepaper, March 2008

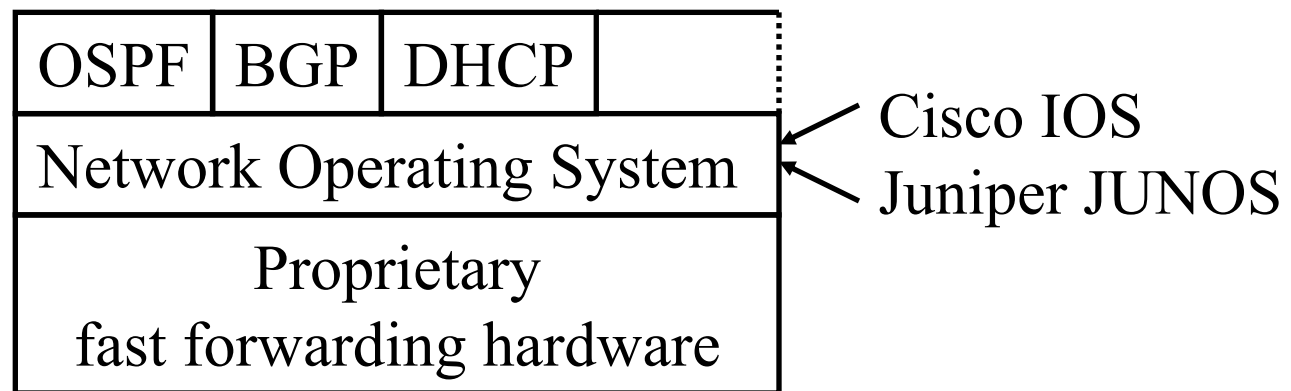http://www.cse.wustl.edu/~jain/talks/adcons.htm

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5. Software Defined Networks

❑ Problem: Multiple tenants in the datacenter

❑ Solution: Use multiple controllers.
   Each tenant can enforce its policies

VLAN1   Flow Table 1   Controller 1

VLAN2   Flow Table 2   Controller 2

Other LANs   Other traffic
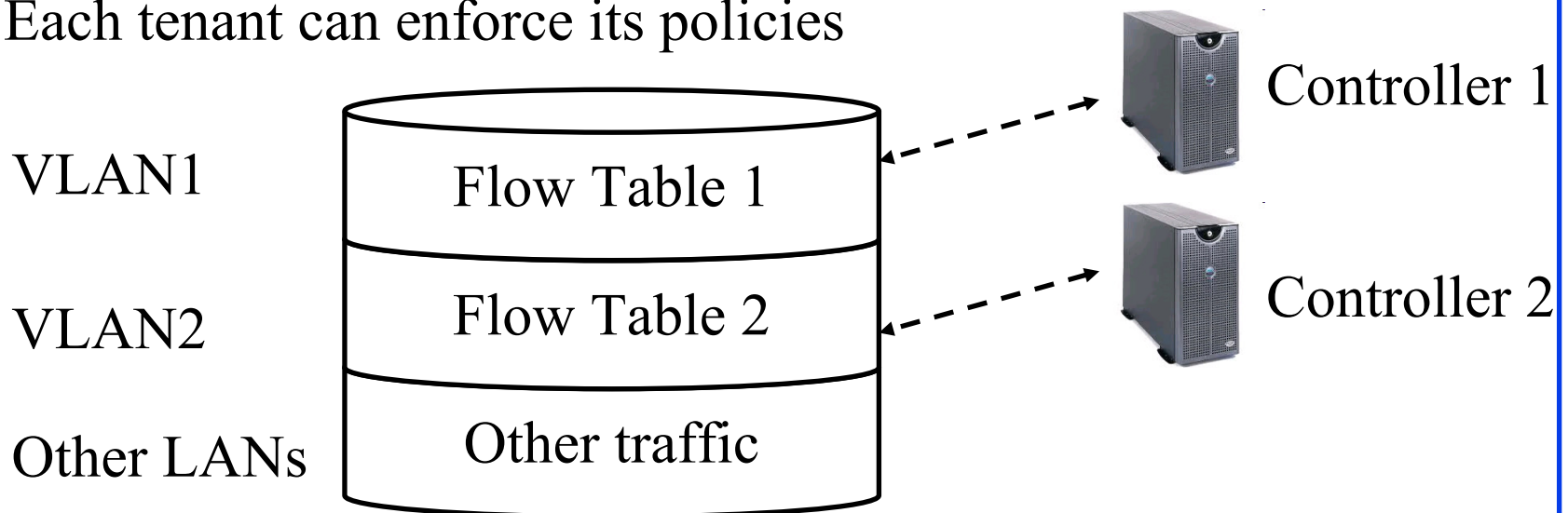
❑ Significant industry interest ⇒ Open Networking Foundation,
   https://www.opennetworking.org/

❑ Can be applied to Knowledge Network in India

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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).

OSPF	BGP	DHCP	
Network Operating System			← Cisco IOS
Proprietary fast forwarding hardware			Juniper JUNOS

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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

Scientific	Business	Batch
OS360 Operating System		
IBM 360 HW, Storage, …		

⇨

MSOffice	OpenOffice	
Windows	OS X	Chrome
Intel	AMD	ARM

⇩

VM1	VM2	VM3
Hypervisor		
Physical HW		

Multi-Tenant SDN Architecture

Enterprise 1	Enterprise 2	Enterprise 3	
Multicasting	Mobility	App1 App2	Applications
Network OS1	Network OS2	Network OS3	Network OS
Network Virtualization			Virtualization

Forwarding HW   Forwarding HW

Forwarding HW   Forwarding HW

Forwarding

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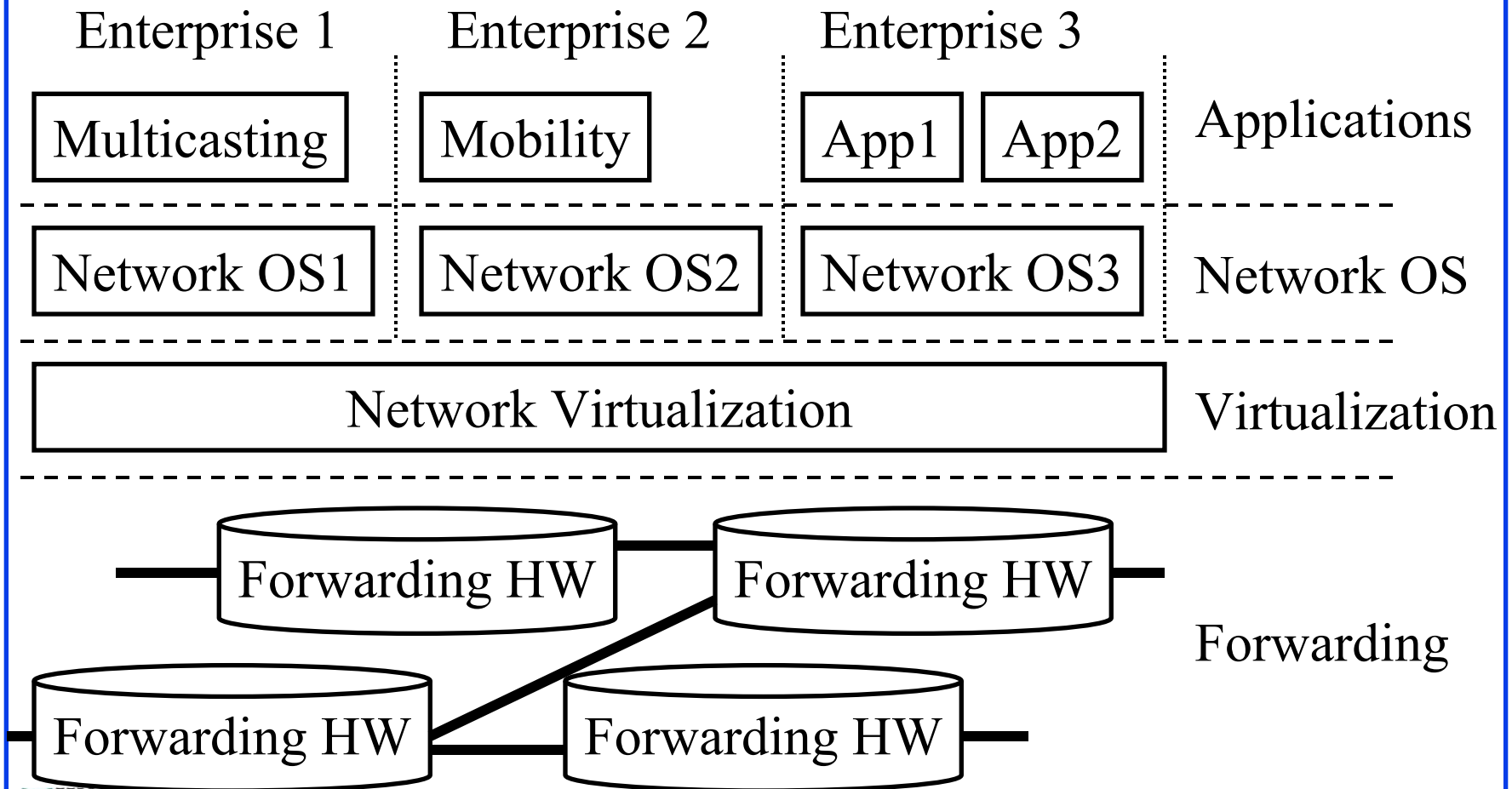
6. Future Internet Projects

❑ In 2005 US National Science Foundation started a large research and infrastructure program on next generation Internet

❑ Q: How would you design Internet today? Clean slate design.

❑ "Future Internet Design" (FIND): 48+ projects

  ❑ Stanford, MIT, Berkeley, CMU, …

  ❑ "An Architecture for Diversified Internet" at WUSTL

❑ "Global Environment for Networking Innovations" (GENI): 29+ projects

❑ European Union: 7th Framework program

❑ Japan: AKARI (A small light in the dark pointing to the future)

❑ China, Korea, Australia, …20+ countries

Ref: Jianli Pan, Subharthi Paul, and Raj Jain, "**A Survey of Research on Future Internet Architectures**," IEEE Comm. Magazine, Vol. 49, No. 7, July 2011, pp. 26-36, http://www1.cse.wustl.edu/~jain/papers/internet.htm
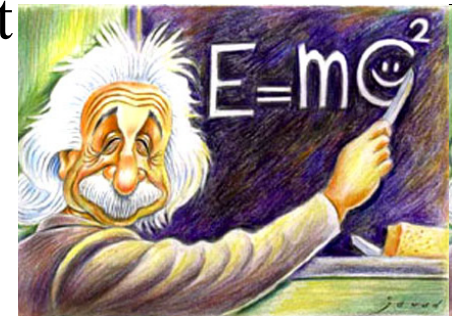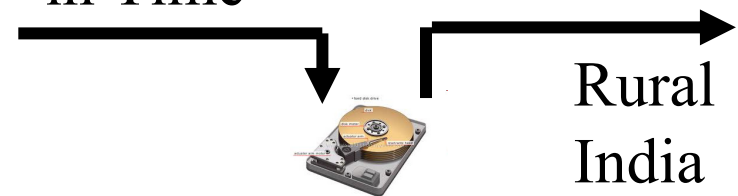
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Trend: Moore's Law

❑   Computing Hardware is cheap

❑   Memory is plenty

⇒ Storage and computing (Intelligence) in the net

❑ Energy ⟷ ❑ Matter

❑ Space ⟶ ❑ Time

❑ Communication ⟷ ❑ Communication
in Space   in Time

Rural
India

❑ Link ❑ Storage (USB, Caching,…)

Next Gen nets will use storage in networks, e.g., DTN, CCN
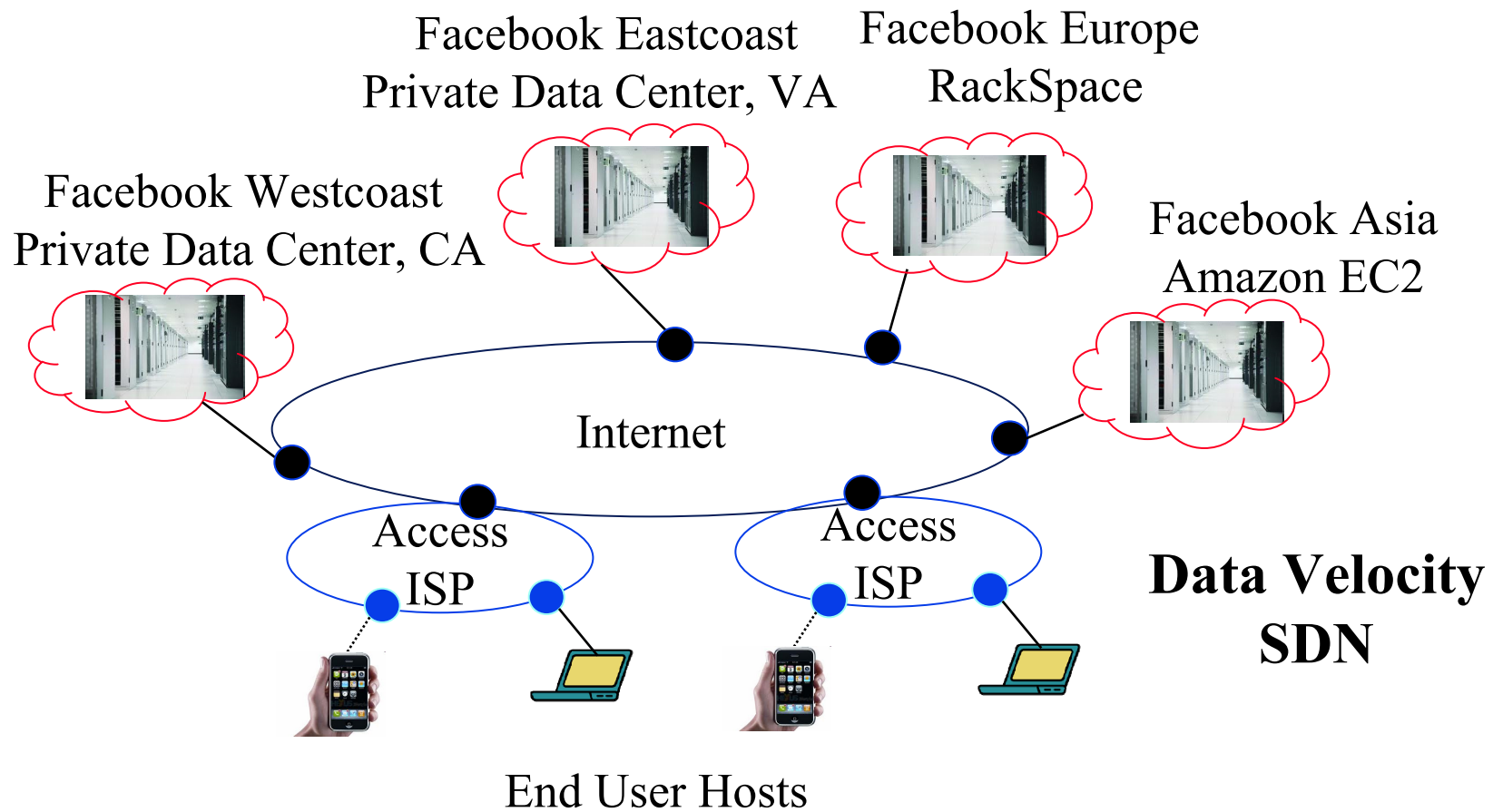
Trend: Profusion of Services

❑ 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.alexa.com/topsites

Ten Key Features that Services Need

Facebook Eastcoast
Private Data Center, VA

Facebook Europe
RackSpace

Facebook Westcoast
Private Data Center, CA

Facebook Asia
Amazon EC2

Internet

Access
ISP

Access
ISP

**Data Velocity
SDN**

End User Hosts

1. **Replication**: Multiple datacenters appear as one

2. **Fault Tolerance**: Connect to B if A is down

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Key Features (Cont)

3. **Load Balancing**: 50% to A, 50% to B
4. **Traffic Engineering**: 80% on Path A, 20% on Path B
5. **Server Mobility**: Move service between clouds
   Dynamic Setup $\Rightarrow$ Networking as a Service
6. **User Mobility**: Gaming/Video/… should not stop as the user moves
7. **Security**: Provenance, Authentication, Privacy, ...
8. **Service composition**: Services using other services
9. **Customization**: Every service has different needs
10. **Flow or Packet based forwarding**: Movies, Storage Backup, …

    ATMoMPLS, TDMoMPLS, FRoMPLS, EoMPLS, …
    Packets in Access, Flows in Core

Trend: Private Smart WANs
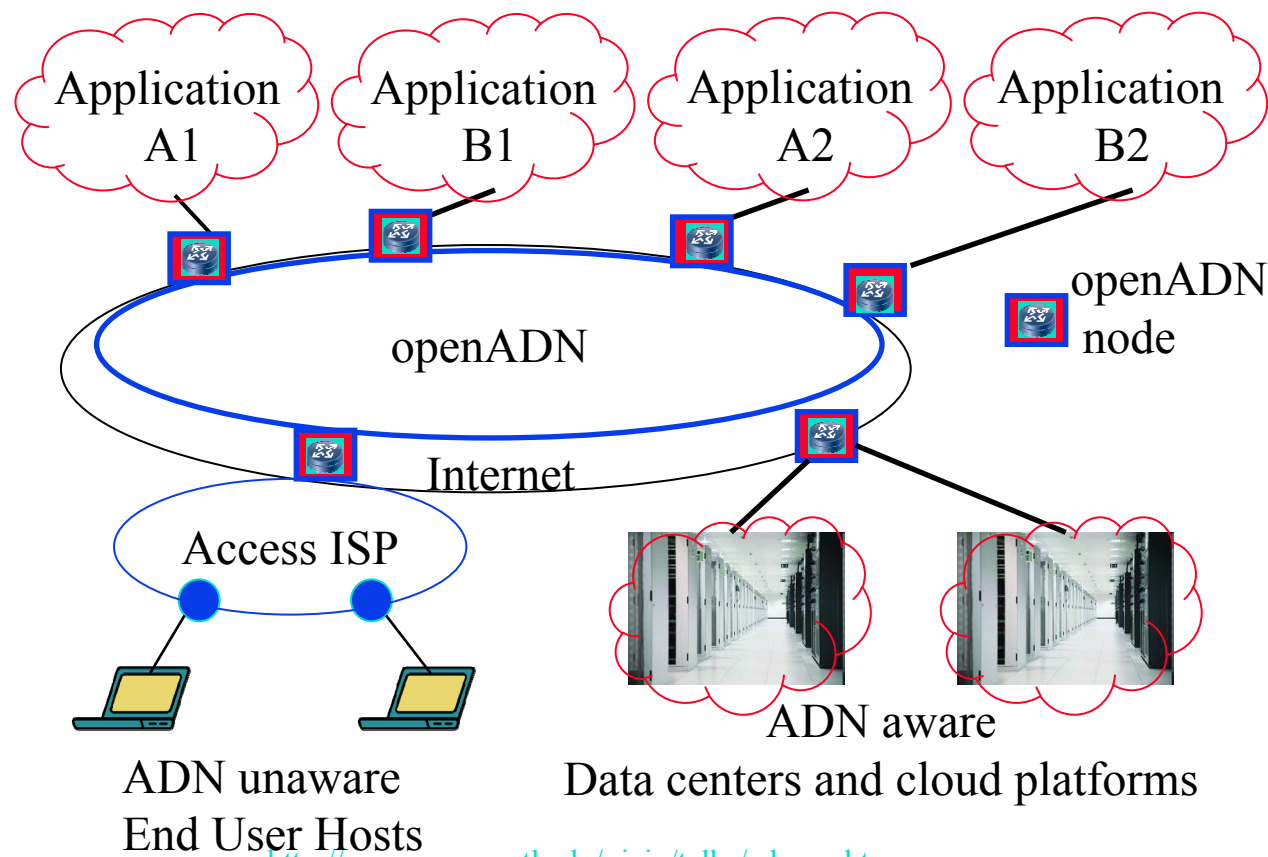
❑ Services totally avoid the Internet core ⇒ Many private WANs

❑ Google WAN, Akamai ⇒ Rules about how to connect users
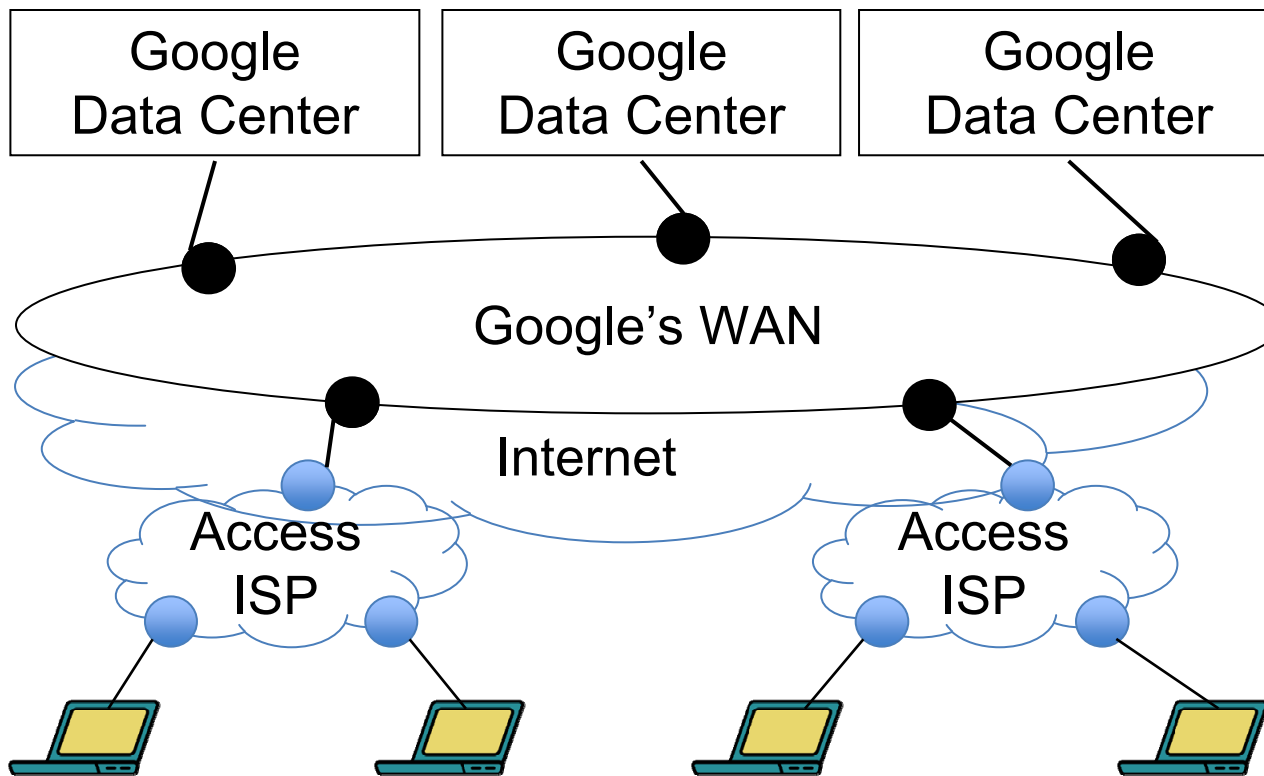
Opportunity for ISPs to offer these types of WAN services

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OpenADN

- High-Speed application delivery on a shared network
- Allows ASPs to quickly setup services

Application A1

Application B1

Application A2

Application B2

openADN node

openADN

Internet

Access ISP

ADN unaware End User Hosts

ADN aware Data centers and cloud platforms

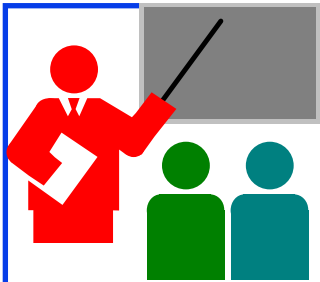Washington University in St.Louis

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.

Summary

1. Peak of **mobile internet** paradigm shift
2. Miniaturization, Mobility, Distance, Applications, Social needs help predict the future
3. Key issues: Security, mobility, energy efficiency, cloud support
4. Profusion of **multi cloud-based applications** on the Internet. Application services need replication, fault tolerance, traffic engineering, security, …
5. **OpenADN** provides these features in a multi-cloud environment with backward compatibility, incremental deployment

Application Delivery: Opportunity for ISP's

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