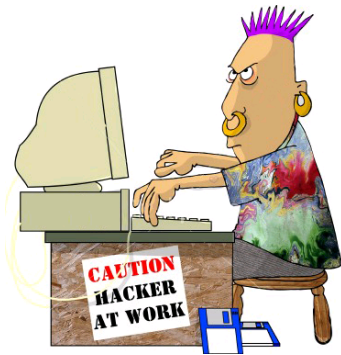# Next Generation Internet and Wireless Networking Research at Washington University

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A talk given to "CS 591: Introduction to Graduate Study in CSE " Class
September 28, 2011

These slides are available on-line at:

http://www.cse.wustl.edu/~jain/talks/cs59111.htm

1

# Overview

1. Why study networking?

2. Current Issues in Networking

3. Our research projects

4. Related networking research and courses

Washington
University in St.Louis

# Why Study Computer Networking?

- ❑ Networking is the "plumbing" of computing
- ❑ Almost all areas of computing are network-based.
  - ➢ Distributed computing
  - ➢ Distributed databases
  - ➢ Distributed storage
  - ➢ Robotics
  - ➢ Distributed Games
- ❑ Fast growing field
- ❑ Job Opportunities: Google, Facebook, eBay, Microsoft, Cisco, HP, Intel, …

http://www.cse.wustl.edu/~jain/talks/cs59111.htm

# Stone Age to Networking Age

❑ Stone, iron, …, automotive, electricity, telephone, jet plane,…, networks caused a fundamental change in our life style





❑ No need to get out for
  ➢ Office
  ➢ Shopping
  ➢ Entertainment
  ➢ Education

❑ Virtual reality will satisfy your needs for
  ❑ Games
  ❑ Tourism
  ❑ Socialization

http://www.cse.wustl.edu/~jain/talks/cs59111.htm

# Current Issues in Networking

1. Network Security
2. Mobile Networking
3. Wireless Networking
4. Energy Efficient Networking
5. Multimedia Networking
6. Datacenter Networking
7. Next Generation Internet

Note: These topics are based on current activity in industry groups like Internet Engineering Task Force (IETF), Internet Research Task Force (IRTF), and Institution of Electrical and Electronic Engineering (IEEE)

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# 1. Security: Cyber Warfare

❑ Nation States are penetrating other nations computers
 $5^{th}$ domain of warfare (after land, sea, air, space)

❑ In 2009, US set up a cyber command

❑ UK, China, Russia, Israel, North Korea have similar centers

❑ Pentagon spent more than $100 million in first half of
2009 in repairing damages
from cyber attacks.

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

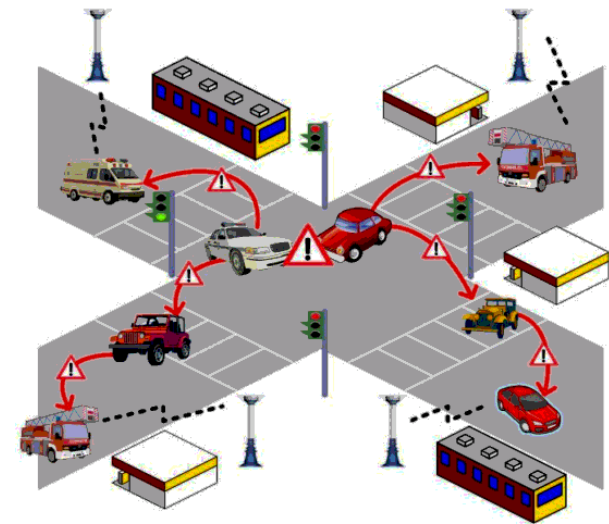Ref: http://en.wikipedia.org/wiki/Cyber_war



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# 2. Mobile Networking

- Smart Phones (iPhone, Blackberry, Android Phones), Net books, Laptops
  $\Rightarrow$ Mobile computers

- Mobility: Keep your networking session connected regardless of your location

- Mobile ≠ Wireless.
  Starting your download at office and continuing it at home is an example of wired mobility

- Cellular phone networks are designed for mobility but Internet protocol is not.

# 3. Wireless Networking

1. Wireless (WiFi) is ubiquitous (Intel Centrino)

2. More Cell phones than POTS.
   Ratio projected to be 4-to-1 by 2012.

3. Wiring more expensive than equipment
   $\Rightarrow$ Wireless Access

4. New Developments:

   ➢ 4G: 1Gbps Metropolitan
     Area Networks
     (LTE-Advanced, WiMAX V2)

   ➢ Vehicular Networking (802.11p)

   ➢ Ad-hoc Wireless Networks

   ➢ TV Band (700 MHz) networking

   ➢ Audio/Video over Wi-Fi (802.11aa)

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# 4. Energy Efficient Networking



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

- You cannot turn off your routers

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

- One small computer server = one SUV with 15 miles/gallon

- Need to design protocols that allow nodes to be off

- Energy Efficient Ethernet:
  - Turns off most of circuits until a bit arrives

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

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# 5. Multimedia Networking

- ❑ Trends:
  - ➢ Audio/Video over networks
  - ➢ Entertainment on cellular phones
  - ➢ Home Entertainment
  - ➢ Movies on Demand
  - ➢ YouTube
- ❑ Issues:
  - ➢ Timing and synchronization
  - ➢ Peer to peer streaming
  - ➢ Stream reservation
  - ➢ Media caching

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# 6. Datacenter Networking

- ❑ Cloud Computing:
  - ➢ Applications through Internet (Google Docs)
  - ➢ Computing through Internet (Amazon EC3)
  - ➢ Storage and backup through Internet



- ❑ Issues:
  - ➢ Inter-Cloud Provider Networking: High-speed links on demand
  - ➢ Policy, Security, QoS issues (Multi-organizational ownership)
- ❑ Data Center Networking: Ethernet optimized for data centers
  - ➢ Congestion control at Multi-Gigabit Speeds
  - ➢ Micro-seconds transaction delays

# 7. Next Generation Internet: Internet 3.0

- Internet 1.0: Before Commercialization
  - First twenty years (1969-1989)
  - No Security, Optimal routing
- Internet 2.0: After Commercialization
  - 1989-2009
  - Security, Policy based routing: ISP
- Internet 3.0:
  - The next 20 years
  - How would you design the networks, if you were to design it today
  - All leading universities all over the world are working on a "clean-slate" design
  - Internet 3.0 is the name of our clean-slate research program

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# Our Research Projects

1. Internet 3.0: Architecture for the Next Generation Internet

2. Communication and Modeling for Green Buildings

3. Communications for Emergency Situations

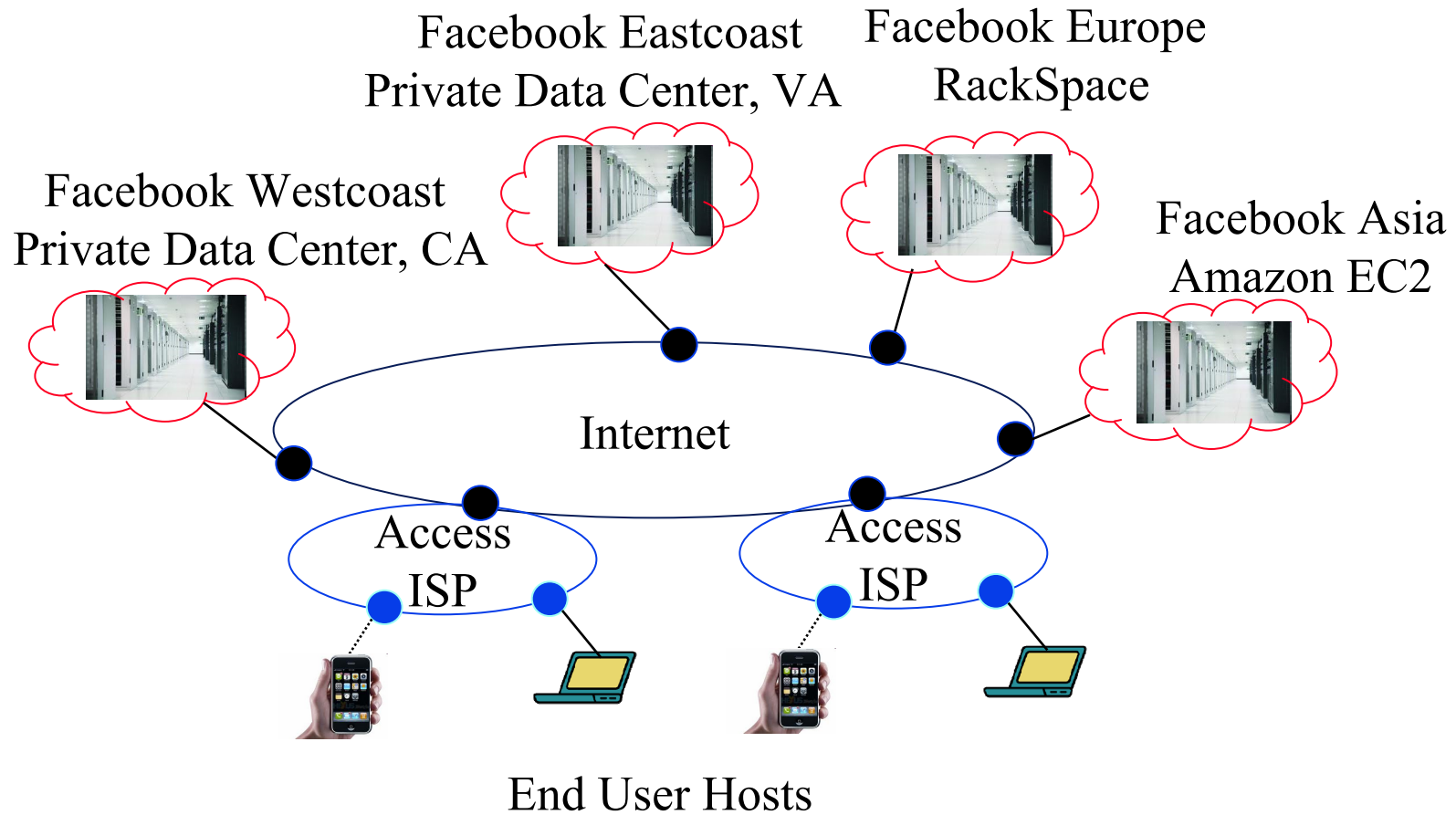4. Next Generation Wireless Networks

5. Aeronautical Networks

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# 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**

Top 500 sites on the web, http://www.alexa.com/topsites
http://www.cse.wustl.edu/~jain/talks/cs59111.htm

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# 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

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

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# Trend: Private Smart WANs

❑ Services totally avoid the Internet core ⇒ Many private WANs

❑ Google WAN, Akamai ⇒ Rules about how to connect users
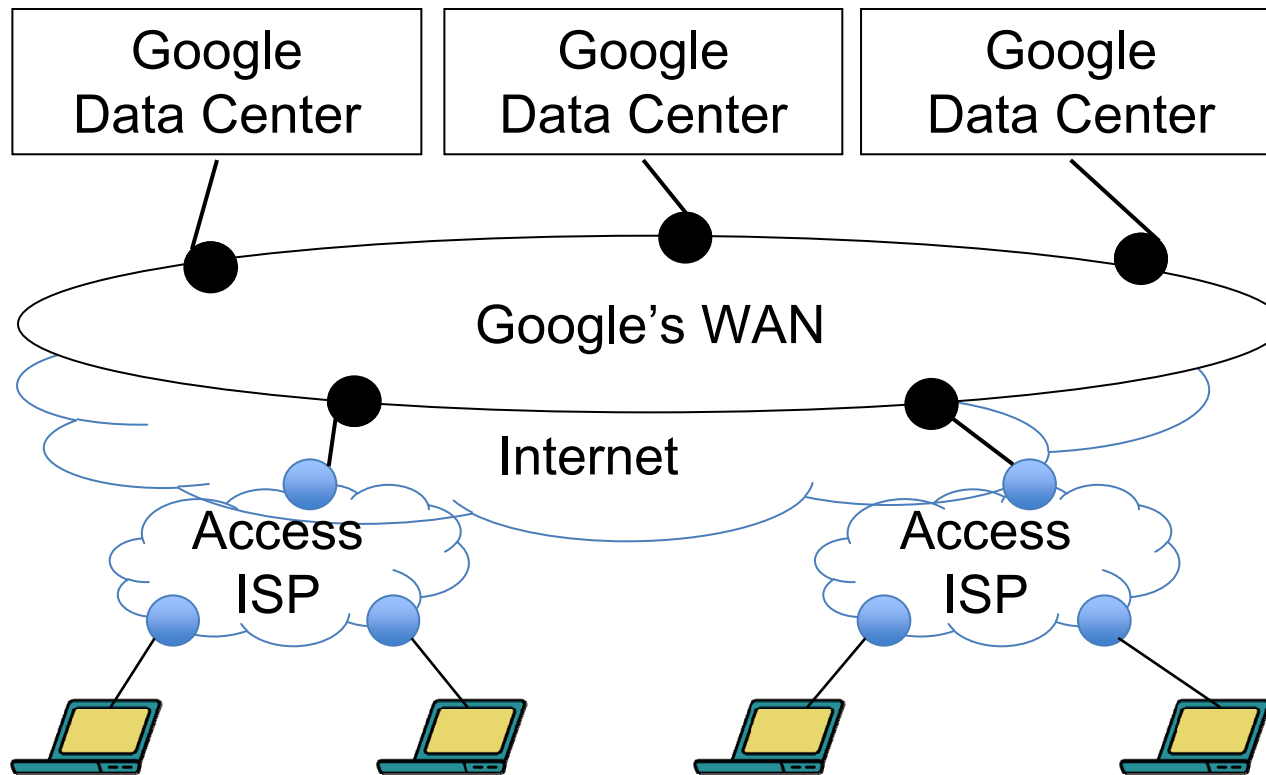


Opportunity for ISPs to offer these types of WAN services

# 1. OpenSDN

❑ High-Speed WAN architected for Service Delivery.

❑ Allows ASPs to quickly setup services

| Service A1 | Service B1 | Service A2 | Service b2 |

OpenSDN

Internet

Access ISP

Access ISP

End User Hosts                    End User Hosts

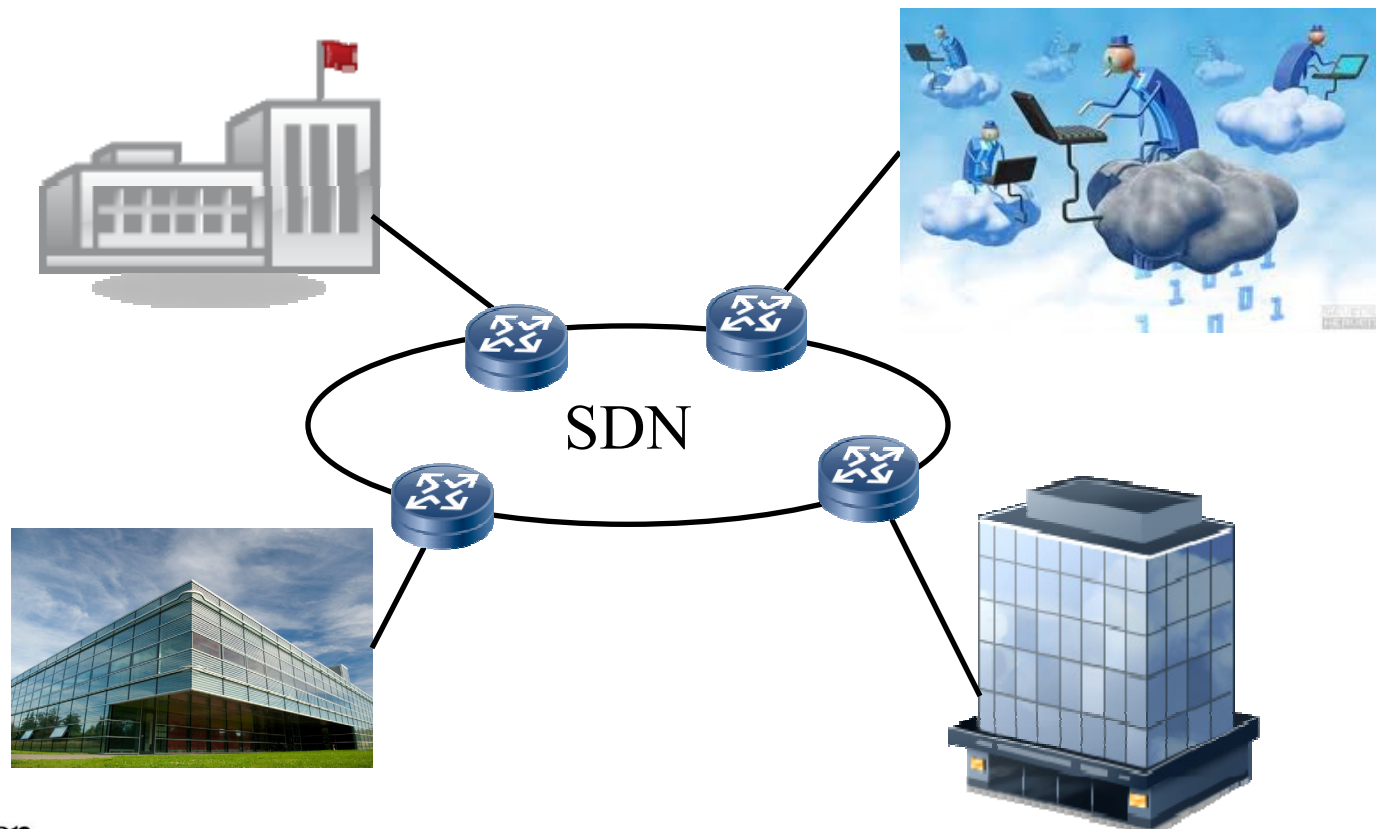Washington University in St.Louis
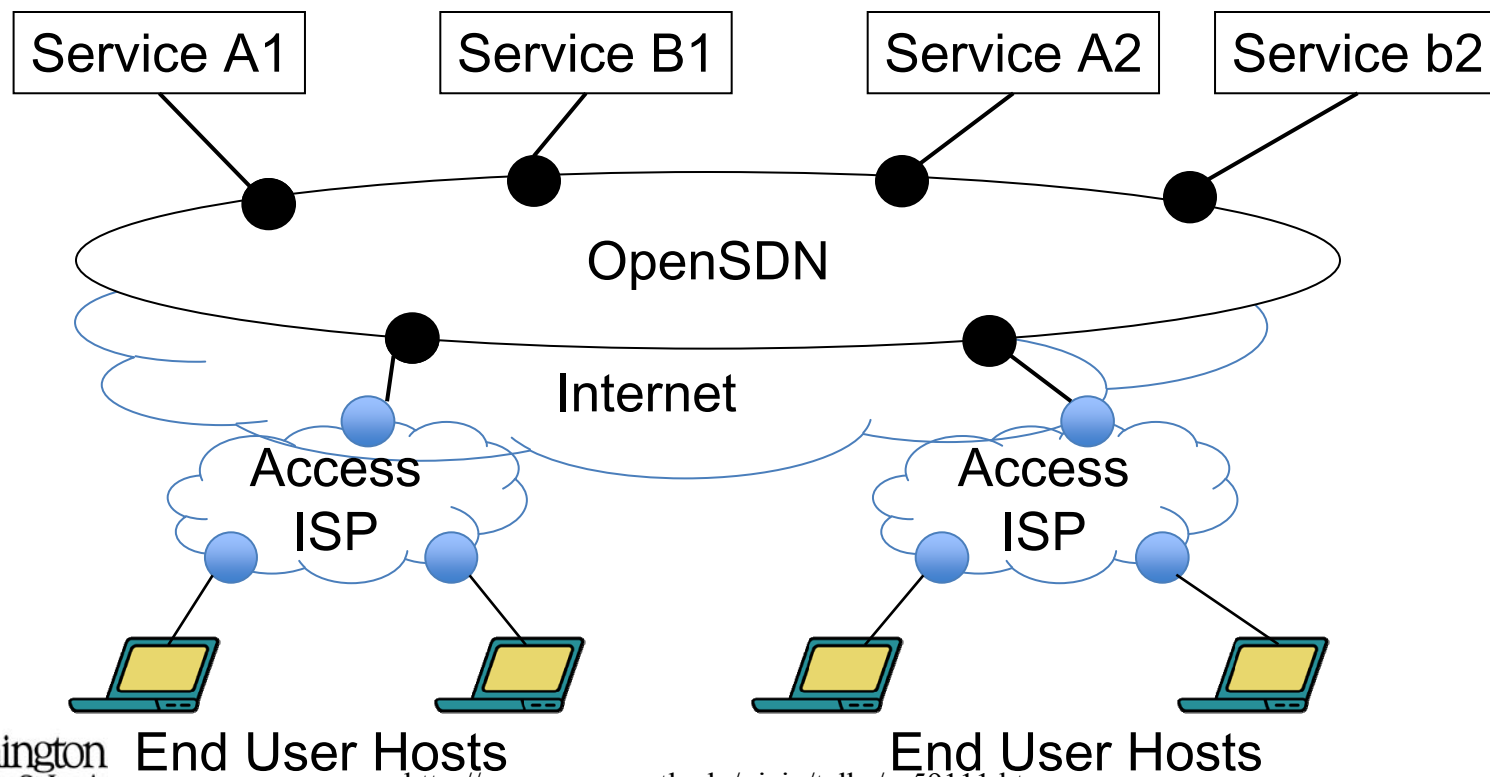
# Five Architecture Design Principles

1. Evolution not replacement.

2. Coexistence (Backward compatibility): Old on New. New on Old

3. Incremental Deployment

4. Economic Incentive for first adopters

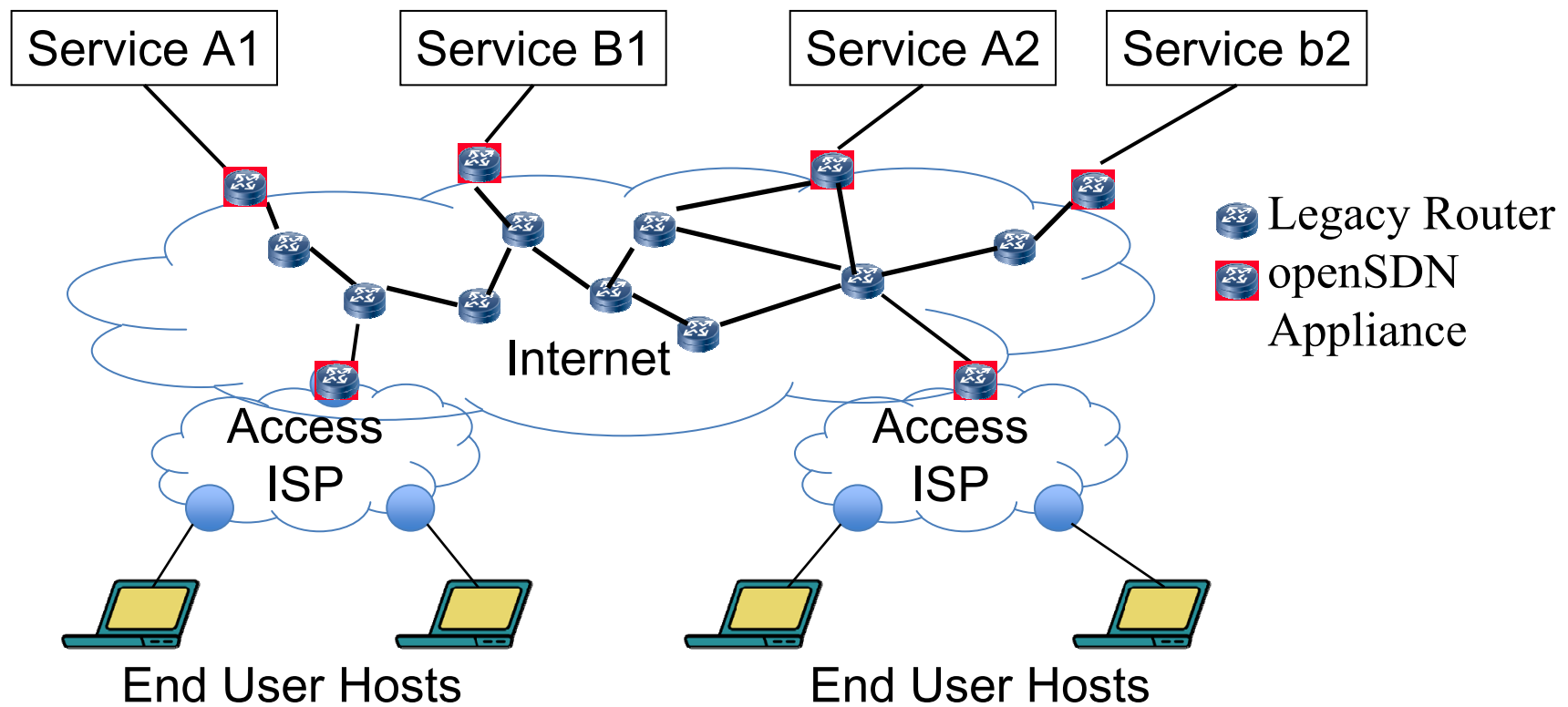5. Customization without loosing control (No active networks)
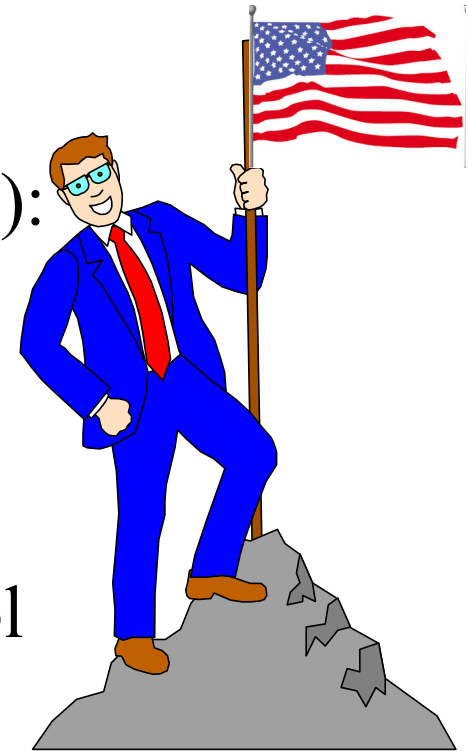
**Most versions of Ethernet followed these principles. Many versions of IP did not.**

# Application: Public+Private Clouds

❑ Multiple sites (including cloud computing) with rules for traffic handling



SDN

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# Implementation: OpenSDN Appliance



Service A1  Service B1  Service A2  Service b2

Internet

Access ISP

Access ISP

End User Hosts

End User Hosts

Legacy Router
openSDN Appliance

# 2. Modeling for Green Buildings
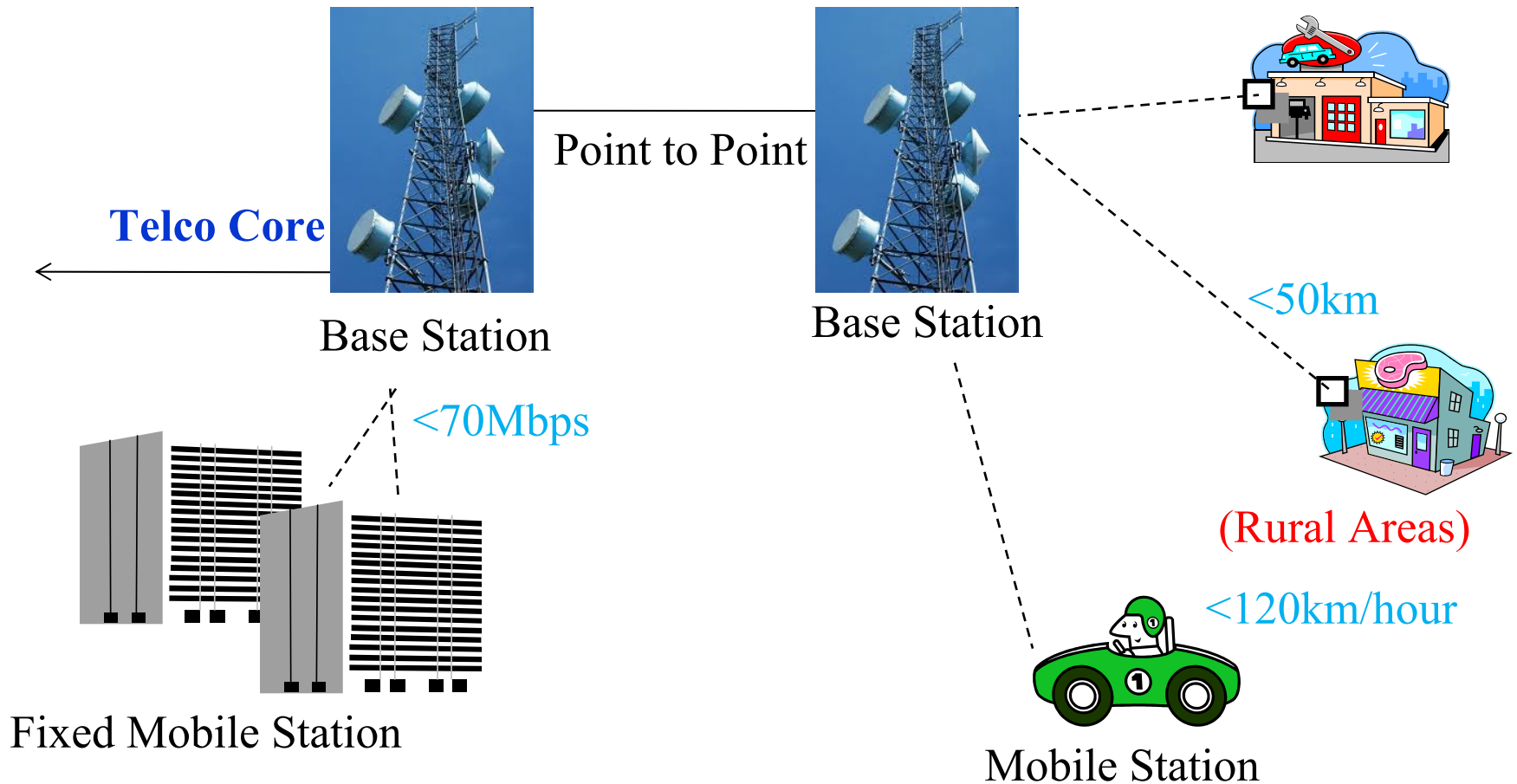
❑ Commercial and residential buildings use 71% of electricity and 39% of energy

❑ Some monitors available but do not use common network

❑ Commercial building studied for 6 months
Usage independent of personnel, time, or outside weather

❑ Plan to study residential buildings. Model. Develop automatic control strategies

❑ Mobile phones for location and control

❑ Clouds for storage, model, and coordination

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# 3. Communications for Emergency Situations

❑ Emergency warning systems: Based on radio and television $\Rightarrow$ Office workers not accessible

❑ Need cellular warning systems

❑ What if towers are damaged?
Can we use WiFi modes for communication?

❑ Goals:

  ➢ Study cellular usage and problems data from Japan March earthquake

  ➢ Develop strategies for a cellular EEW for US

# 4. Next Generation Wireless

## Best of WiFi + Cellular



Point to Point

**Telco Core**

Base Station

Base Station

<50km

<70Mbps

(Rural Areas)

<120km/hour

Fixed Mobile Station

Mobile Station

http://www.cse.wustl.edu/~jain/talks/cs59111.htm

# WiMAX and LTE: Key Features

- WiMAX = Wireless Interoperability for Microwave Access ⇒ Industry group for interoperability

- Long Term Evolution (LTE)

- Up to 50 km <u>or</u> Up to 70 Mbps.

- Data rate vs Distance trade off w adaptive modulation. ⇒ High rate near the tower. Lower as distance increases

- Both are 3.5G technologies

- 1 Gb/s in the next generation ⇒ 4G

# Scheduling in WiMAX
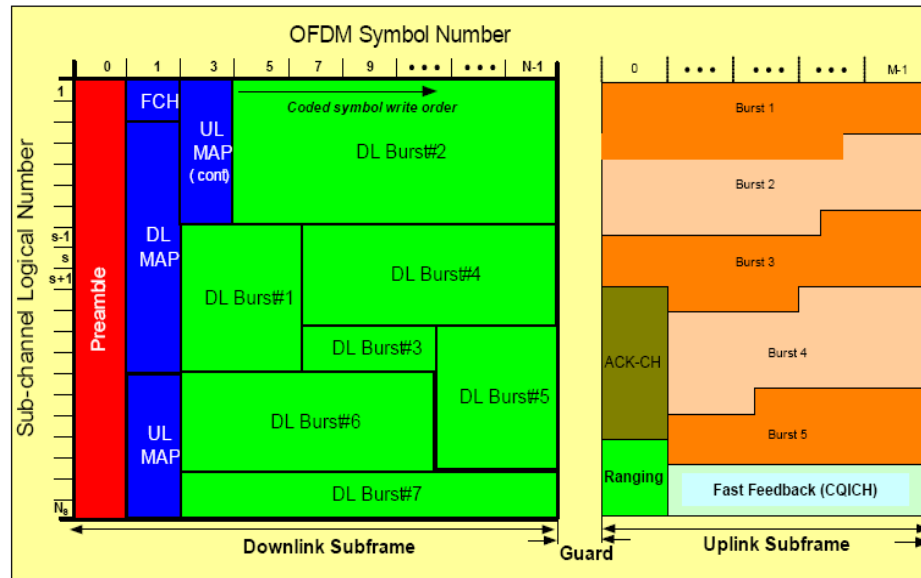


- ❑ Each user is given some frequencies for some time
  - ➢ Two dimensional bin packing problem $\Rightarrow$ NP-Hard
- ❑ Quality of the wireless channel is typically different for different users, and randomly changes with time (on both slow and fast time scales)
- ❑ Ref: Our paper in IEEE J-SAC, Feb 2009

# Mobile Video Modeling

❑ MPEG4 compressed video frame sizes can be modeled as a time series

❑ Seasonal Auto-Regressive Integrated Moving Average (ARIMA) model for Mobile Video

❑ One model that seems to fit many movies

❑ Developing a workload generator for use in WiMAX simulation studies

❑ Ref: Our SAM paper

http://www.cse.wustl.edu/~jain/talks/cs59111.htm

# **Aeronautical Datalinks: Challenges**

❑ 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 is designed for 60 km/hr

  ➢ Aeronautical links need to cover 600 nm/hr (1080 km/hr)

❑ Unmanned Aircrafts: Border patrol, Drones
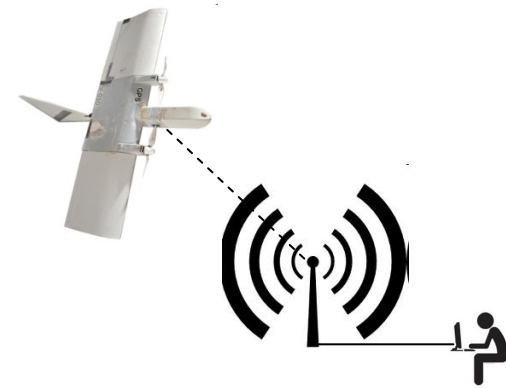
# Key Distinction of Our Research

❑ Research topic of current interest to Industry

❑ Funded by industry partners

❑ Impact real-world by participating in standards
   organizations and industry forums:
   ATM Forum, IEEE Standards, American National
   Standards Institute (ANSI), International
   Telecommunications Union (ITU), Internet
   Engineering Task Force (IETF), Internet Research
   Task Force (IRTF), WiMAX Forum

❑ Work on long term as well as short term research

http://www.cse.wustl.edu/~jain/talks/cs59111.htm

# Networking Courses at WUSTL

1. **CSE 473: Introduction To Computer Networks** (every fall)
2. CSE 521S: Wireless Sensor Networks
3. CSE 537S: Mobile Computing
4. **CSE 571S: Network Security** (Fall 2011)
5. ESE 572S: Signaling and Control in Communications Networks
6. CSE 573S: Protocols For Computer Networks
7. **CSE 574S**: **Wireless and Mobile Networking** (Spring 2010)
8. CSE 577M: Design And Analysis of Switching Systems
9. CSE 7700: Research Seminar On Networking and Communications

# Summary
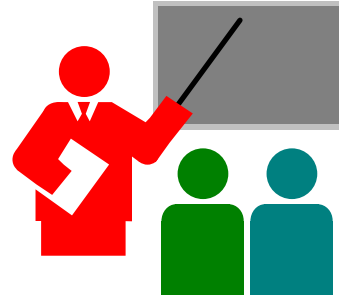
1. Computer networking is the backbone of all computing $\Rightarrow$ Cyber age
2. Key Issues: Security, Mobility, Energy, datacenters
3. Wireless is the major source of carrier revenue
   $\Rightarrow$ Significant growth in Wireless networking
4. Profusion of services on the Internet. Services need replication, fault tolerance, traffic engineering, security, …
5. OpenSDN provides these features with rule-based delegation, support for legacy nodes, data-control plane separation

http://www.cse.wustl.edu/~jain/talks/cs59111.htm

# References

❏ Audio/Video recordings and podcasts of several of our classes are available on-line for everyone:

  ➢ CSE 473: Introduction to Computer Networks,
    http://www.cse.wustl.edu/~jain/cse473-11/index.html

  ➢ CSE 571S: Network Security,
    http://www.cse.wustl.edu/~jain/cse571-11/index.html

  ➢ CSE 574S: Wireless Networks,
    http://www.cse.wustl.edu/~jain/cse574-10/index.html

  ➢ CSE 567: Computer Systems Analysis
    http://www.cse.wustl.edu/~jain/cse567-11/index.html

❏ See http://www.cse.wustl.edu/~jain/papers.html for a list of our papers