

Next Generation Internet and Wireless Networking Research at Washington University in St. Louis



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These slides are available on-line at:

<http://www.cse.wustl.edu/~jain/talks/cs59113.htm>



1. Why study networking?
2. Current Issues in Networking
3. Our research projects
4. Related networking research and courses

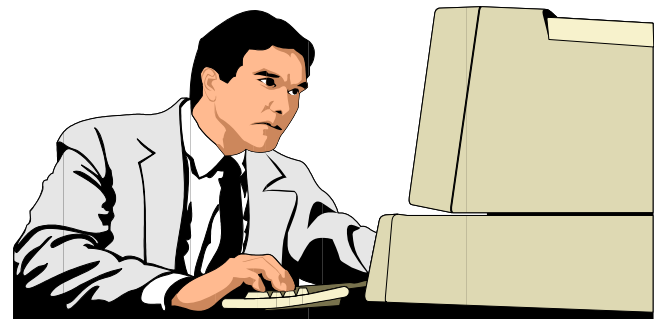
Why Study Computer Networking?

- ❑ 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
- ❑ All top computer companies are networking companies:
Google, Facebook, eBay, Microsoft, Cisco, HP, Intel, ...



Stone Age to Networking Age

- ❑ Stone, iron, ..., automotive, electricity, telephone, ..., networks caused a fundamental change in our life style

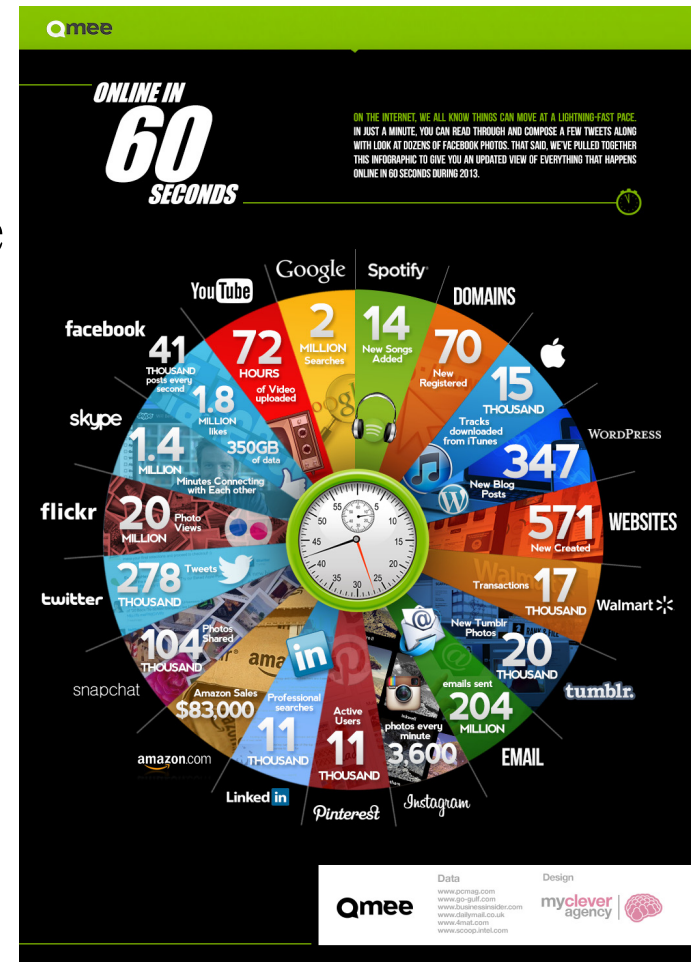


- ❑ No need to get out for
 - Office
 - Shopping
 - Entertainment
 - Education
- ❑ Virtual reality will satisfy your needs for
 - ❑ Games
 - ❑ Tourism
 - ❑ Socialization

What Happens on the Internet in 60 seconds?

□ Every Minute:

- 204 Million emails
- 2 Million searches on Google
- 350 GB of data to Facebook
- 72 hrs of video to YouTube
- 270,000 tweets
- 15000 songs from iTunes



Source: Qmee, "What happens on-line in 60 seconds," <http://blog.qmee.com/qmee-online-in-60-seconds/>
Washington University in St. Louis <http://www.cse.wustl.edu/~jain/talks/cs59113.htm>

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Current Issues in Networking

1. Network Security
2. Virtualization
3. Networking issues for Datacenters and Clouds
4. Software defined networking
5. Internet of things
6. Mobile, Wireless, and Multimedia
7. Energy and Sustainability

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)

1. Security: Cyber Warfare

- ❑ Nation States are penetrating other nations computers
5th 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



2. Virtualization in Computing

“Virtualization means that Applications can use a resource without any concern for where it resides, what the technical interface is, how it has been implemented, which platform it uses, and how much of it is available.”

-Rick F. Van der Lans

□ Storage:

- Virtual Memory ⇒ L1, L2, L3, ... ⇒ Recursive
- Virtual CDs, Virtual Disks (RAID), Cloud storage

□ Computing:

- Virtual Desktop ⇒ Virtual Server ⇒ Virtual Datacenter
Thin Client ⇒ VMs ⇒ Cloud

□ Networking: Plumbing of computing

- Virtual Channels, Virtual LANs, Virtual Private Networks, but there is much more ...

3. Datacenter Networking and Clouds

❑ Cloud Computing:

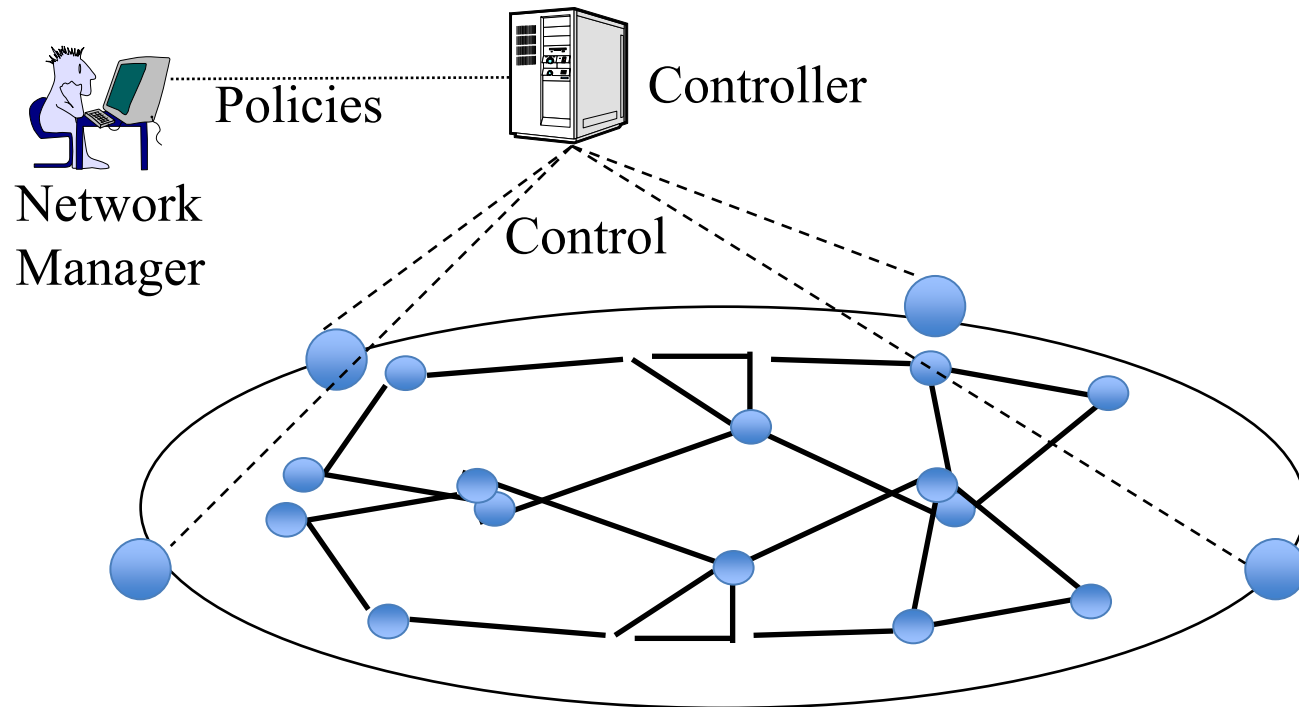
- Applications through Internet (Google Docs)
- Computing through Internet (Amazon EC3)
- Storage and backup through Internet (iCloud, Google Drive)



❑ Issues: Ethernet optimized for data centers

- Scale: Thousands of virtual machines.
- Mobility: Fast mobility from one physical server to next
- Distance: Datacenters across street, across the world
- Fast: Micro-seconds transaction delays
- Multi-tenant security, policy, QoS issues

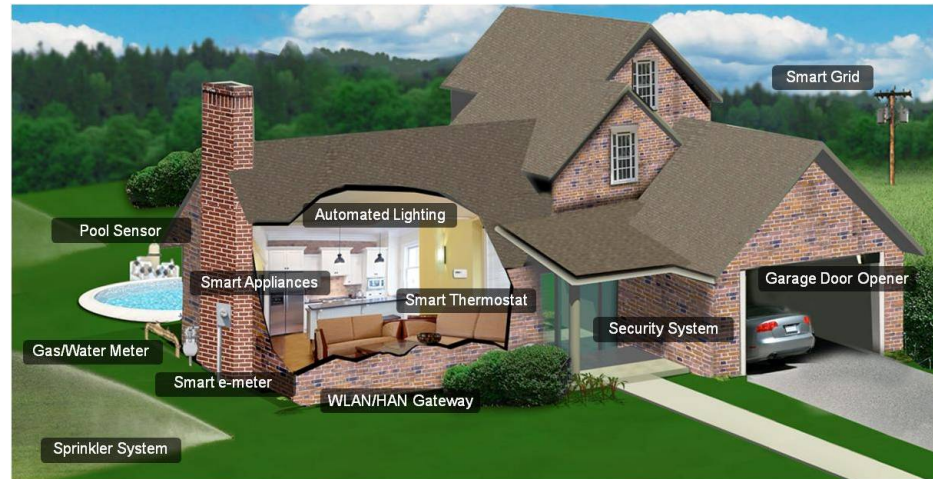
4. Software Defined Networking



- ❑ Centralized controller for route computation
- ❑ Controller can be programmed \Rightarrow Software Defined
- ❑ Policies can be changed on the fly.
- ❑ Easy orchestration of thousands of switches and routers

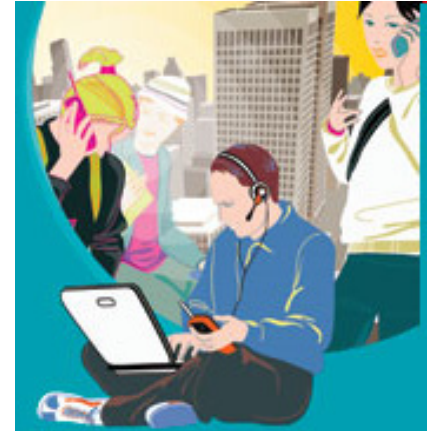
5. Internet of Things

- ❑ Phones are not the only thing that can be smart
- ❑ With internet connectivity, your glasses, clothes, medicine box, refrigerators, heating/cooling appliances, all controls in your car improve your life, happiness, productivity, and save you money



6. Mobile/Wireless for Multimedia

- ❑ Smart Phones (iPhone, Blackberry, Android Phones), Net books, Laptops
⇒ Mobile computers
- ❑ Mobility: Keep your networking session connected regardless of your location
- ❑ Most of the mobile devices are wireless
- ❑ Most of the mobile traffic is video
- ❑ Issues: Errors, Disconnection, Limited bandwidth, Limited distance



7. Energy and Sustainability

- ❑ 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
- ❑ Also, networking can help reduce energy consumption in other areas



Our Research Projects

1. Mobile Applications Delivery using Software Defined Networking
2. Communication and Modeling for Energy and Sustainability
3. Wireless Mesh Networking

Clouds and Mobile Apps

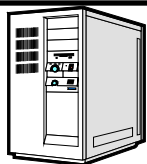
- ❑ August 25, 2006: Amazon announced EC2
⇒ Birth of Cloud Computing in reality
(Prior theoretical concepts of computing as a utility)
- ❑ *Web Services To Drive Future Growth For Amazon* (\$2B in 2012, \$7B in 2019)
- Forbes, Aug 12, 2012
- ❑ June 29, 2007: Apple announced iPhone
⇒ Birth of Mobile Internet, Mobile Apps
 - Almost all services are now mobile apps: Google, Facebook, Bank of America, ...
 - Almost all services need to be global (World is flat)
 - Almost all services use cloud computing



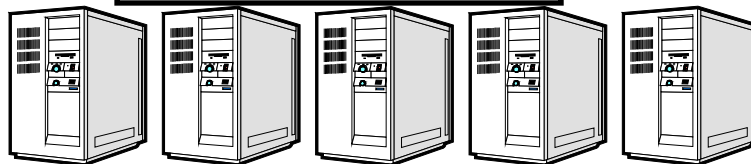
Networks need to support efficient service setup and delivery

Service Center Evolution

1. Single Server



2. Data Center

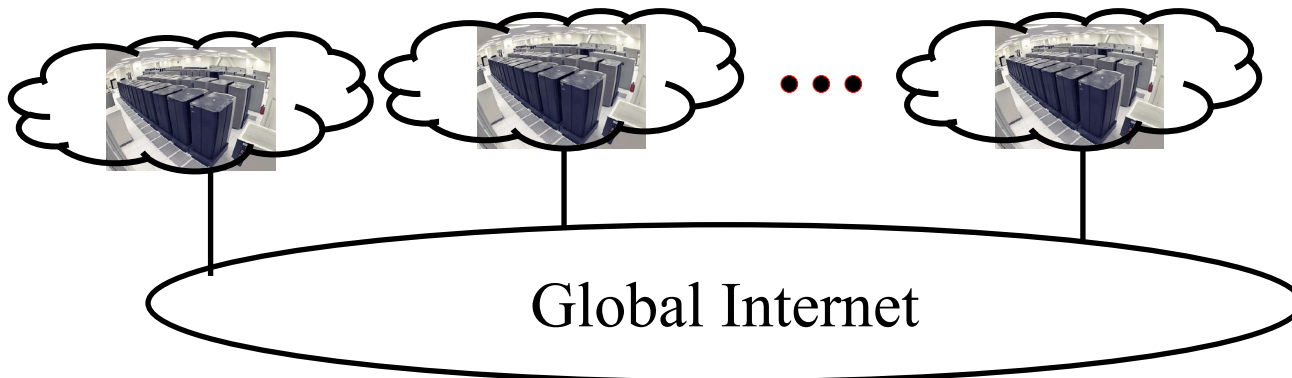


Load Balancers

SSL Off loaders

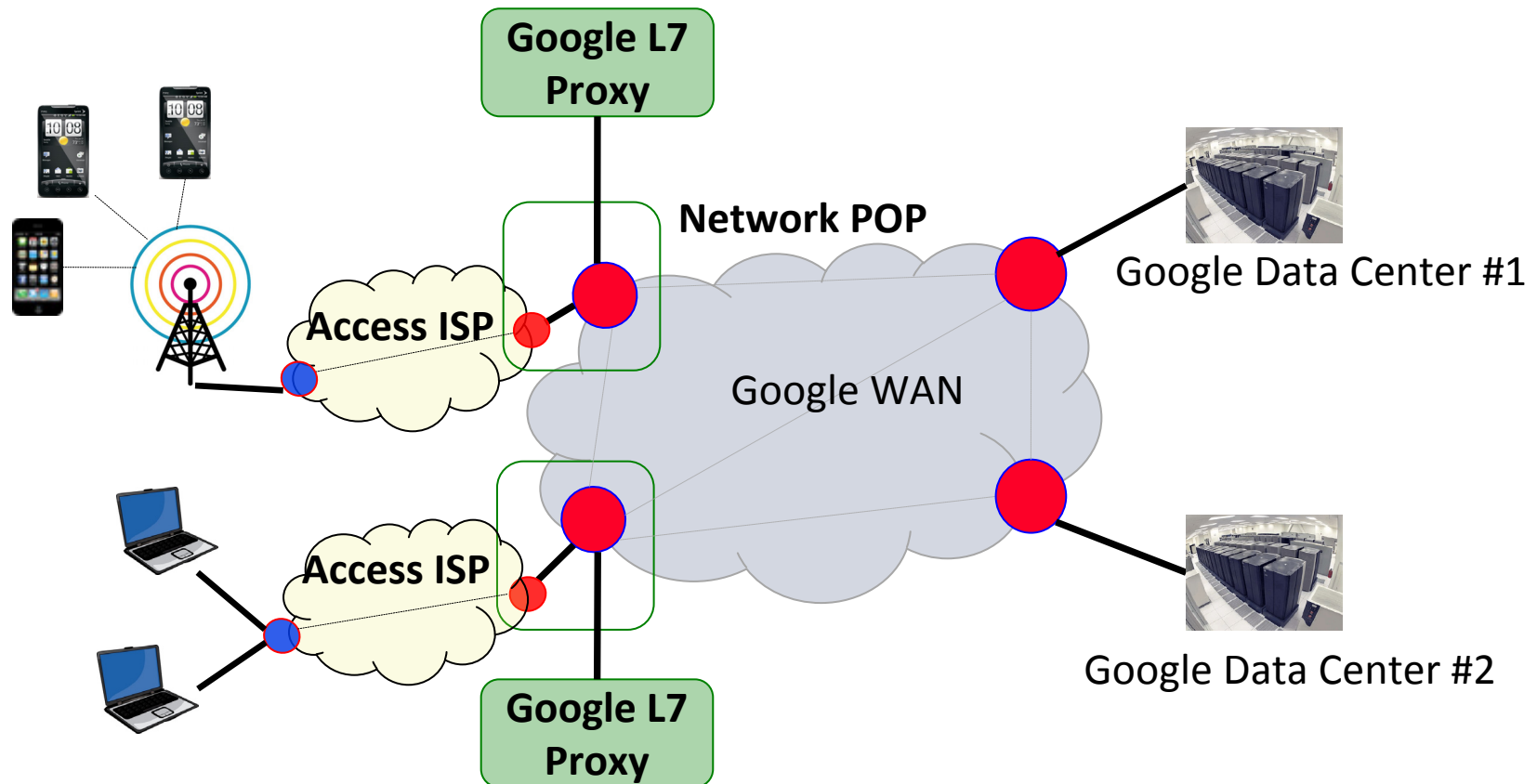
Application Replication, Partitioning

3. Multi-Cloud



Need to make the global Internet look like a data center

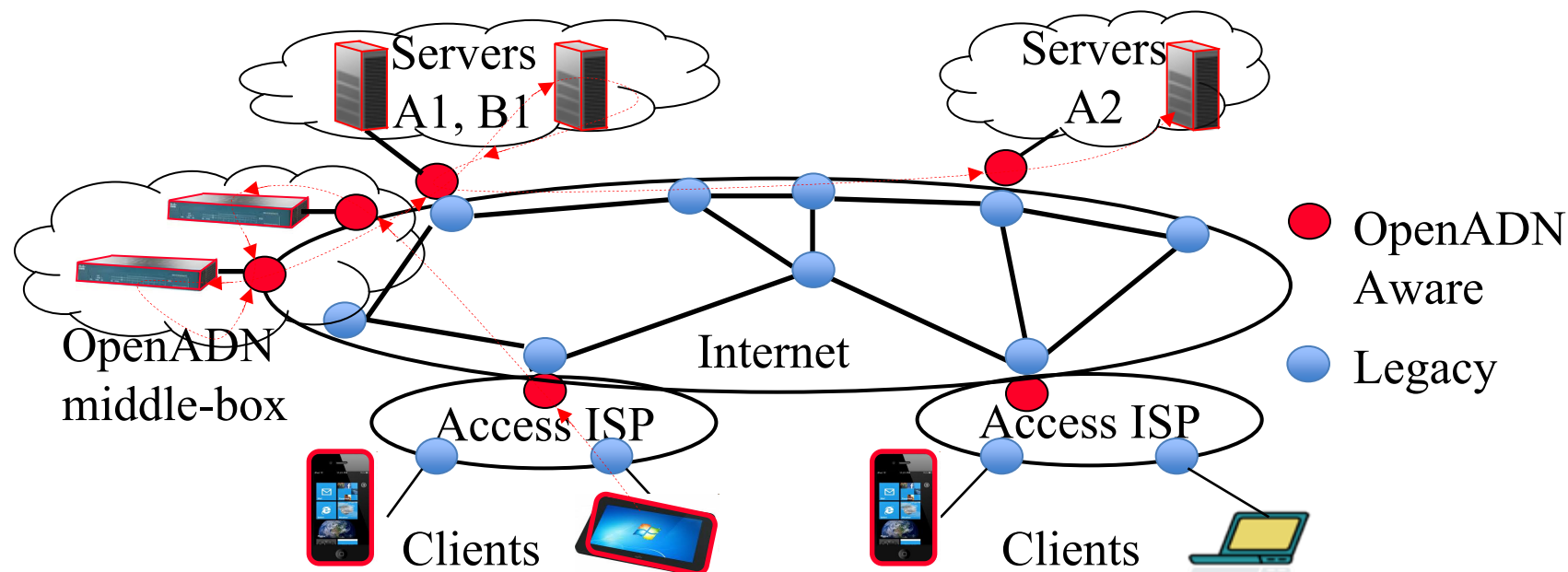
Google WAN



- ❑ Google appliances in Tier 3 ISPs
- ❑ Details of Google WAN are not public
- ❑ ISPs can not use it: L7 proxies require data visibility

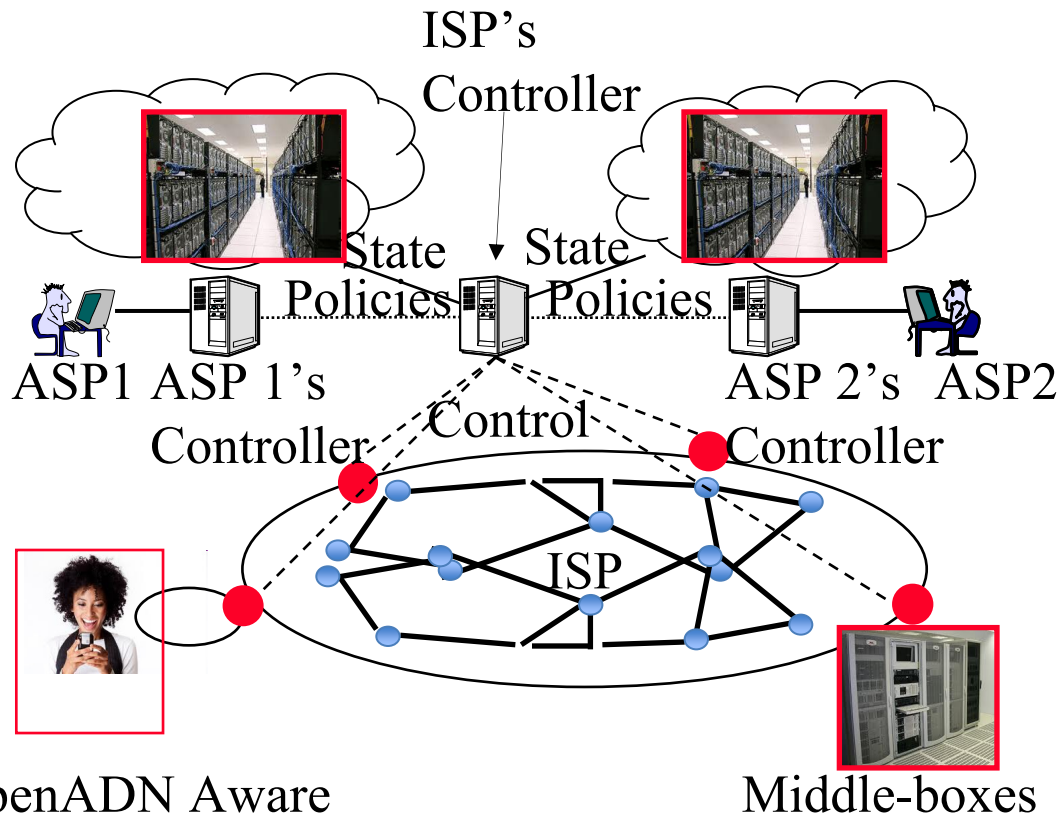
Our Solution: OpenADN

- ❑ Open Application Delivery Networking Platform
Platform = OpenADN aware clients, servers, switches, and middle-boxes
- ❑ Allows Application Service Providers (ASPs) to quickly setup services on Internet using cloud computing \Rightarrow Global datacenter



OpenADN using SDN

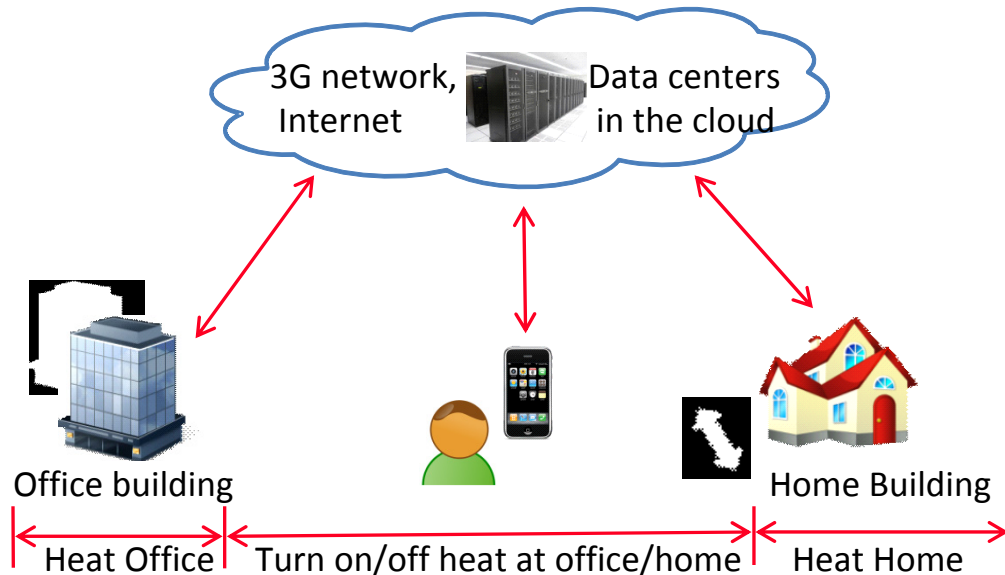
- ASP's controller communicates with ISP's controller



- OpenADN Aware
- Legacy (OpenADN Unaware)

2. Modeling for Sustainability

- ❑ Buildings are responsible for around 38% of the total carbon dioxide emissions; 71% of the total electrical energy consumption; 39% of the total energy usage
- ❑ Goal: enable building- and user-level energy proportionality
- ❑ Approach: smart location-based automated control



3. Wireless Networking

1. Wireless (WiFi) is ubiquitous (Intel Centrino)
 2. New Developments:
 - 5G: 1Gbps Metropolitan Area Networks (LTE-Advanced, WiMAX V2)
 - Vehicular Networking (802.11p)
 - Ad-hoc Wireless Networks
 - Super WiFi using TV Band (700 MHz) for long-haul communication
- ❑ Wireless access for remote/rural areas



Key Distinction of Our Research

- ❑ Goal: Impact to the real-world
- ❑ Research topics of 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

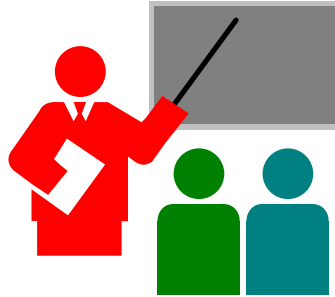


Networking Courses at WUSTL

1. **CSE 473: Introduction To Computer Networks**
(every fall)
2. CSE 521S: Wireless Sensor Networks
3. CSE 537S: Mobile Computing
4. CSE 570S: Virtualization, Clouds,
Big Data, SDN, IoT (Fall 2013)
5. **CSE 571S: Network Security** (Fall 2014)
6. ESE 572S: Signaling and Control in Communications
Networks
7. **CSE 574S: Wireless and Mobile Networking** (Spring 2014)
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
⇒ Cyber age. Networking companies are the leading edge.
2. Key Networking Issues: Security, Virtualization, Data Center and Clouds, Software defined networking, Mobility and Wireless, Energy and Sustainability
3. Services use globally distributed clouds and need networking. OpenSDN provides these features using SDN.
4. Energy and sustainability using networking
5. Wireless networking for rural/remote areas

References

- ❑ Recordings and podcasts of our classes are available:
 1. CSE 473: Introduction to Computer Networks,
<http://www.cse.wustl.edu/~jain/cse473-11/index.html>
 2. CSE 571S: Network Security,
<http://www.cse.wustl.edu/~jain/cse571-11/index.html>
 3. CSE 574S: Wireless Networks,
<http://www.cse.wustl.edu/~jain/cse574-10/index.html>
 4. CSE 567: Computer Systems Analysis
<http://www.cse.wustl.edu/~jain/cse567-13/index.html>
 5. CSE 570: Recent Advances in Networking
<http://www.cse.wustl.edu/~jain/cse570-13/index.html>
- ❑ See <http://www.cse.wustl.edu/~jain/papers.html> for a list of our papers

Acronyms

- ❑ ABR Available bit rate
- ❑ ASP Application Service Provider
- ❑ ATM Asynchronous Transfer Mode
- ❑ CD Compact Disk
- ❑ ECN Explicit congestion notification
- ❑ EFCI Explicit Forward Congestion Indication
- ❑ FECN Forward Explicit Congestion Notification
- ❑ GB Gigabyte
- ❑ IEEE Institution of Electrical and Electronic Engineering
- ❑ IETF Internet Engineering Task Force
- ❑ IoT Internet of Things
- ❑ IP Internet Protocol
- ❑ IRTF Internet Research Task Force
- ❑ ISP Internet Service Provider
- ❑ ITU International Telecommunications Union
- ❑ LAN Local Area Network

Acronyms (Cont)

- ❑ LTE Long Term Evolution
- ❑ MHz Mega Hertz
- ❑ OpenADN Open Application Delivery Networking
- ❑ SDN Software Defined Networking
- ❑ SUV Sport Utility Vehicle
- ❑ TCP Transmission Control Protocol
- ❑ TV Television
- ❑ VM Virtual Machine
- ❑ WAN Wide Area Network
- ❑ WiFi Wireless Fidelity
- ❑ WiMAX Worldwide Interoperability for Microwave Access