

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



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A talk given to “CS 131R: Seminar in Computer Science I” Class
October 12, 2015

These slides are available on-line at:

<http://www.cse.wustl.edu/~jain/talks/cs13115.htm>



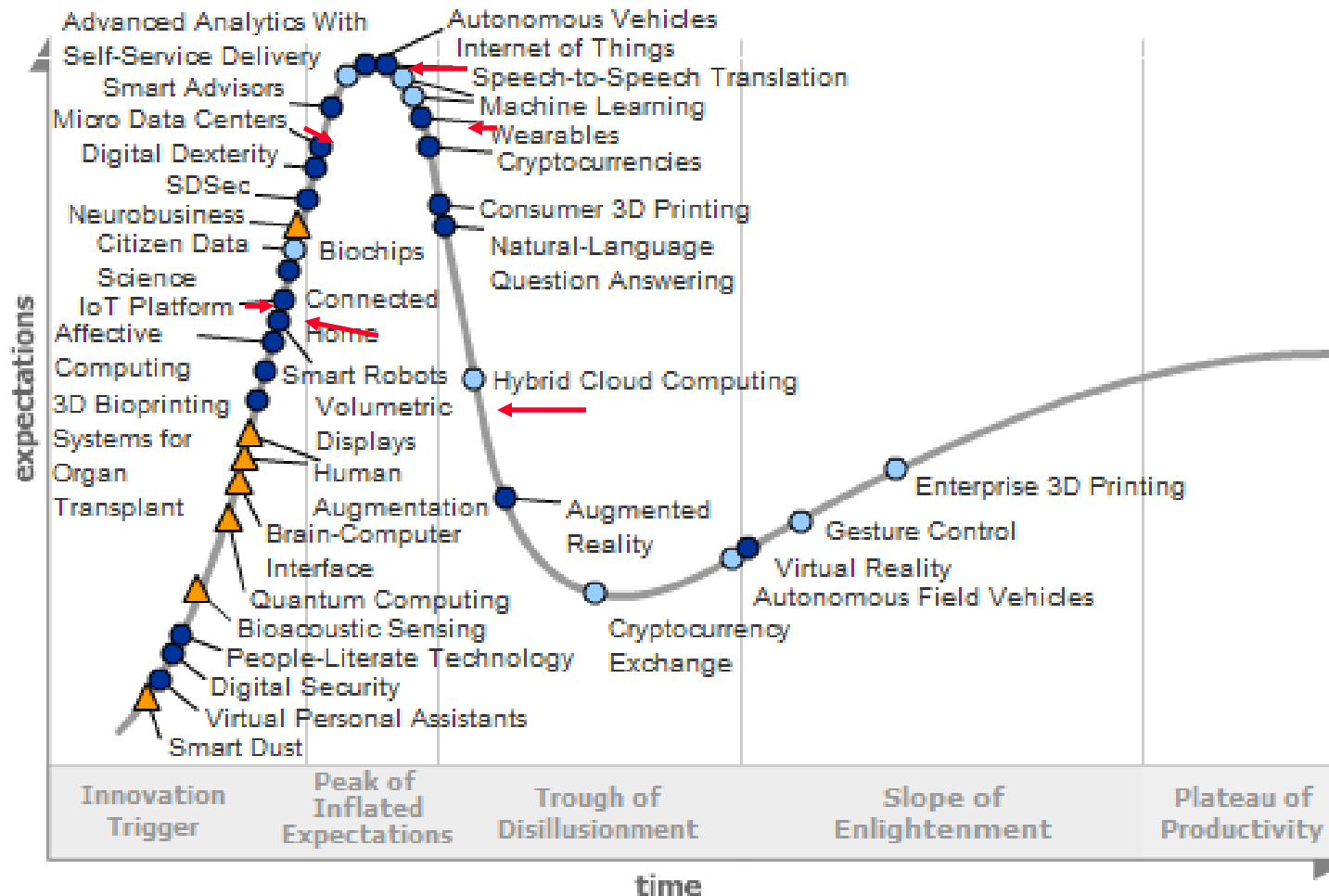
1. Why study networking?
2. Current Issues in Networking
3. Our research projects
4. Related networking research and courses

Why Study Computer Networking?

- ❑ Networking is the “plumbing” of computing
- ❑ Almost all areas of computing are network-based.
 - Distributed computing
 - Big Data
 - Robotics
 - Distributed Games
- ❑ Fast growing field
- ❑ All top companies are networking companies: Apple, Google, Microsoft, Amazon, Facebook, Cisco, HP, Intel, IBM, ...

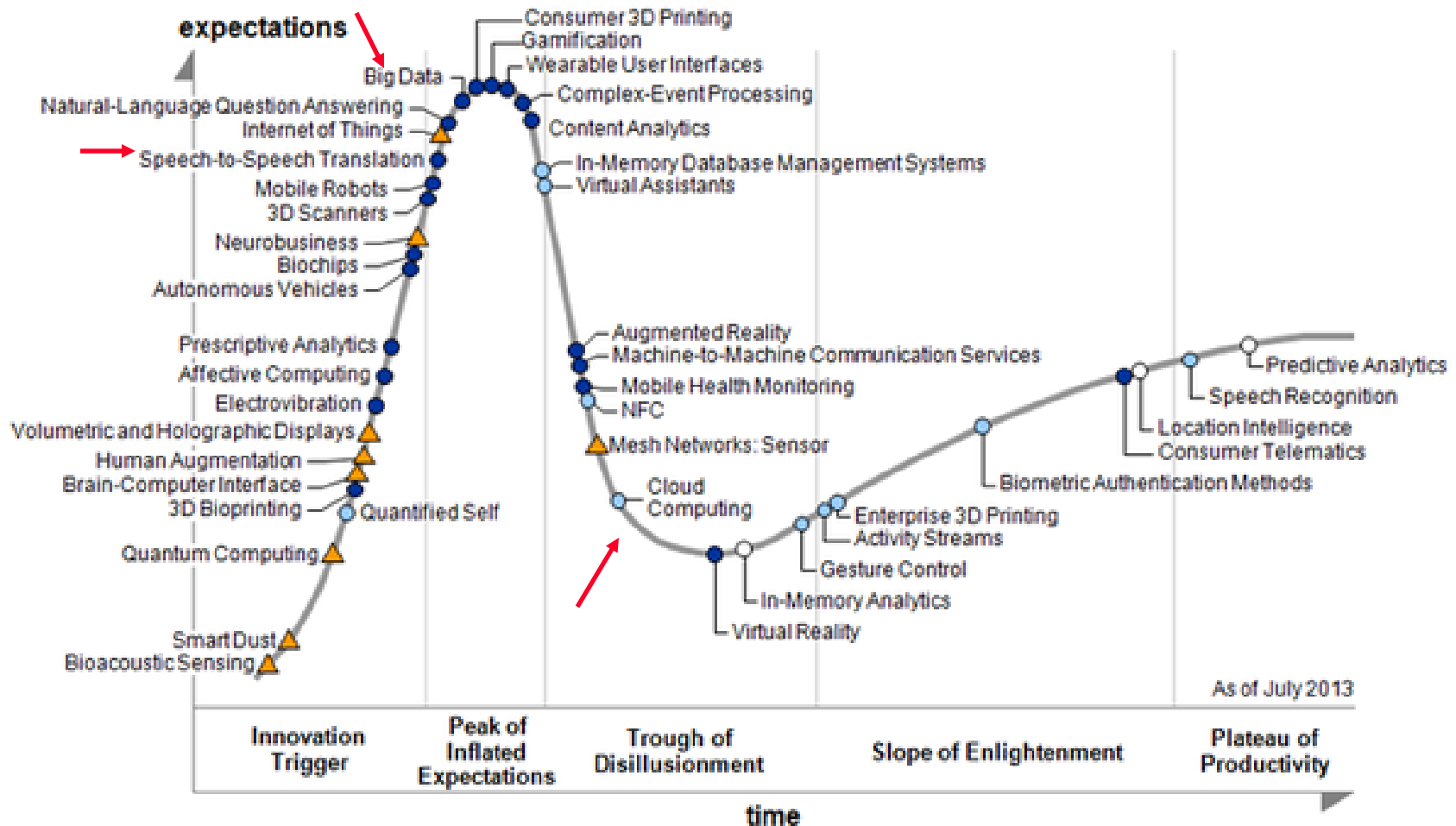


Gartner Hype Cycle 2015



Ref: Gartner, "Hype Cycle for Emerging Technologies, 2015," July 2015, [Available to subscribers only], <http://www.gartner.com/document/3100227?ref=QuickSearch&sthkw=hype%20cycle%202015&refval=156919648&qid=fe61993355944ace1c8c01ec2df676d9>

Gartner Hype Cycle 2013



Plateau will be reached in:

○ less than 2 years ● 2 to 5 years ● 5 to 10 years ▲ more than 10 years ⊗ obsolete before plateau

Ref: <http://www.zdnet.com/gartners-2013-emerging-technologies-hype-cycle-focuses-on-humans-and-machines-7000019564/>

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Current Hot Topics in Networking



1. Security: Cyber Warfare
2. Datacenter Networking and Clouds
3. Software Defined Networking
4. Wireless Networking
5. Mobile/Wireless for Multimedia
6. Internet of Things

1. Security: Cyber Warfare

- ❑ Security of computers, companies, smart grid, and nations
- ❑ Nation States are penetrating other nations computers
5th domain of warfare (after land, sea, air, space)
- ❑ In 2010, US set up US Cyber Command
- ❑ UK, China, Russia, Israel, North Korea have similar centers
- ❑ Many cyber wars: North Korea vs. USA, Israel vs. Syria, South Korea vs. North Korea, India vs. Pakistan, ...

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



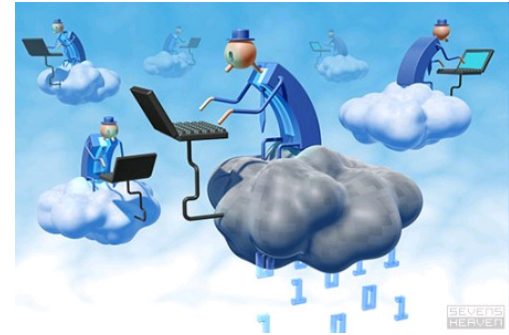
Old



New

Clouds and Mobile Apps

- ❑ August 25, 2006: Amazon announced EC2
⇒ Birth of Cloud Computing in reality
(Prior theoretical concepts of computing as a utility)
\$4.6 B in 2014, \$6.2 B in 2015, a growth rate of 49% with 17% margins, much higher than the overall Amazon business
- ❑ 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



2. Datacenter Networking and Clouds

□ Cloud Computing:

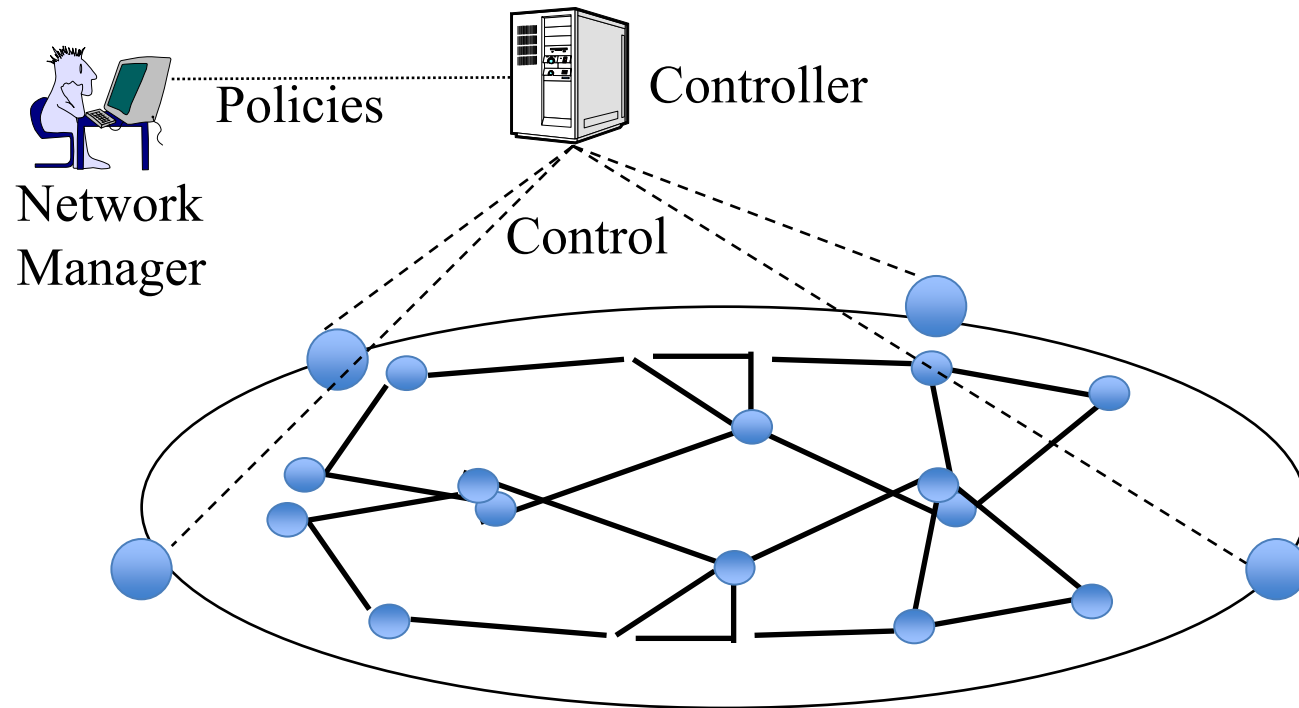
- Applications through Internet (Google Docs)
- Computing through Internet (Amazon EC3)
- Storage and backup through Internet (iCloud, Google Drive)



□ 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

3. 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

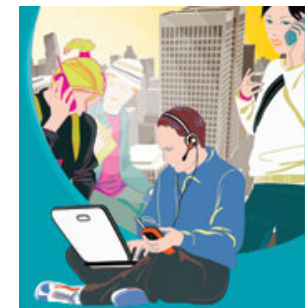
4. Wireless Networking

1. Wireless (WiFi) is ubiquitous (Intel Centrino)
2. New Developments:
 - 5G: 1Gbps Metropolitan Area Networks (LTE-Advanced)
 - Vehicular Networking (802.11p)
 - Cognitive networks: Sharing unused spectrum



5. Mobile/Wireless for Multimedia

- ❑ Smart Phones (iPhone, Blackberry, Android Phones), Net books, Laptops
P Mobile computers
- ❑ 2014 **mobile** data traffic was 2.5×10^{18} B/month.
30× the size of the entire global Internet in 2000 (75 PB/mth).
- ❑ Mobile **video** traffic was more than 55% of the mobile traffic in 2014.
- ❑ Issues: Errors, Disconnection, Limited bandwidth, Limited distance



Ref: Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2014–2019, Feb 3, 2015,

http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.pdf

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6. Internet of Things



Smart Watch



Smart TV



Smart Car



Smart Health



Smart Home



Smart Kegs



Smart Space



Smart Industries



Smart Cities

What's Smart?

- ❑ Old: Smart = Can think \Rightarrow Can compute
- ❑ Now: Smart = Can find quickly, Can Delegate \Rightarrow Communicate = Networking
- ❑ Smart Grid, Smart Meters, Smart Cars, Smart homes, Smart Cities, Smart Factories, Smart Smoke Detectors, ...



Think



Communicate



Not-Smart

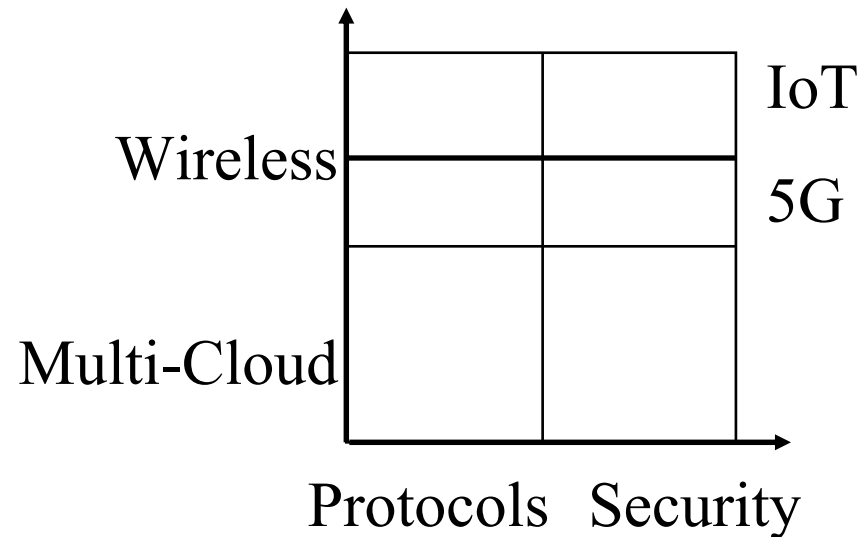


Smart

Cavemen of 2050

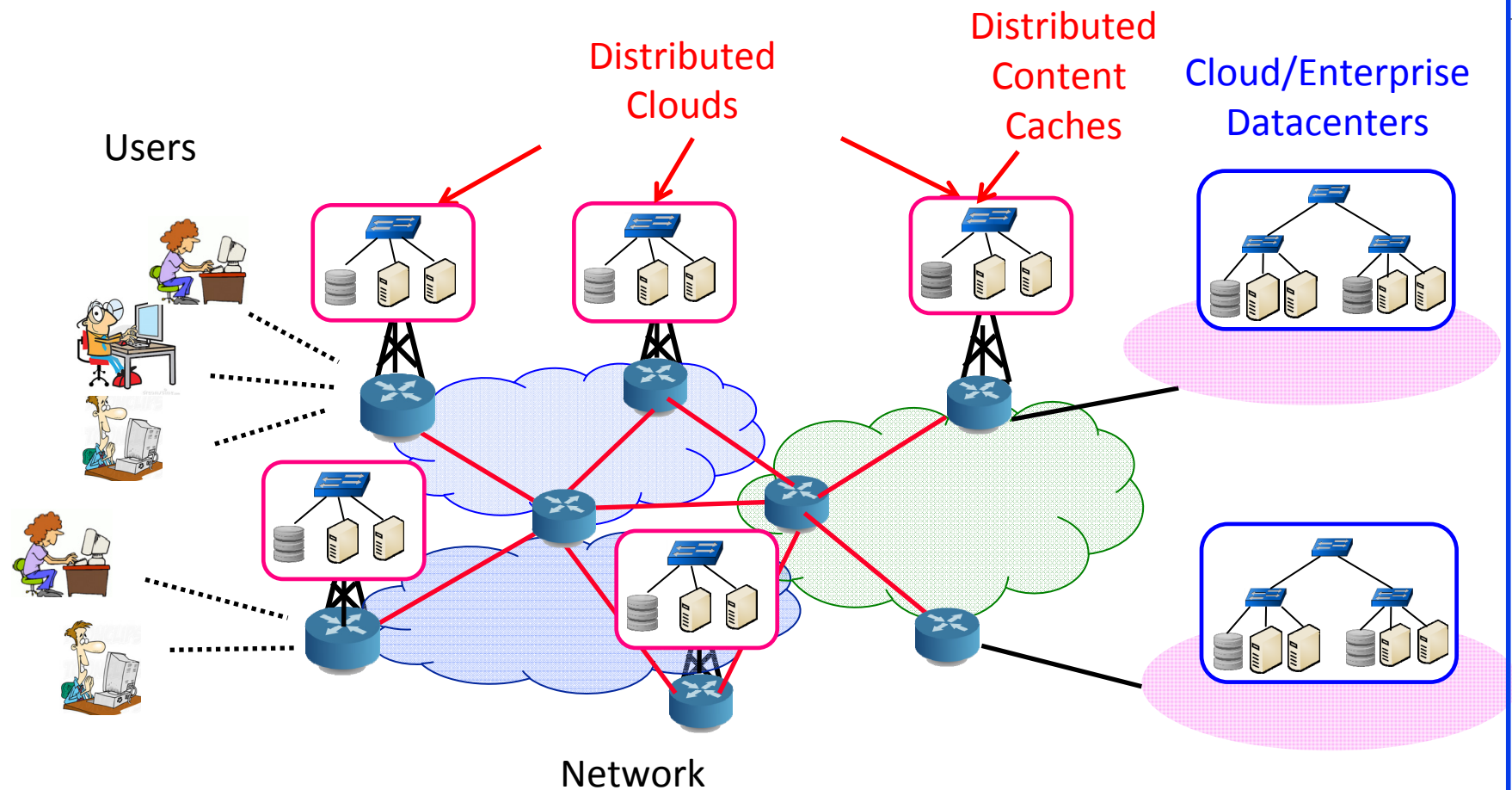


Our Research Areas



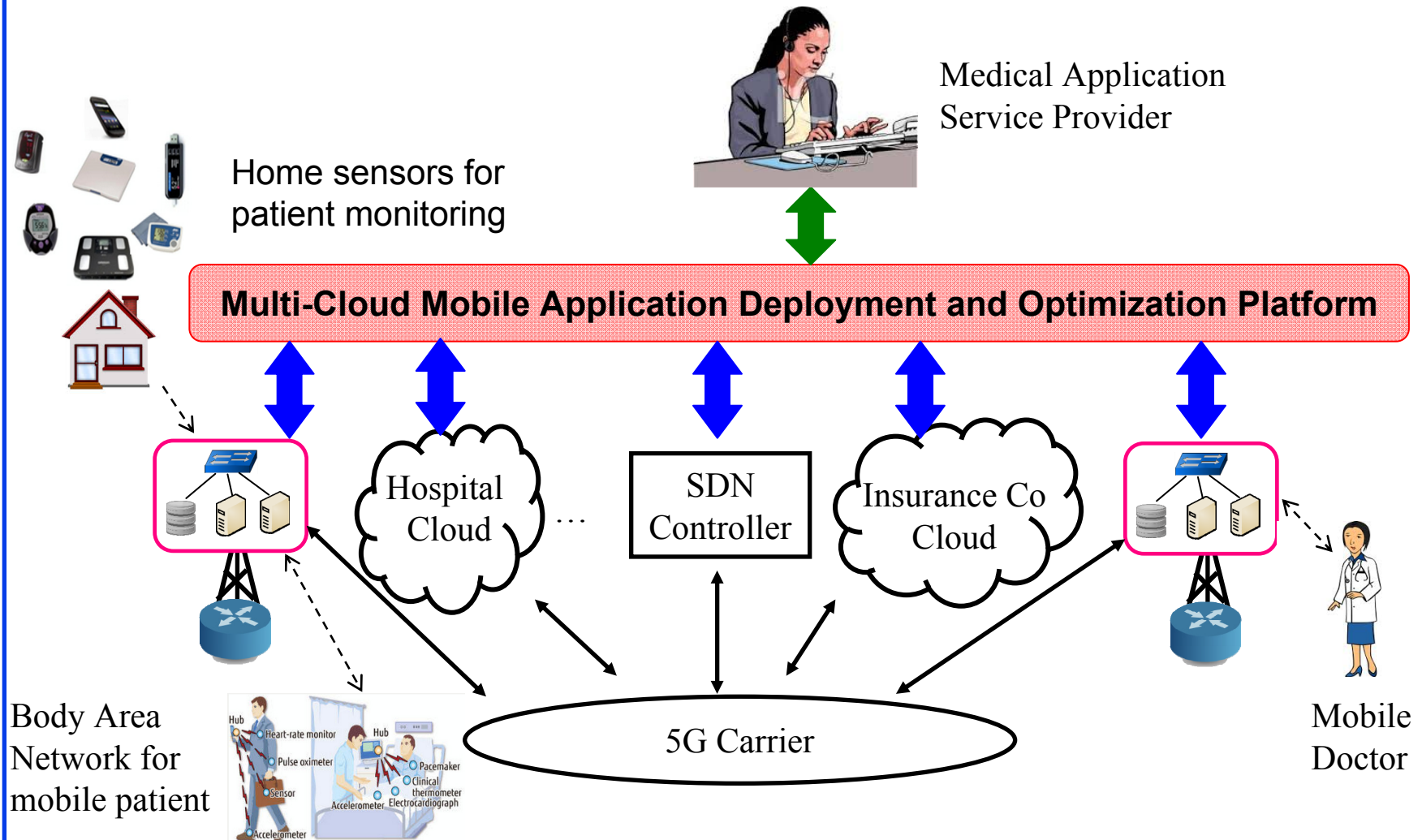
1. Multi-Cloud Management
2. Multi-Cloud for 5G: NFV
3. Protocols for IoT
4. IoT Security
5. Multi-Cloud Security
6. Communication using UAVs

Trend: Micro-Clouds on Towers

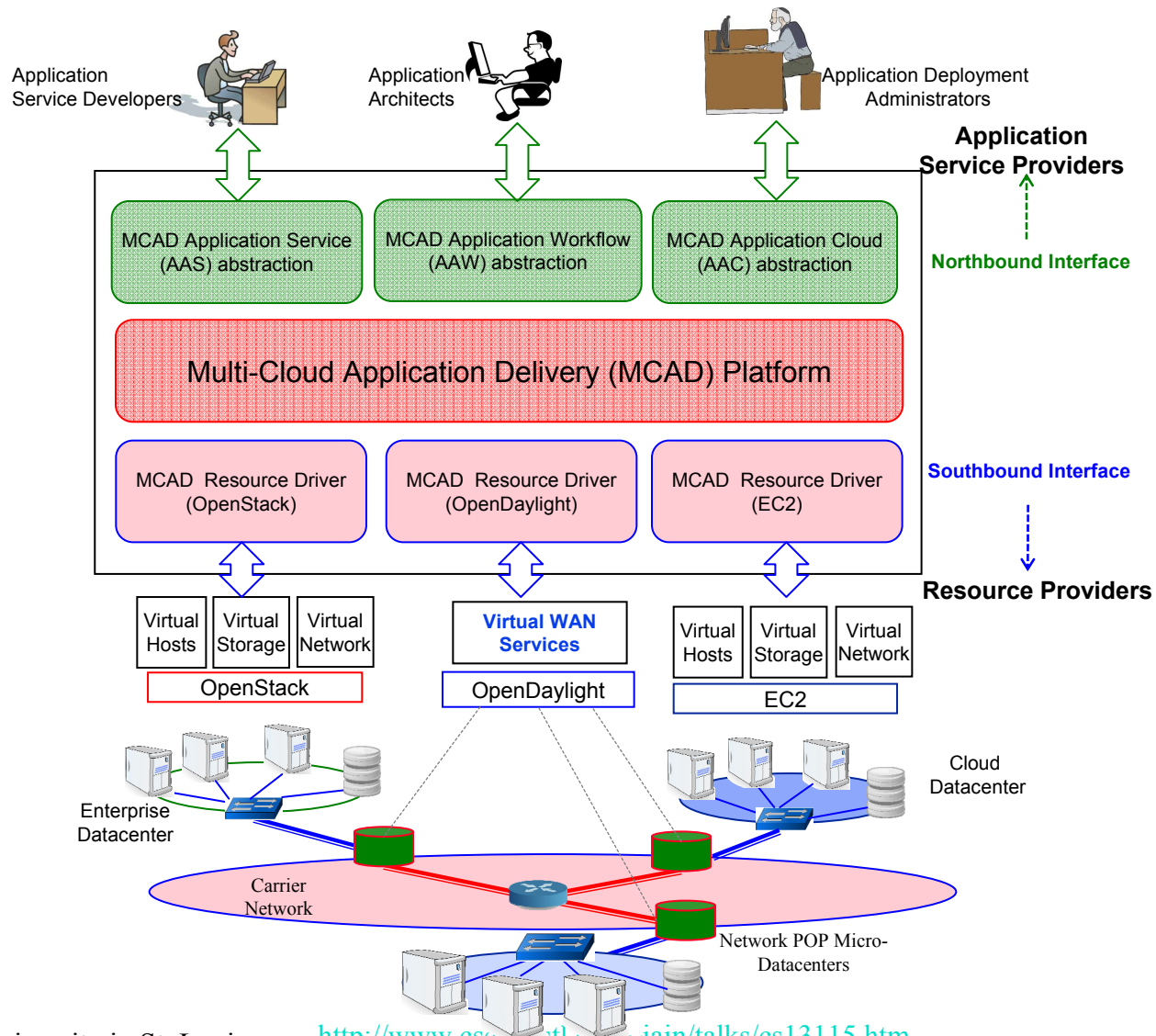


New Business Opportunities: Datacenters on Towers, Internet of Things

Mobile Healthcare Use Case

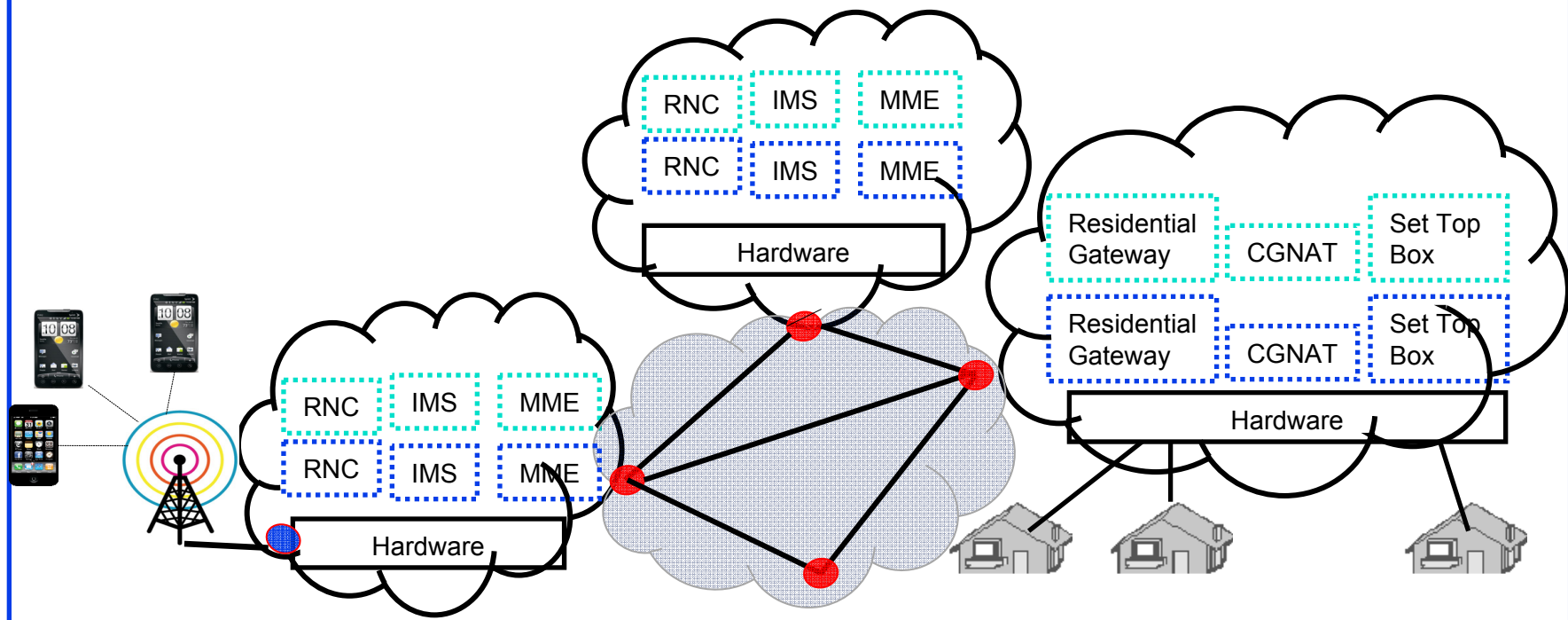


Multi-Cloud Management



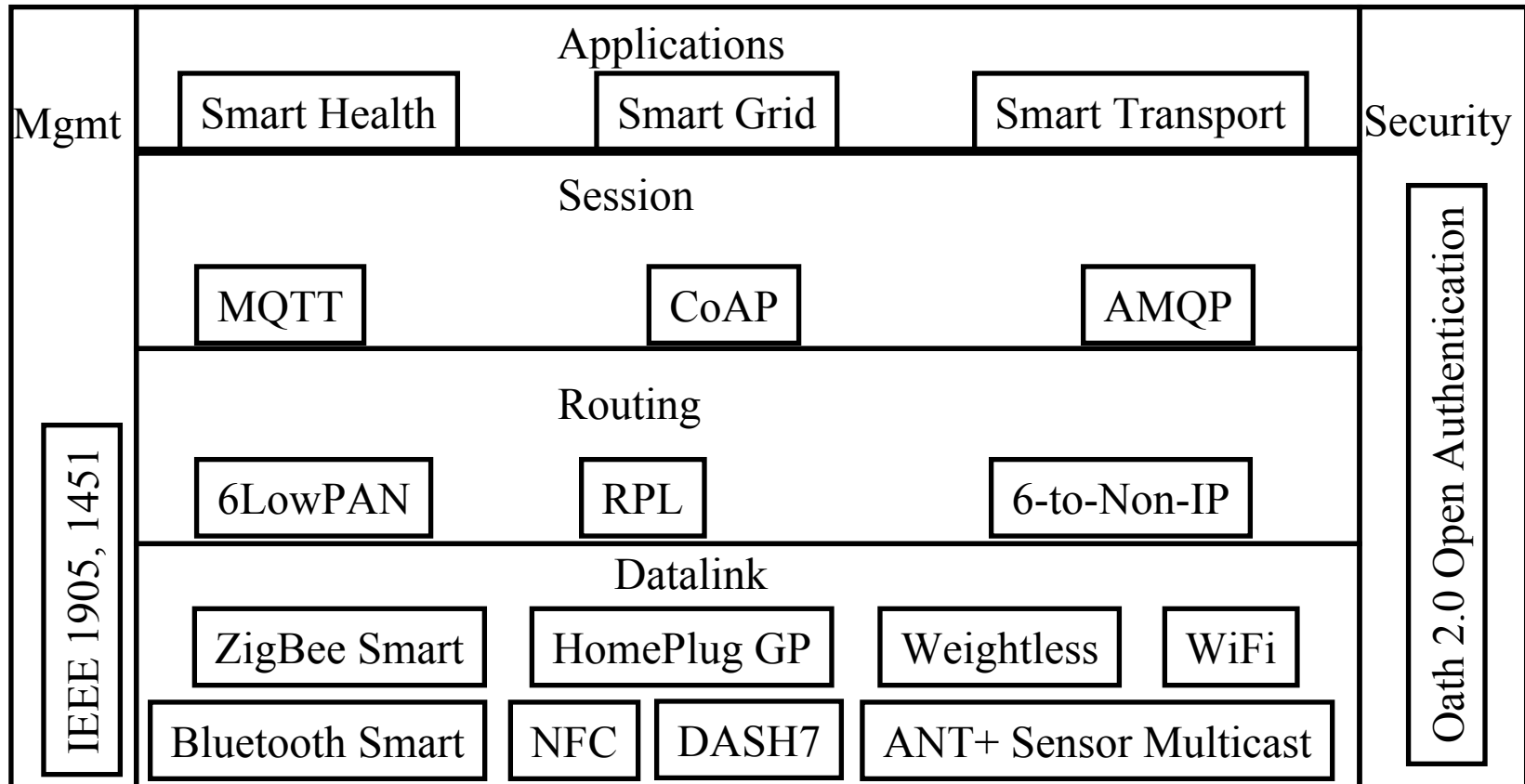
Multi-Cloud for 5G: NFV

- ❑ NFV = Network Function Virtualization
Use of clouds by telecom carriers
- ❑ Problem: Where to place which function and move as the traffic pattern changes \Rightarrow Service Function Chaining



Protocols for IoT

- How to design these thin energy efficient protocols?

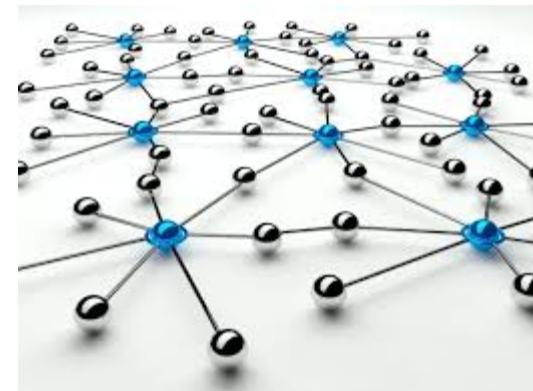


Ref: <http://tools.ietf.org/html/draft-rizzo-6lo-6legacy-00>, <http://en.wikipedia.org/wiki/OAuth>, <http://en.wikipedia.org/wiki/ANT%2B>
http://en.wikipedia.org/wiki/Near_field_communication, http://en.wikipedia.org/wiki/Weightless_%28wireless_communications%29

IoT Security

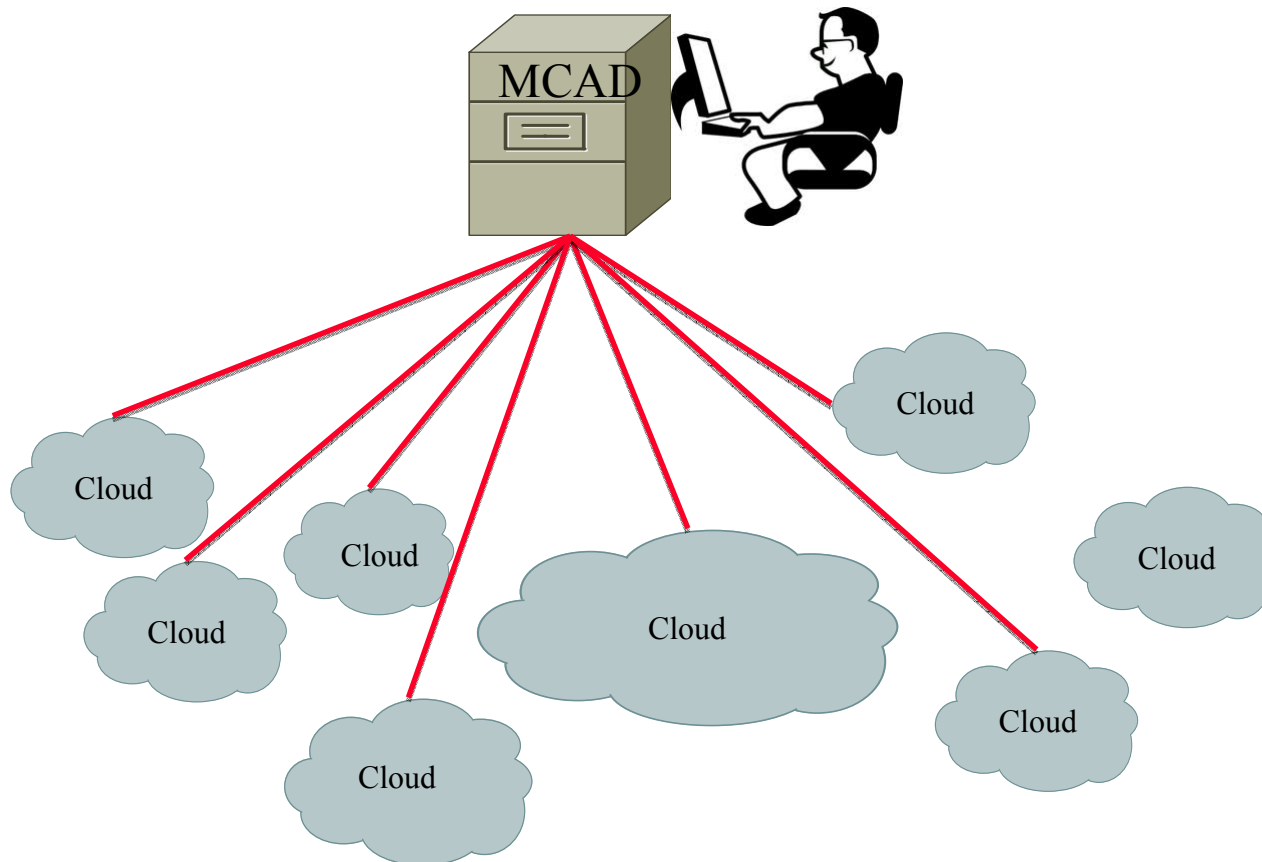
Attack Surface

1. IoT Devices
2. IoT Gateway: Smart Phone
3. Local Area Network: WiFi, Ethernet, Powerline, ...
4. IP Network: DNS, Routers, ...
5. Cloud
6. Management Platform: Web interface
7. Life Cycle Management: Booting, Pairing, Updating, ...
8. IoT wireless access technology: DECT, Bluetooth, WiFi, ZigBee, Z-wave, ...
9. Higher-layer Protocols: Transport, Application

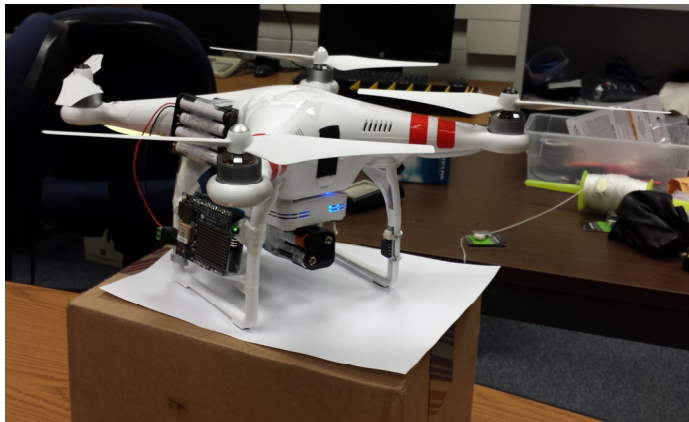
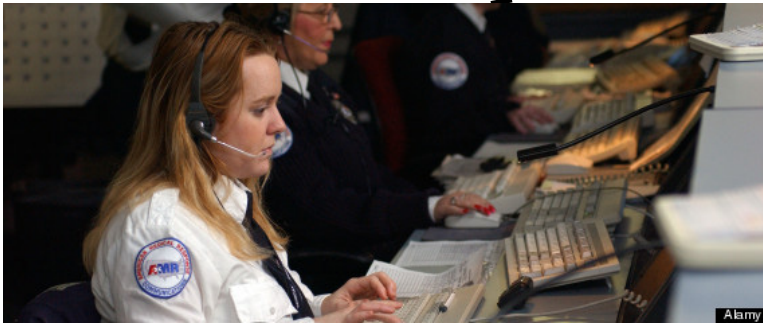


Multi-Cloud Security

- Can one cloud provider be trusted by another?
Would Google trust Microsoft, Amazon, or Apple?



Communication using UAVs



Key Distinction of Our Research

- ❑ Goal: Impact to the real-world
DECbit congestion indication in almost all networking architectures since its invention
- ❑ Funded by industry partners:
Intel, Cisco, Broadcom, Boeing, ...
- ❑ Impact real-world by participating in standards organizations and industry forums:
ATM Forum, IEEE Standards, American National Standards Institute (ANSI), Internet Engineering Task Force (IETF), WiMAX Forum
- ❑ Work on long term as well as short term research

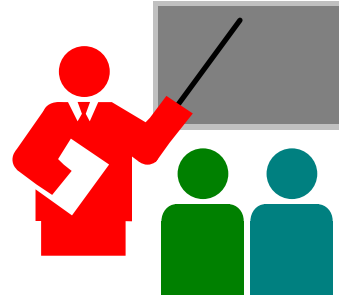


Networking Courses at WUSTL

1. **CSE 473: Introduction To Computer Networks** (every fall) – Prerequisite for all other networking classes
2. CSE 521S: Wireless Sensor Networks
3. CSE 537S: Mobile Computing
4. CSE 570S: Virtualization, Clouds, Big Data, SDN, IoT (Fall 2015)
5. **CSE 571S: Network Security** (Fall 2014)
6. ESE 572S: Signaling and Control in Communications Networks
7. **CSE 574S: Wireless and Mobile Networking** (Spring 2016)
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, Data Center and Clouds, Software defined networking, Mobility and Wireless, Internet of Things
3. We are working on:
 1. Multi-Cloud Management
 2. Multi-Cloud Security
 3. IoT Security
 4. IoT+UAV Protocols

References: Class Recordings

- Recordings of all of my classes and talks are available on YouTube and on my website:
 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/cse571-14/index.html>
 3. CSE 574S: Wireless Networks,
<http://www.cse.wustl.edu/~jain/cse574-14/index.html>
 4. CSE 567: Computer Systems Analysis
<http://www.cse.wustl.edu/~jain/cse567-15/index.html>
 5. CSE 570: Recent Advances in Networking
<http://www.cse.wustl.edu/~jain/cse570-15/index.html>

Recent Papers

- Jianli Pan, Raj Jain, Subharthi Paul, Tam Vu, Abusayeed Saifulla, Mo Sha, **"An Internet of Things Framework for Smart Energy in Buildings: Designs, Prototype, and Experiments,"** Internet of Things Journal, 2015, DOI: 10.1109/JIOT.2015.2413397, http://www.cse.wustl.edu/~jain/papers/iot_enrg.htm
- Jianli Pan, Raj Jain, Subharthi Paul, **"A Survey of Energy Efficiency in Buildings and Microgrids using Networking Technologies,"** IEEE Communications Surveys & Tutorials, Vol. 16, No. 3, 2014, pp. 1709-1731, <http://www.cse.wustl.edu/~jain/papers/energy.htm>
- Subharthi Paul, Raj Jain, Mohammed Samaka, Jianli Pan, **"Application Delivery in Multi-Cloud Environments using Software Defined Networking,"** Computer Networks Special Issue on cloud networking and communications, Available online 22 Feb 2014, <http://www.cse.wustl.edu/~jain/papers/comnet14.htm>
- Raj Jain and Subharthi Paul, **"Network Virtualization and Software Defined Networking for Cloud Computing - A Survey,"** IEEE Communications Magazine, Nov 2013, pp. 24-31, http://www.cse.wustl.edu/~jain/papers/net_virt.htm

Recent Talks

- ❑ Raj Jain, "**Smart Cities: Technological Challenges and Issues**," IEEE CS Keynote at 21st Annual International Conference on Advanced Computing and Communications (ADCOM) 2015, Chennai, India, September 19, 2015, Chennai, India, September 18, 2015, <http://www.cse.wustl.edu/~jain/talks/smrtcit.htm>
- ❑ Raj Jain, "**Internet of Things: Challenges and Issues**," IEEE CS Keynote at 20th Annual Conference on Advanced Computing and Communications (ADCOM 2014), Bangaluru, India, September 19, 2014, http://www.cse.wustl.edu/~jain/talks/iot_ad14.htm
- ❑ Raj Jain, "**AppFabric: Application Deployment and Service Chaining in Future NFV Cloud WAN Environments**," Cisco Research Seminar, San Jose, CA, May 15, 2014, http://www.cse.wustl.edu/~jain/talks/apf_csc.htm
Raj Jain, "**SDN and NFV: Facts, Extensions, and Carrier Opportunities**," AT&T Labs SDN Forum Seminar, April 10, 2014, http://www.cse.wustl.edu/~jain/papers/adn_att.htm
- ❑ Raj Jain, "**Networking for Big Data**," IEEE CS Keynote at 19th Annual International Conference on Advanced Computing and Communications (ADCOM) 2013, Chennai, India, October 22, 2013. <http://www.cse.wustl.edu/~jain/talks/adcom13.htm>

Acronyms

❑ ATM	Asynchronous Transfer Mode
❑ 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
❑ ITU	International Telecommunications Union
❑ LAN	Local Area Network
❑ LTE	Long Term Evolution
❑ MHz	Mega Hertz
❑ OpenADN	Open Application Delivery Networking
❑ SDN	Software Defined Networking

Acronyms (Cont)

- ❑ TCP Transmission Control Protocol
- ❑ TV Television
- ❑ VM Virtual Machine
- ❑ WAN Wide Area Network
- ❑ WiFi Wireless Fidelity
- ❑ WiMAX Worldwide Interoperability for Microwave Access