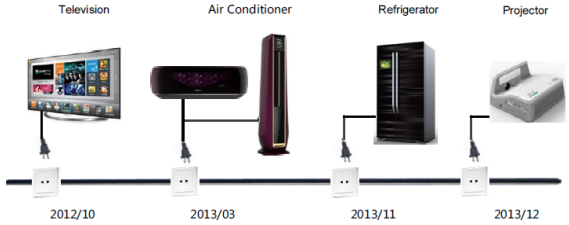
Next Generation Internet and Wireless Networking, and Security Research at Washington University in St. Louis



RAJ JAIN

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

A talk given to "CS 591: Introduction to Graduate Study in CSE" Class
October 5, 2015

These slides are available on-line at:

http://www.cse.wustl.edu/~jain/talks/cs59115.htm

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Overview

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

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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, …

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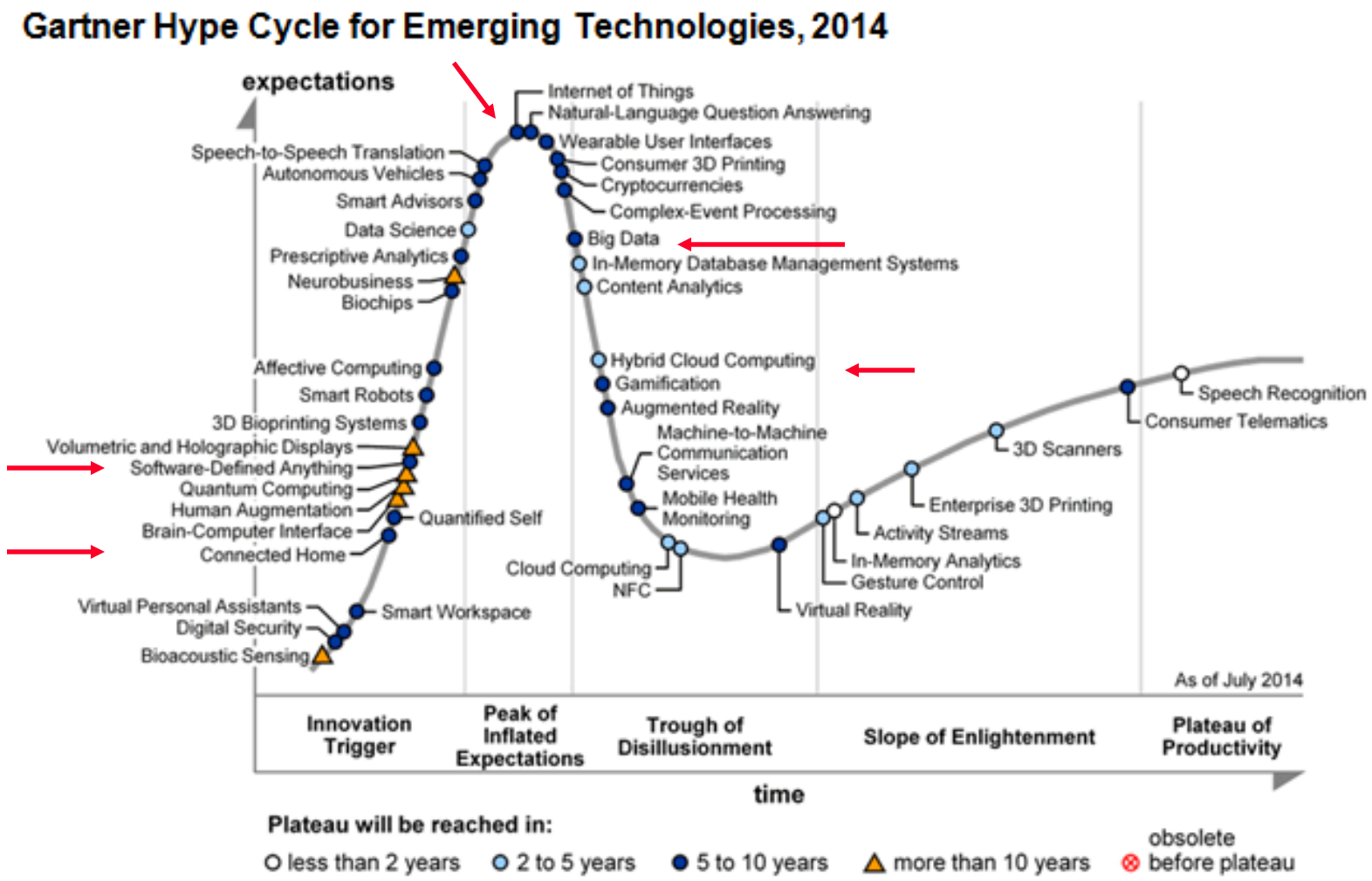
Gartner Hype Cycle 2014



Ref: http://www.forbes.com/sites/gartnergroup/2014/09/17/digital-business-technologies-dominate-gartner-2014-emerging-technologies-hype-cycle/

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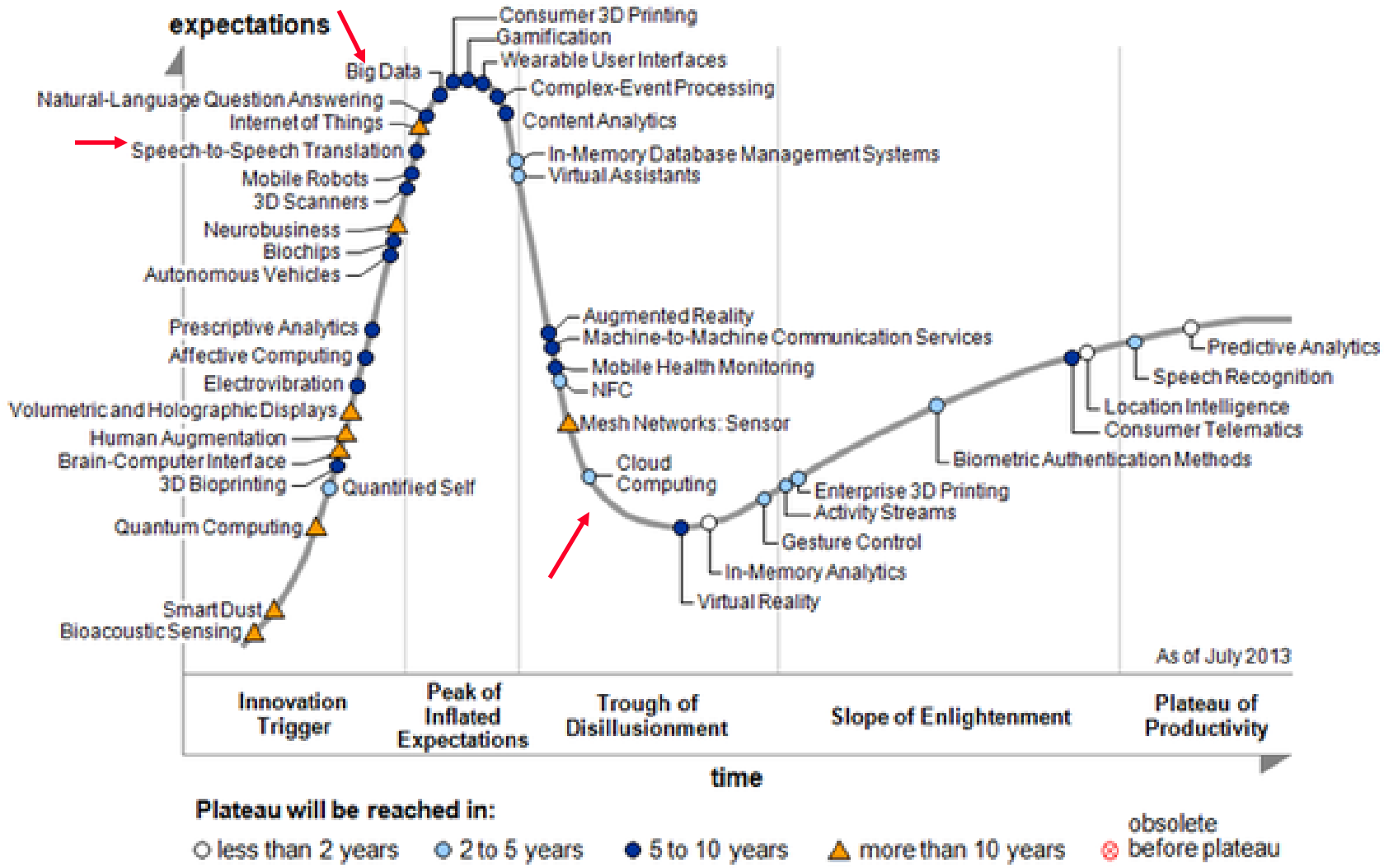
Gartner Hype Cycle 2013



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

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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

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

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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

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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

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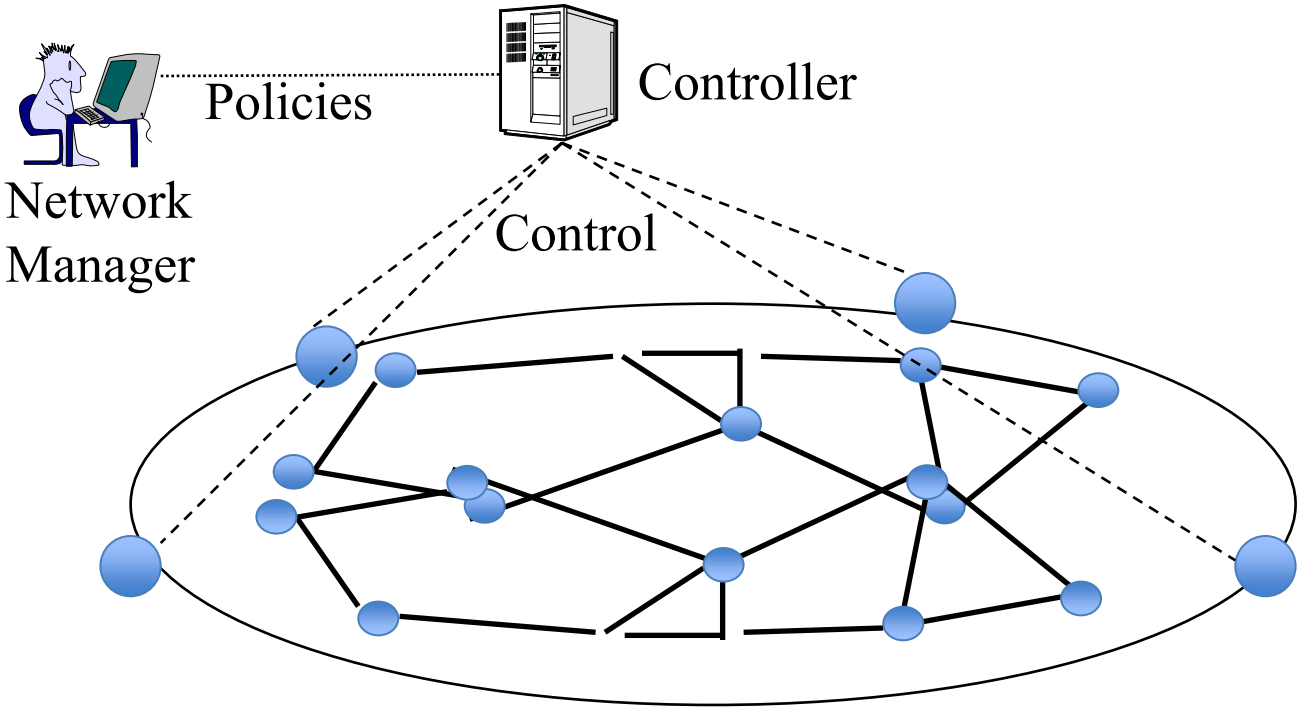
3. Software Defined Networking



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

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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

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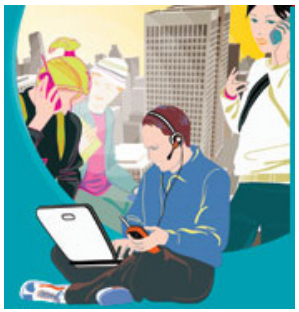
5. Mobile/Wireless for Multimedia

- Smart Phones (iPhone, Blackberry, Android Phones), Net books, Laptops
  Þ 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



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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

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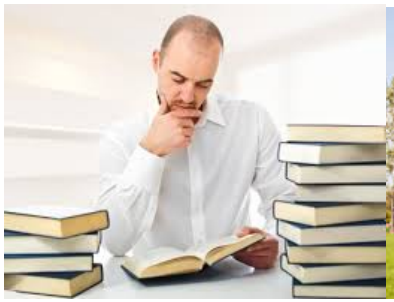
What's Smart?

- Old: Smart = Can think ⇒ Can compute
- Now: Smart = Can find quickly, Can Delegate
  ⇒ Communicate = Networking
- Smart Grid, Smart Meters, Smart Cars, Smart homes, Smart Cities, Smart Factories, Smart Smoke Detectors, …

Think

Communicate



Not-Smart

Smart

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Cavemen of 2050

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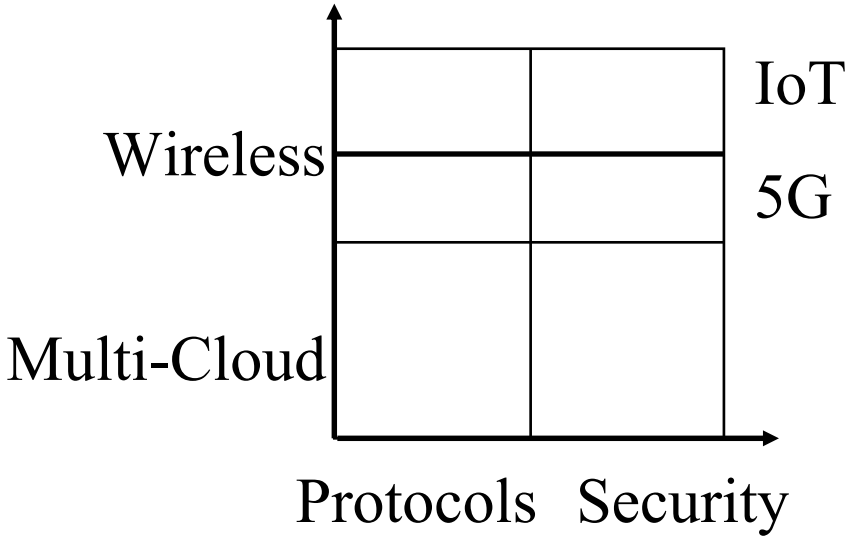
Our Research Areas



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

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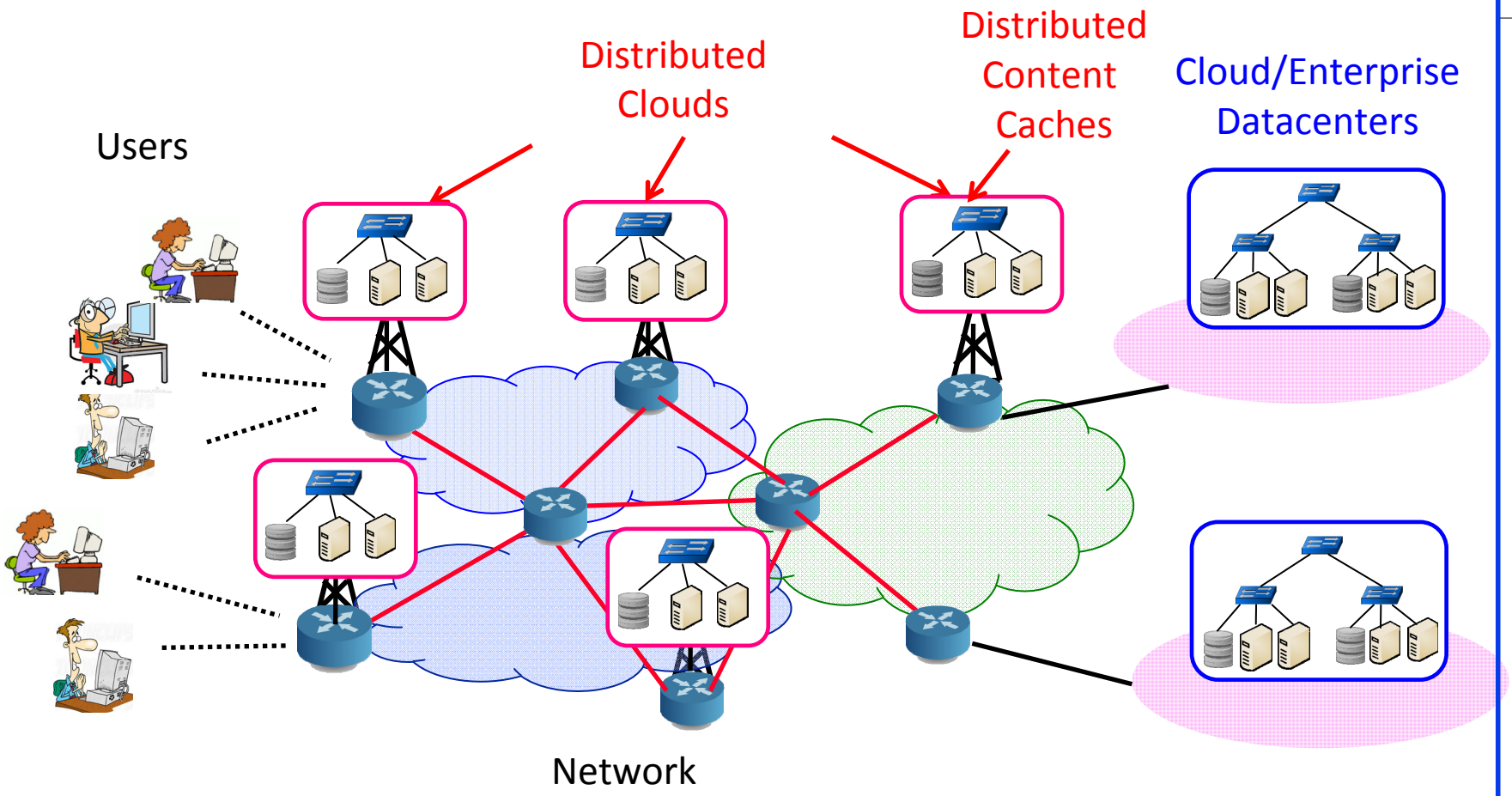
Trend: Micro-Clouds on Towers



New Business Opportunities: Datacenters on Towers, Internet of Things

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Mobile Healthcare Use Case

Medical Application
Service Provider

Home sensors for
patient monitoring

Multi-Cloud Mobile Application Deployment and Optimization Platform

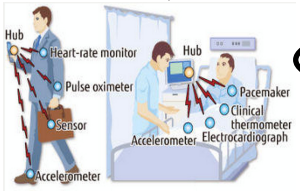
Hospital Cloud

SDN Controller

Insurance Co Cloud

Mobile
Doctor

Body Area
Network for
mobile patient



5G Carrier

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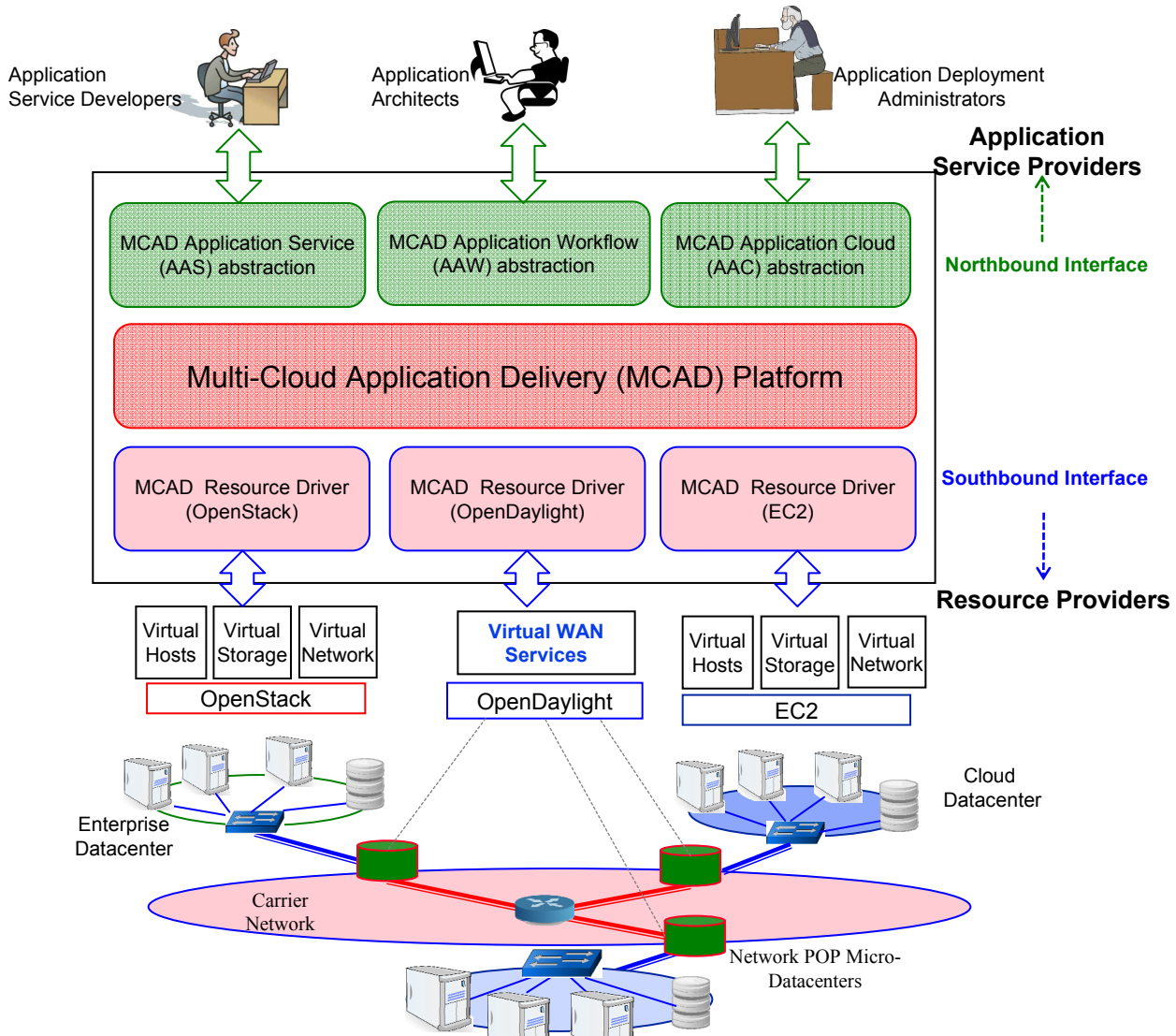
Multi-Cloud Management



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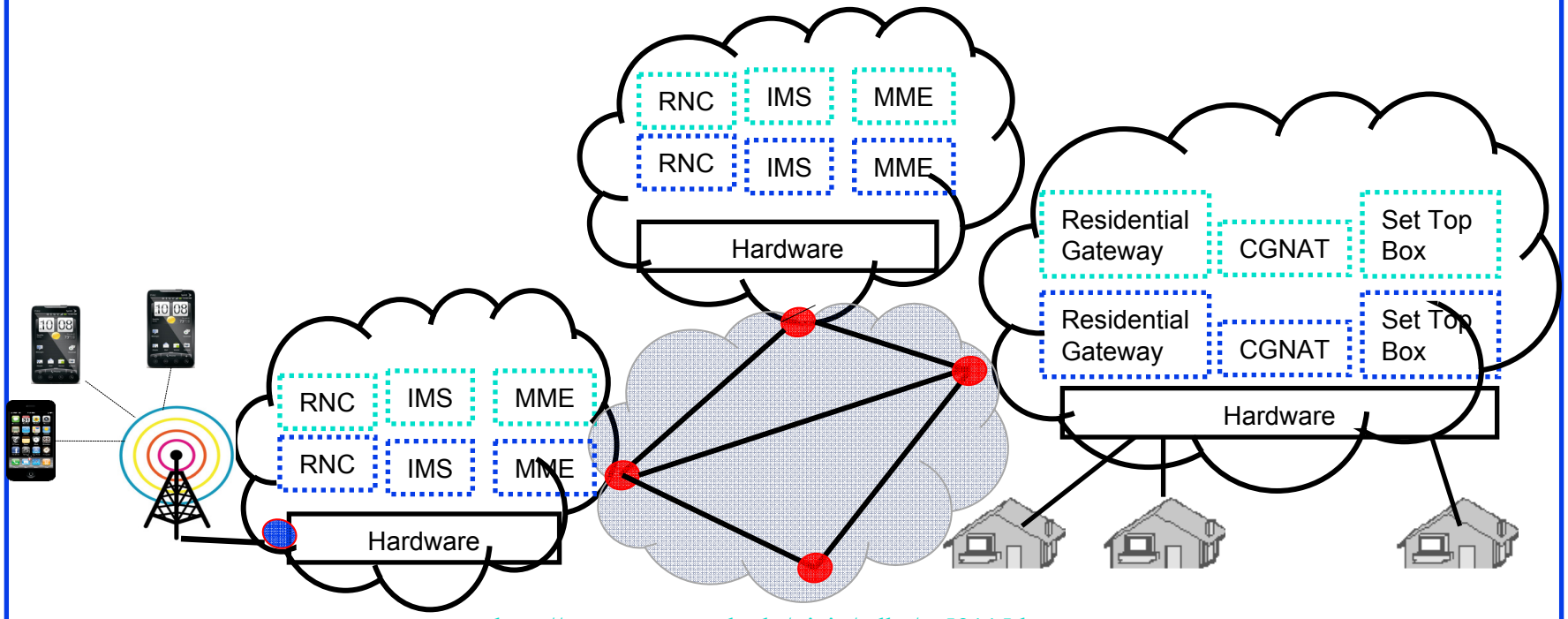
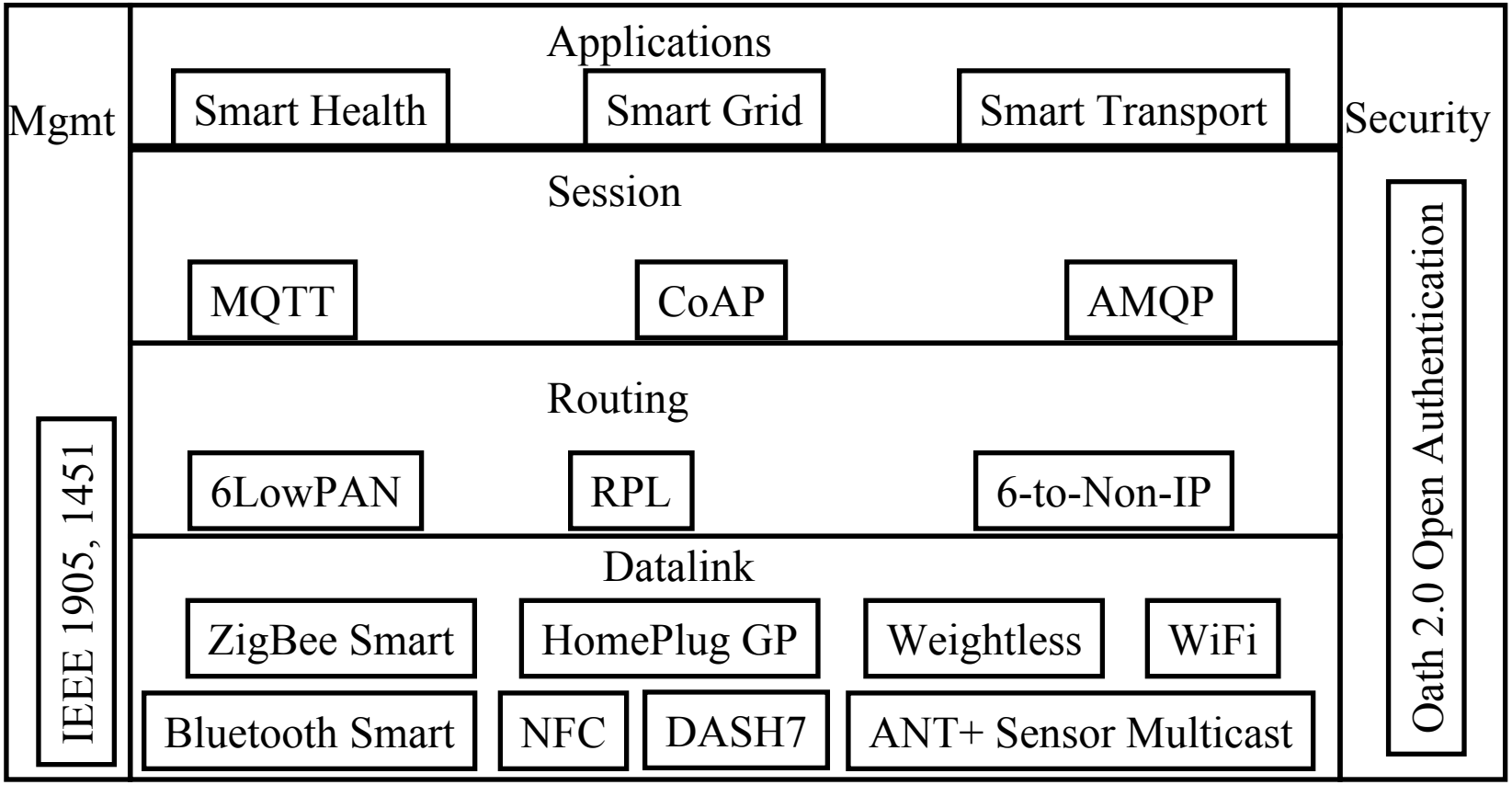
Multi-Cloud for 5G: NFV

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



Protocols for IoT

- How to design these thin energy efficient protocols?



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http://en.wikipedia.org/wiki/Near_field_communication, http://en.wikipedia.org/wiki/Weightless_%28wireless_communications%29

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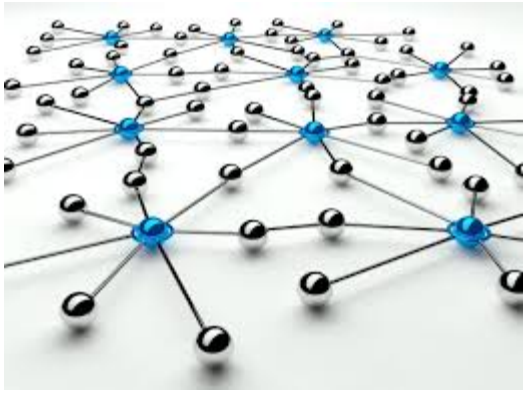
IoT Security

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



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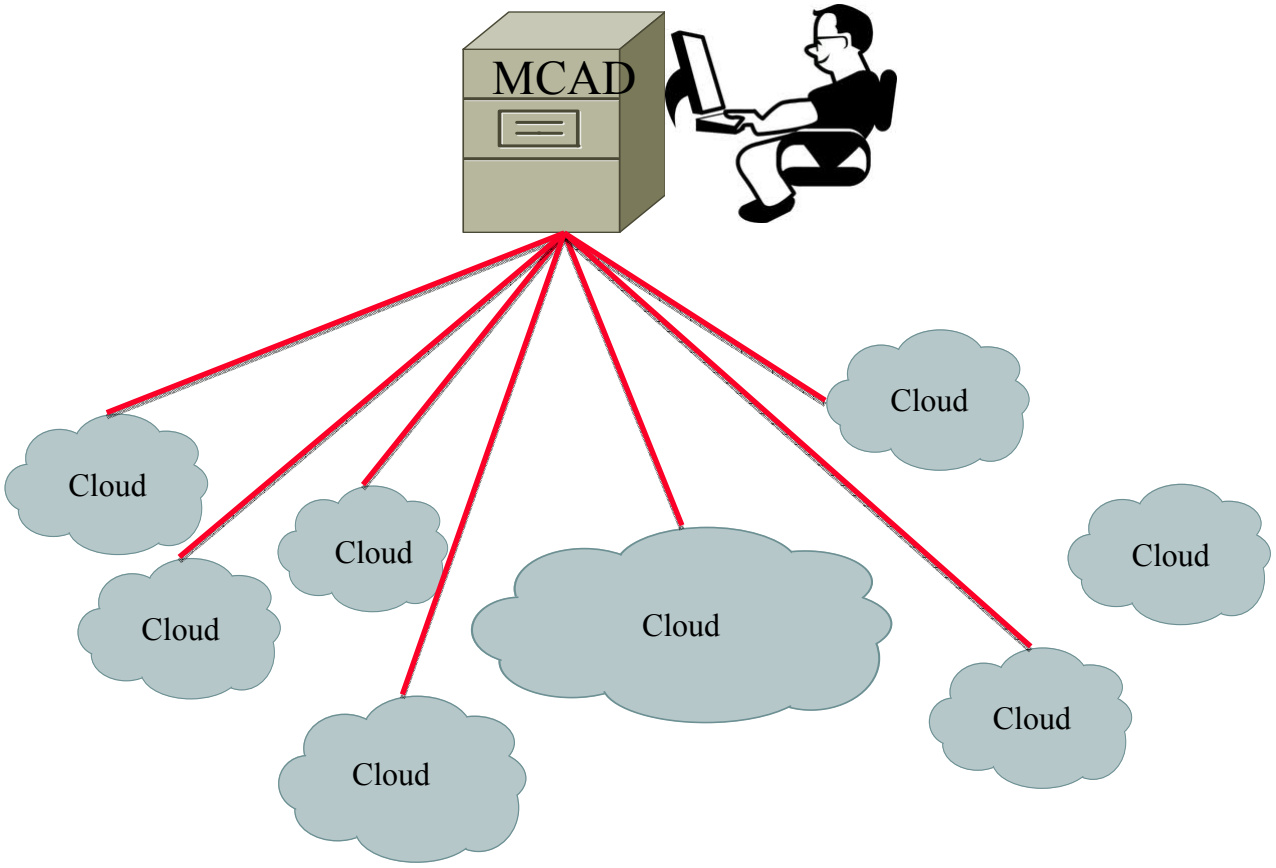
Multi-Cloud Security

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



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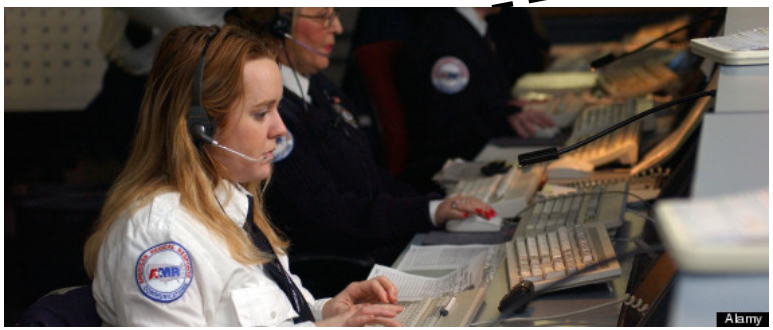
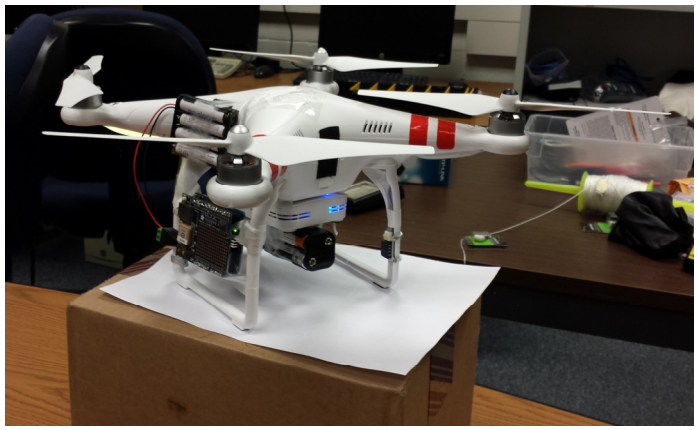
Communication using UAVs





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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

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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

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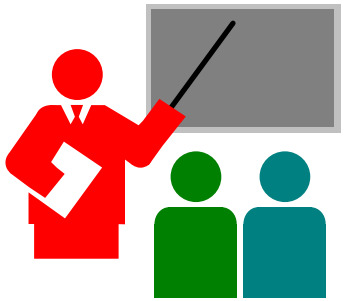
Summary



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

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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

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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 Energey Efficiency in Buildings and Microgrids using Networking Technologies**," IEEE Communications Surveys &s; 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 Managzine, Nov 2013, pp. 24-31, http://www.cse.wustl.edu/~jain/papers/net_virt.htm

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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

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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

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Acronyms (Cont)

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

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