Next Generation Internet, Wireless, and Network Security 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/cs13116.htm

Overview

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

Why Study Computer Networking?

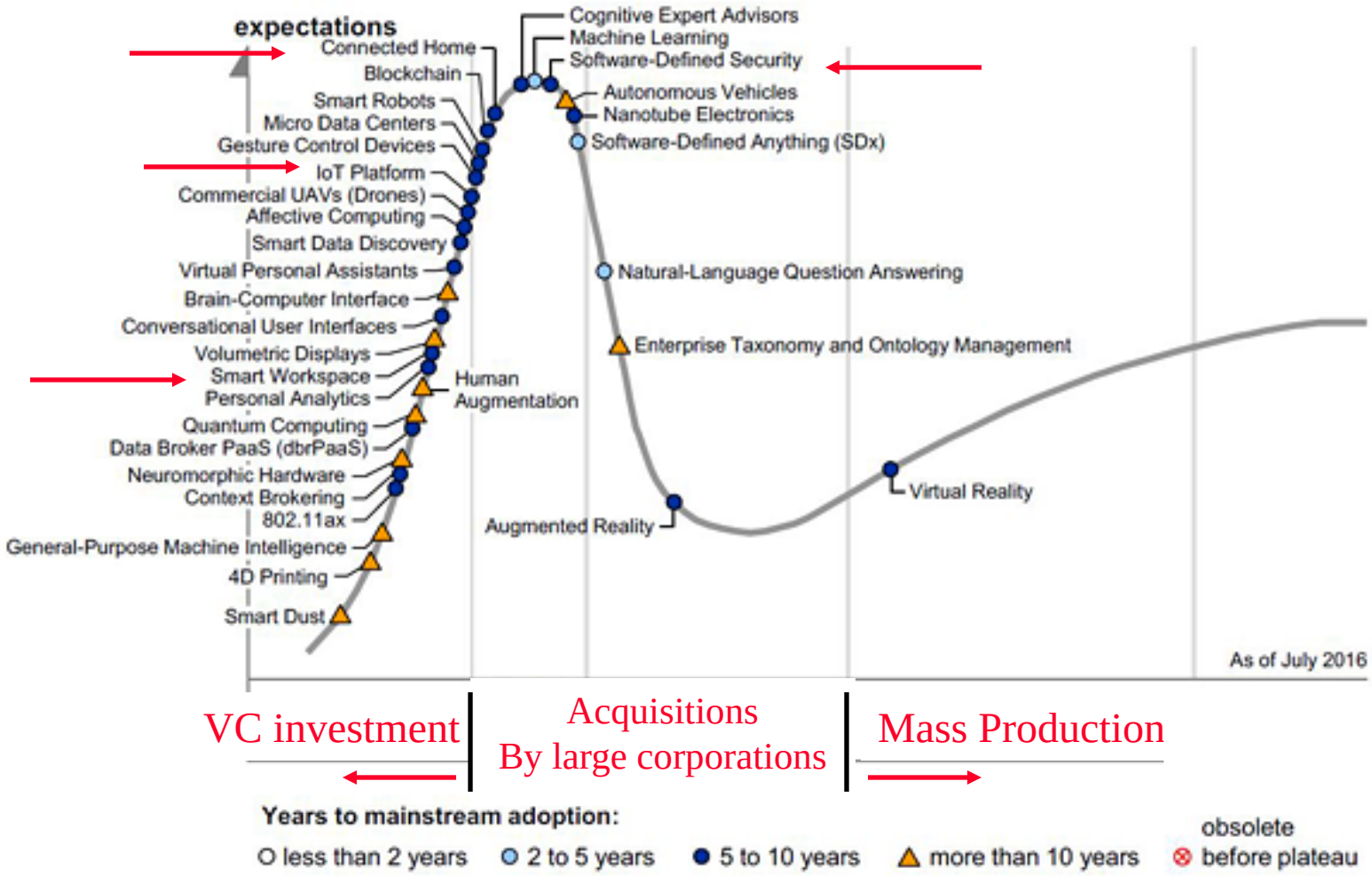
- Networking is the "plumbing" of computing
- Almost all areas of computing are network-based.
  - Distributed computing
  - Big Data
  - Cloud Computing
  - Internet of Things

- Fast growing field
- All top companies are networking companies: Apple, Google, Microsoft, Amazon, Facebook, Cisco, HP, Intel, IBM, …

Current Hot Topics in Networking

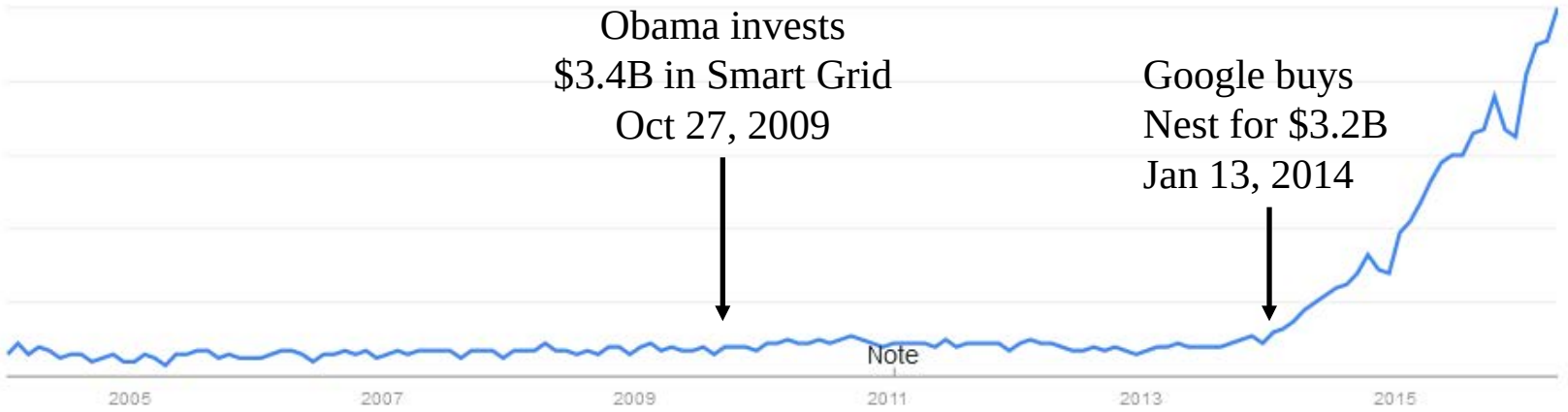
1. Internet of Things
2. Security: Cyber Warfare
3. Datacenter Networking and Clouds
4. Mobile/Wireless Networking

Gartner Hype Cycle 2016



Ref: Gartner, "Hype Cycle for Emerging Technologies, 2016," July 2016, [subscribers only], gartner.com/document/3383817

Google Trends



- Around for 10 years
- IERC-European Research Cluster on the Internet of Things funded under 7th Framework in 2009
  ⇒ "Internet of European Things"
- US interest started in 2009 w $3.4B funding for **smart grid** in American Recovery and Reinvestment Act of 2009

1. Internet of Things

Smart Watch

Smart TV

Smart Car

Smart Health

Smart Home

Smart Kegs

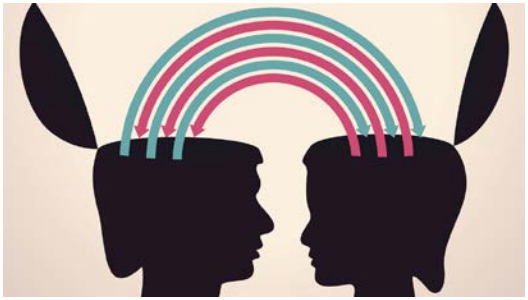
Smart Space

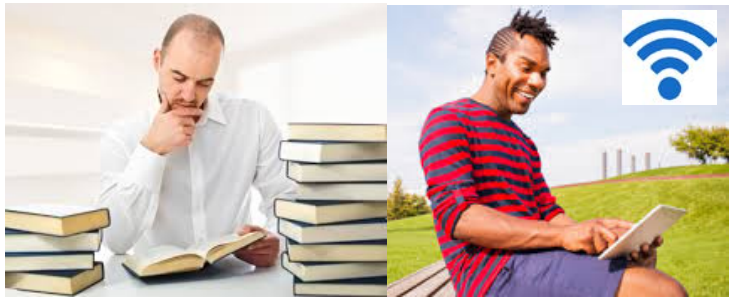
Smart Industries

Smart Cities

What's Smart?

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





Not-Smart Smart

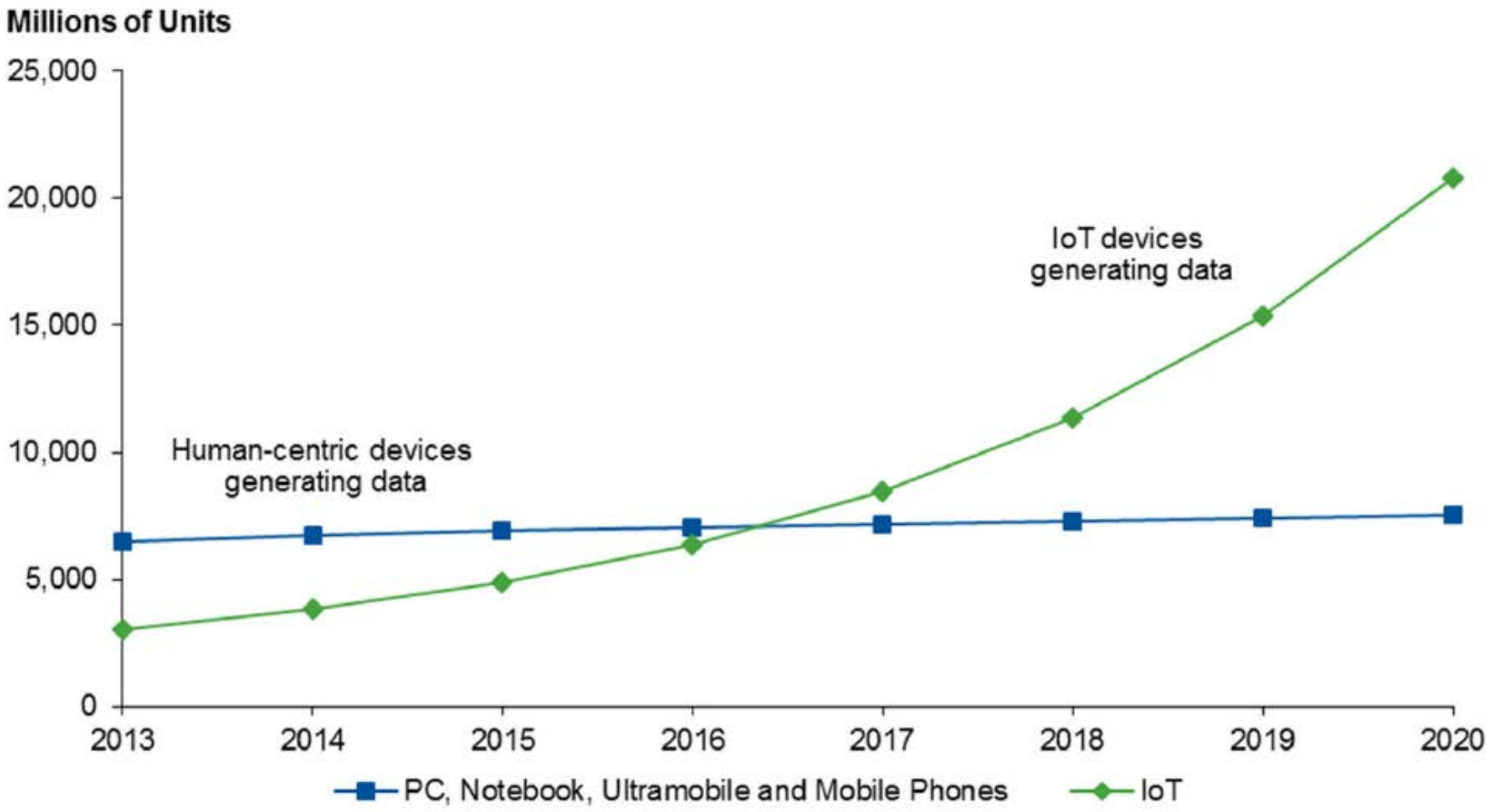
Cavemen of 2050

IoT is a Data ($) Mine

Ref: https://www.pinterest.com/iofficecorp/humor/

Washington University in St. Louis http://www.cse.wustl.edu/~jain/talks/cs13116.htm

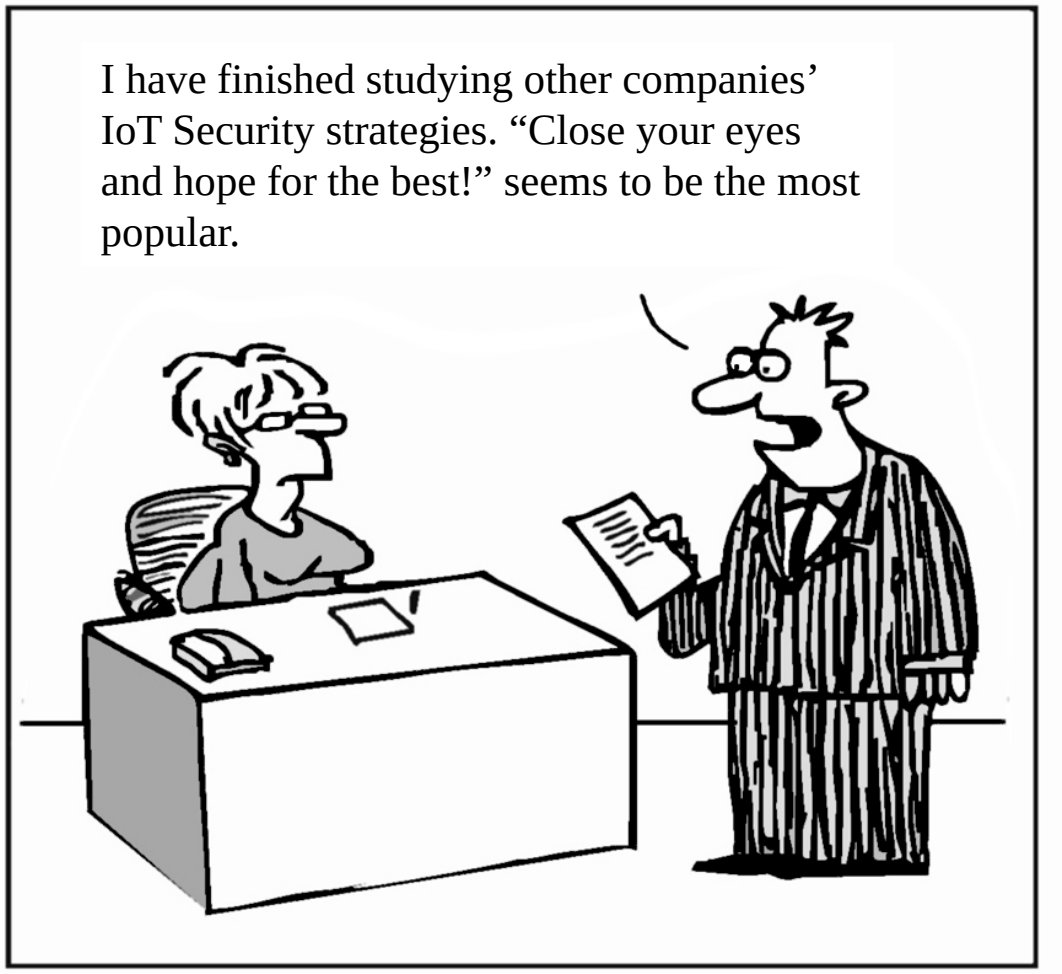
Computing vs. IoT



- 21 Billion devices by 2020

Ref: M. Moran, "Why the Internet of Things Will Dwarf Social (Big Data)," Gartner Report #G00289622, February 2016

IoT Security: Popular Approach



Ref: http://cloudtweaks.com/2011/08/the-lighter-side-of-the-cloud-the-migration-strategy/

Internet of Harmful Things

Imagine, as researchers did recently at Black Hat, someone hacking your connected toilet, making it flush incessantly and closing the lid repeatedly and unexpectedly.

Ref: http://www.computerworld.com/article/2486502/security0/worm-may-create-an-internet-of-harmful-things--says-symantec--take-note--amazon-.html

DEFCON 2015

DEFCON 2015 (Cont)

- Hacking a Linux rifle
- Hacking smart safes
- Wirelessly steal cars
- Hack a Tesla
- Hack ZigBee
- Hacking IoT baby monitors
- Hacking FitBit Aria
- Cracking crypto currency
- Hack out of home detention
- Insteon's false security
- Hacking RFID, NFC
- DARPA Cyber Grand Challenge **$2M**

Ref: https://www.ethicalhacker.net/features/opinions/first-timers-experience-black-hat-defcon

Attack Surface

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

2. 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, …

Old

New

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

3. Cloud Computing

- August 25, 2006: Amazon announced EC2
  ⇒ Birth of Cloud Computing in reality
  (Prior theoretical concepts of computing as a utility)
  $10 B in 2016, a growth rate of 49% with 17% margins, much higher than the overall Amazon business

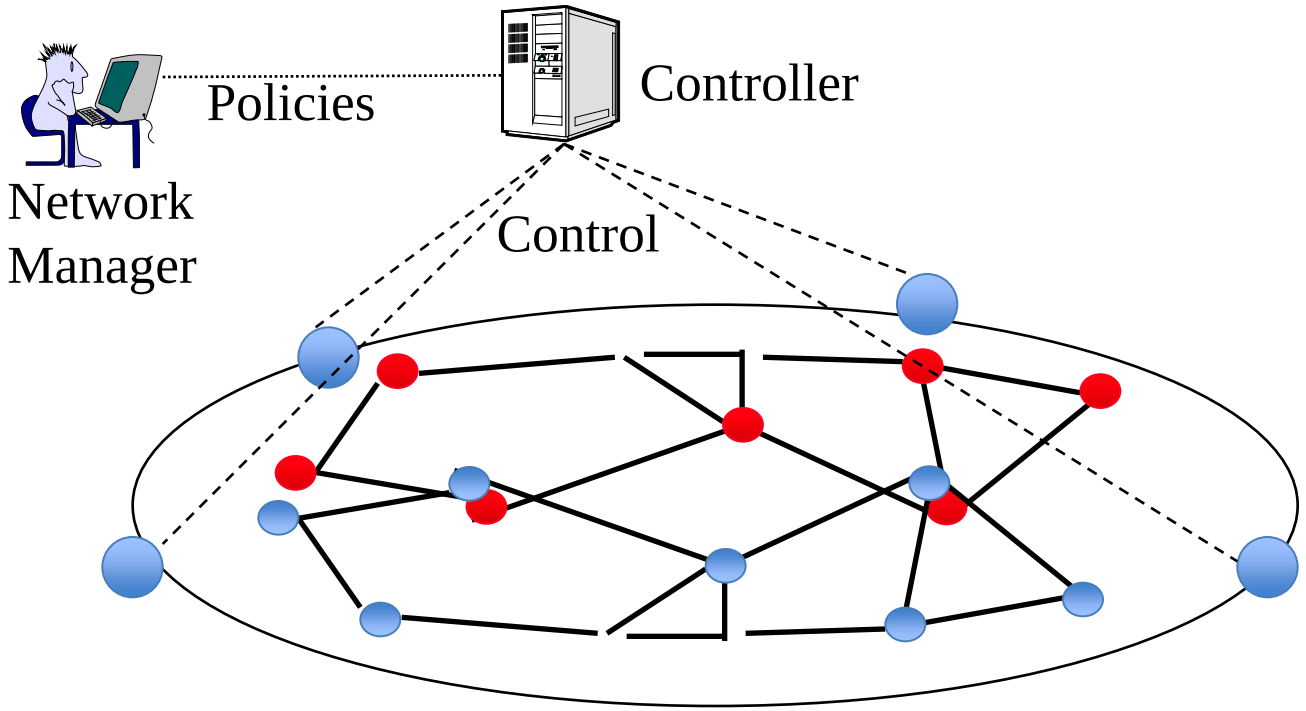
- Cloud Computing:
  - Applications through Internet (Google Docs)
  - Computing through Internet (Amazon EC3)
  - Storage and backup through Internet (iCloud, Google Drive)

4. Mobile/Wireless

- June 29, 2007: Apple announced iPhone
  ⇒ Birth of Mobile Internet, Mobile Apps
  - Almost all services are now mobile apps: Google, Facebook, Bank of America, …

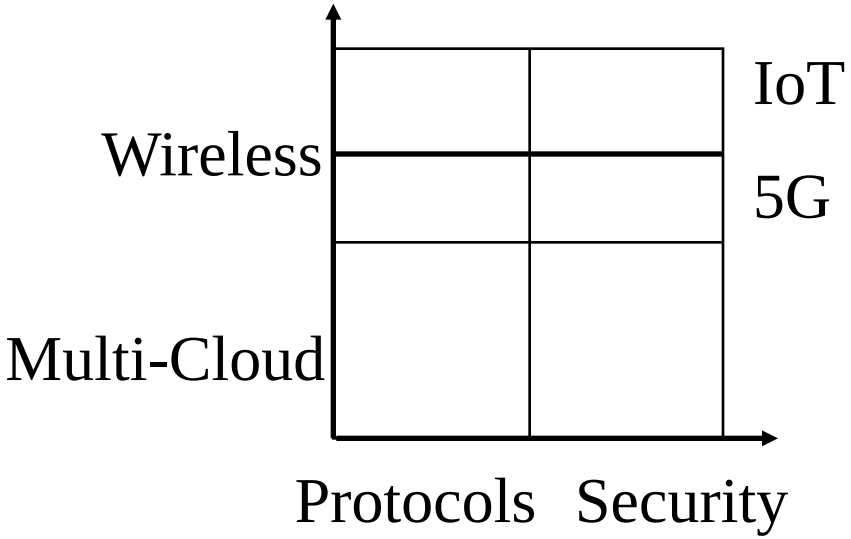
- Wireless (WiFi) is ubiquitous (Intel Centrino)
- New Developments:
  - 5G: 1Gbps
  - Vehicular Networking

5. 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

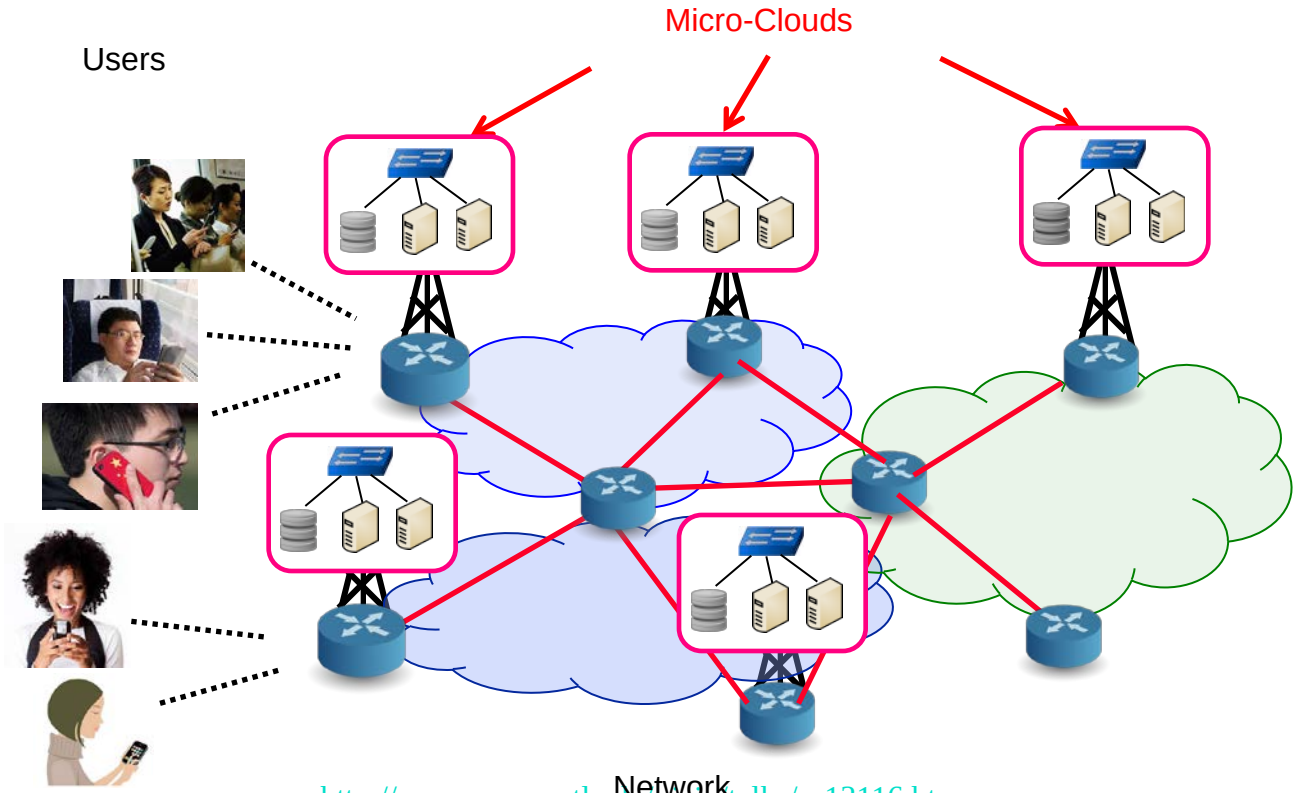
Our Research Areas



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

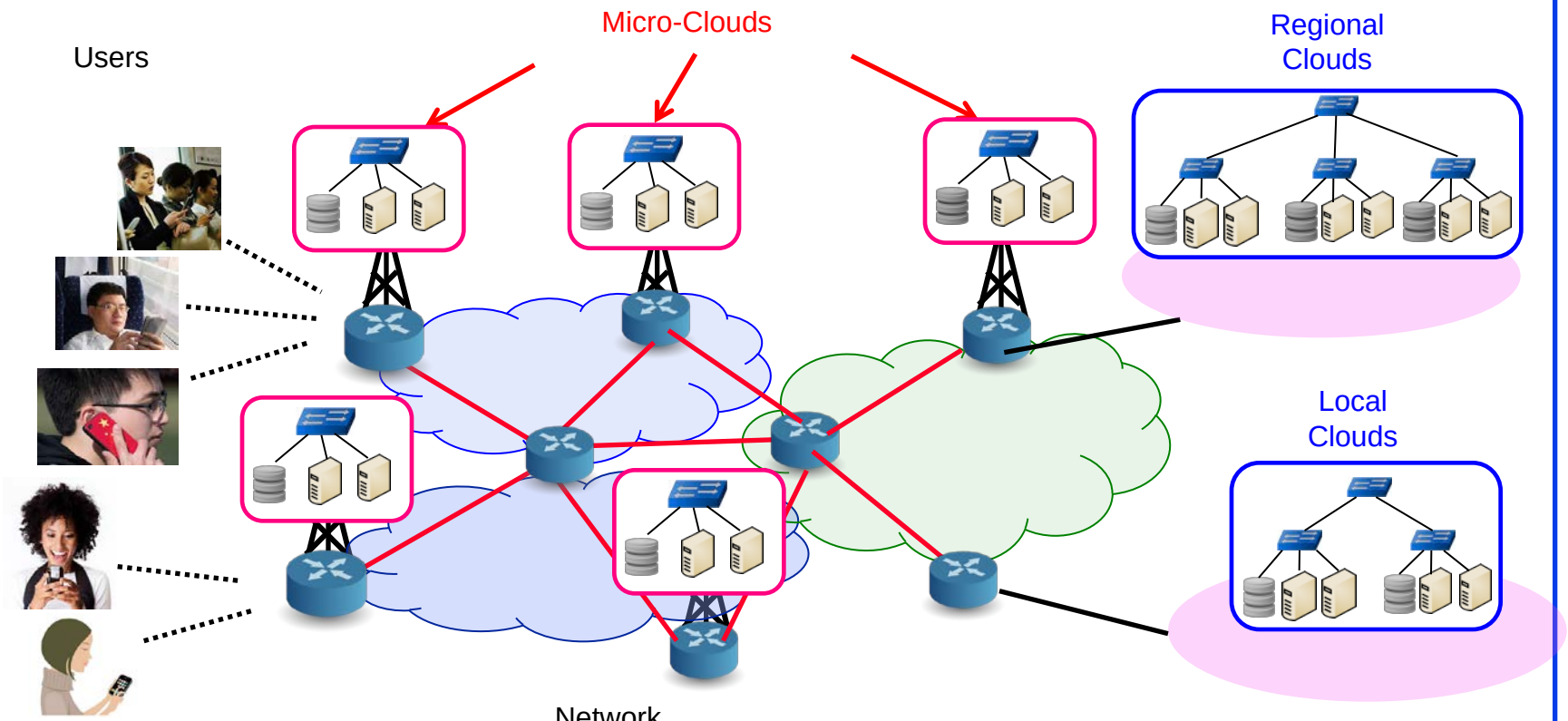
Trend: Computation in the Edge

- To service mobile users/IoT, the computation needs to come to edge ⇒ Micro-cloud on the tower
  ⇒ Mobile-Edge Computing



Trend: Multi-Cloud

- Larger and infrequent jobs serviced by local and regional clouds ⇒ Fog Computing



Mobile Healthcare Use Case

Medical Application Service Provider

Home sensors for patient monitoring

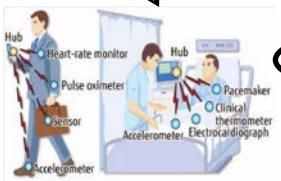
Multi-Cloud Mobile Application Deployment and Optimization Platform

Hospital Cloud

…

SDN Controller

Insurance Co Cloud

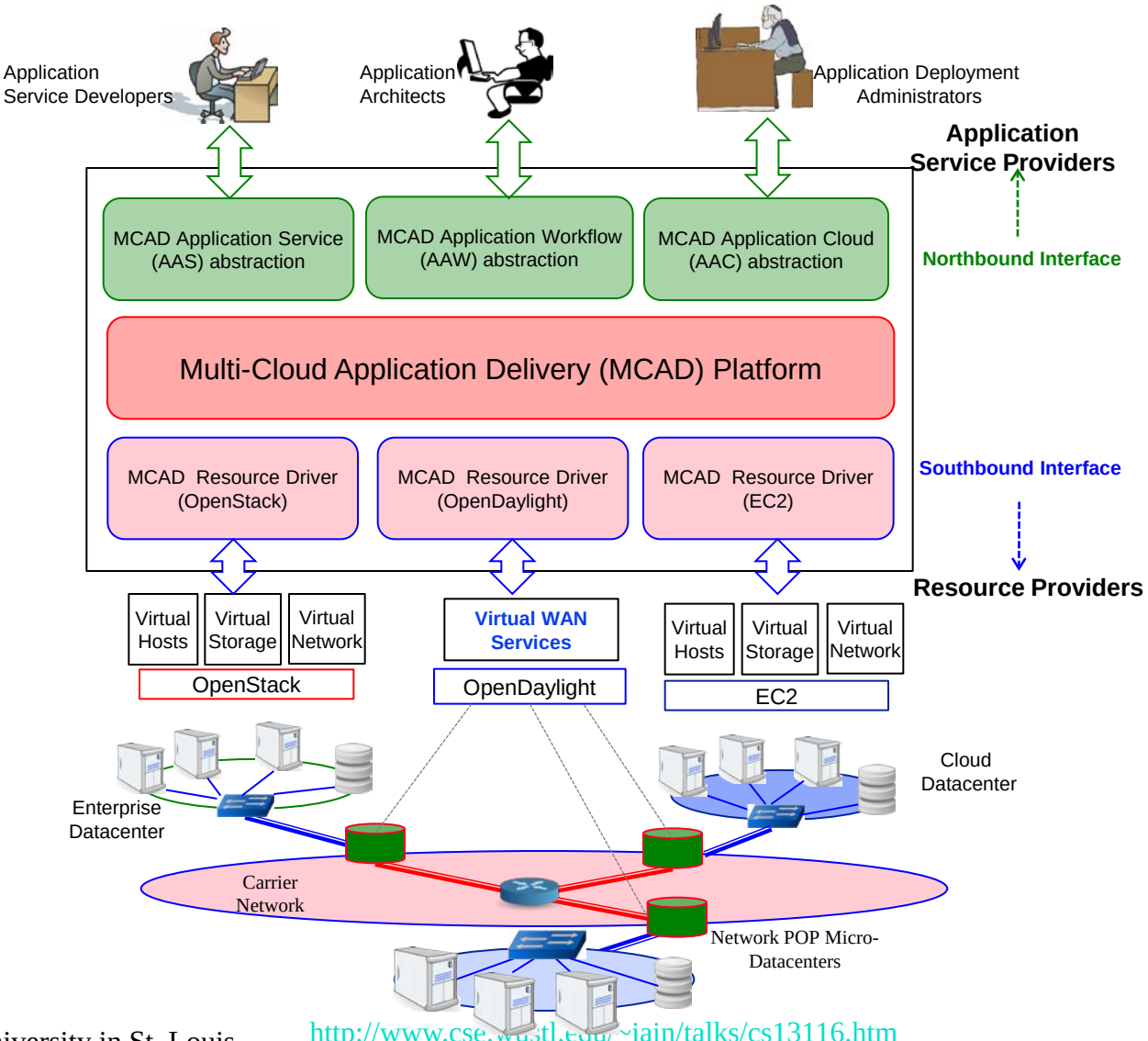


Body Area Network for mobile patient

5G Carrier

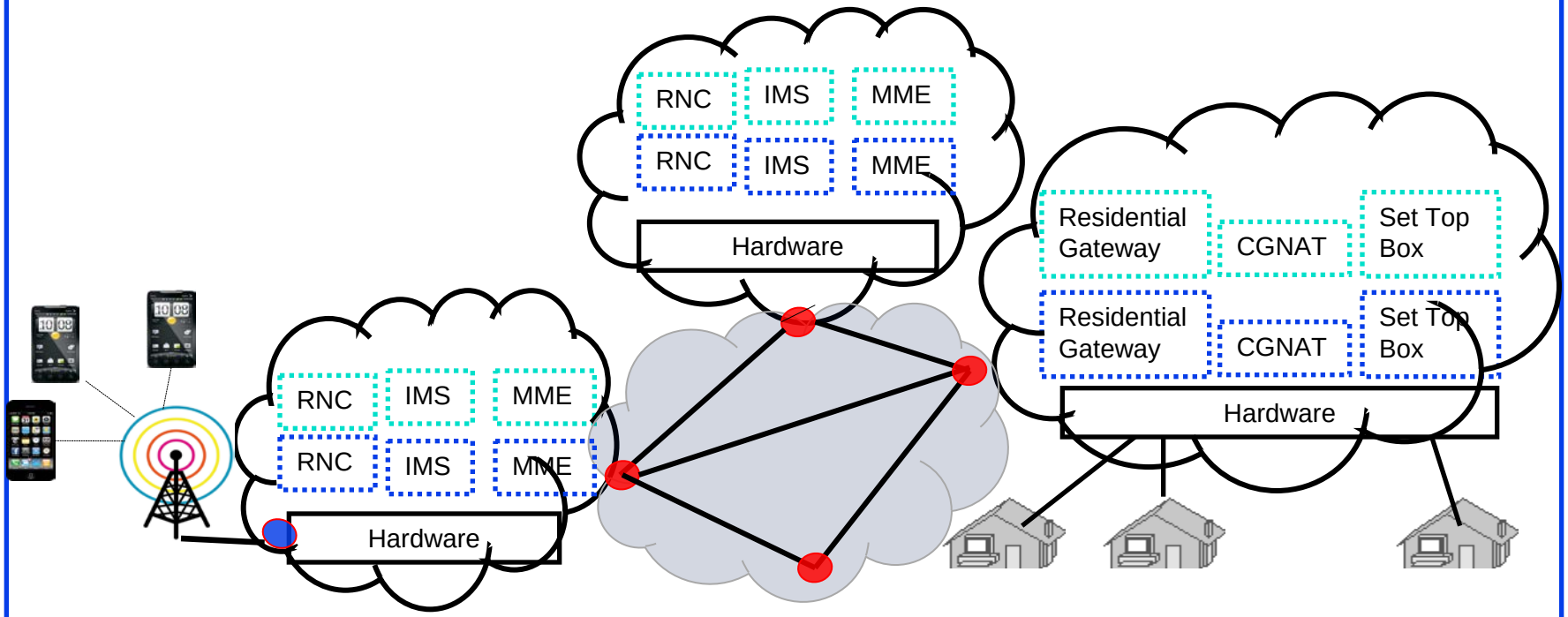
Mobile Doctor

Multi-Cloud Management

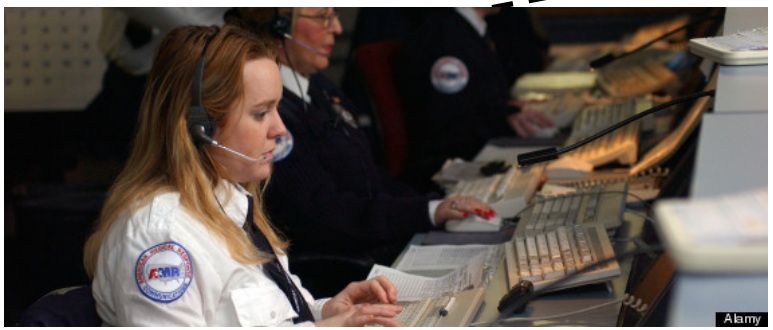


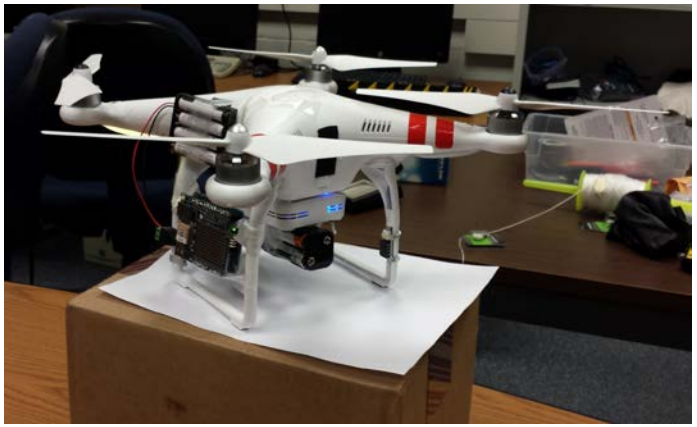
Multi-Cloud for 5G: NFV

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



Communication using UAVs



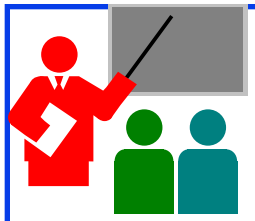


Key Distinction of Our Research

- 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 2017)
5. **CSE 571S: Network Security** (Spring 2017)
6. ESE 572S: Signaling and Control in Communications Networks
7. **CSE 574S**: **Wireless and Mobile Networking** (Spring 2018)
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. Smart ≠ High-Speed Computation,
   Smart ≠ Big Data Storage,
   Smart = Networked
3. Computation is moving to the Edge
   ⇒ Fog Computing
   ⇒ Multi-Cloud/Inter-Cloud
4. Our MCAD abstracts/virtualizes the cloud interfaces and allows automated management of security and other policies of multi-cloud applications
5. We are working on:
   1. Multi-Cloud Management
   2. Multi-Cloud + IoT Security
   3. 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
     http://www.cse.wustl.edu/~jain/cse473-16/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/cse574-16/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

- Lav Gupta, Raj Jain, H. Anthony Chan, "**Mobile Edge Computing - an important ingredient of 5G Networks**," IEEE Softwarization Newsletter, March 2016, http://sdn.ieee.org/newsletter/march-2016/mobile-edge-computing-an-important-ingredient-of-5g-networks
- Lav Gupta, Raj Jain, Mohammed Samaka, "Analysis of Application Delivery Platform for Software Defined Infrastructures," International Journal of Communication Networks and Distributed Systems, Accepted for publication, http://www.cse.wustl.edu/~jain/papers/ijcnds16.htm
- Lav Gupta, Raj Jain, and Gabor Vaszkun, "**Survey of Important Issues in UAV Communication Networks**," IEEE Communications Surveys and Tutorials, Volume PP, Issue 99, November 3, 2015, http://www.cse.wustl.edu/~jain/papers/uav_comst.htm
- Daniel M Batista, Gordon Blair, Fabio Kon, Raouf Boutaba, David Hutchison, Raj Jain, Ramachandran Ramjee, Christian Esteve Rothenberg, "**Perspectives on software-defined networks: interviews with five leading scientists from the networking community**" Journal of Internet Services and Applications 2015, 6:22, http://www.cse.wustl.edu/~jain/papers/jisa15.htm
- 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, http://www.cse.wustl.edu/~jain/papers/iot_enrg.htm

Recent Talks

- Raj Jain, "**Blockchains: The Revolutionary Trust Protocol**," BEL Keynote at 22nd Annual International Conference on Advanced Computing and Communications (ADCOM 2016), Bangaluru, India, Sep 10, 2016, http://www.cse.wustl.edu/~jain/talks/blc_ad16.htm
- Raj Jain, "**Software Defined Networking at the Tactical Edge**," Talk at Bharat Electronics Limited, Bangalore, India, September 10, 2016, http://www.cse.wustl.edu/~jain/talks/sdn_bel.htm
- Raj Jain, "**Internet of Things and Smart Cities Security: Challenges and Issues**," Keynote at 1st Annual Research Workshop on Advances & Innovations in Cyber Security, Memphis, TN, June 10, 2016, http://www.cse.wustl.edu/~jain/talks/iots_tns.htm
- Raj Jain, "**Five Trends in Computing Leading to Multi-Cloud Applications and Their Management**," Seminar at Qatar Mobility and Innovation Center, Doha, Qatar, January 4, 2016, http://www.cse.wustl.edu/~jain/talks/apf_qmic.htm
- 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

Acronyms

- AAC Application Cloud Abstraction
- AAS Application Service Abstraction
- AAW Application Workflow Abstraction
- ABR Available Bit Rate
- ANSI American National Standards Institute
- API application programming interface,
- ATM Asynchronous Transfer Mode
- CGNAT Carrier Grade Network Address Translation
- CSE Computer Science and Engineering
- DARPA Defense Advanced Research Project Agency
- DECbit Digital Equipment Corporation Bit
- DEFCON D-E-F conference
- DNS Domain Name System
- EC2 Elastic Compute 2
- ECN Explicit congestion notification
- EFCI Explicit Forward Congestion Indication

Acronyms (Cont)

- ESE Electrical Systems Engineering
- FECN Forward Explicit Congestion Notification
- GB Gigabyte
- IEEE Institution of Electrical and Electronic Engineering
- IERC European Research Cluster on the Internet of Things
- IETF Internet Engineering Task Force
- IMS Internet Multimedia System
- IoT Internet of Things
- IP Internet Protocol
- IRTF Internet Research Task Force
- ITU International Telecommunications Union
- LAN Local Area Network
- LTE Long Term Evolution
- MCAD Multi-Cloud Application Delivery
- MHz Mega Hertz
- MME Mobility Management Entity

Acronyms (Cont)

- NFC Near Field Communication
- NFV Network Function Virtualization
- OpenADN Open Application Delivery Networking
- POP Point of Presence
- RFID Radio Frequency Identifier
- RNC Radio Network Controller
- SDN Software Defined Networking
- TCP Transmission Control Protocol
- TV Television
- UAV Unmanned Aerial Vehicle
- VC Venture Capitalist
- VM Virtual Machine
- WAN Wide Area Network
- WiFi Wireless Fidelity
- WiMAX Worldwide Interoperability for Microwave
- XML Extended Markup Language

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