Slide 1

Internet, Multi-Cloud, Wireless, and Network 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 23, 2017
These slides are available on-line at:

http://www.cse.wustl.edu/~jain/talks/cs13117.htm

Slide 2

Overview

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

Slide 3

Networking = "Plumbing"

❑ Networking is the "plumbing" of computing
❑ Almost all areas of computing are network-based.
   ➢ Distributed computing
   ➢ Big Data
   ➢ Cloud Computing
   ➢ Internet of Things
   ➢ Smart Cities
❑ Networking is the backbone of computing.
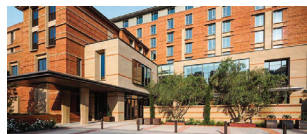
> Networking is already great!

Slide 4

Networking is Fueling All Sectors of Economy

❑ Networking companies are among the most valued companies: Apple, AT&T, Samsung, Verizon, Microsoft, China Mobile, Alphabet, Comcast, NTT, IBM, Intel, Cisco, Amazon, Facebook, …
   ⇒ All tech companies that are hiring currently are networking companies
❑ Note: Apple became highly valued only after it switched from computing to communications (iPhone)

> Networking = Economic Indicator

Selecting the Right Field

❑ Important question for **students**, academics, entrepreneurs, and companies
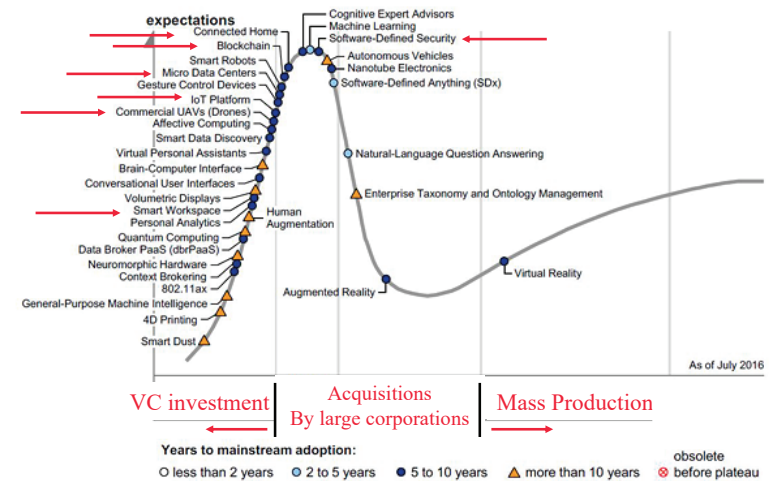
❑ Goal: To impact

❑ Follow the **paradigm shifts**:
  ➢ 1980: Operating Systems
  ➢ 1990: Performance Analysis
  ➢ 2000: Networking
  ➢ 2013: Multi-Cloud Computing
  ➢ 2017: Whatever is being **hyped** this year?

Gartner Hype Cycle 2016

expectations

Cognitive Expert Advisors
Machine Learning
Software-Defined Security
Connected Home
Blockchain
Autonomous Vehicles
Smart Robots
Nanotube Electronics
Micro Data Centers
Software-Defined Anything (SDx)
Gesture Control Devices
IoT Platform
Commercial UAVs (Drones)
Affective Computing
Smart Data Discovery
Virtual Personal Assistants
Natural-Language Question Answering
Brain-Computer Interface
Conversational User Interfaces
Volumetric Displays
Smart Workspace
Human Augmentation
Enterprise Taxonomy and Ontology Management
Personal Analytics
Quantum Computing
Data Broker PaaS (dbrPaaS)
Neuromorphic Hardware
Context Brokering
802.11ax
Virtual Reality
General-Purpose Machine Intelligence
Augmented Reality
4D Printing
Smart Dust

As of July 2016

VC investment   Acquisitions By large corporations   Mass Production

Years to mainstream adoption:
○ less than 2 years   ◉ 2 to 5 years   ● 5 to 10 years   △ more than 10 years   obsolete ⊗ before plateau

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

Trend 1: Smart Everything

|		
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

  These slides and recording of this talk are available on-line at:
  http://www.cse.wustl.edu/~jain/talks/aeect17.htm

❑ Smart Grid, Smart Meters, Smart Cars, Smart homes, Smart Cities, Smart Factories, Smart Smoke Detectors, …
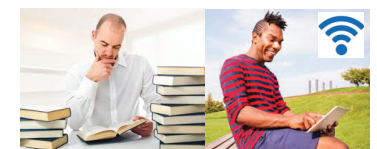
Not-Smart   Smart

Cavemen of 2050

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)

Trend 2: Micro-Cloud Computing

❑ Cloud computing was invented in 2006

❑ Then: Cloud = Large Data Center
Multiple VMs managed by a cloud management system (OpenStack)

❑ Today: Cloud = Computing using virtual resources

  ➢ µCloud = Cloud in a server with multiple VMs.

  ➢ Each VM with Multiple Containers ⇒ Multiple Services

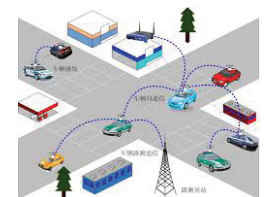
Mobile/Wireless

❑ 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)
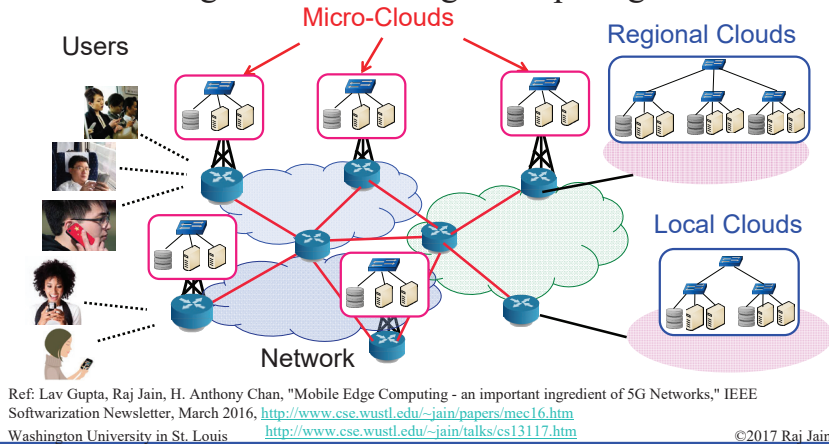❑ New Developments:
  ➢ 5G: 1Gbps
  ➢ Vehicular Networking

Trend 3: Mobile Edge Computing

❑ To service mobile users/IoT, the computation needs to come to edge ⇒ Mobile Edge Computing

Users   Micro-Clouds   Regional Clouds

Local Clouds

Network

Ref: Lav Gupta, Raj Jain, H. Anthony Chan, "Mobile Edge Computing - an important ingredient of 5G Networks," IEEE Softwarization Newsletter, March 2016, http://www.cse.wustl.edu/~jain/papers/mec16.htm


Trend 4: Micro-Services

❑ All major applications, such as, Facebook, Netflix, etc. consist of a number of micro-services that are instantiated on demand on virtual machines

Users   Micro-Clouds   Regional Clouds

Local Clouds

Network
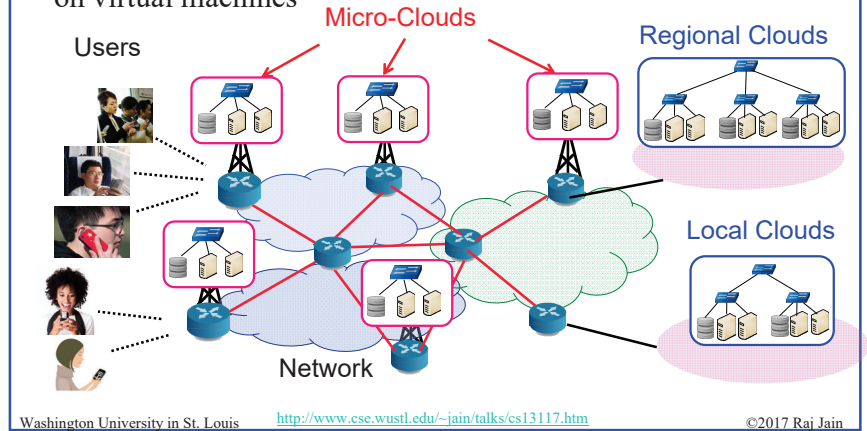
Trend 5: Software Defined Everything

❑ SDN was invented in 2009
❑ Then: SDN:
  ➢ Separation of control and data planes
  ➢ Centralization of Control
  ➢ Standard Protocol between the planes
❑ Now: Software Defined Everything (SDE) = **Disaggregation** of hw/sw
  ➢ Commodity hardware
  ➢ Software that runs on commodity hw
  ➢ Open Source Software
    ⇒ Service industry
  ➢ Controller replaced by Orchestrator
  ➢ Centralization of policies

Control Plane

Data Plane … Data Plane
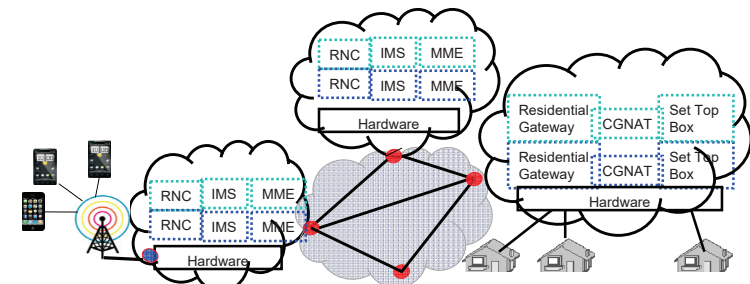
Orchestrator

SW … SW
HW   HW
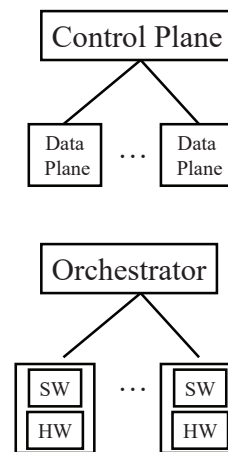
Ref: D. M Batista, G. Blair, F. Kon, R. Boutaba, D. Hutchison, R. Jain, R. Ramjee, C. Rothenberg, "Perspectives on software-defined networks: interviews with five leading scientists from the networking community" Journal of Internet Services and Applications 2015, 6:22, http://www.cse.wustl.edu/~jain/papers/jisa15.htm

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Trend 6: 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

RNC IMS MME
RNC IMS MME
Hardware

Residential Gateway CGNAT Set Top Box
Residential Gateway CGNAT Set Top Box
Hardware

RNC IMS MME
RNC IMS MME
Hardware

Ref: 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

Trend 7: Software Defined Multi-Cloud

❑ Orchestrating devices to Orchestrating Clouds

Datacenter Applications

Global Applications
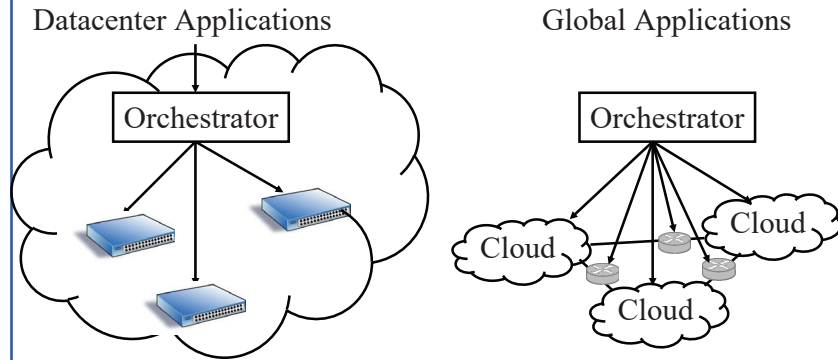
Ref: Subharthi Paul, Raj Jain, Mohammed Samaka, Jianli Pan, "Application Delivery in Multi-Cloud Environments using Software Defined Networking," Computer Networks Special Issue on cloud networking and communications, December 2013, http://www.cse.wustl.edu/~jain/papers/comnet14.htm
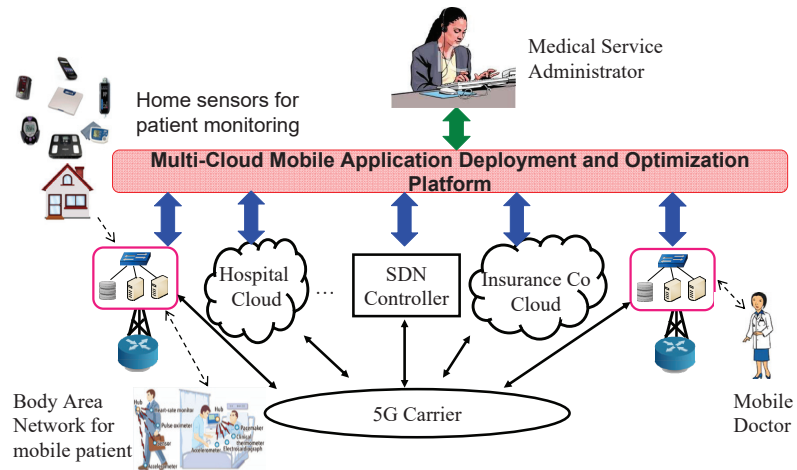
OpenADN Multi-Cloud Management
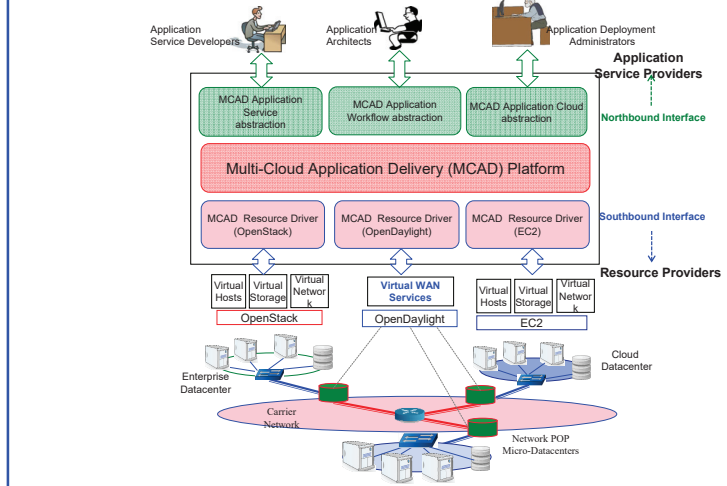
Ref: Lav Gupta, Raj Jain, Mohammed Samaka, "Analysis of Application Delivery Platform for Software Defined Infrastructures," International Journal of Communication Networks and Distributed Systems, 2016, Vol. 5, http://www.cse.wustl.edu/~jain/papers/ijcnds16.htm

Mobile Healthcare Use Case

Trend 9: 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

Internet of Harmful Things

Researchers at DEFCON 3, hacked a smart toilet, making it flush incessantly and closing the lid repeatedly and unexpectedly. Causing a **Denial of Service** Attack.

DEFCON

- ❑ Hacker's conference
- ❑ Held in Las Vegas every July
- ❑ 20,000+ attendees
- ❑ All anonymous

DEFCON 2017

- ❑ Hacking voting machines
- ❑ Hack connected vehicles
- ❑ Hacking the cloud
- ❑ Hacking travel routers
- ❑ Clone RFID in real time
- ❑ Breaking the Uber badge ciphers
- ❑ Counterfeit hardware security devices, RSA tokens
- ❑ Fool antivirus software using AI
- ❑ How to track government spy planes
- ❑ Break bitcoin hardware wallets
- ❑ DARPA Cyber Grand Challenge (2015, 2016)
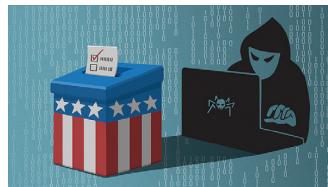
Confidentiality
Integrity
Authentication

Teaching CIA methods w/o hacking is not sufficient

Trend 10: Blockchains

- ❑ Blockchain is the technology that made Bitcoin secure
- ❑ Blockchain was invented by the inventor of Bitcoin
- ❑ After Bitcoin became successful, people started looking into the technology behind Bitcoin and found:
  - ➢ Blockchain is the key for its success
  - ➢ Two complete strangers can complete a transaction without a third party

Example of a Contract: Wedding

Wedding (Cont)

❑ **Centralized**   ❑ **Decentralized**

❑ Centralized registry	❑ Decentralized
❑ Single point of failure	❑ No single point of failure
❑ Easier to hacked	❑ Very difficult to hack

Google Trend: Blockchains

Jul 2012   Feb 2014   Aug 2015   Mar 2017
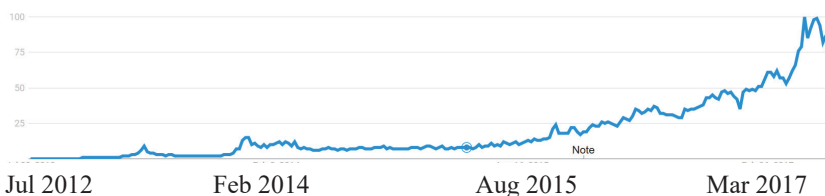
❑ Countries with most interest in Blockchains:
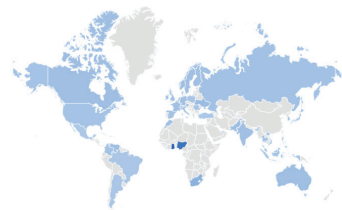
1	Ghana	100
2	Nigeria	68
3	Singapore	25
4	Hong Kong	22
5	South Africa	20

Trend: Centralized to Decentralized

❑ **Trend**: Make everything decentralized with no central point of control
❑ Two perfect strangers can exchange money, make a contract without a trusted third party
❑ Decentralized systems are
  1. More reliable: Fault tolerant
  2. More secure: Attack tolerant
  3. No single bottleneck ⇒ Fast
  4. No single point of control ⇒ No monopoly
❑ Blockchain is one way to do this among **untrusted multi-domain** systems.

> Time is a cycle: Distributed vs. Centralized debate

Blockchains

- **How** is it done?
  - A singly linked chain of blocks of verified signed transactions is replicated globally on millions of nodes
  - You will have to change millions of nodes to attack/change
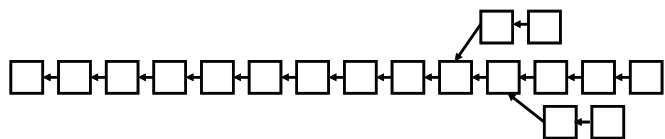
- **Who** is interested: Banks, Hospitals, Venture Capitalists, …
  ⇒ Researchers, students, …

Examples of Centralized Systems

- **Banks**: Allow money transfer between two accounts
- **Currency**: Printed and controlled by the government
- **Stock Exchanges**: Needed to buy and sell stocks
- **Networks:** Certificate Authorities, DNS
- In all cases:
  1. There is a central third party to be trusted
  2. Central party maintains a large database of information ⇒ Attracts Hackers
  3. Central party may be hacked ⇒ affects millions
  4. Central party is a single point of failure. Can malfunction or be bribed.

Ref: A. Narayanan, et al, "Bitcoin and Cryptocurrency Technologies," Princeton University Press, 2016, 304 pp.

Blockchains For Cities

- Land titles
- Vehicle registries
- Business license
- Criminal records
- Passports
- Birth certificates
- Death certificates
- Building permits
- Gun permits

Ref: http://ledracapital.com/blog/2014/3/11/Bitcoin-series-24-the-mega-master-blockchain-list

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Blockchains for Cities (Cont)

THE COINTELEGRAPH
future of money

BTC $ 4 859.02 ▲ 0.83 %
BCH $ 312.85 ▲ 0.14 %

News ⌄   Guides & Analytics ⌄   Events ⌄   Explained   ICO Calendar

By Joshua Althauser   9 HOURS AGO

Indian State Uses Blockchain Technology to Stop Land Ownership Fraud

Networking Applications of Blockchains

❑ Multi-Domain Systems:
- ➢ Multiple Cloud Service Providers
- ➢ Multiple cellular providers
- ➢ Multi-Interface devices: WiFi, Cell, Bluetooth, …
- ➢ BGP: BGP Authentication

❑ Globally Centralized Systems:
- ➢ DNS
- ➢ Certificate Authorities

Explore blockchains for multi-domain/centralized systems

Communication using UAVs
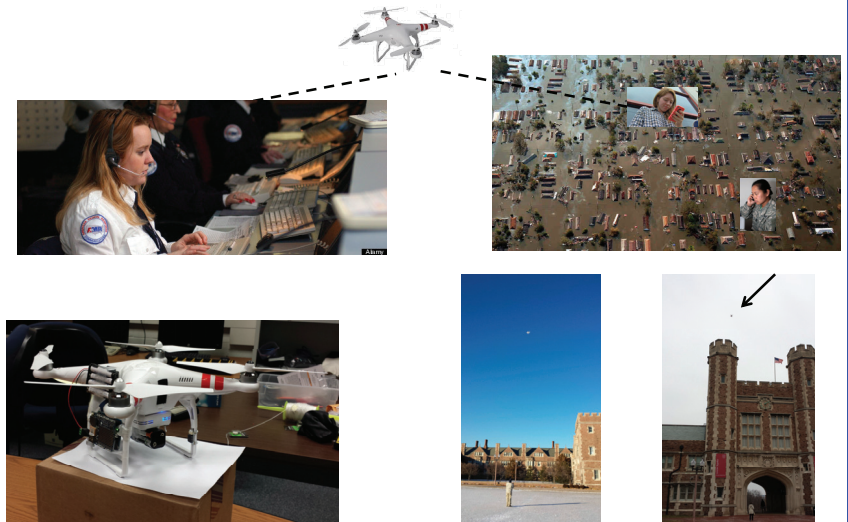
Key Distinction of Our Research

❑ 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: Advanced Networking:**
Clouds, Big Data, SDN, IoT (Spring 2018)
5. **CSE 574S: Wireless and Mobile Networking** (Fall 2018)
6. **CSE 571S: Network Security** (Spring 2019)
7. CSE 7700: Research Seminar On Networking and
Communications

Summary

1. Computer networking is the backbone of all computing $\Rightarrow$ Cyber age. Networking companies are the leading edge.
2. Smart $\neq$ High-Speed Computation,
   Smart $\neq$ Big Data Storage,
   Smart = Networked
3. Clouds are getting smaller, Carriers and enterprises moving to clouds, leading to clouds everywhere $\Rightarrow$ multi-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
   2. IoT Security
   3. 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/cse473-16/index.html
2. CSE 571S: Network Security,
   http://www.cse.wustl.edu/~jain/cse571-17/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/cse567-17/index.html
5. CSE 570: Recent Advances in Networking
   http://www.cse.wustl.edu/~jain/cse570-15/index.html

Recent Papers

❑ Xin Li, M. Samaka, H. A. Chan, D. Bhamare, L. Gupta, C. Guo, and Raj Jain, "**Network Slicing for 5G: Challenges and Opportunities**," IEEE Internet Computing, Vol. 21, Issue 5, September 18, 2017, pp. 20-27, http://www.cse.wustl.edu/~jain/papers/slic_ic.htm

❑ D. Bhamare, M. Samaka, A. Erbad, Raj Jain, L. Gupta, H. A. Chan, "**Optimal Virtual Network Function Placement and Resource Allocation in Multi-Cloud Service Function Chaining Architecture**," Computer Communications, Vol. 102, April 2017, pp. 1-16, http://www.cse.wustl.edu/~jain/papers/comcom17.htm

❑ T. Salman, Raj Jain, "**A Survey of Protocols and Standards for Internet of Things**," Advanced Computing and Communications, Vol. 1, No. 1, March 2017, http://www.cse.wustl.edu/~jain/papers/iot_accs.htm

❑ L. Gupta, Raj Jain, H. A. 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

❑ L. Gupta, Raj Jain, and G. 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

Recent Talks

❑ Raj Jain, "**Current Trends in Networking With Applications to Internet of Things and Smart Cities**," Keynote at 2017 IEEE Jordan Conference on Applied Electrical Engineering and Computing Technologies (AEECT), Amman, Jordan, October 12, 2017, http://www.cse.wustl.edu/~jain/talks/aeect17.htm

❑ Raj Jain, "**Blockchains: Networking Applications**," An invited talk at the 38th IEEE Sarnoff Symposium, Newark, NJ, Sep 19, 2017, http://www.cse.wustl.edu/~jain/talks/blc_srnf.htm

❑ Raj Jain, "**The Catch-up Game: Quest for the Impact**," Keynote at ACM SIGCOMM 2017, Los Angeles, CA, August 22, 2017, http://www.cse.wustl.edu/~jain/talks/sigcomm.htm

❑ Raj Jain, "**Unmanned Aerial Systems: Networking Applications, Challenges and Issues**," Keynote at Midwest Drone Introduction, St. Louis, MO, October 15, 2016, http://www.cse.wustl.edu/~jain/talks/unmanned.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

- ABR   Available Bit Rate
- ACM   Automatic Computing Machinery
- ADCOM   Advanced Computing
- AI   Artificial Intelligence
- ANSI   American National Standards Institute
- API   Application Programming Interface
- AT&T   American Telephone and Telegraph
- ATM   Asynchronous Transfer Mode
- BGP   Border Gateway Protocol
- CA   California
- CGNAT   Carrier Grade Network Address Translator
- CIA   Confidentiality, Integrity, Authentication
- CS   Computer Science
- CSE   Computer Science and Engineering
- DARPA   Defense Advanced Research Project Agency
- DECbit   Digital Equipment Corporation Bit

Acronyms (Cont)

- DECT   Digital Enhanced Cordless Telecommunications
- DEFCON   D-E-F (sequential letters of the alphabet) Conference
- DNS   Domain Name Service
- DSL   Digital Subscriber Line
- EC2   Asynchronous Transfer Mode
- ECN   Explicit congestion notification
- EFCI   Explicit Forward Congestion Indication
- FTTH   Fiber to the Home
- GIS   Geographical Information Systems
- GPS   Global Positioning Systems
- HW   Hardware
- IBM   International Business Machine Corporation
- iCloud   Apple's Cloud Service
- IEEE   Institution of Electrical and Electronic Engineering
- IETF   Internet Engineering Task Force
- IMS   Internet Multimedia System
- IoT   Internet of Things

Acronyms (Cont)

- IP   Internet Protocol
- LAN   Local Area Network
- MCAD   Multi-Cloud Application Delivery
- MME   Multi-media Multicasting Entity
- MO   Missouri
- NFC   Near-Field Communications
- NVF   Network Function Virtualization
- NJ   New Jersey
- NTT   Nippon Telephone and Telegraph
- OpenADN   Open Application Delivery Networking
- PHY   Physical Layer
- POP   Point of Presense
- PP   Pages
- RFID   Radio Frequency Identifier
- RNC   Radio Network Controller
- RSA   Rivest, Silverman, Adleman
- SDE   Software Define Everything

Acronyms (Cont)

- SDN   Software Defined Networking
- SIGCOMM   Special Interest Group in Data Communications
- SOA   Service Oriented Architecture
- SW   Software
- TCP   Transmission Control Protocol
- TV   Television
- UAV   Unmanned Aerial Vehicle
- UK   United Kingdom
- ULE   Ultra Low Energy
- VC   Virtual Circuit
- VM   Virtual Machine
- WAN   Wide Area Network
- WiFi   Wireless Fidelity
- WiMAX   Worldwide Interoperability for Microwave Access
- WUSTL   Washington University in St. Louis
- XML   Extended markup language

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http://www.cse.wustl.edu/~jain/talks/cs13117.htm

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