

Our Research on Networking, Security, Internet of Things, Blockchains, and Drones



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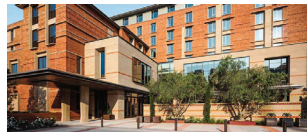
These slides and a video recording of this talk are at:
<http://www.cse.wustl.edu/~jain/cse591-18/cs59118.htm>



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

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!

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

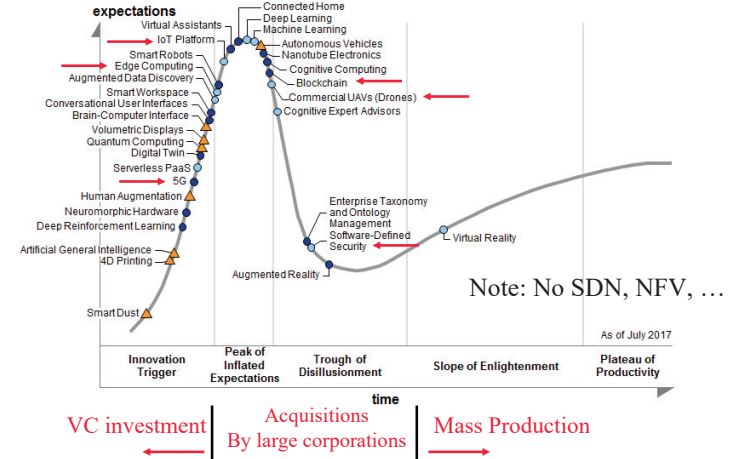
❑ Goal: To impact

❑ 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 2017



Ref: Gartner, "Hype Cycle for Emerging Technologies, 2017," July 2017, [subscribers only]

Current Hot Topics in Networking



1. Internet of Things (IoT)
2. Security
3. Edge Computing and Multi-Cloud
4. Blockchains
5. Drones

Trend: 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 \Rightarrow Computation
= Can Recall \Rightarrow Storage
- 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, ...



Not-Smart Smart

IoT is a Data (\$) Mine



Trend: 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

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

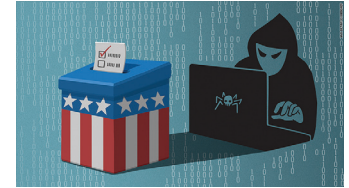
Ref: <https://www.ethicalhacker.net/features/opinions/first-timers-experience-black-hat-defcon>
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DEFCON 2017

- ❑ 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)



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Trend: 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)



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Trend: 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
 - μ Cloud = Cloud in a server with multiple VMs.
 - Each VM with Multiple Containers ⇒ Multiple Services



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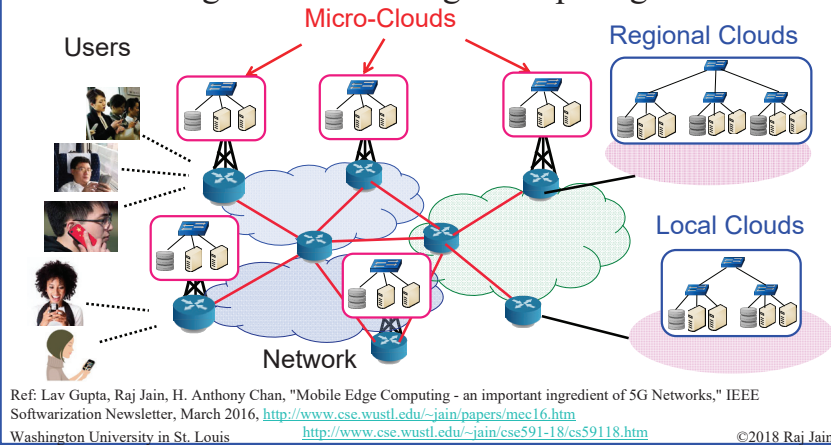
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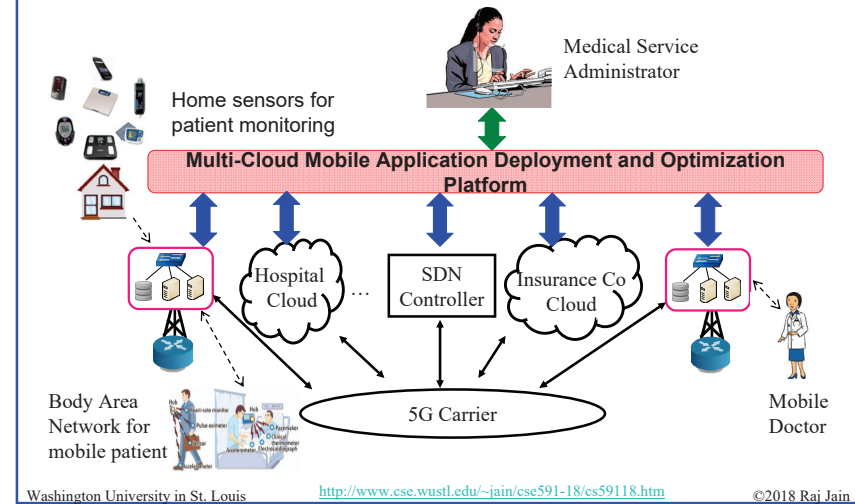
Trend: Mobile Edge Computing

- To service mobile users/IoT, the computation needs to come to edge \Rightarrow Mobile Edge Computing



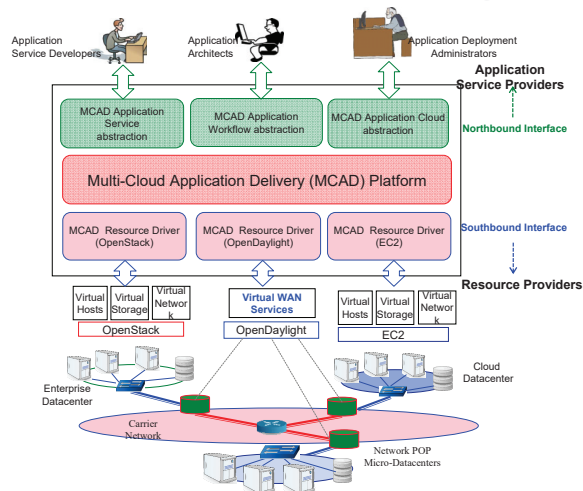
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Mobile Healthcare Use Case



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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>
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Trend: 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

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Example of a Contract: Wedding



Wedding (Cont)

Centralized

Decentralized



- Centralized registry
- Single point of failure
- Easier to hacked

- Decentralized
- No single point of failure
- Very difficult to hack

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
 - More reliable: Fault tolerant
 - More secure: Attack tolerant
 - No single bottleneck \Rightarrow Fast
 - No single point of control \Rightarrow No monopoly
- Blockchain is one way to do this among **untrusted multi-domain** systems.

Time is a cycle: Distributed vs. Centralized debate

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:
 - There is a central third party to be trusted
 - Central party maintains a large database of information \Rightarrow Attracts Hackers
 - Central party may be hacked \Rightarrow affects millions
 - Central party is a single point of failure. Can malfunction or be bribed.

Trend: Drones



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Our Research

1. Multi-Cloud Management: Machine learning for Fault and performance management
2. Multi-Cloud for 5G: Network Function Virtualization
Micro-edge computing, micro-service placement
3. IoT Security 1: Industrial Control Systems Security
4. IoT Security 2: Healthcare Security
5. Multi-Cloud Security: Scientific Collaboration Security
6. Communication using UAVs

5 Funded
Research
Projects

Techniques:

1. Machine learning and Deep Learning
2. Blockchains

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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**
(Spring 2019) – 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**
7. 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. Smart ≠ High-Speed Computation,
Smart ≠ Big Data Storage,
Smart = Networked
3. Clouds are getting smaller, Carriers and enterprises moving to clouds, leading to clouds everywhere ⇒ multi-cloud
4. Our MCAD allows automated management of multi-cloud applications
5. We are working on:
 1. Multi-Cloud management
 2. Multi-Cloud security
 3. Industrial Control Systems and healthcare Security
 4. UAV applications

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/cse570-18/index.html>

Recent Papers

- D. Bhamare, A. Erbad, R. Jain, M. Zolanvari, M. Samaka, "Efficient Virtual Network Function Placement Strategies for Cloud Radio Access Networks," Computer Communications, Volume 127, May 2018, pp. 50-60, ISSN 0140-3664, DOI:[10.1016/j.comcom.2018.05.004](https://doi.org/10.1016/j.comcom.2018.05.004)
- L. Gupta, M. Samaka, R. Jain, A. Erbad, D. Bhamare, H. A. Chan, "Fault and Performance Management in Multi-Cloud Based NFV using Shallow and Deep Predictive Structures," Journal of Reliable Intelligent Environments, Vol. 3, No. 4, Dec. 2017, pp. 221-231,
<http://www.cse.wustl.edu/~jain/papers/jrie17.htm>
- T. Salman, D. Bhamare, A. Erbad, R. Jain, M. Samaka, "Machine Learning for Anomaly Detection and Categorization in Multi-cloud Environments," The 4th IEEE International Conference on Cyber Security and Cloud Computing (IEEE CSCloud 2017), New York, June 26-28, 2017, DOI: 10.1109/CSCloud.2017.15,
<http://www.cse.wustl.edu/~jain/papers/cscloud.htm>
- 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,
<http://www.cse.wustl.edu/~jain/talks/smrctit.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
- ❑ CA California
- ❑ CGNAT Carrier Grade Network Address Translator
- ❑ CS Computer Science
- ❑ CSE Computer Science and Engineering
- ❑ DARPA Defense Advanced Research Project Agency
- ❑ DECBIT Digital Equipment Corporation Bit
- ❑ DECT Digital Enhanced Cordless Telecommunications
- ❑ DEFCON D-E-F (sequential letters of the alphabet) Conference

Acronyms (Cont)

- ❑ DNS Domain Name Service
- ❑ EC2 Asynchronous Transfer Mode
- ❑ ECN Explicit congestion notification
- ❑ GIS Geographical Information Systems
- ❑ IBM International Business Machine Corporation
- ❑ iCloud Apple's Cloud Service
- ❑ IEEE Institution of Electrical and Electronic Engineering
- ❑ IETF Internet Engineering Task Force
- ❑ IoT Internet of Things
- ❑ IP Internet Protocol
- ❑ LAN Local Area Network
- ❑ MCAD Multi-Cloud Application Delivery
- ❑ MO Missouri
- ❑ NJ New Jersey
- ❑ NFV Network Function Virtualization
- ❑ NTT Nippon Telephone and Telegraph

Acronyms (Cont)

- ❑ OpenADN Open Application Delivery Networking
- ❑ PHY Physical Layer
- ❑ POP Point of Presence
- ❑ PP Pages
- ❑ RFID Radio Frequency Identifier
- ❑ RSA Rivest, Silverman, Adleman
- ❑ SDN Software Defined Networking
- ❑ SIGCOMM Special Interest Group in Data Communications
- ❑ TCP Transmission Control Protocol
- ❑ TV Television
- ❑ UAV Unmanned Aerial Vehicle
- ❑ UK United Kingdom
- ❑ VC Virtual Circuit
- ❑ WAN Wide Area Network
- ❑ WiMAX Worldwide Interoperability for Microwave Access
- ❑ WUSTL Washington University in St. Louis
- ❑ XML Extended markup language

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