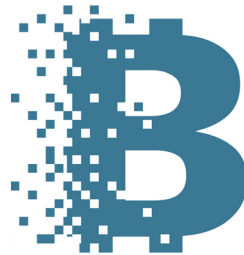
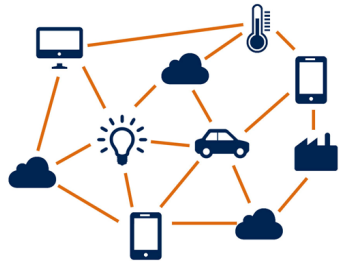


Our Research on Networking, Security, Internet of Things, Blockchains, and Drones



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A talk in “CSE 591: Introduction to Graduate Studies in CSE”
September 12, 2018

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)



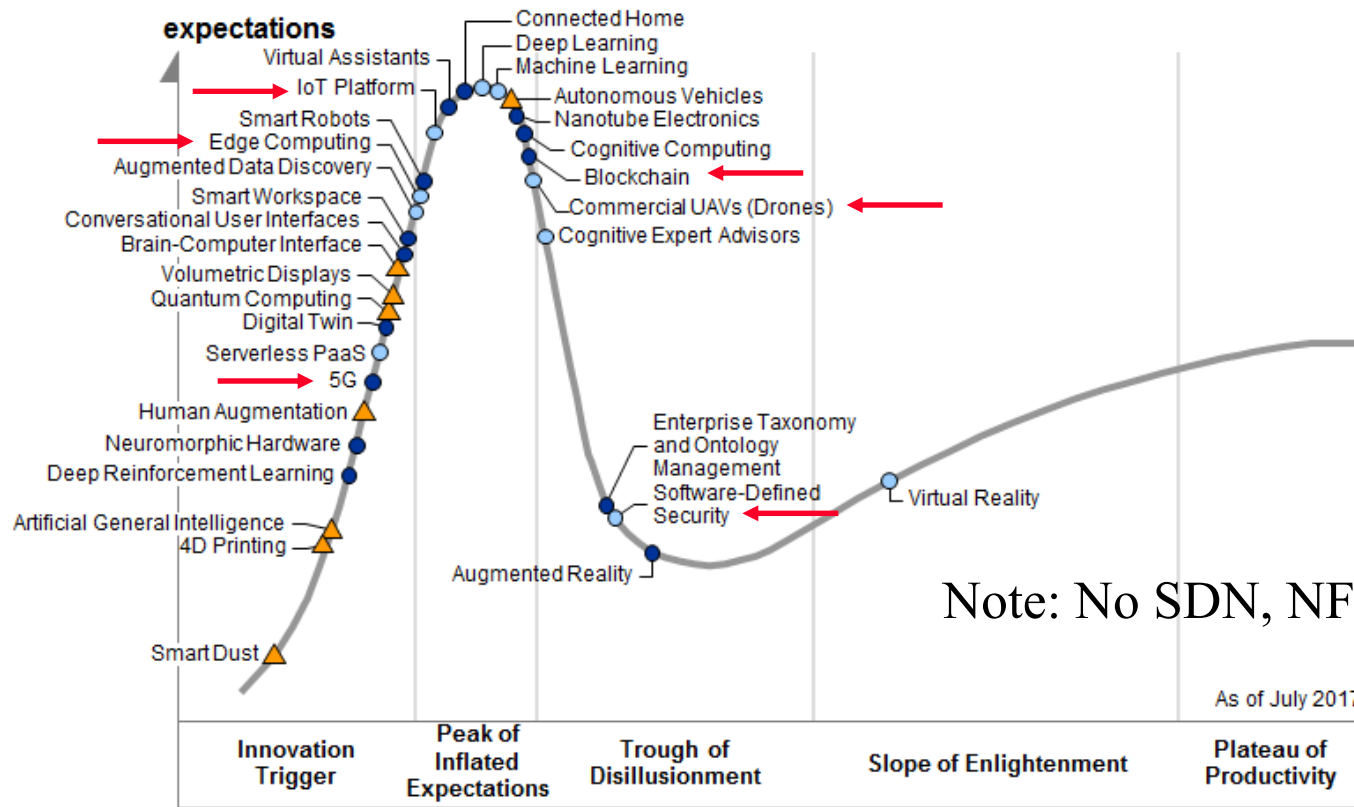
Networking = Economic Indicator

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



VC investment ← | Acquisitions By large corporations | → Mass Production

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

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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



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Ref: <https://www.pinterest.com/ioofficecorp/humor/>

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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

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

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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.



Ref: <http://www.computerworld.com/article/2486502/security0/worm-may-create-an-internet-of-harmful-things--says-symantec--take-note--amazon-.html>
Washington University in St. Louis <http://www.cse.wustl.edu/~jain/cse591-18/cs59118.htm>

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>

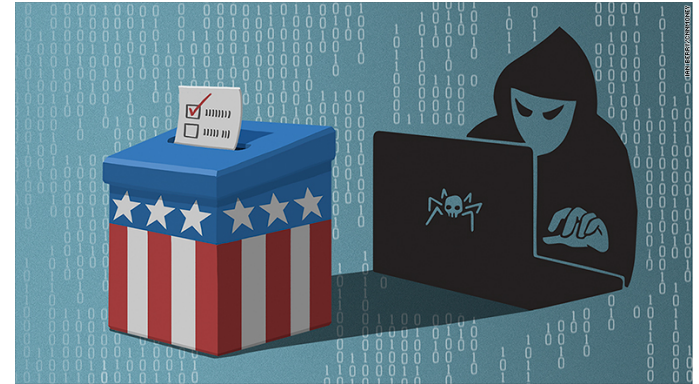
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DEFCON 2017

- ❑ 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)



Trend: Cloud Computing

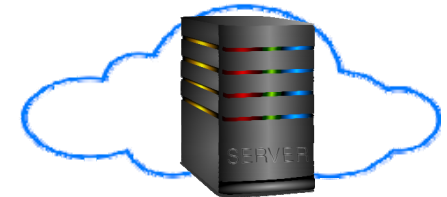
- ❑ August 25, 2006: Amazon announced EC2
⇒ Birth of Cloud Computing in reality
(Prior theoretical concepts of computing as a utility)
\$10 B in 2016, a growth rate of 49% with 17% margins, much higher than the overall Amazon business



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

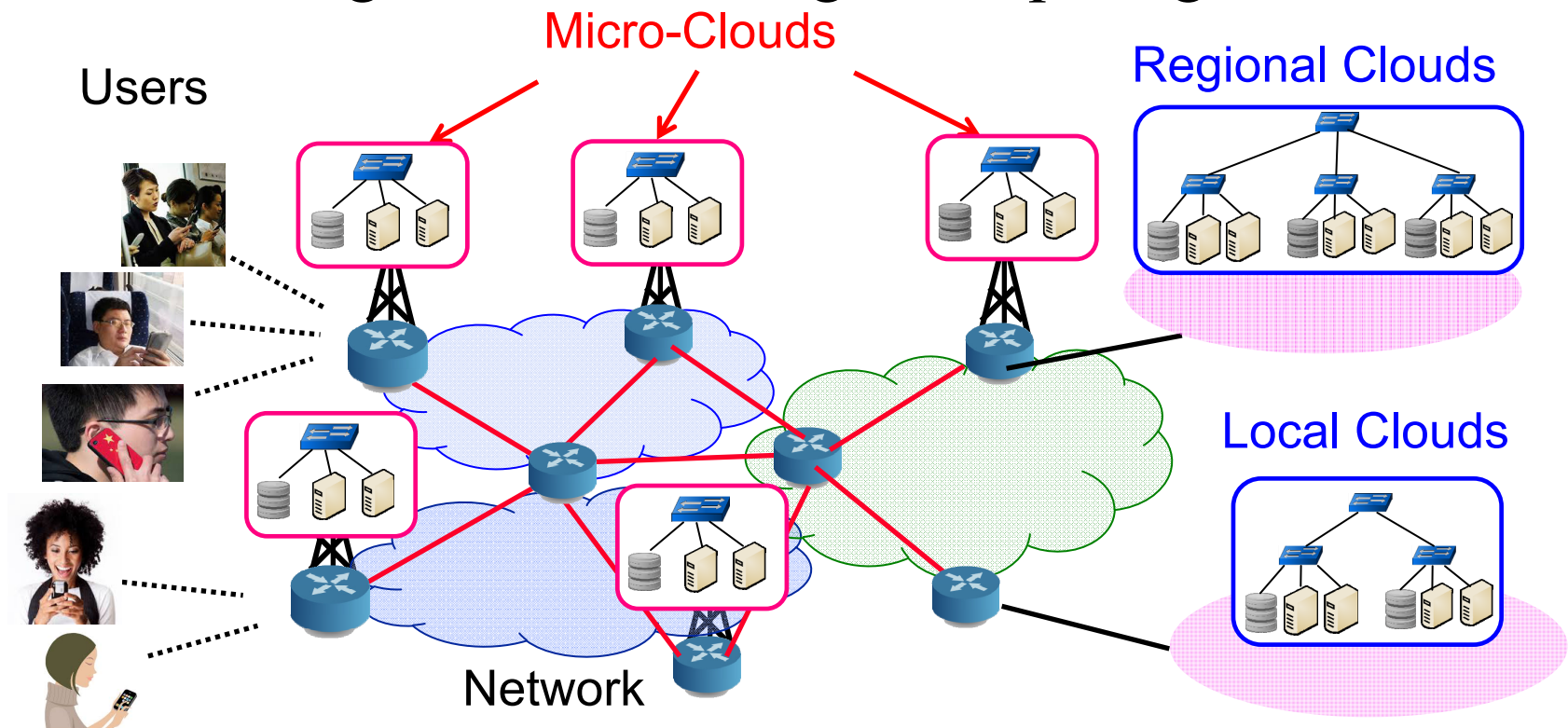
Trend: Micro-Cloud Computing

- ❑ 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 \Rightarrow Multiple Services



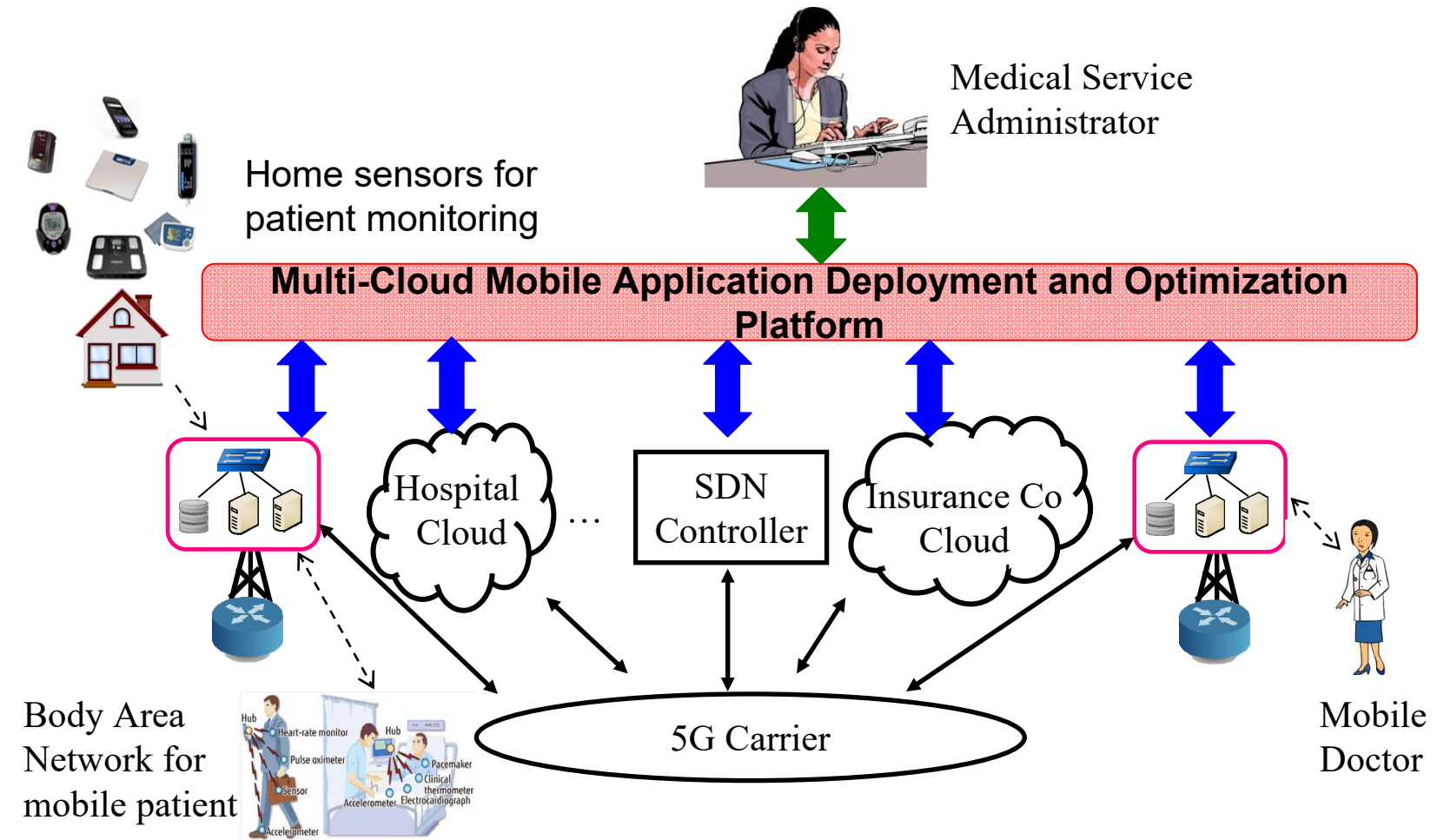
Trend: Mobile Edge Computing

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

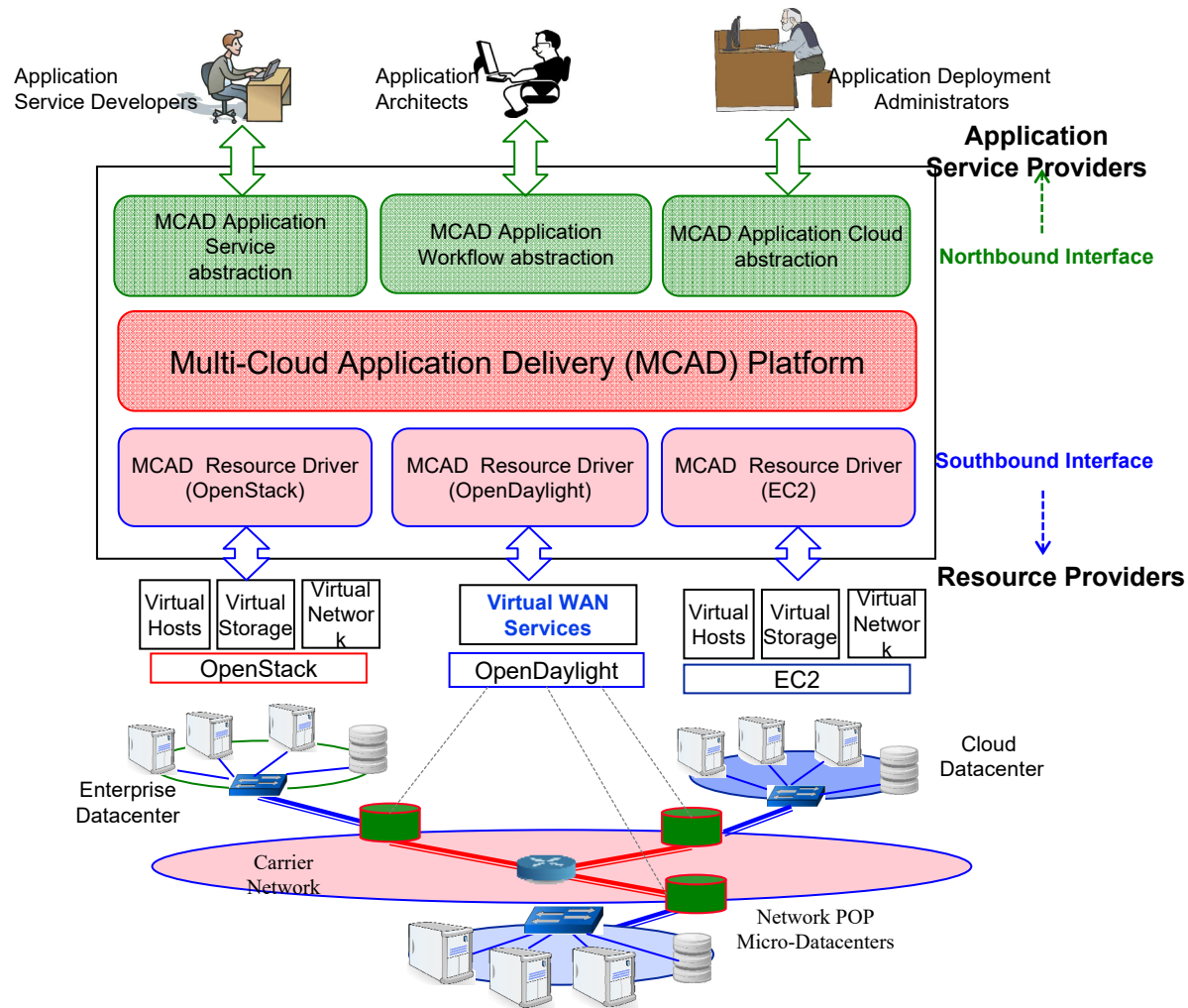


Ref: Lav Gupta, Raj Jain, H. Anthony Chan, "Mobile Edge Computing - an important ingredient of 5G Networks," IEEE Softwarization Newsletter, March 2016, <http://www.cse.wustl.edu/~jain/papers/mec16.htm>

Mobile Healthcare Use Case



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>

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

Example of a Contract: Wedding



Wedding (Cont)

❑ Centralized



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

❑ Decentralized



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

Trend: Centralized to Decentralized

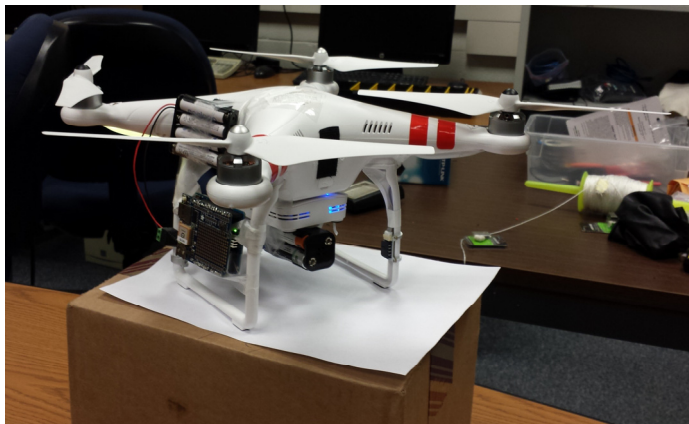
- ❑ **Trend:** Make everything decentralized with no central point of control
- ❑ Two perfect strangers can exchange money, make a contract without a trusted third party
- ❑ Decentralized systems are
 1. More reliable: Fault tolerant
 2. More secure: Attack tolerant
 3. No single bottleneck \Rightarrow Fast
 4. 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:
 1. There is a central third party to be trusted
 2. Central party maintains a large database of information \Rightarrow Attracts Hackers
 3. Central party may be hacked \Rightarrow affects millions
 4. Central party is a single point of failure.
Can malfunction or be bribed.

Trend: Drones



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

Key Distinction of Our Research

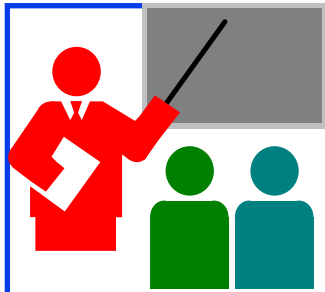
- ❑ Goal: Impact to the real-world
DECbit congestion indication in almost all networking architectures since its invention
- ❑ Funded by industry partners:
Intel, Cisco, Broadcom, Boeing, ...
- ❑ Impact real-world by participating in standards organizations and industry forums:
ATM Forum, IEEE Standards, 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**
(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





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, 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
- ❑ 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 Presense
- ❑ 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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