Networking Developments for IoT: Current Research Issues

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These slides and a video of this talk are at:
http://www.cse.wustl.edu/~jain/talks/iot_ssic.htm

Overview

1. Areas of Research for IoT
2. Security
3. Blockchains
4. AI and Machine Learning
5. Micro-Clouds, Edge Computing

Trend: Smart Everything

Smart Watch

Smart TV

Smart Car

Smart Health

Smart Home

Smart Kegs

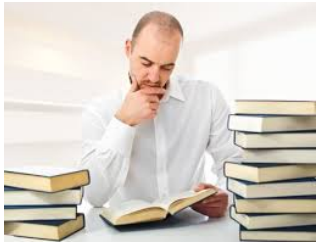
Smart Space

Smart Industries

Smart Cities

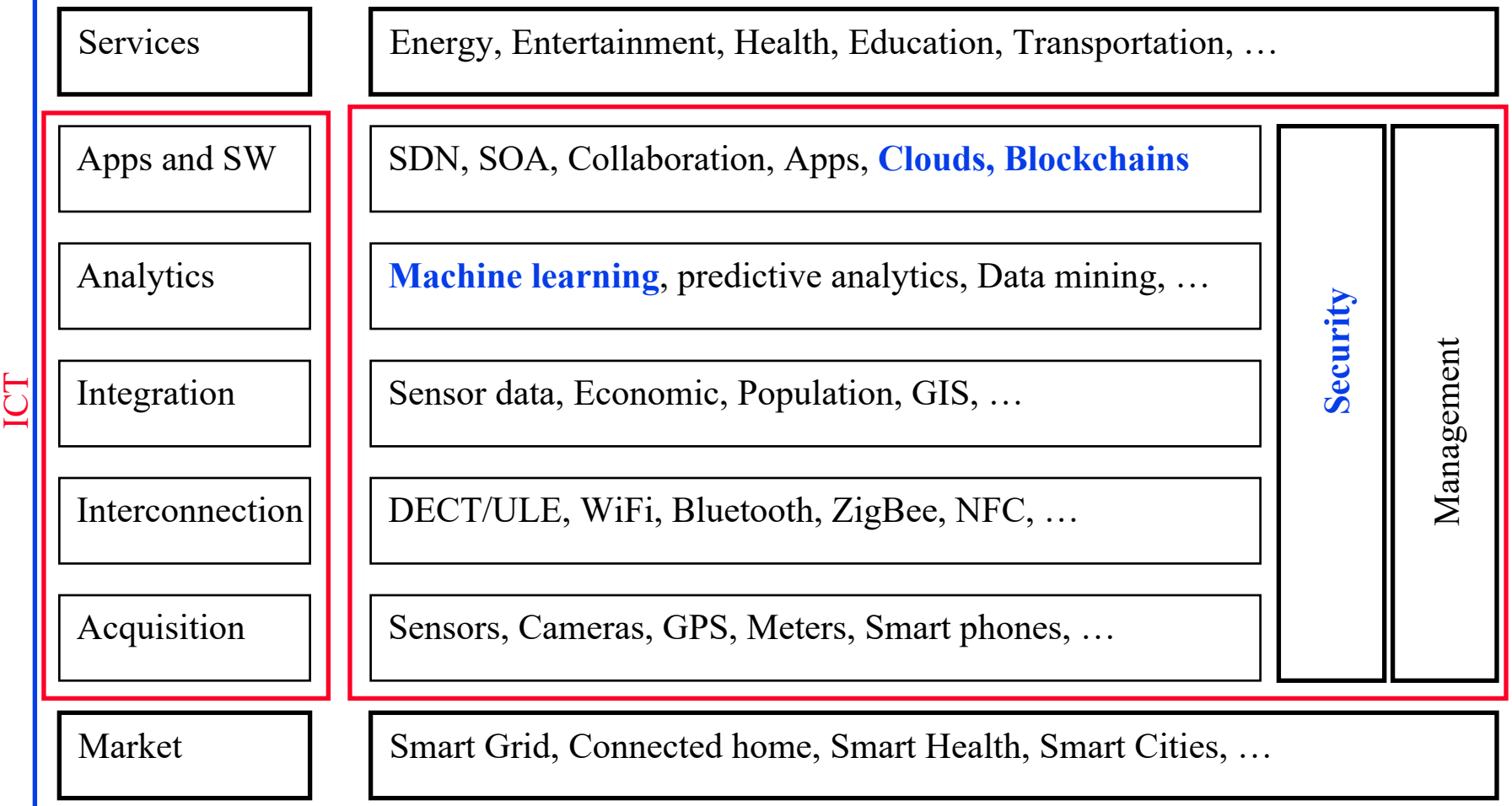
What's Smart?

- Old: Smart = Can think ⇒ Computation
- Later: Smart = Can recall ⇒ Storage
- Now: Smart = Can communicate ⇒ Connected
- Smart Grid, Smart Meters, Smart Cars, Smart homes, Smart Cities, Smart Factories, Smart Smoke Detectors, …

Not-Smart 

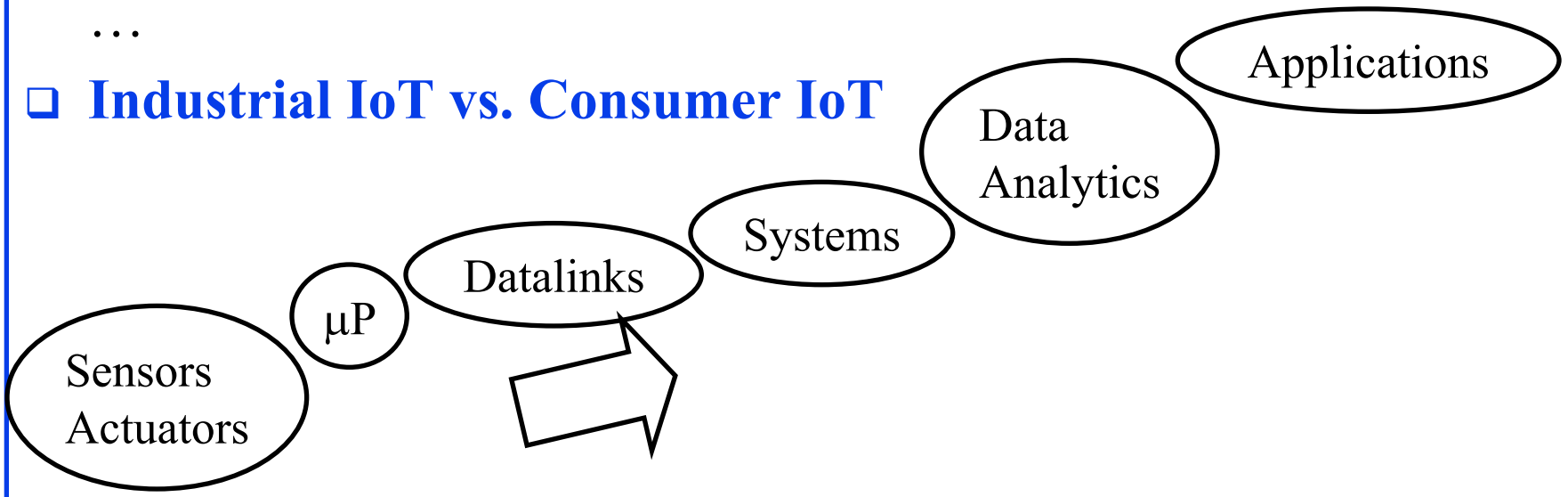
Smart 

A 7-Layer Model of IoT



Business Opportunities

- Components: Sensors, wireless radios, protocols,
- Smart Objects: Smart TV, Camera, Watch, …
- Systems: Buildings, Cars, Health, …
- Network service providers: ISP
- Application Service Providers: Monitoring, Analytics, Apps, …
- **Industrial IoT vs. Consumer IoT**



IoT is a Cloud Data ($) Mine

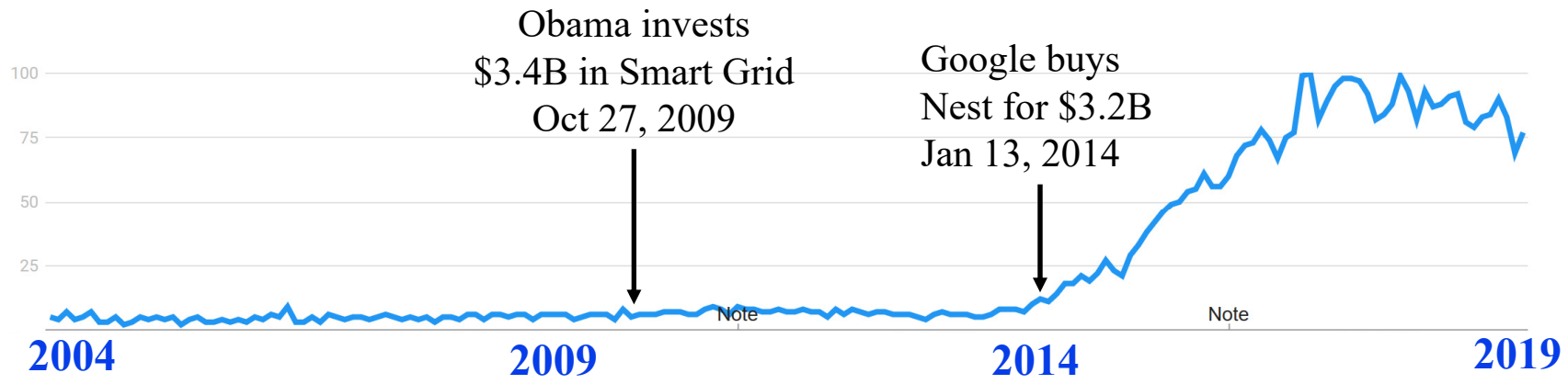
- Most of the revenue in IoT is not in devices but in Data
- All IoT devices come with their own cloud
  - Google Cloud, Apple Cloud, Microsoft Cloud, …

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

Areas of Research for IoT

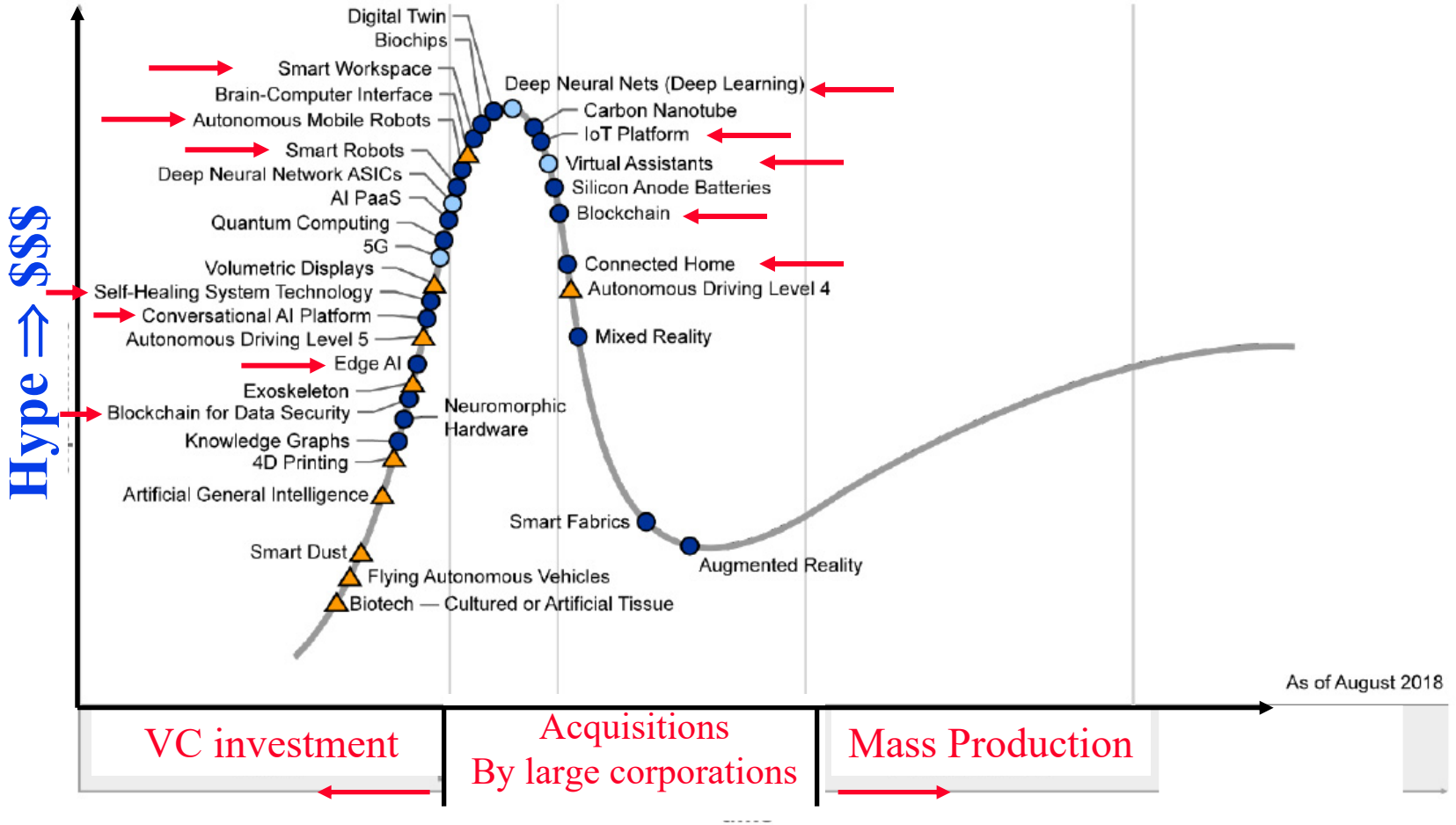
1. PHY: Smart devices, sensors giving real-time information, …
2. Datalink: WiFi, Bluetooth, ZigBee, 802.11ah, …
   Broadband: DSL, FTTH, Wi-Fi, LPWAN, 5G, …
3. Routing: Mesh networking, …
4. Analytics: Big-data, data mining, **Machine learning**, Predictive analytics, …
5. Apps & SW: SDN, SOA, **Cloud computing**, Web-based collaboration, Social networking, **Blockchains**, …
6. Applications: Remote health, On-line education, on-line laboratories, …
7. **Security**: Privacy, Trust, Identity, Anonymity, …

Google Trends



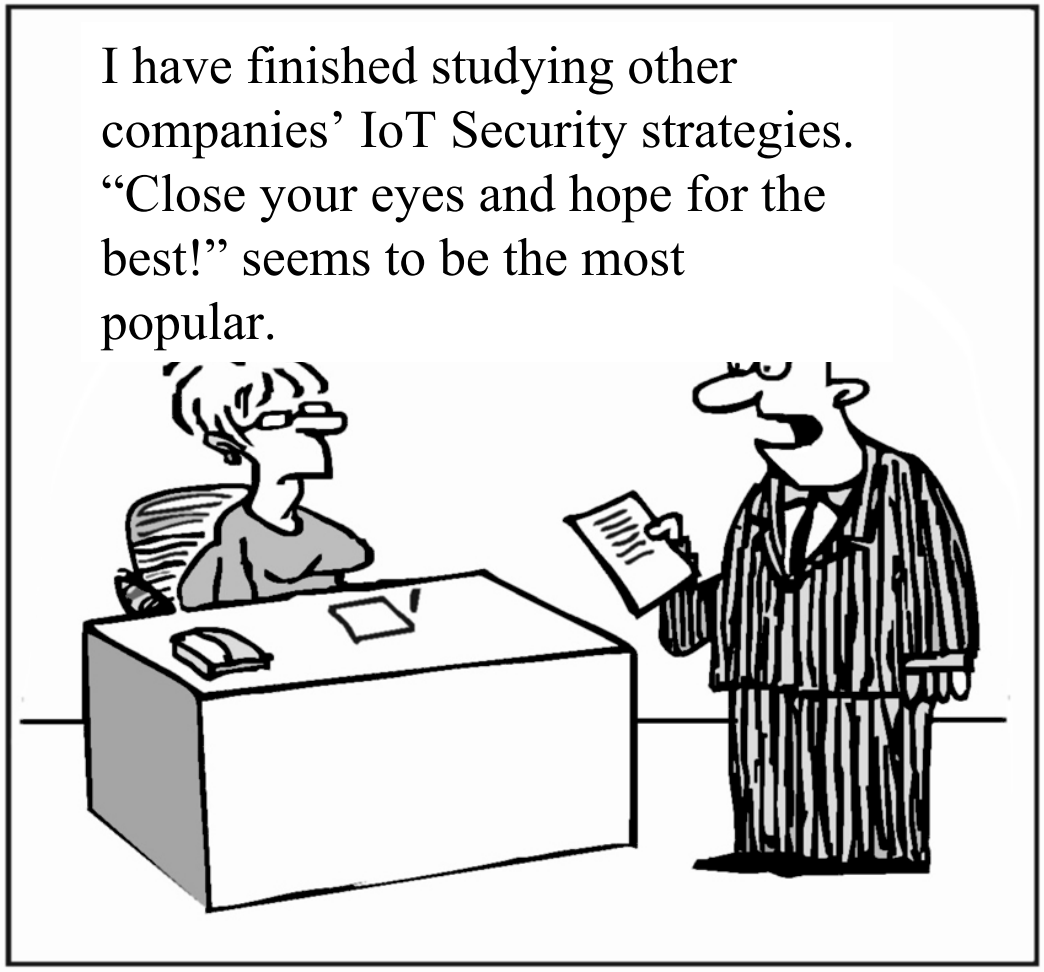
- Around for 10 years
- IERC-European Research Cluster on the Internet of Things funded under 7th Framework in 2009
  ⇒ "Internet of European Things"
- US interest started in 2009 w $3.4B funding for **smart grid** in American Recovery and Reinvestment Act of 2009

Gartner's Hype Cycle For Emerging Tech 2018



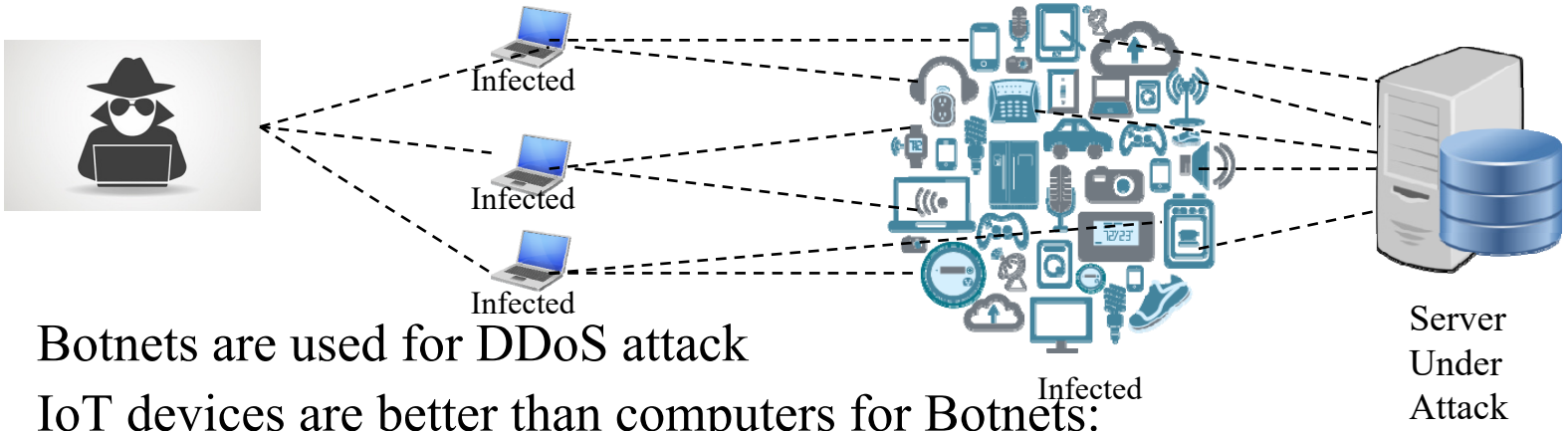
Ref: M. Walker, "Hype Cycle for Emerging Technologies, 2018," Gartner Report G00340159, 6 Aug. 2018, 73 pp.

IoT Security: Popular Approach



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

IoT as an Attack Weapon



- Botnets are used for DDoS attack
- IoT devices are better than computers for Botnets:
  - Very high population compared to computers
  - Mostly unprotected with default passwords, open ports
  - Cameras, Routers, …
- Oct 21, 2016: Mirai bot used 62 default usernames and passwords to infect 380,000 IoT devices and then caused a DDoS attack on a popular DNS service dyn.com
  ⇒ Disabled many other sites for hours
- Mirai bot has made its source code public ⇒ Any kid can use it.
  ⇒ Xiangmai has recalled 10,000 webcams.

Ref: T. Green, "The secret behind the success of Mirai IoT botnets," Network World, Oct 27, 2016, http://www.networkworld.com/article/3136314

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 (DoS)** Attack.

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

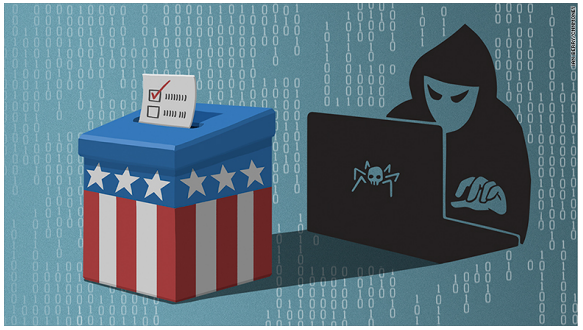
DEFCON

- Hacker's conference
- Held in Las Vegas every July
- 25,000+ attendees
- All anonymous

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

Recent DEFCON Topics

- Hacking voting machines
- Outsmarting the smart city (2018)
- Abusing smart cities (2016)
- How to track government spy planes
- 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
- Break bitcoin hardware wallets
- DARPA Cyber Grand Challenge (2015, 2016)



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, …

Trend: Blockchains

- Blockchain is the technology that made Bitcoin secure
- Blockchain was invented by the inventor of Bitcoin in October 2008 with source code on 9 January 2009.
- 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/contract without a third party

Wedding

Wedding

- Centralized
- Decentralized

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

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

Trend: Centralized to Distributed

- **Trend**: Make everything decentralized with no central point of trust
- Two perfect strangers can exchange money, make a contract without a trusted third party
- Decentralized systems are
  1. More secure: Attack tolerant
  2. No single bottleneck
  3. More reliable: Fault tolerant
  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

Examples of Centralized Systems

- **Banks**: Allow money transfer between two accounts
- **City Records**
- **Voting Authorities**
- **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: Tara Salman, Maede Zolanvari, Aiman Erbad, Raj Jain, and Mohammed Samaka, "**Security Services Using Blockchains:A State of the Art Survey**" IEEE Communications Surveys and Tutorials, Accepted September 2018, 28 pp., http://www.cse.wustl.edu/~jain/papers/bcs.htm

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

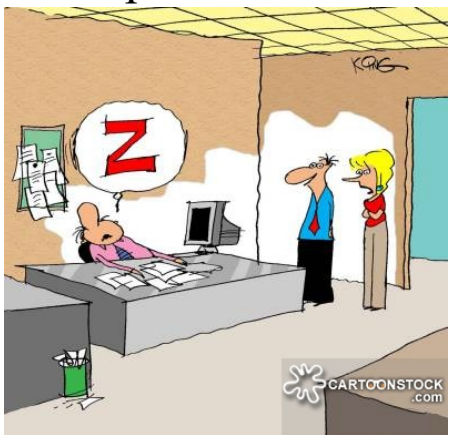
Explore blockchains for multi-domain/centralized systems

Blockchain Challenges

- High computational cost ⇒ 7 bitcoin transactions per second vs. 1,700 visa credit card transactions
- Software bugs ⇒ Stolen money ⇒ Forking in Ethereum
- All data is public in public blockchains

Trend: Smart Things to Intelligent Things

- AI for Security, Computer Vision, Speech Recognition, Operation, data analytics
- Devices that can recognize you, your voice (Alexa/Siri), and are autonomous
- **Autonomous**:
  - **Self-Discover**: Find its components
  - **Self-Organize and Self-configure**: Trending. Predict.
  - **Auto-Manage** = Auto-BSS (bill)/Auto-OSS (provision)
  - **Self-Monitor**: Counters and Probes. Telemetry
  - **Self-Diagnose and Self-Heal**: Self-Report to human operator



Network Manager

Ref: Kireerti Kompella, https://datatracker.ietf.org/meeting/98/materials/slides-98-nmrg-self-driving-networks

Intent-Based Policy Management

- **Intent**: Tell what you want. Not how you want it done.
  E.g., Tell Google maps where you want to go. Not how to.
- **Invariance**: Intent doesn't change if the network changes, devices fail, …
- **Portability**: Independent of infrastructure, equipment vendors, service providers, protocols used, media used, …
- **Compose-ability**: Can use any infrastructure, …
- **Scalable**: From one to billions. Single controllers not scalable.
- Action requires context: Actions need to adopt to changes in infrastructure
- OpenDaylight has a new project on Network Intent Composition (NIC)

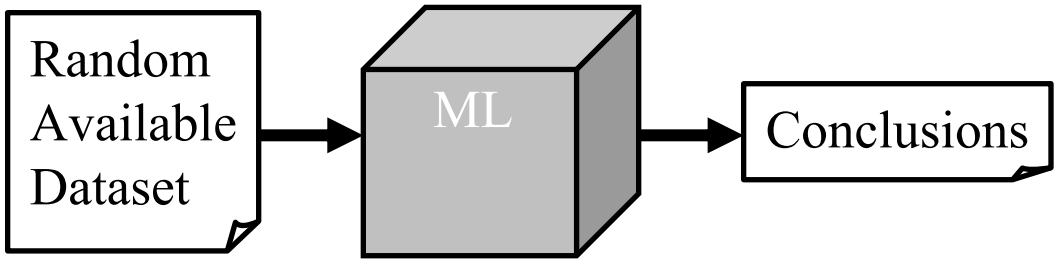
Ref: https://www.sdxcentral.com/articles/contributed/network-intent-summit-perspective-david-lenrow/2015/02/
https://wiki.opendaylight.org/view/Project_Proposals:Network_Intent_Composition

Machine Learning Everywhere

- Intelligent security
- Intelligent human interface
- Intelligent data compression and analytics
  - Intelligent Things
  - Intelligent Gateways/Servers
  - Intelligent Edge/Core Clouds
  - Intelligent LAN/WAN Networks

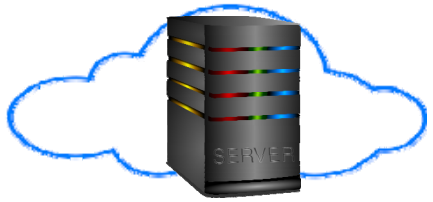
Machine Learning Challenges

- Machine learning is currently a blackbox
- ML algorithms are developed/used without domain expertise
- Data cleanliness, labeling, feature extractions, all require domain knowledge, e.g.,
  What is the distance between Port 80, Port 81, and Port 8080?
- Data Imbalance (1 in a million packet is an attack packet).
- Synthetic data is used ⇒ Garbage-In, Garbage-Out
- Results are stated without model validation.
- Explainability issue ⇒ No idea of why the results are what they are



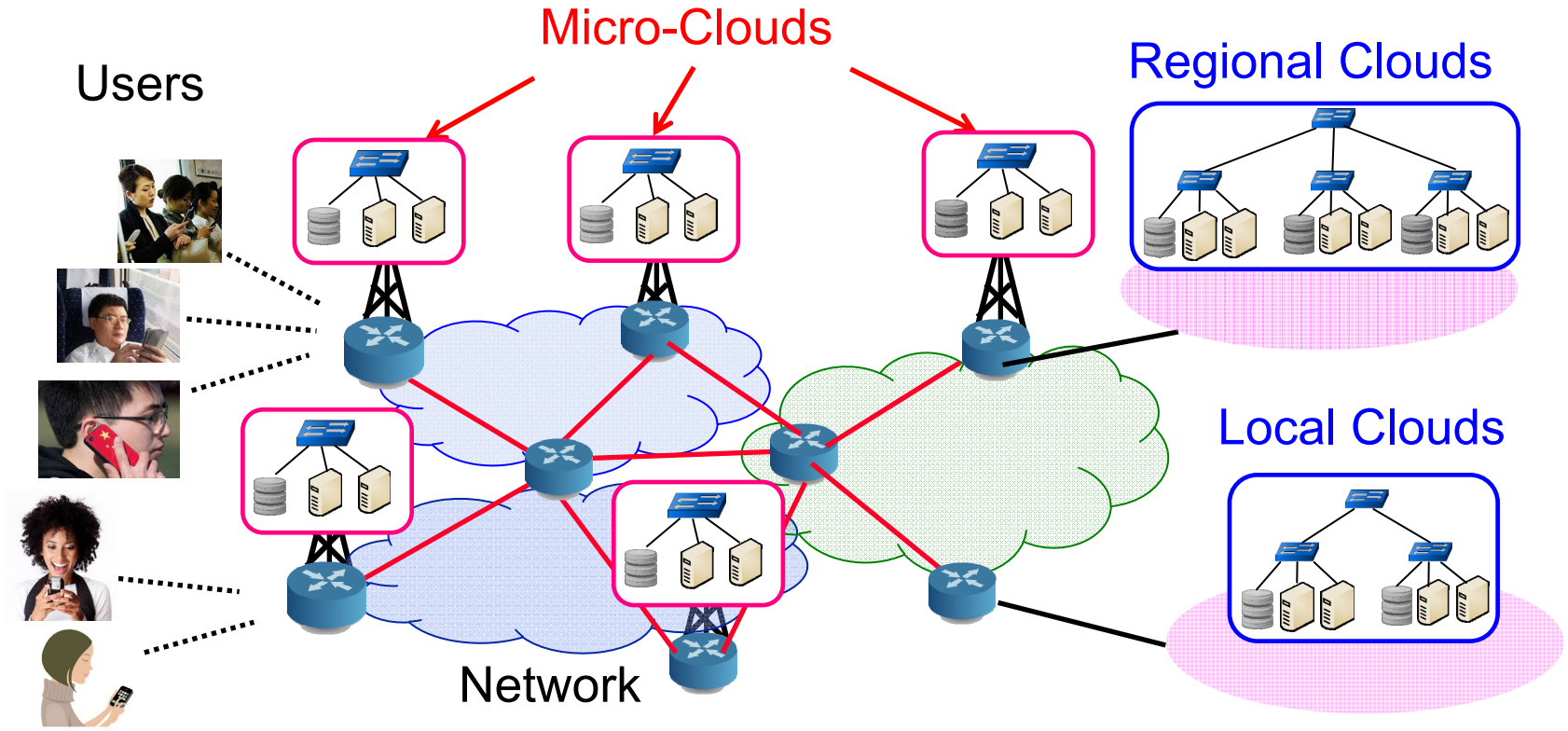
Trend: Clouds to Micro-Clouds

- 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.
  - VMs managed via cloud management SW, e.g., OpenStack



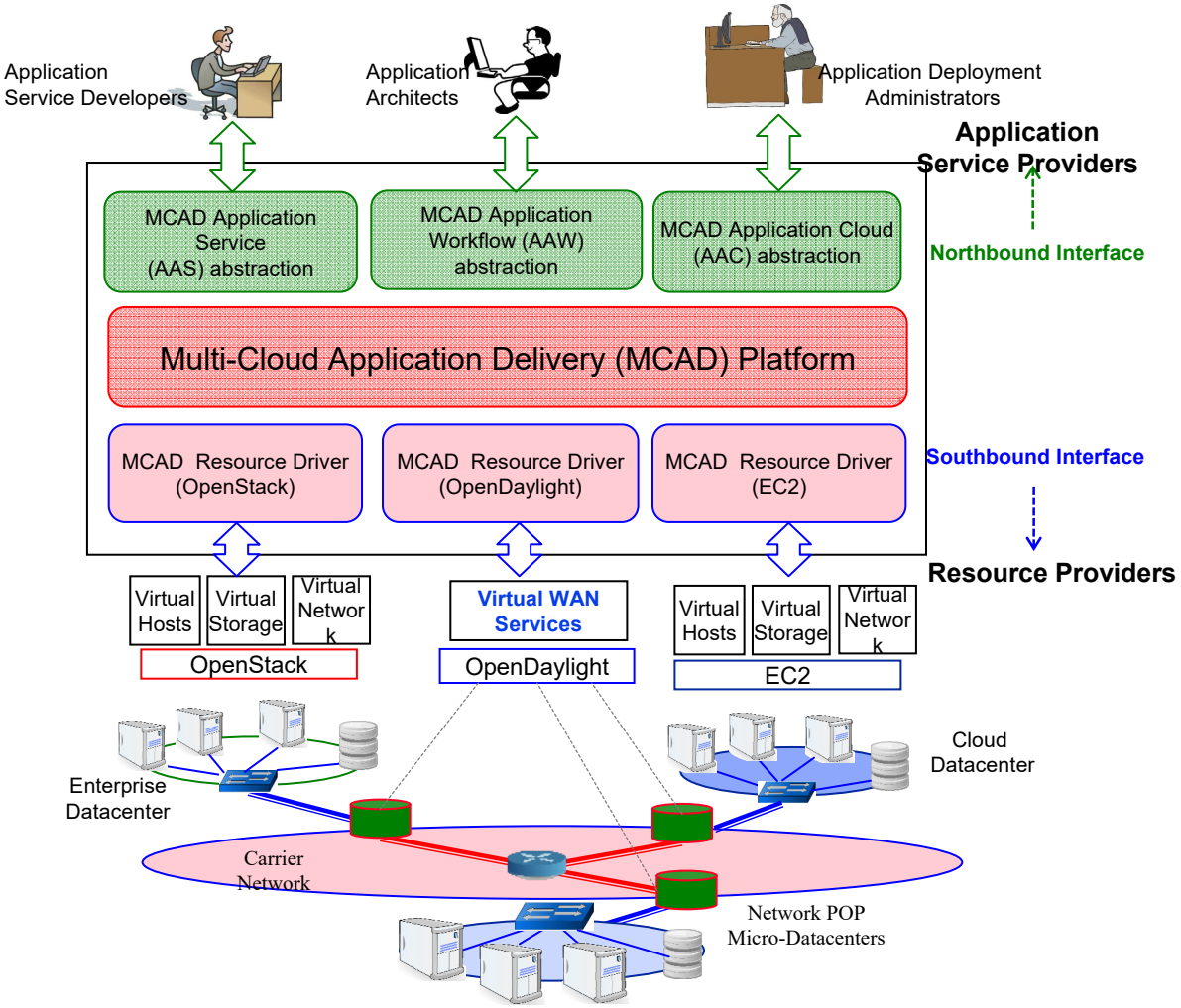
Trend: Core to Edge Computing

- To service mobile users/IoT, the computation needs to come to edge ⇒ Mobile Edge Computing, 5G Small cells



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

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

IoT Use Case for Multi-Clouds

Emergency Service Administrator

sensors for smart services

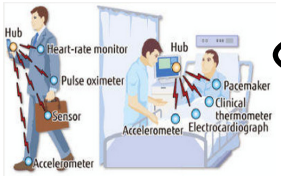
Multi-Cloud Mobile Application Deployment and Optimization Platform

Ambulence Cloud

Network Controller

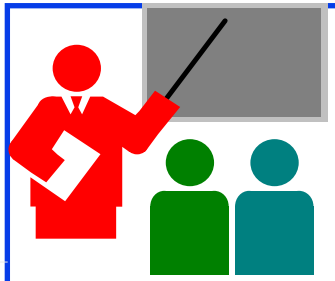
Hospital Cloud

911 Call



5G Carrier

Doctor



Summary

1. Smart ≠ High-Speed Computation, Smart ≠ Big Data Storage, Smart = Networked, Smart = Latest Technology
2. IoT research areas are easy via the 7-layer model
   Research issues in every layer: Sensors, data link, routing, applications, analytics.
3. Security is the biggest issue with no simple solutions but need to avoid common simple mistakes
4. Blockchains offer a distributed alternative to centralized solutions for IoT management
5. AI, Machine Learning, Deep Learning is here.
   Move from smart things to intelligent things
6. Clouds are getting smaller ⇒ Micro-Cloud, Edge Computing ⇒ Multi-Cloud

Related Papers (Cont)

IoT:

- Tara 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

Blockchains:

- Tara Salman, Maede Zolanvari, Aiman Erbad, Raj Jain, and Mohammed Samaka, "**Security Services Using Blockchains:A State of the Art Survey**" IEEE Communications Surveys and Tutorials, Accepted September 2018, 28 pp., http://www.cse.wustl.edu/~jain/papers/bcs.htm

Related Papers (Cont)

AI for Networking:

- Lav Gupta, M. Samaka, Raj Jain, Aiman Erbad, Deval Bhamare, H. Anthony Chan, "**Fault and Performance Management in Multi-Cloud Based NFV using Shallow and Deep Predictive Structures**," 26th International Conference on Computer Communications and Networks (ICCCN 2017), Vancouver, Canada, July 31-Aug 3, 2017, http://www.cse.wustl.edu/~jain/papers/icccn17.htm
- Tara Salman, Deval Bhamare, Aiman Erbad, Raj Jain, Mohammed 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, http://www.cse.wustl.edu/~jain/papers/cscloud.htm
- Lav Gupta, Mohammed Samaka, Raj Jain, Aiman Erbad, Deval Bhamare, Chris Metz, "**COLAP: A Predictive Framework for Service Function Chain Placement in a Multi-cloud Environment**," The 7th IEEE Annual Computing and Communication Workshop and Conference (CCWC), Las Vegas, Jan 9-11, 2017, http://www.cse.wustl.edu/~jain/papers/clp_ccwc.htm
- Deval Bhamare, Tara Salman, Mohammed Samaka, Aiman Erbad, Raj Jain, "**Feasibility of Supervised Machine Learning for Cloud Security**," 3rd International Conference on Information Science and Security (ICISS2016), December 19th - 22nd, 2016, Pattaya, Thailand,, http://www.cse.wustl.edu/~jain/papers/iciss16.htm

Related Papers (Cont)

Multi-Cloud:

- Deval Bhamare, Mohammed Samaka, Aiman Erbad, Raj Jain, Lav Gupta, H. Anthony 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
- Deval Bhamare, Raj Jain, Mohammed Samaka, Aiman Erbad, "**A Survey on Service Function Chaining**," Journal of Network and Computer Applications, Vol. 75, Nov 2016, pp. 138-155, http://www.cse.wustl.edu/~jain/papers/jnca16.htm
- Lav Gupta, Prof Raj Jain, Prof Mohammed Samaka, Prof Aiman Erbad, and Dr. Deval Bhamare, "**Performance Evaluation of Multi-Cloud Management and Control Systems**," Recent Advances in Communications and Network Technology, 2016, Vol. 5, Issue 1, pp. 9-18, http://www.cse.wustl.edu/~jain/papers/racnt.htm
- Subharthi Paul, Raj Jain, Mohammed Samaka, Aiman Erbaud, "**Service Chaining for NFV and Delivery of other Applications in a Global Multi-Cloud Environment**," 21st Annual International Conference on Advanced Computing and Communications (ADCOM) 2015, Chennai, India, September 18-20, 2015, http://www.cse.wustl.edu/~jain/papers/adn_in15.htm

Recent Papers (Cont)

- Deval Bhamare, Raj Jain, Mohammed Samaka, Gabor Vaszkun, Aiman Erbad, "Multi-Cloud Distribution of Virtual Functions and Dynamic Service Deployment: OpenADN Perspective," Proceedings of 2nd IEEE International Workshop on Software Defined Systems (SDS 2015), Tempe, AZ, March 9-13, 2015, 6 pp. http://www.cse.wustl.edu/~jain/papers/vm_dist.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 Magazine, Nov 2013, pp. 24-31, http://www.cse.wustl.edu/~jain/papers/net_virt.htm

Related Papers (Cont)

Edge Computing:

- 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
- Deval Bhamare, Aiman Erbad, Raj Jain, Mohammed Samaka, "**Automated Service Delivery Platform for C-RANs**," The IEEE Third International Workshop on Mobile Cloud Computing systems, Management, and Security (MCSMS) 2017, Valencia Spain, May 8-11, 2017, http://www.cse.wustl.edu/~jain/papers/mcsms17.htm,

Related Talks/Class Lectures

- Raj Jain, "**CSE 570: Recent Advances in Networking**," Spring 2018, http://www.cse.wustl.edu/~jain/cse570-18/index.html
- Raj Jain, "Extending Blockchains for Risk Management and Decision Making," Invited talk at Innovation and Breakthrough Forum 2018, Hong Kong, Nov. 9, 2018, http://www.cse.wustl.edu/~jain/talks/pbc_ibf.htm
- Raj Jain, "Trends and Issues in Softwarization of Networks: What's In, What's Out," Invited talk at Hong Kong University of Science and Technology, Nov. 8, 2018, http://www.cse.wustl.edu/~jain/talks/hkust18.htm
- 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

Related Talks/Class Lectures (Cont)

- 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, "Smart Cities: Technical Issues and Challenges," A talk given at Smart City Meet up, University City, MO, August 10, 2017, http://www.cse.wustl.edu/~jain/talks/smrtcity.htm
- Raj Jain, "Blockchains: The Distributed Trust Technology," Keynote at The 2017 International Conference on Computer, Information and Telecommunication Systems (CITS 2017), Dalian, China, July 21, 2017, http://www.cse.wustl.edu/~jain/talks/cits17.htm
- Raj Jain, "Seven Trends Leading to Opportunities in Multi-Cloud Global Application Delivery," Keynote at 2016 International Conference on Communications, Image, and Signal Processing (CCISP), Dubai, November 19, 2016. http://www.cse.wustl.edu/~jain/talks/ccisp16.htm
- Raj Jain, "Multi-Cloud Global Application Delivery for Internet of Things and Smart Cities," Keynote at the 2nd IEEE International Conference on Collaboration and Internet Computing (CIC), Pittsburgh, PA, Nov 1, 2016, http://www.cse.wustl.edu/~jain/talks/adn_cic.htm

Related Talks/Class Lectures (Cont)

- 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 Leading to Opportunities in Multi-Cloud Global Application Delivery," Research seminar at Cisco, San Jose, March 18, 2016, http://www.cse.wustl.edu/~jain/talks/cisco16.htm
- Raj Jain, "Internet of Things: Research Challenges and Issues," Keynote at the Internet of Things World Forum, Research and Innovation Symposium, Dubai, December 5-6, 2015, http://www.cse.wustl.edu/~jain/talks/iotwrld.htm

Acronyms

- 5G Fifth Generation
- AAC Abstraction for Application Cloud
- AAS Application Service Abstraction
- AAW Abstraction for Application Workload
- ACM Automatic Computing Machinery
- ADCOM Advanced Computing and Communications
- AI Artificial Intelligence
- BGP Border Gateway Protocol
- BSS Business Support Systems
- CCWC Computing and Communication Workshop and Conference
- COLAP Cost optimized latency aware placement
- CSCloud Computer Science Cloud
- DARPA Defense Advanced Research Project Agency
- DDoS Distributed Denial of Service
- DEFCON d-e-f conference (named after alphabets d, e, f)

Acronyms (Cont)

- DNS Domain Name System
- DoS Denial of Service
- DSL Digital Subscriber Line
- EC2 Elastic Compute 2
- FTTH Fiber to the home
- GIS Geographical Information Systems
- GPS Global Positioning System
- IEEE Institution of Electrical and Electronic Engineers
- IERC European Research
- IoT Internet of Things
- ISP Internet Service provider
- MCAD Multi-Cloud Application Delivery
- ML Machine Learning
- NFV Network Function Virtualization
- NIC Network Interface Card
- OpenADN Open Application Delivery Networking

Acronyms (Cont)

- OSS Operations Support Systems
- PHY Physical Layer
- PKI Public Key Infrastructure
- RAN Radio Access Networks
- RFID Radio Frequency Identifier
- RSA Rivest, Silverman, Adleman
- SDN Software Defined Networking
- SDS Software Defined Systems
- SOA Service oriented Architecture
- SW Software
- TV Television
- USA United States of America
- VC Venture Capitalist
- VM Virtual Machine
- WiFi Wireless Fidelity
- XML eXtended Markup Language

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