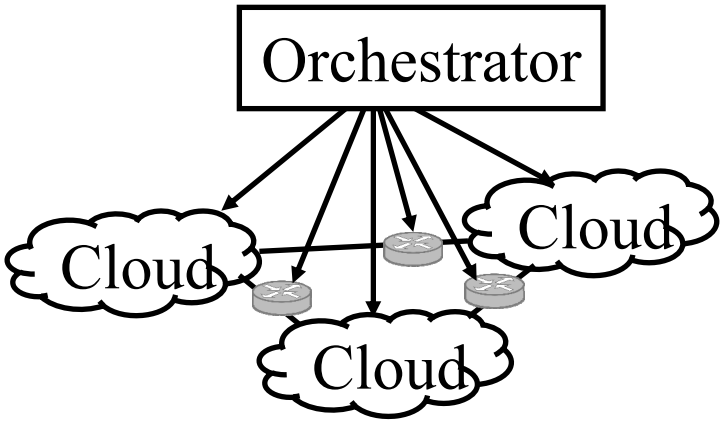
Trends and Issues in Softwarization of Networks: What's In, What's Out



Raj Jain
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Invited Talk at Hong Kong University of Science and Technology, Hong Kong, Nov. 8, 2018

These slides and recording of this talk are available on-line at:
http://www.cse.wustl.edu/~jain/talks/hkust18.htm

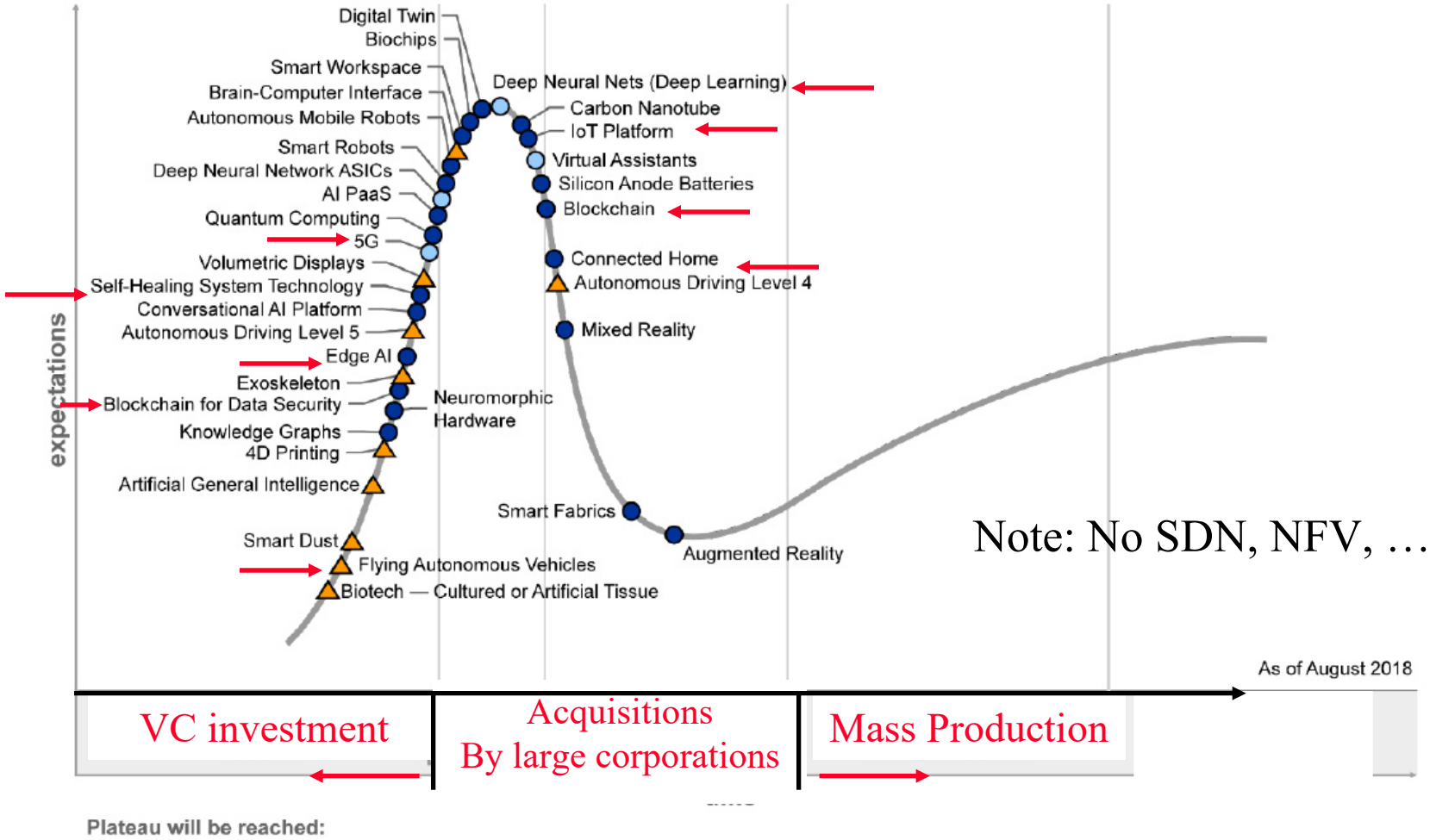
Overview

1. What has changed in the last five years?
2. What has happened to SDN, NFV, and Clouds?
3. What's in, what's out?

Selecting the Right Problems

- Important question for **students**, academics, entrepreneurs, and companies
- Goal: To impact
- Follow the **paradigm shifts**:
  - 1980: Ethernet
  - 1990: ATM Networks
  - 2000: Optical Networks
  - 2005: Wireless Networks
  - 2010: Next Generation Internet/SDN
  - 2013: Multi-Cloud Computing
  - 2018: Whatever is being **hyped** this year?

Gartner Hype Cycle 2018

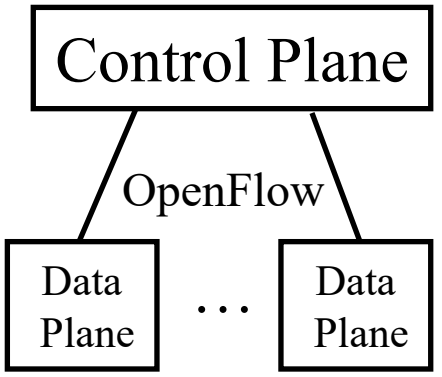


Note: No SDN, NFV, …

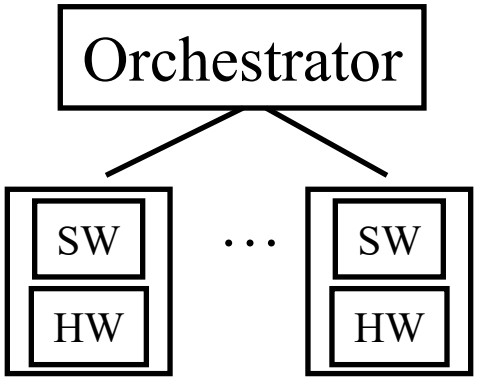
Ref: M. Walker, "Hype Cycle for Emerging Technologies, 2018," Gartner Report G00340159, 6 Aug. 2018, 73 pp.

Trend 1: SDN to Disaggregation

- SDN was invented in 2009
- Then: SDN:
  - Separation of control and data planes
  - Centralization of Control
  - Standard Protocol between the planes



- Now: Software Defined = **Disaggregation** of HW/SW
  - Commodity hardware
  - Software that runs on commodity HW
  - Legacy protocols survive



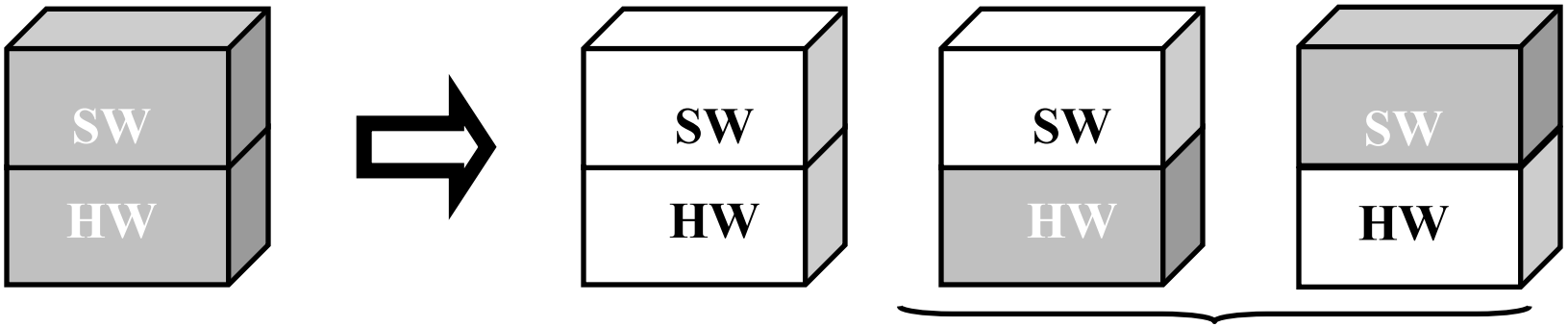
Ref: D. M Batista, G. Blair, F. Kon, R. Boutaba, D. Hutchison, R. Jain, R. Ramjee, C. Rothenberg, "Perspectives on software-defined networks: interviews with five leading scientists from the networking community" Journal of Internet Services and Applications 2015, 6:22, http://www.cse.wustl.edu/~jain/papers/jisa15.htm

Disaggregation: Black Box to White Box

- All specialization and differentiation via software

⇒ White box networking

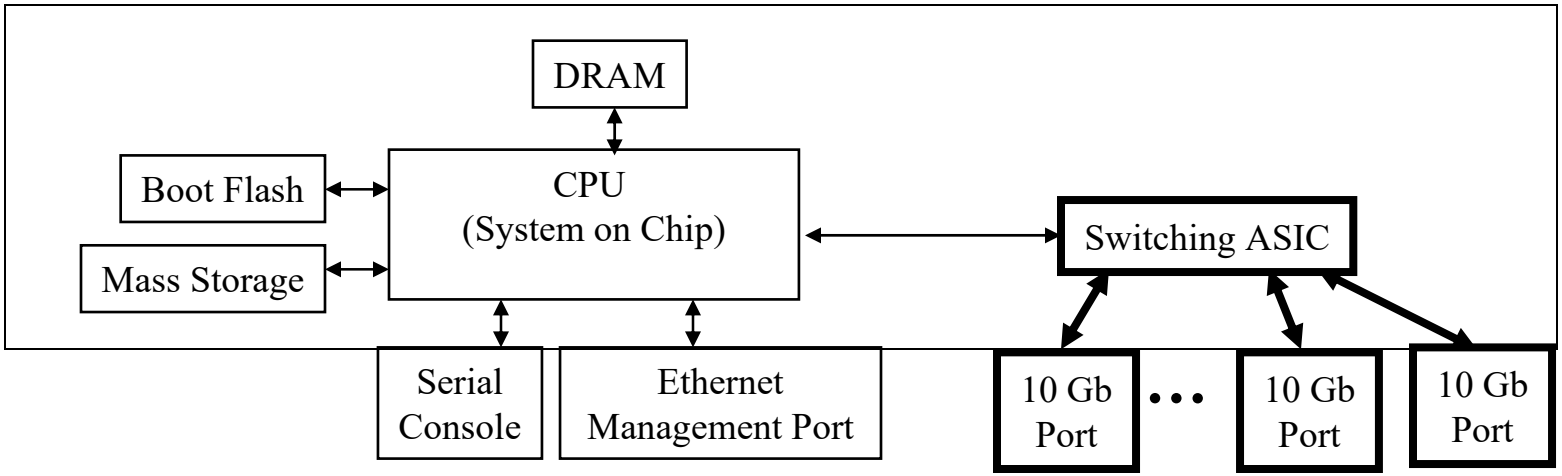
- **Black Box**: Proprietary HW with Proprietary SW
- **White Box**: Open Source Hardware and Software
- Software on a different hardware ⇒ hardware can change
  Different software on a hardware ⇒ Software can change
- **Bright Box**: Branded White box =
  Branded SW on open HW or Open SW on Branded HW



Ref: A. Lerner, "Branded Switching + White-Box Switching = Brite-Box Switching," Nov 14, 2014, https://blogs.gartner.com/andrew-lerner/2014/11/19/britefuture/

White Box Switches

- Switches by EdgeCore Networks (ACTON), Quanta, HPE, DNI, Dell, Mellanox, Delta Agema, Celestica, Alpha Networks, Ingrasys, Inventec, Netberg
- Switching ASICs by Broadcom, Marvell, Intel/Fulcrum, Mellanox, Barefoot, and Cavium
- CPUs: Intel Rangeley/Atom, Freescale, ARM A9



Ref: ONL Hardware Support and Certification, http://www.opennetlinux.org/hcl
Washington University in St. Louis http://www.cse.wustl.edu/~jain/talks/hkust18.htm

Trend 2: Separation of Control to Orchestration of Policies

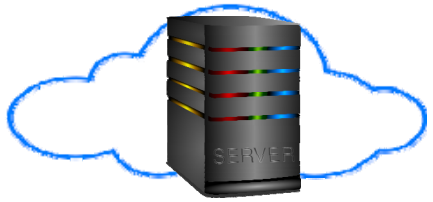
Separation and Centralization of Control Plane

Orchestration of Policies

Micromanagement is not scalable

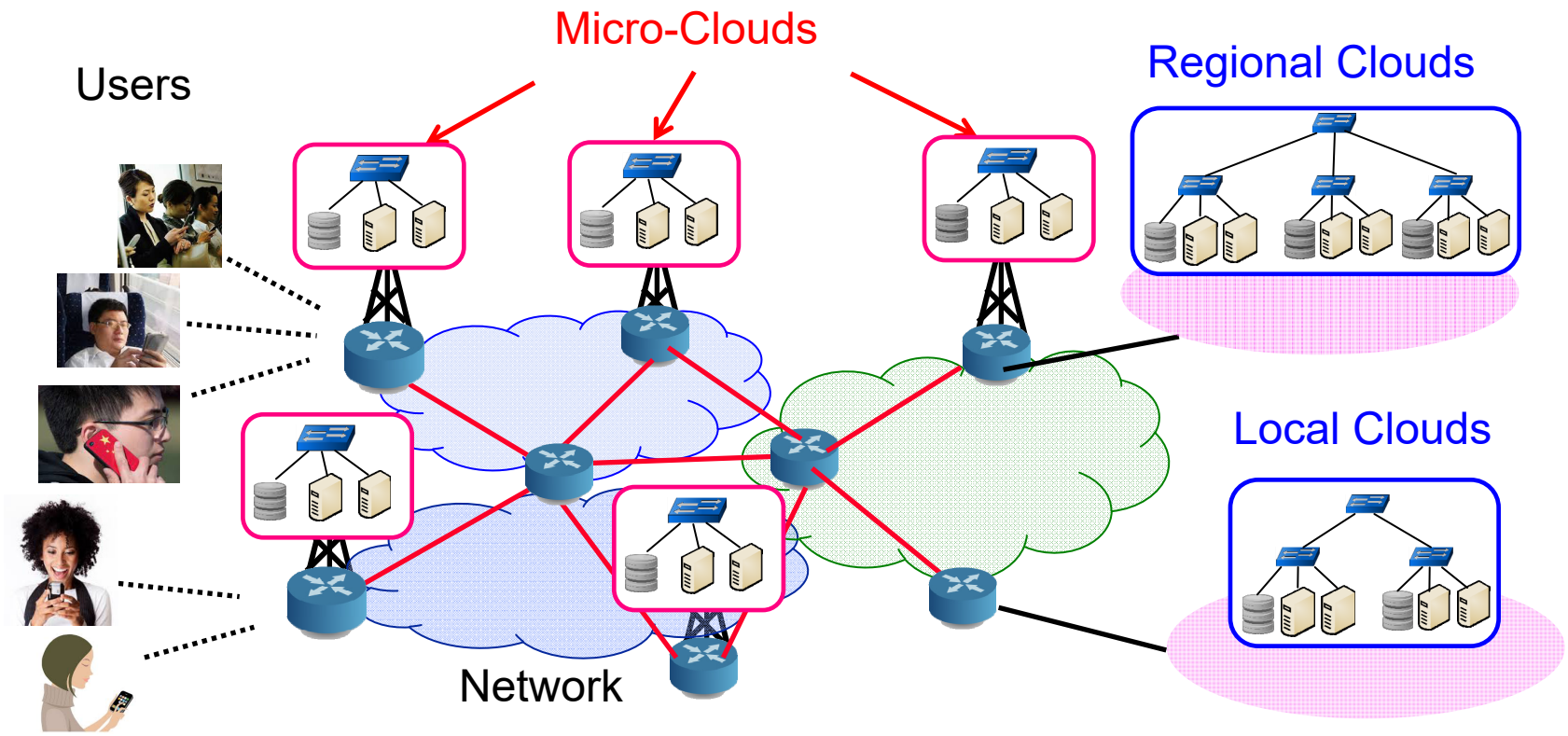
Trend 3: Clouds to Micro-Clouds

- 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 4: Core to Edge Computing

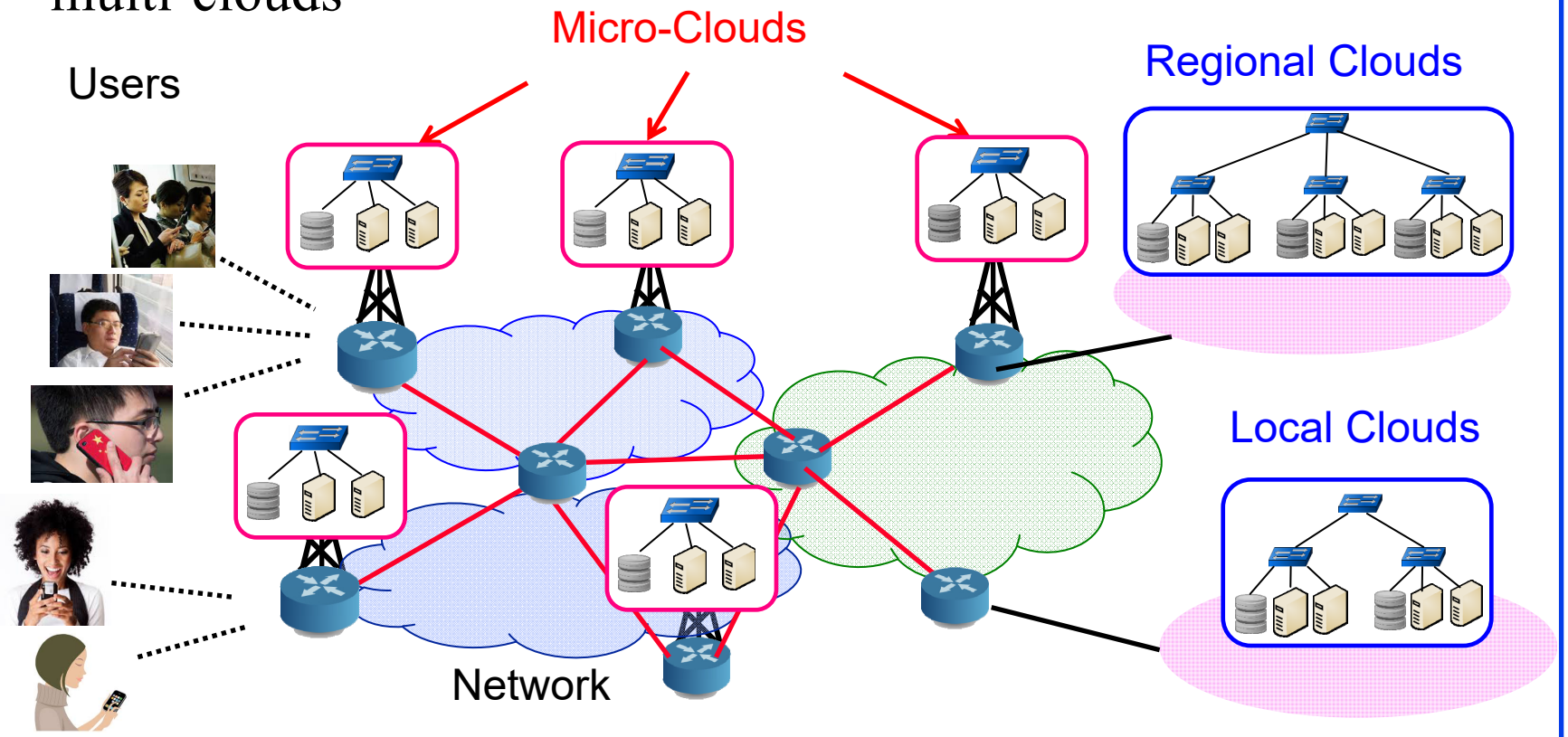
- To service mobile users/IoT, the computation needs to come to edge ⇒ Mobile Edge Computing



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

Trend 5: Services to Micro-Services

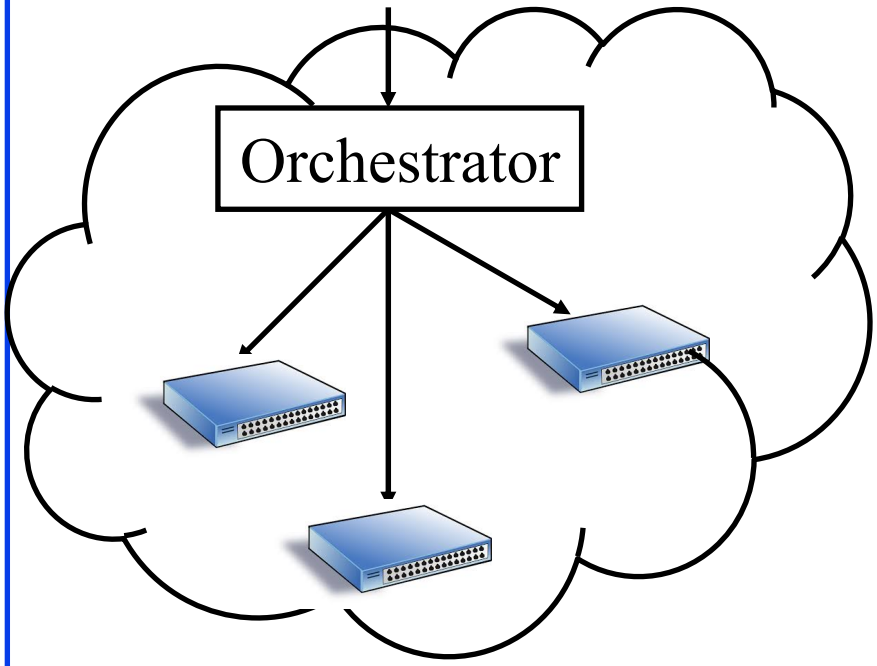
- **Decomposition**: Applications are broken in to smaller pieces that can be developed, tested, and run in isolation on multi-clouds



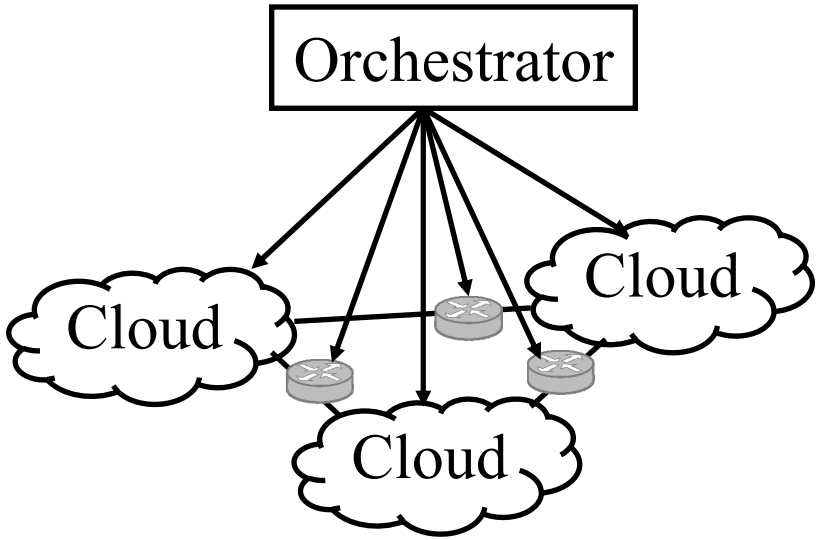
Trend 6: Orchestration of Switches to Orchestration of Multi-Cloud

- Orchestrating devices to Orchestrating Clouds
- Micro-Service placement and optimization in multi-clouds

Datacenter Applications



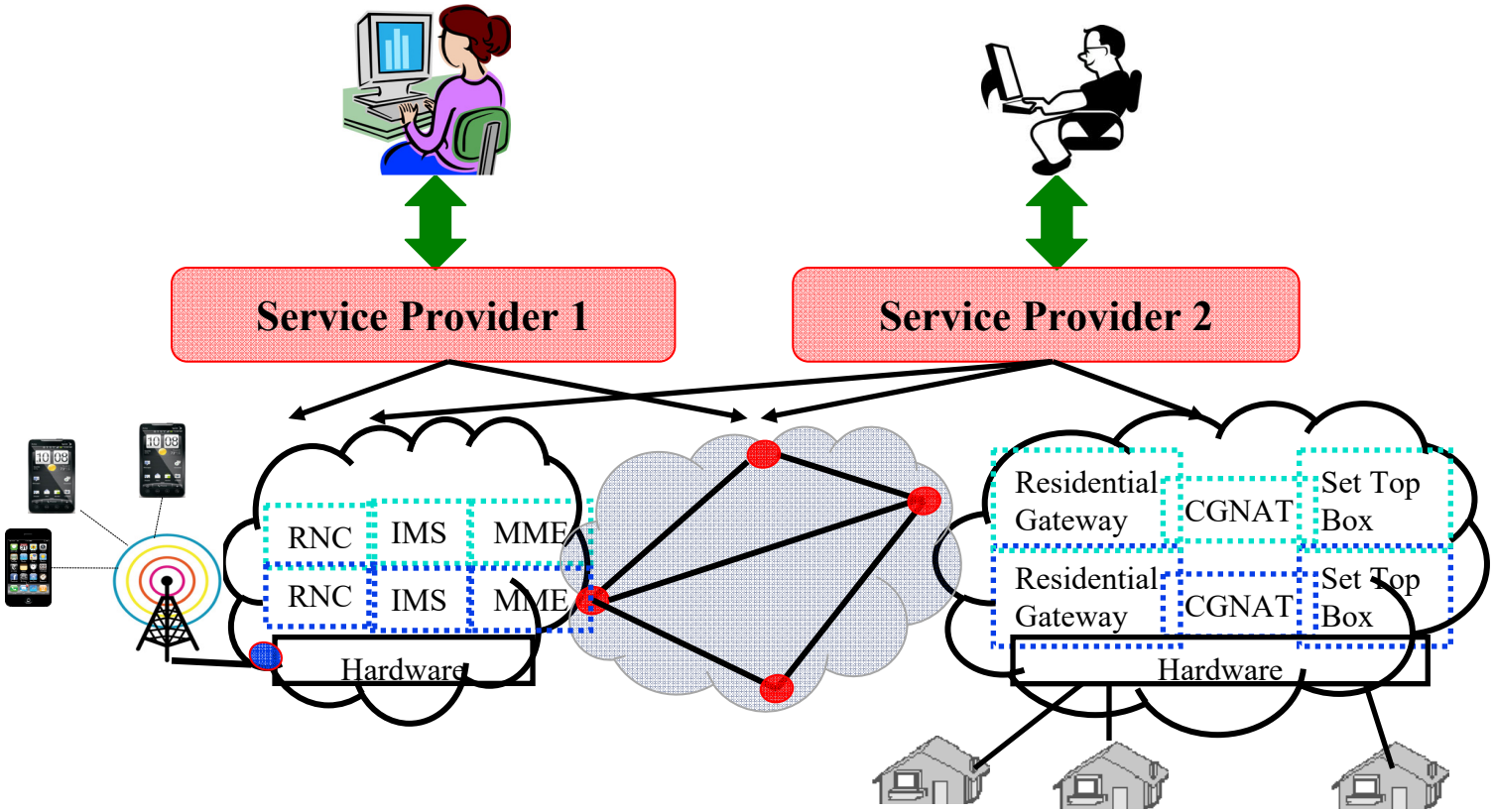
Global Applications



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

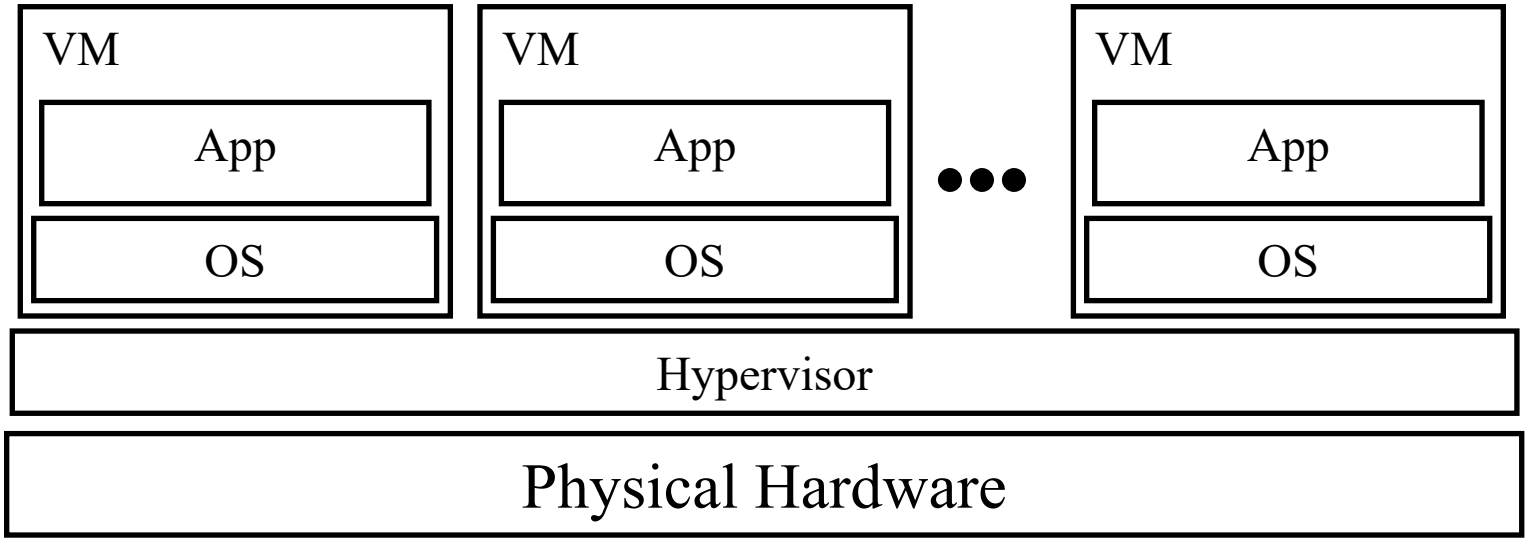
Network Function Virtualization (NFV)

- Network Functions on Virtual Machines in a cloud



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

Problems with Virtual Machines



- Each VM requires an operating system (OS)
  - Each OS requires a license ⇒ **CapEx**
  - Each OS has its own compute and storage overhead
  - Needs maintenance, updates ⇒ **OpEx**
  - **VM Tax** = added CapEx + OpEx

Trend 7: Virtualization to Containerization

- Run many apps in the same virtual machine
  - These apps share the OS and its overhead
  - Can't access each other's resources without explicit permission
  - Like apartments in a complex ⇒ Containers

Kata Containers

- Containers do have less security than VMs
- Kata Containers = VM + Container hybrid
- Combines "Intel Clear Containers" and "HyperV runV"
- Open source project under OpenStack Foundation
- Performance like containers, isolation and security like VMs
- Package once and run anywhere
  - VMware, Google, and Amazon are all moving towards this approach

Ref: https://katacontainers.io/
https://www.forbes.com/sites/janakirammsv/2017/12/11/why-kata-containers-is-good-for-the-industry-and-customers/2/#3d8cc2e9404f

Standards are Slow

- Initially, Standards ⇒ Interoperability
  Iff all companies implement the same way
- Standards = Compromises ⇒ We agree to disagree
  All differing opinions are part of the standard as option
  Different companies choose different options
  ⇒ No Interoperability
- Need Interoperability organizations
  - WiFi ⇒ Approves the subset of standard that is mandatory
- All this introduces delay
  ⇒ The standard out of date when it is ready for implementation
- IEEE 802.11ah-2016 Long-Range WiFi for IoT. Started 2010.
  Taken over by competition: ZigBee, LoraWAN, …

Ref: http://www.ieee802.org/11/Reports/802.11_Timelines.htm

Standards are not Open

- Open ⇒ Anyone can implement it without fee
- IETF allows "non-discriminatory and reasonable licensing fee"
  ⇒ Not really open
- Open Source Initiative (OSI) Criteria:
  - No intentional secrets
  - Free and publicly available
  - All patents must be royalty-free for unrestricted use
  - No license agreements, NDA, or paperwork to implement
  - Not dependent on non-open standards

Ref: https://en.wikipedia.org/wiki/Open_standard, https://opensource.org/osr

Trend 8: Standards to Open Source SW

- Standardization to Rough Consensus and Running Code
- IETF has ~100 working groups
  Open Linux Foundation has >100 open source networking projects. Their website can't be kept uptodate.
- 4 Opens:
  - Open Source
  - Open Design
  - Open Development
  - Open Community

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/contract 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 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
     $\Rightarrow$ 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.

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
  - Public Key Infrastructure
    - Certificate Authorities issue certificates
    - Single Point of Failure
    - Example: Diginotar – Dutch CA compromised in 2011

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

Smart Everything

Smart Watch

Smart TV

Smart Car

Smart Health

Smart Home

Smart Kegs

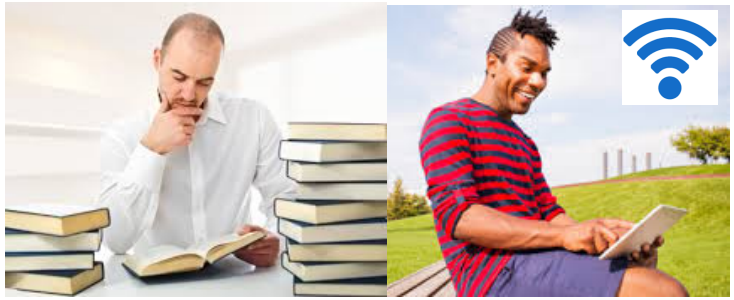
Smart Space

Smart Industries

Smart Cities

What's Smart?

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

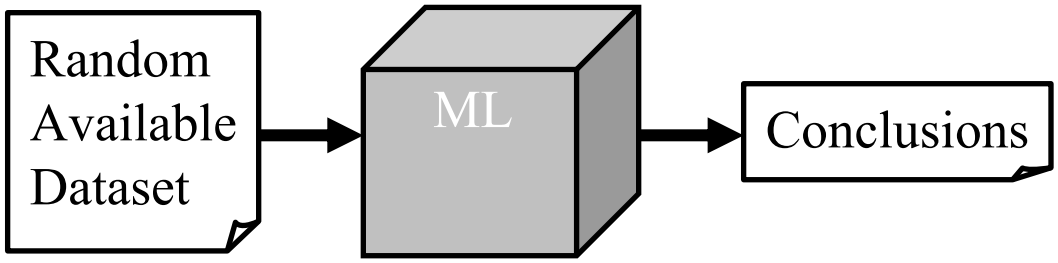


Not-Smart Smart

- Smart = Apply the latest **technology** to solve problems

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).
- Use 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 11: Managed to Self-Driven Networks

- **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

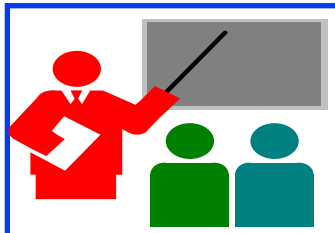
Network Manager

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



Summary

#	Past	Present/Future
1	SDN	Disaggregation
	Proprietary Black Boxes	Standardized White Boxes
2	Control	Orchestration
3	Clouds	Micro-Clouds
4	Core	Edge
5	Services	Micro-services
6	Orchestration of Switches	Orchestration of Multi-Cloud
7	Virtualization	Containerization
8	Standards	Open-Source SW
9	Centralized	Distributed
10	Smart	Intelligent
11	Managed	Self-Driven

1. Networking is changing faster than PhD research cycles
2. For impact/success, publishing is not sufficient. Implement your research in open source SW.

Related Papers

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

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 Papers (Cont)

Micro-Services:

- Deval Bhamare, Mohammed Samaka, Aiman Erbad, Raj Jain, Lav Gupta, "**Exploring Micro-Services for Enhancing Internet QoS**," Transactions on Emergin Telecommunications Technologies, Accepted June, 2018, ISSN: 2161-3915, DOI: 10.1002/ett.3445, http://www.cse.wustl.edu/~jain/papers/ms_ett18.htm
- Deval Bhamare, Aiman Erbad, Raj Jain, Maede Zolanvari, Mohammed 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
- Deval Bhamare, Mohammed Samaka, Aiman Erbad, Raj Jain, Lav Gupta, H. Anthony Chan, "**Multi-Objective Scheduling of Micro-Services for Optimal Service Function Chains**," International Conference on Communications (ICC 2017), May 21-25, 2017, http://www.cse.wustl.edu/~jain/papers/icc17.htm

Related Papers (Cont)

Micro-Services (Cont):

- Deval Bhamare, Raj Jain, Mohammed Samaka, Gabor Vaszkun, Aiman Erbad, "**Multi-Cloud Distribution of Virtual Functions and Dynamic Service Deployment: OpenADN Perspective**," 2015 IEEE International Conference on Cloud Engineering (IC2E), Tempe, AZ, March 9-13, 2015, pp. 299-304, http://www.cse.wustl.edu/~jain/papers/vm_dist.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, ISSN: 10848045, DOI: 10.1016/j.jnca.2016.09.001, http://www.cse.wustl.edu/~jain/papers/jnca16.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)

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

Blockchain:

- 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, September 2018, 28 pp., http://www.cse.wustl.edu/~jain/papers/bcs.htm
- Tara Salman, Raj Jain, and Lav Gupta, "**Probabilistic Blockchains: A Blockchain Paradigm for Collaborative Decision-Making**," 9th IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON 2018), New York, NY, November 8-10, 2018, 9 pp., http://www.cse.wustl.edu/~jain/papers/pbc_uem.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, "**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, "**Recent Advances in Networking and their Impact on Smart Cities**," Keynote at 4th IEEE International Smart Cities Conference (ISC2), Kansas City, MO, September 16-19, 2018, http://www.cse.wustl.edu/~jain/talks/smrtciti.htm

List of Acronyms

- API — Application Programming Interface
- CapEx — Capital Expenditure
- CE — Community Edition
- CLI — Command Language Interface
- CNCF — Cloud Native Computing Foundation
- DCT — Docker Content Trust
- EE — Enterprise Edition
- ID — Identifier
- OCI — Open Cloud Initiative
- OpEx — Operational Expenses
- OS — Operating System
- TCP — Transmission Control Protocol
- VM — Virtual Machine
- VXLAN — Virtual eXtended Local Area Network

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