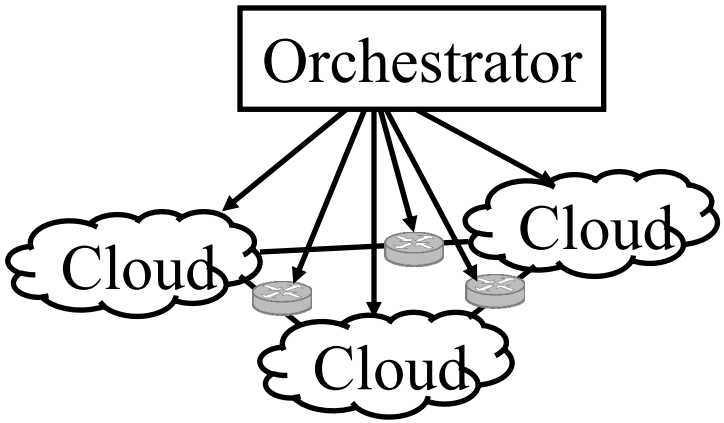
Trends and Issues in Softwarization of Networks: What's In, What's Out



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Invited Talk at IEEE Workshop on Network Automation
Piscataway, NJ, February 25, 2019

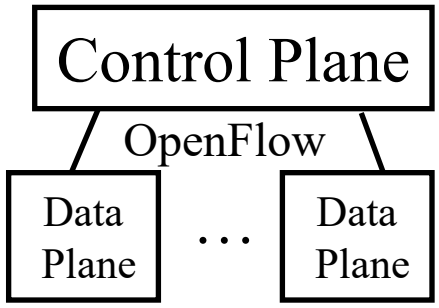
These slides and recording of this talk are available on-line at:
http://www.cse.wustl.edu/~jain/talks/inetauto.htm

Overview

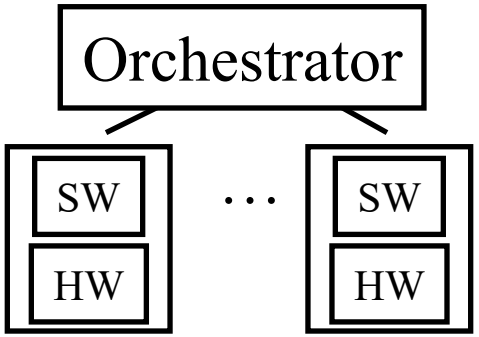
1. What has changed in the last five years?
2. What has happened to OpenFlow, SDN, and Clouds?
3. Twelve Trends ⇒ What's in, what's out?

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



- **203** Papers on OpenFlow on IEEExplore in 2018!
- Now: Software Defined = **Disaggregation** of HW/SW
  - Commodity hardware
  - Software on commodity HW
  - Legacy protocols survive

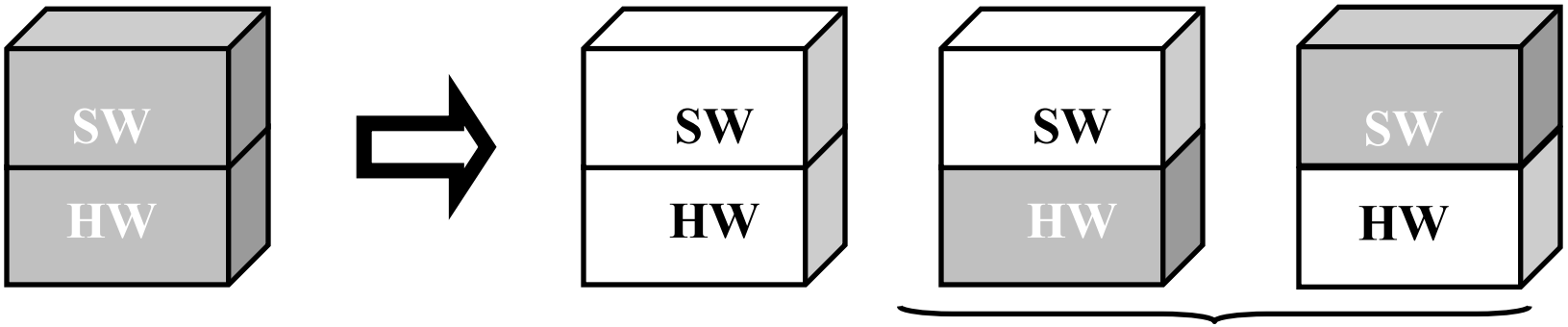


Ref: D. M Batista, G. Blair, F. Kon, R. Boutaba, D. Hutchison, R. Jain, R. Ramjee, C. Rothenberg, "Perspectives on software-defined networks: interviews with five leading scientists from the networking community" Journal of Internet Services and Applications 2015, 6:22, http://www.cse.wustl.edu/~jain/papers/jisa15.htm

J. Skorupa and D. Ciscato, "State of SDN: If You Think SDN Is the Answer, You're Asking the Wrong Question," Gartner Report G00325601, 24 August 2017, 9 pp.

Disaggregation: Black Box to White Box

- 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/

Trend 2: Separation of Control to Orchestration of Policies

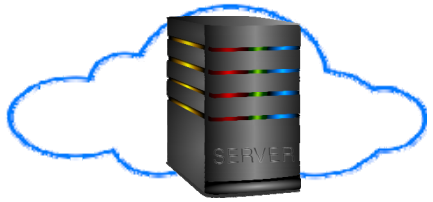
Separation and Centralization of Control Plane

Orchestration of Policies

Micromanagement is not scalable

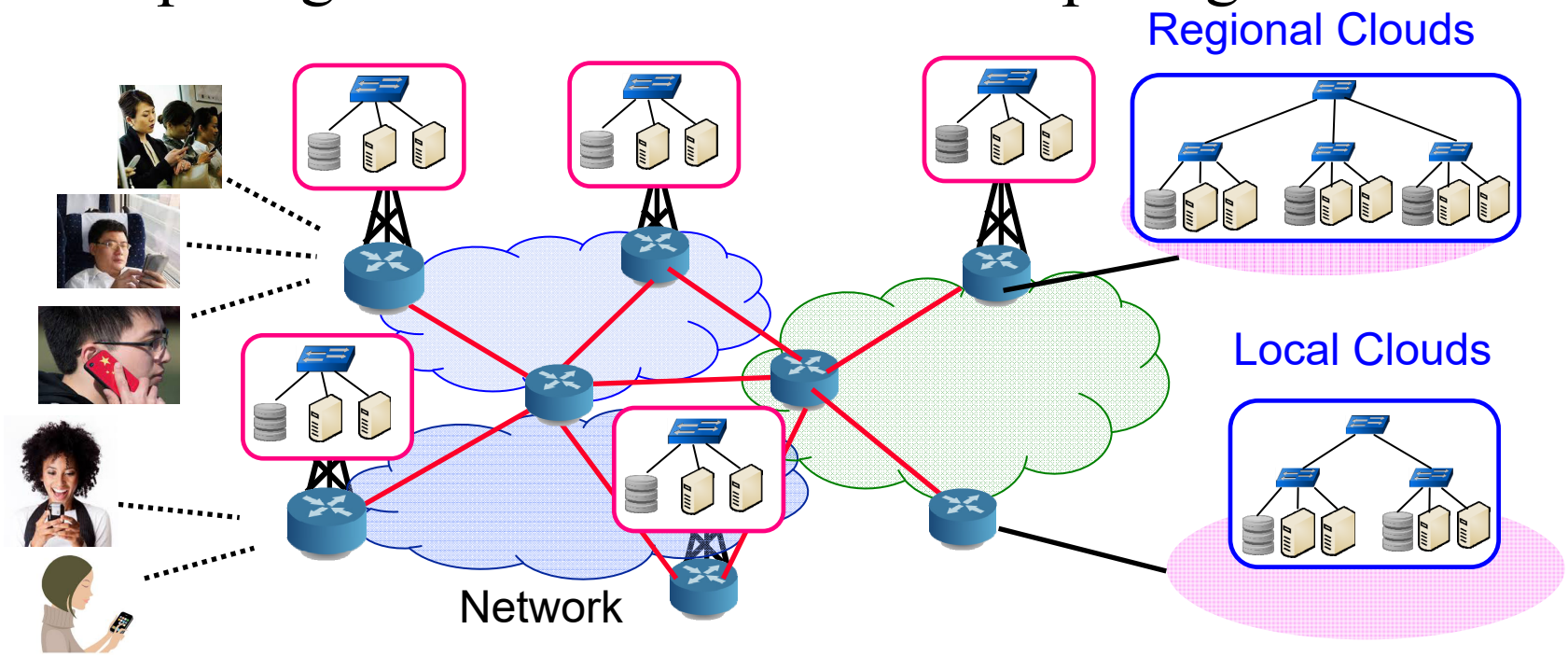
Trend 3: Clouds to Micro-Clouds

- 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

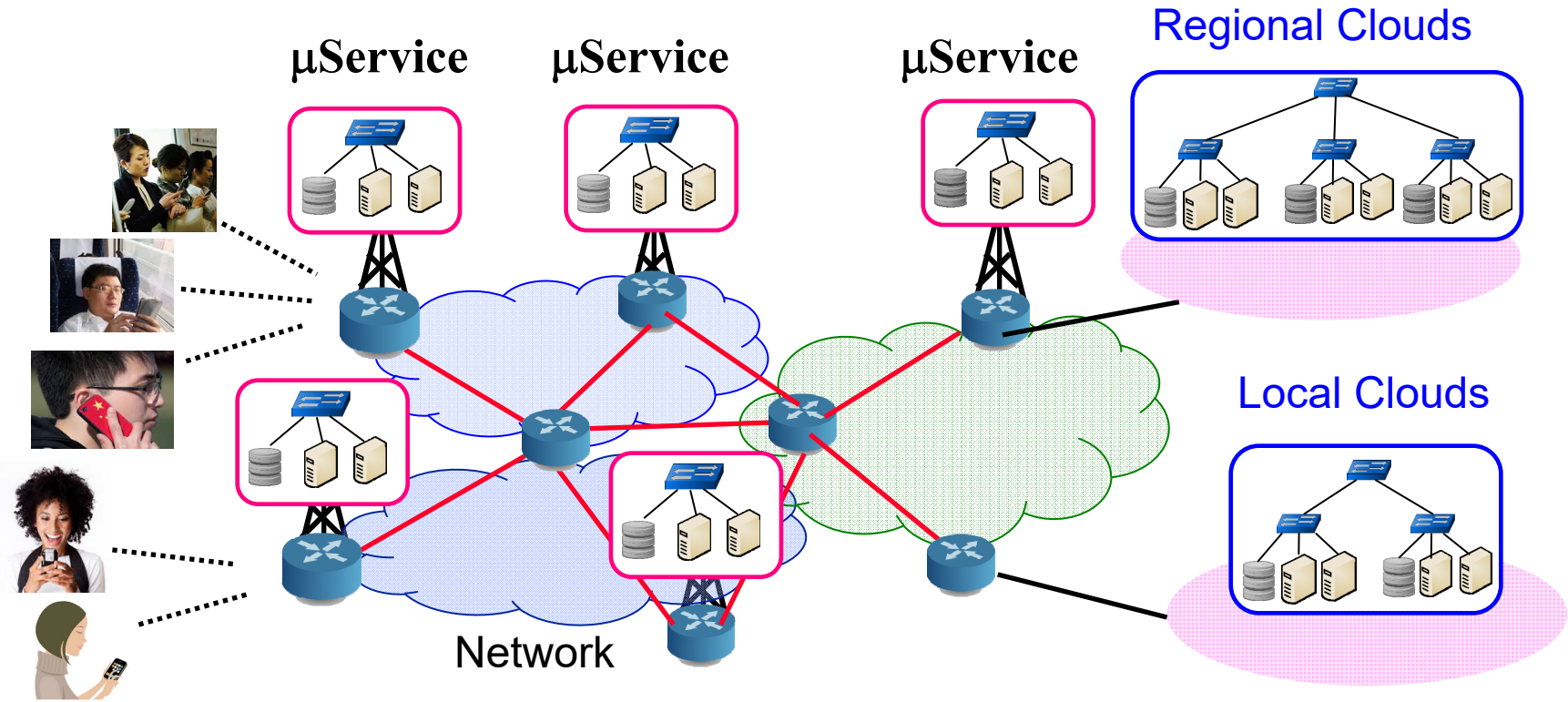
- To service mobile users/IoT, the computation needs to come to edge ⇒ Mobile Edge Computing. Edge computing = Distributed Cloud Computing



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 run in isolation on multi-clouds

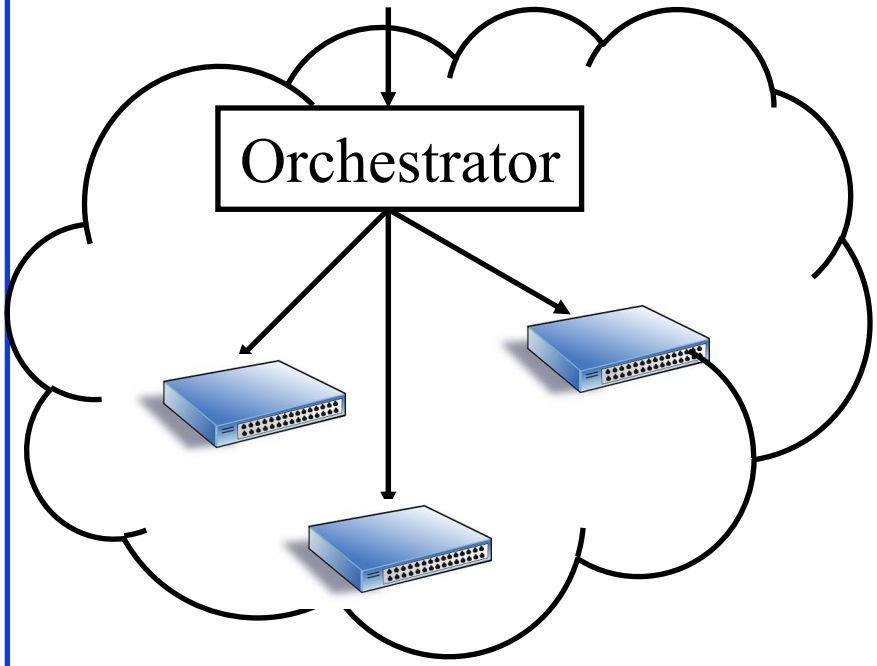


Ref: D. Bhamare, M. Samaka, A. Erbad, R. Jain, L. Gupta, H. A. Chan, "**Multi-Objective Scheduling of Micro-Services for Optimal Service Function Chains**," ICC 2017, May 21-25, 2017, http://www.cse.wustl.edu/~jain/papers/icc17.htm

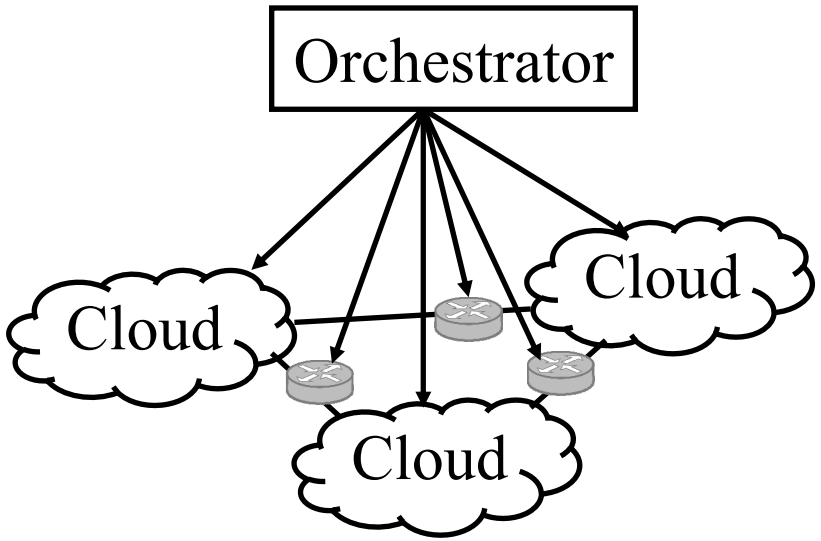
Trend 6: Orchestration of Switches to Orchestration of Multi-Cloud

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

Datacenter Applications

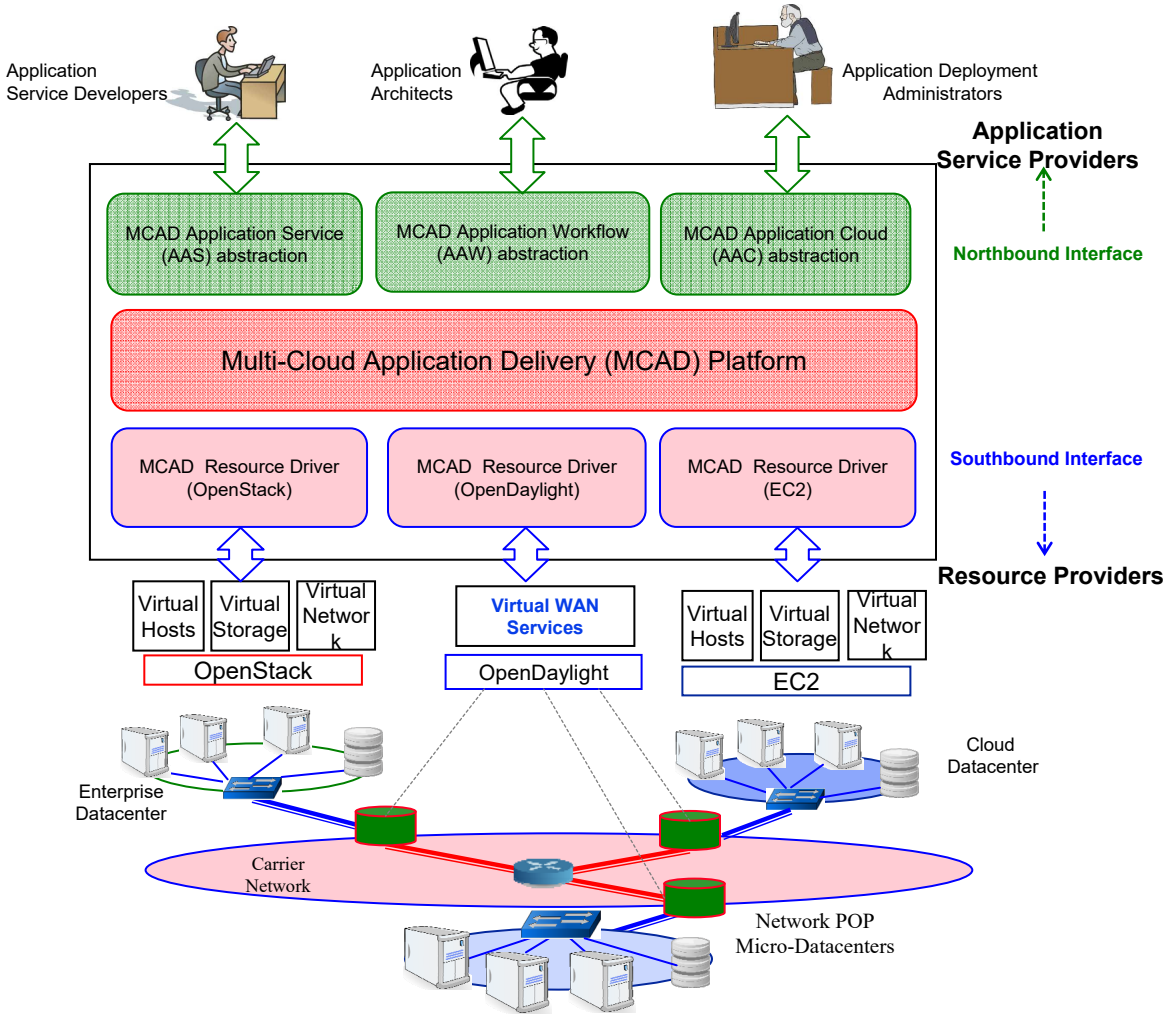


Global Applications



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

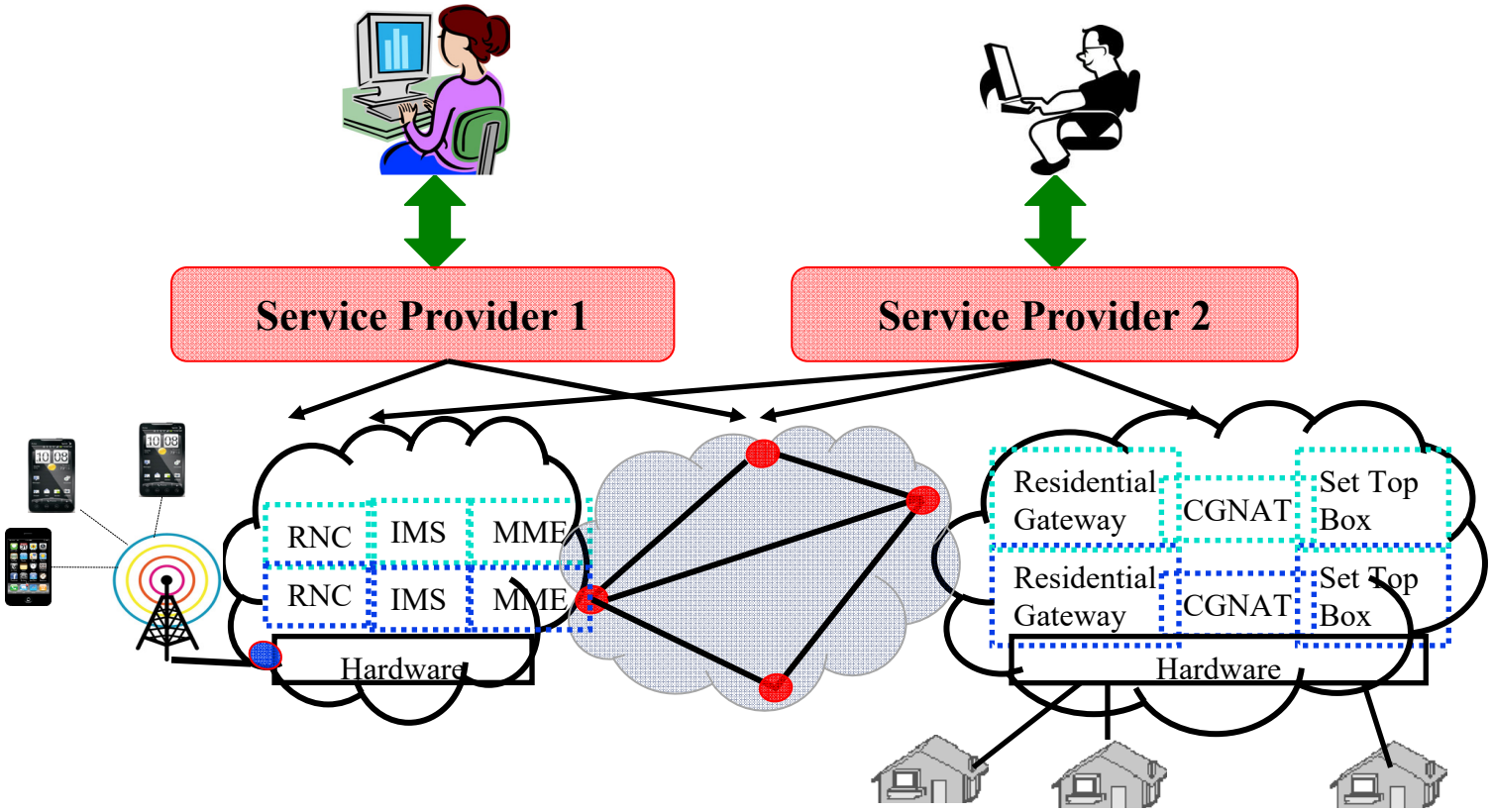
OpenADN Multi-Cloud Management



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

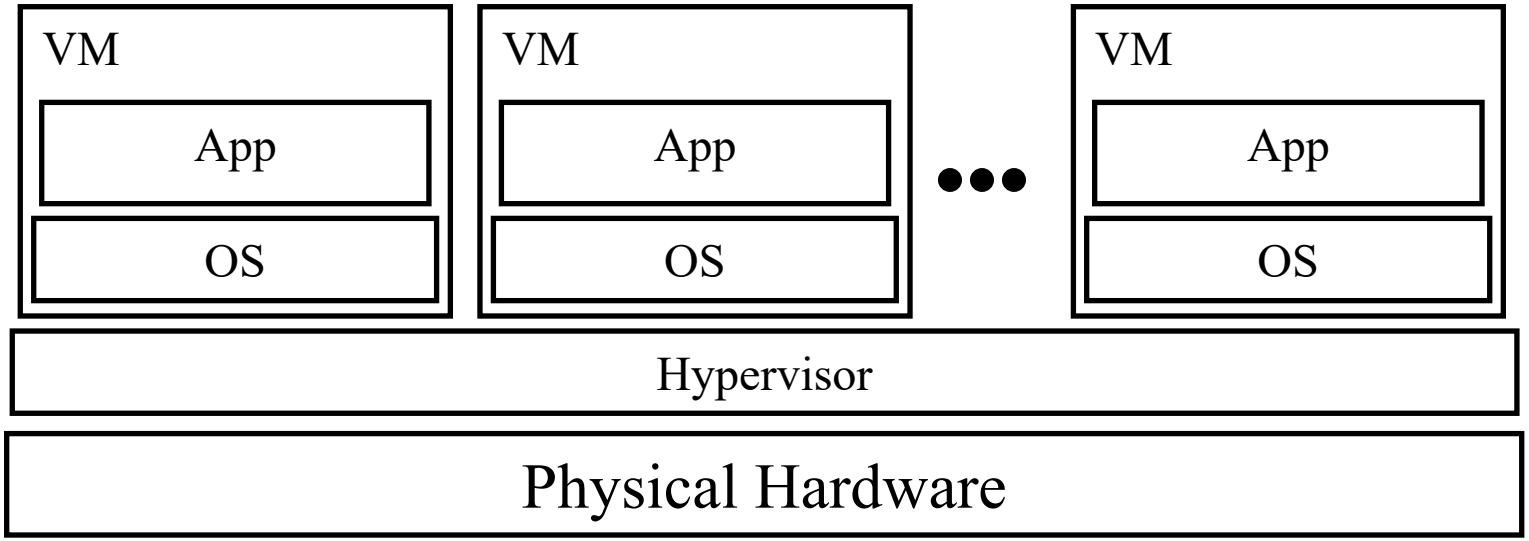
Network Function Virtualization (NFV)

- 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
- **Cloud-Native** = Containerized micro-services

Ref: Janakiram, "10 Key Attributes of Cloud-Native Applications," 19 Jul 2018, https://thenewstack.io/10-key-attributes-of-cloud-native-applications/

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
  Too many options ⇒ No Interoperability
- Need Interoperability organizations
  - IEEE 802.11 vs WiFi
- Many standards out of date when it is ready for implementation
- "non-discriminatory and reasonable licensing fee"
  ⇒ Not really open
- 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

Trend 8: Standards to Open Source

- Standard vs. Rough Consensus and Running Code
- IETF has ~100 working groups
  Open Linux Foundation has >100 open-source networking projects.
- **Open-Source Everything**:
  - Open Network Automation Platform (ONAP)
  - AI Developer Toolkits
  - Open-Source Base Station
  - DevOps Tool chain
  - Open-Source Hardware
  - OS Containers
  - Open-Source Blockchain

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 9: Centralized to Decentralized

- **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.

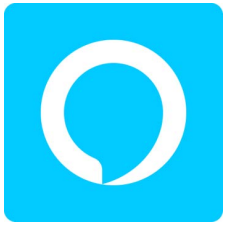
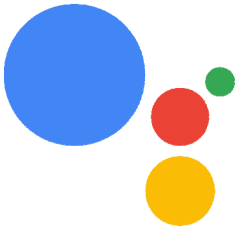
Time is a cycle: Decentralized vs. Centralized debate

Examples of Centralized Multi-Domain Systems

- **Banks**: Allow money transfer between two accounts
- **City Records**
- **Networks:** Certificate Authorities, DNS, Data ownership and privacy, Data provenance, Integrity assurance
- In all cases:
  1. There is a central third party to be trusted
  2. Central party maintains a large database
     ⇒ 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

Trend 10: Smart to Intelligent

 Intelligent Clock	 Intelligent TV	 Intelligent Car
 Intelligent Health	 Intelligent Home Security	 Intelligent Microwave
 Intelligent Light	 Amazon Alexa	 Google Assistant

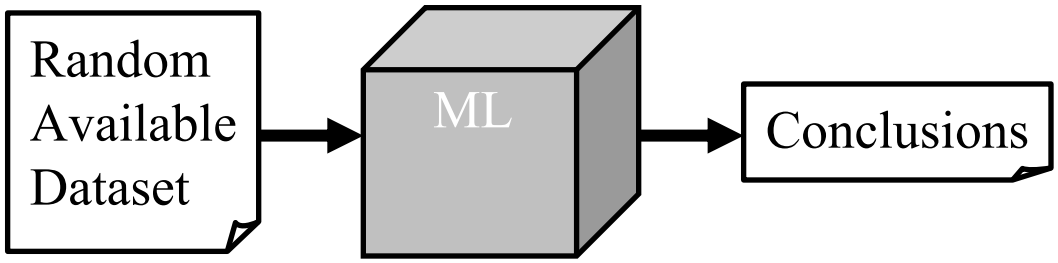
Edge AI

- Edge Computing + AI ⇒ AI in things
- Amazon's DeepLens camera has built-in AI
  Google Clips camera knows what to photograph
- Moving AI to the Edge
  ⇒ Data Compression and Anomaly Detection
- Deep Neural Network ASICs
  ⇒ GPUs replaced by Tensor Processing Units (TPUs)

Ref: A. Teng, G. Brocklehurst, "Hype Cycle for Semiconductors and Electronics Technologies, 2018," Gartner ID G00340360, 30 July 2018, 61 pp.

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?
- Synthetic data is used ⇒ Garbage-In, Garbage-Out
- Results are stated without model validation.



Trend 11: AI to Explainable AI

- Data Imbalance (1 in a Billion packet is an attack packet).
  In most papers, 10-15% of the packets are attack packets
- Explainability issue
  ⇒ No idea of why the results are what they are
  Can't discover bugs in ML model implementations

Machine Learning is what only machines can do, but human cannot do and cannot explain

Ref: M. Zolanvari, M. A. Teixeira, R. Jain, "**Effect of Imbalanced Datasets on Security of Industrial IoT Using Machine Learning**," 2018 IEEE International Conference on Intelligence and Security Informatics (ISI), Miami FL, Nov. 9 - 11, 2018, 6 pp., http://www.cse.wustl.edu/~jain/papers/imb_isi.htm

M. Zolanvari, M. A. Teixeira, R. Jain, "**An Explainable Machine Learning Based Security Framework: A Special Case on Industrial IoT," Submitted February 2019.**

AI is Everywhere Except Networks

- Everything in my home is intelligent except my network devices: Routers, Base stations, switches
- None of them speak Alexa.
  None of them can be programmed with IFTTT
- Wishlist:
  - Address assignments
  - Traffic prioritization
  - Port forwarding
  - VPN into home
  - Get the configuration from another device nearby
  - Congestion control, Routing, …

Trend 12: Managed to Self-Driven Networks

- **Self-Discover**: Find its components
- **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
- **Self-Organizing Network (SON)** capabilities since 3GPP R8

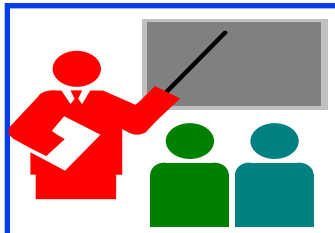
Network Manager

Ref: Kireerti Kompella, https://datatracker.ietf.org/meeting/98/materials/slides-98-nmrg-self-driving-networks
http://www.cse.wustl.edu/~jain/talks/inetauto.htm

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). IETF, and many vendors Apstra, Cisco, Forward, Juniper, Veriflow, and Waltz are working on it.

Ref: https://www.sdxcentral.com/articles/contributed/network-intent-summit-perspective-david-lenrow/2015/02/
https://docs.opendaylight.org/en/stable-fluorine/user-guide/network-intent-composition-(nic)-user-guide.html



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	AI	Explainable AI
12	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://www.cse.wustl.edu/~jain/papers/mec16.htm
- 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

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

Related Papers (Cont)

Micro-services (Cont)

- 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
- 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

Related Papers (Cont)

Micro-Services (Cont):

- 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

AI for Networking:

- Marcio Andrey Teixeira, Tara Salman, Maede Zolanvari, Raj Jain, Nader Meskin, and Mohammed Samaka, "**SCADA System Testbed for Cybersecurity Research Using Machine Learning Approach**," Future Internet 2018, 10(8), 76, http://www.cse.wustl.edu/~jain/papers/ics_ml.htm
- 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

Related Papers (Cont)

AI for Networking (Cont):

- 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, 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
- 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

Related Talks/Class Lectures

- 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, "**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

Acronyms

- 3GPP 3rd Generation Partnership Project
- AAC Application Cloud Abstraction
- AAS Application Service Abstraction
- AAW Application Workflow Abstraction
- ACM Automatic Computing Machinery
- ADCOM Advanced Computing and Communications
- AI Artificial Intelligence
- ATM Asynchronous Transfer Mode
- BSS Business Support System
- CapEx Capital Expenditure
- COLAP Cost optimized latency aware placement
- DevOps Development to Operations
- DNS Domain Name Systems
- EC2 Elastic Compute 2
- GPUs Graphics Processing Unit
- HW Hardware

Acronyms (Cont)

- ID Identifier
- IEEE Institution of Electrical and Electronic Engineers
- IETF Internet Engineering Task Force
- IFTTT If This Then That
- IoT Internet of Things
- MCAD Multi-cloud Application Delivery
- ML Machine Learning
- NFV Network Function Virtualization
- NIC Network Interface Card
- ONAP Open Network Automation Platform
- OpenADN Open Application Delivery Network
- OpEx Operational Expenses
- OS Operating System
- QoS Quality of Service
- RAN Radio Access Networks
- SCADA Supervisory Control and Data Acquisition

Acronyms (Cont)

- SDN Software Defined Networks
- SON Self-Organizing Network
- SW Software
- TPUs Tensor Processing Units
- TV Telivision
- VC Venture Capital
- VM Virtual Machine
- WiFi Wireless Fidelity
- XML Extended Markup Language

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