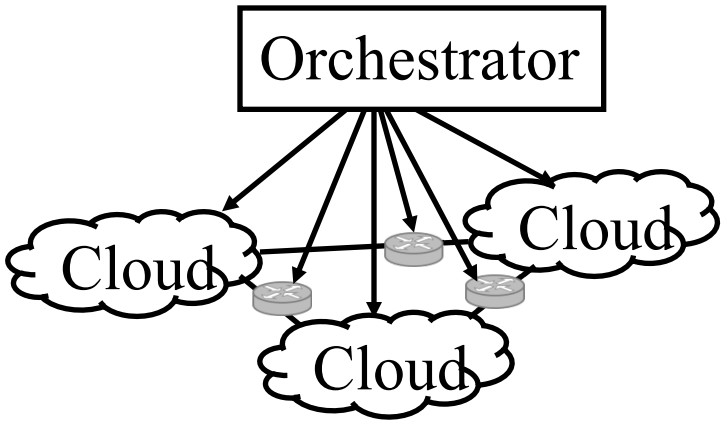
Trends and Issues in Networking: What's In, What's Out



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Keynote at the Third International Conference on Computing and Network Communications (CoCoNet'19)
Trivandrum, India, December 18, 2019

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

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Overview

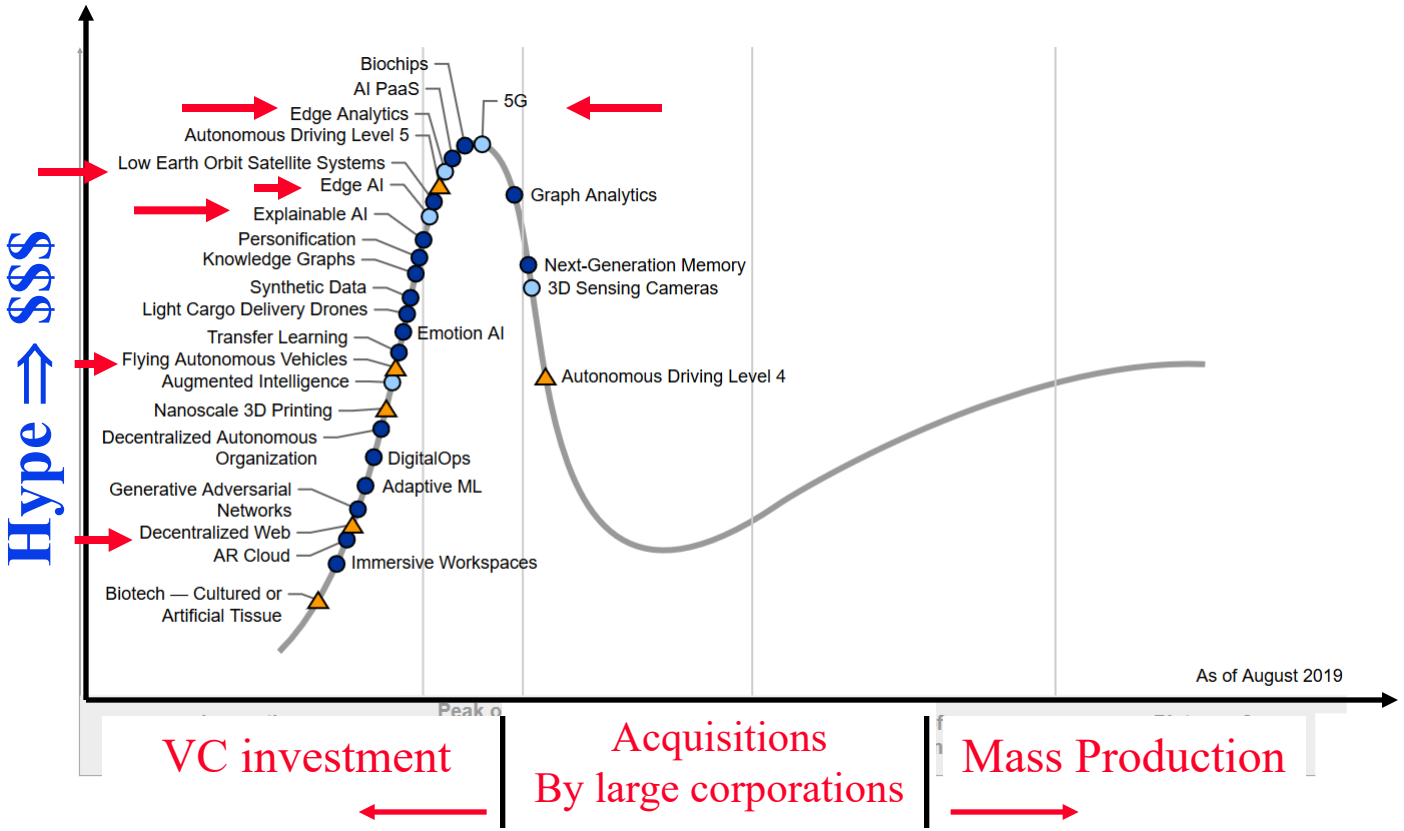
1. What has changed in the last five years?
2. What has happened to OpenFlow, SDN, and Clouds?
3. Thirteen Trends ⇒ What's in, what's out?

What's In What's Out?

- 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
  - 2008: Next Generation Internet/SDN
  - …
  - 2019: Whatever is being **hyped** this year?

Industries adopt by necessity.
Academics continue to develop deeper expertise on what they already know.

Gartner Hype Cycle of Emerging Tech 2019



Ref: B. Burke, D. Smith, "Hype Cycle for Emerging Technologies, 2019," Gartner Report G00370466, 6 Aug. 2019, 68 pp.

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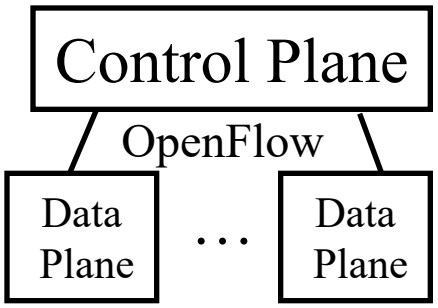
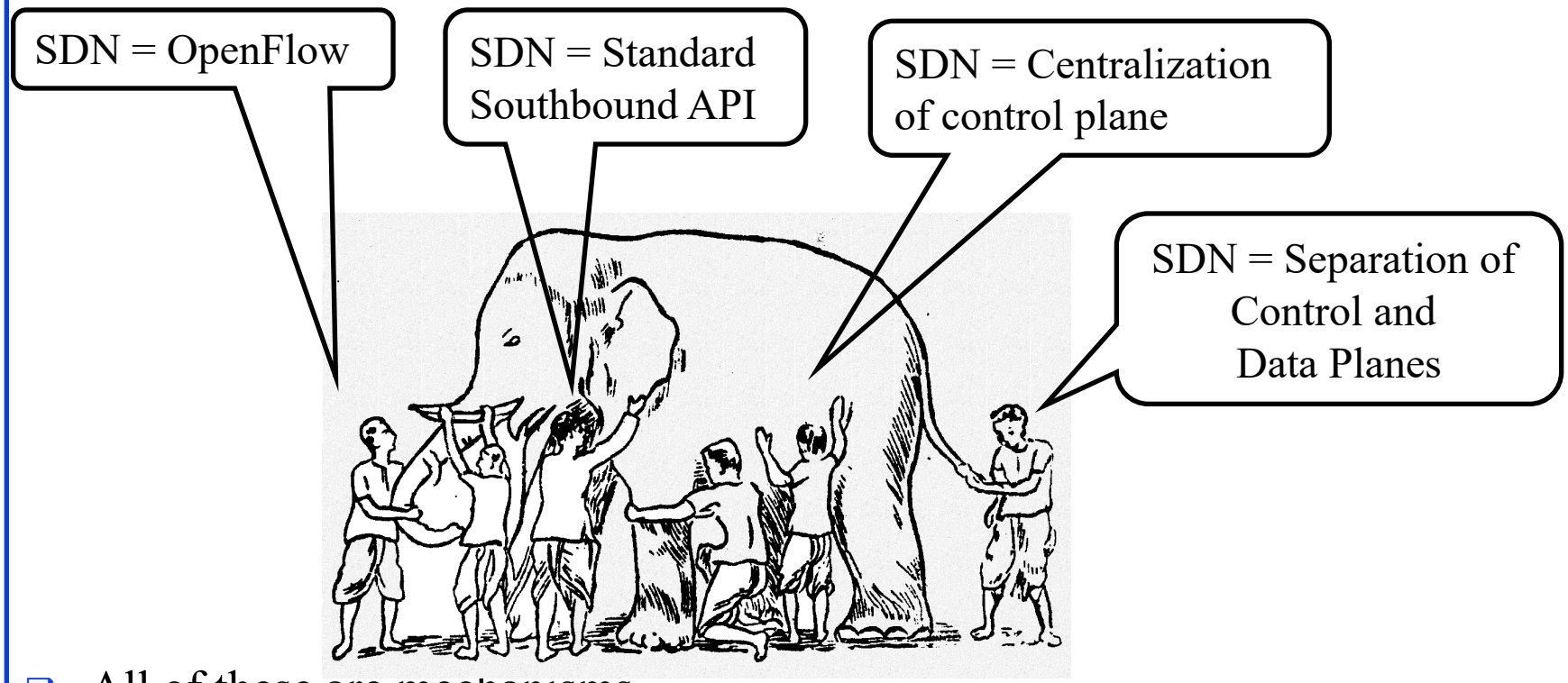
SDN: Planes of Networking

- SDN was invented in 2008. Then: SDN:
  - Separation of control and data planes
  - Centralization of Control
  - Standard Protocol between the planes
  - Future of Networking and the Past of the Protocols
    ⇒ Legacy protocols will go away



- **Data Plane**: All bits sent by the user
- **Control Plane**: All bits or activities that are not sent by the user but are necessary to perform data plane activities
  - Making routing tables
  - Base station beacons announcing availability of services
- Centralized Control Plane
  ⇒ Switches only implement packet forwarding
  ⇒ Switches are simpler and cheaper

What SDN is Not?



- All of these are mechanisms.
- SDN is *not* about a mechanism.
- It is a framework ⇒ Many solutions

SDN definition has changed but many academics are still unaware.
167 Papers on OpenFlow on IEEExplore in 2019!

Trend 1: Separation of Control to Orchestration of Policies

Separation and Centralization of Control Plane

Centralized Orchestration of Policies

Micromanagement is not scalable

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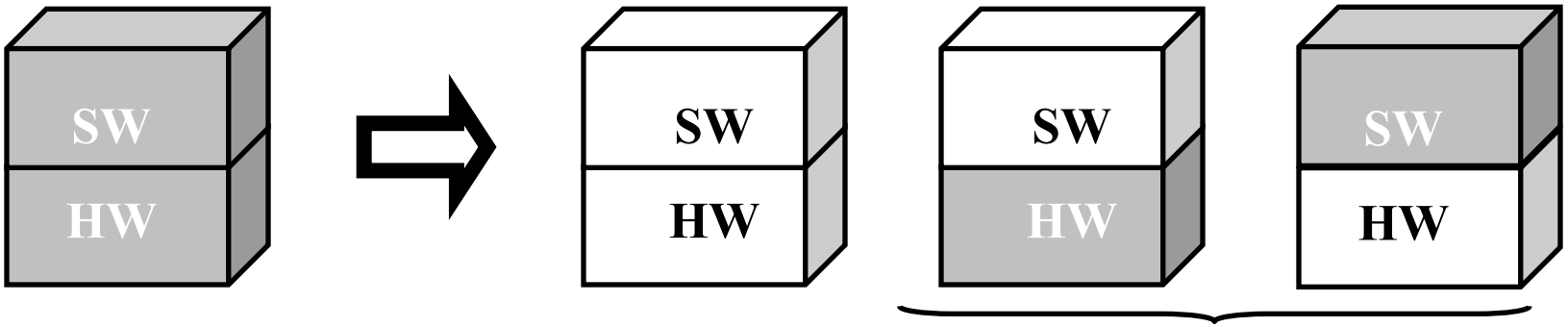
Trend 2: Disaggregation: Black Box to White Box

- Software Defined = Differentiation via software
  ⇒ White box networking
- **Black Box**: Proprietary HW with Proprietary SW
- **White Box**: Open Source Hardware and Software
  ⇒ You can choose hardware and software
- **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/

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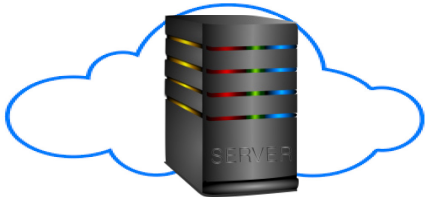
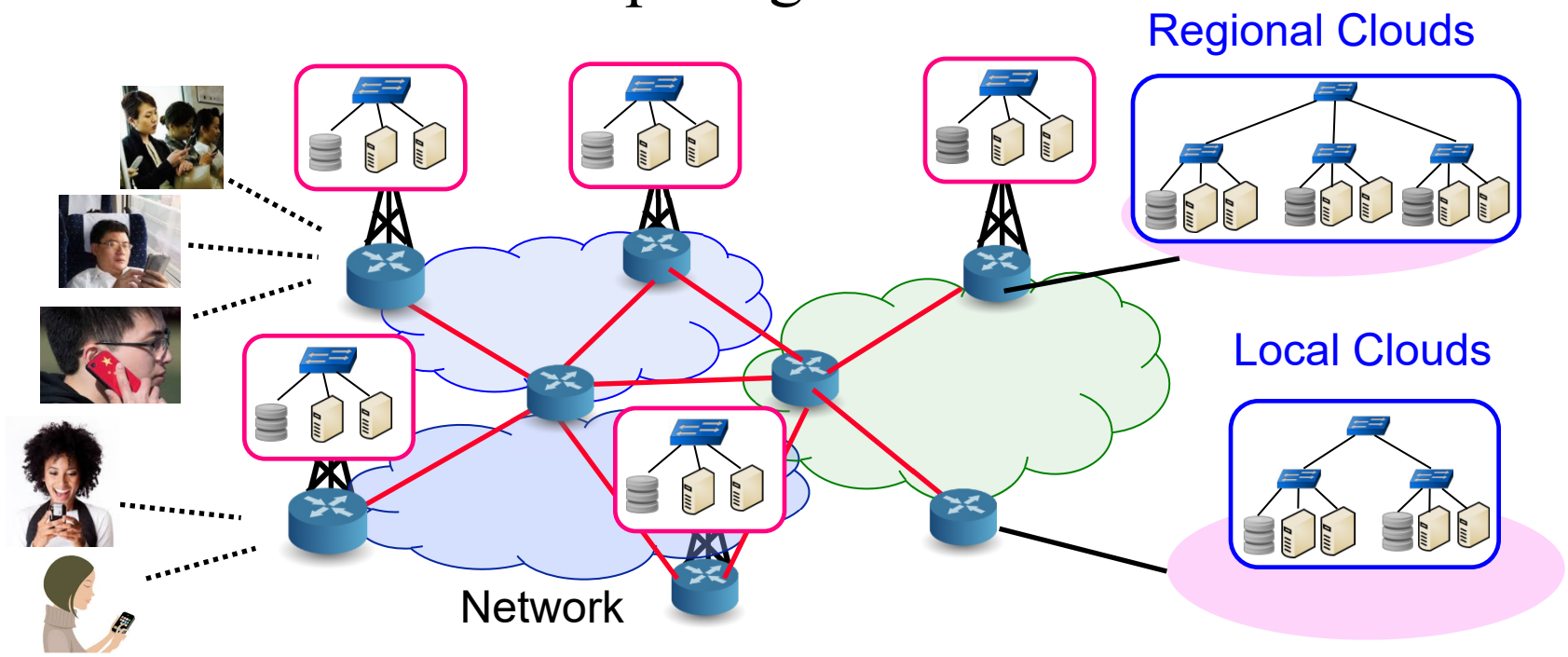
Trend 3: Clouds to Micro-Clouds

- 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, Computation needs to come to edge ⇒ Mobile Edge Computing ⇒ Multi-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

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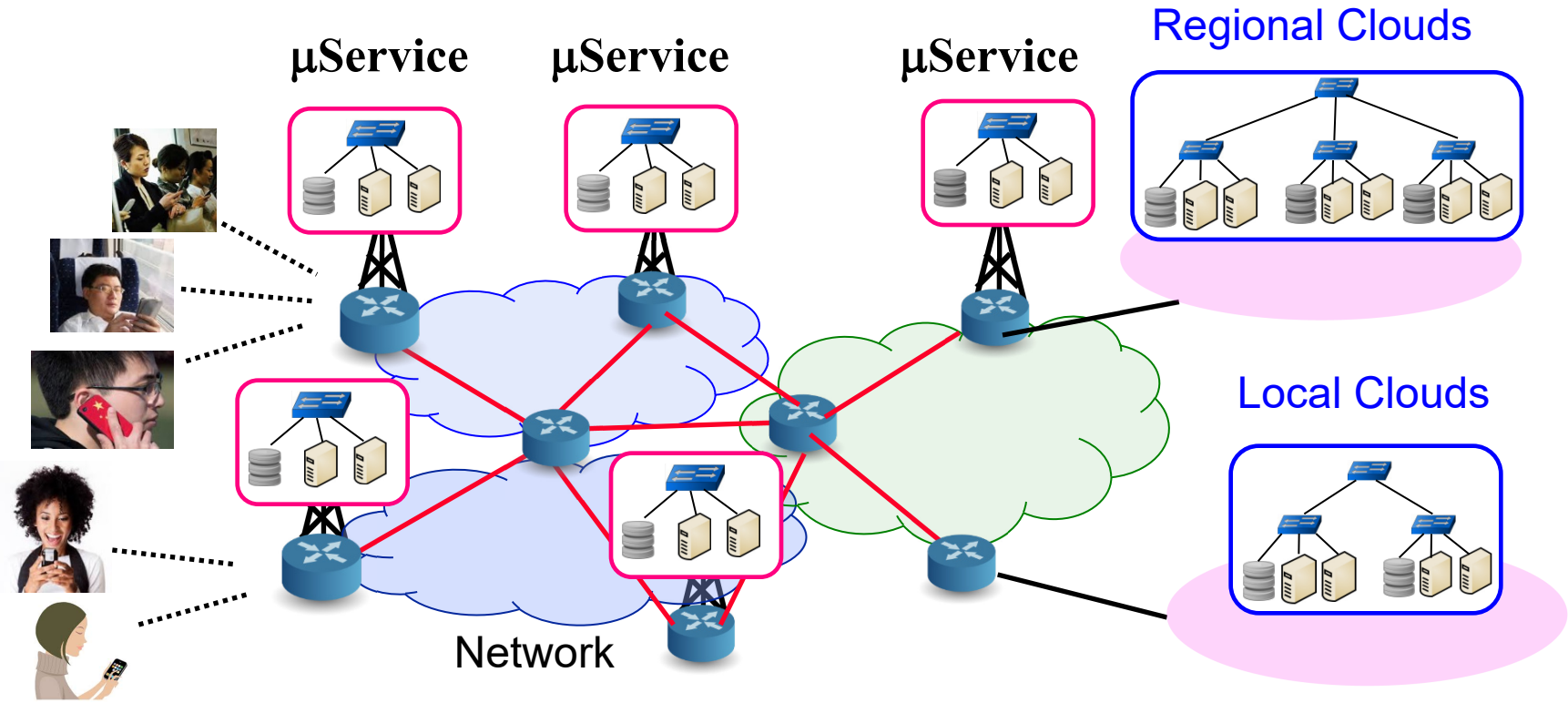
Trend 5: Services to Micro-Services

- **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

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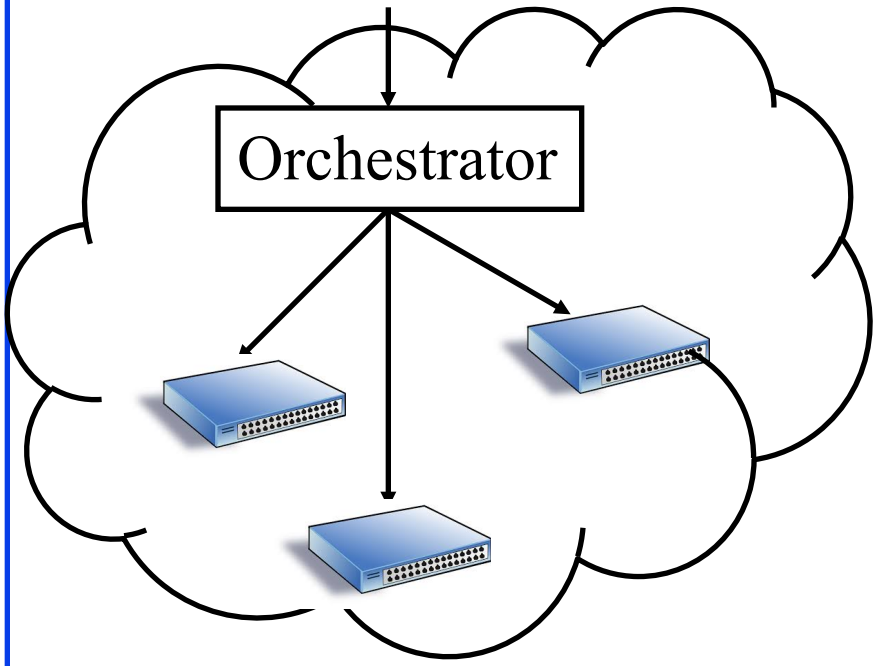
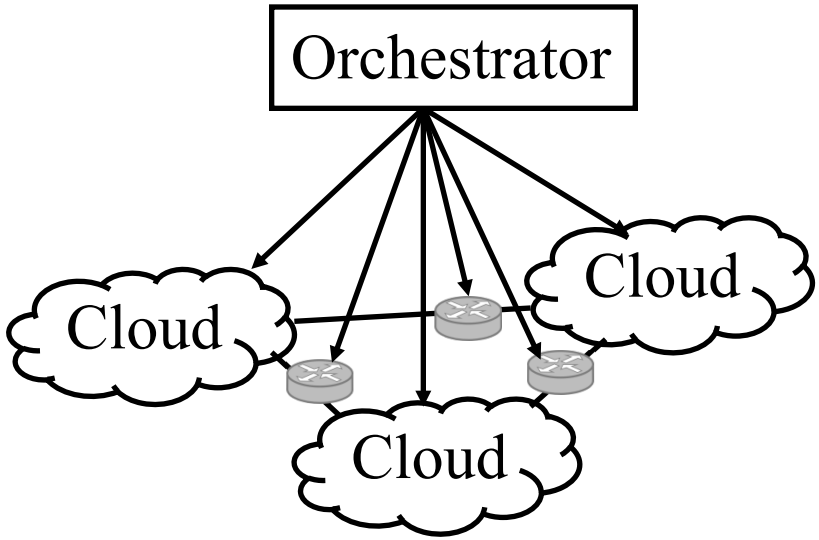
Trend 6: Orchestration of Switches to Orchestration of Multi-Cloud

- 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

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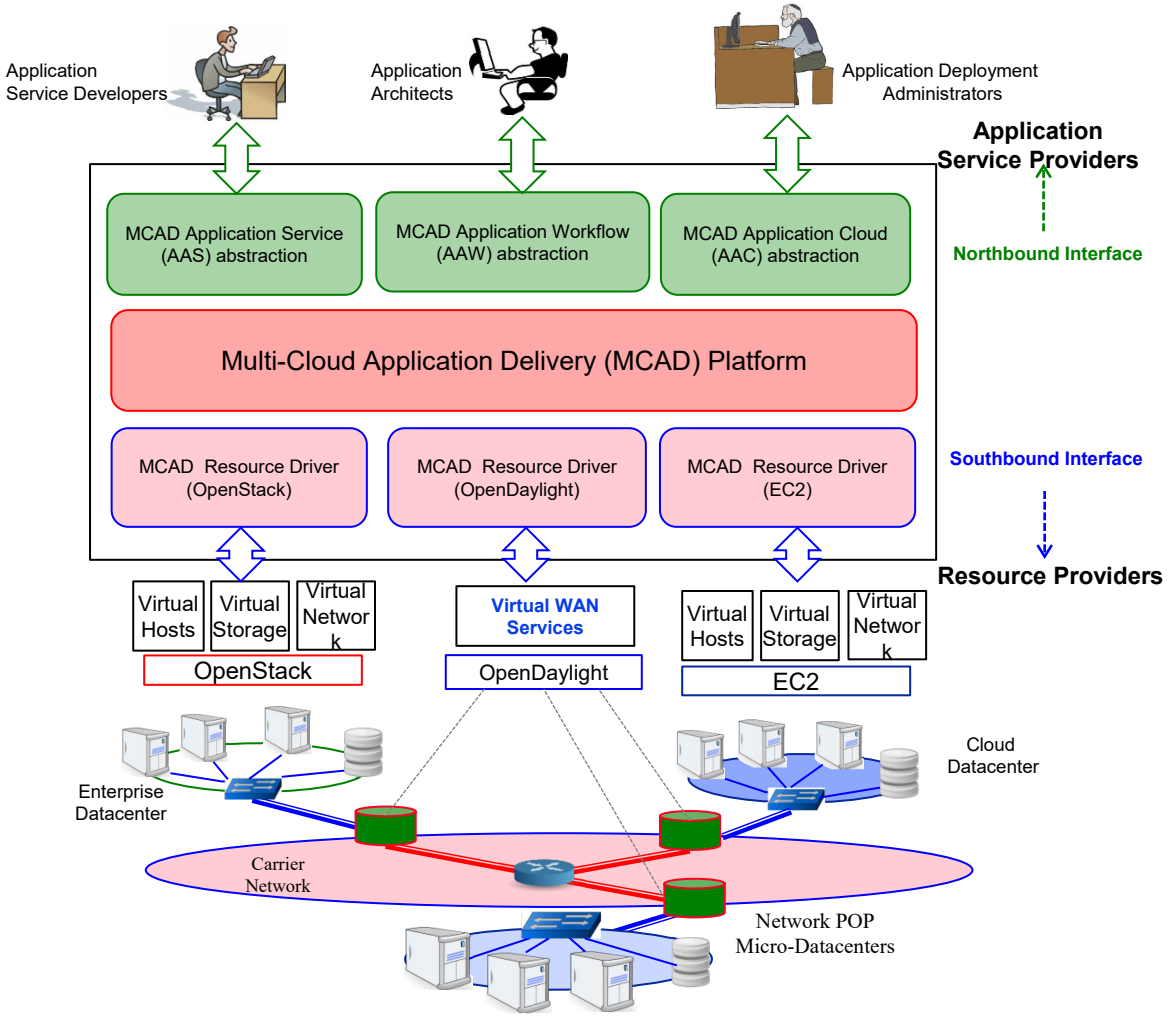
OpenADN Multi-Cloud Management



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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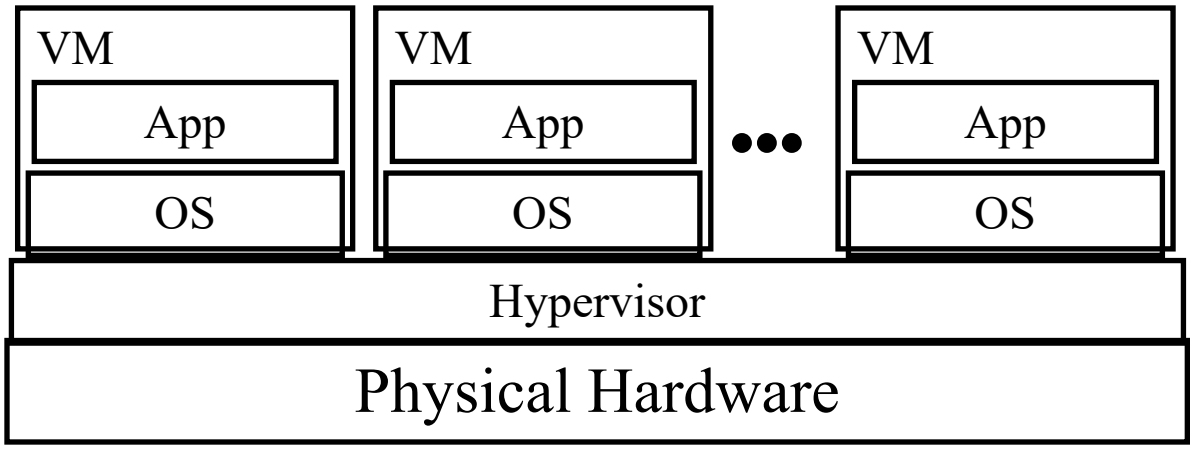
Network Function Virtualization (NFV)

- Network Functions on Virtual Machines in a cloud



- **Problems with Virtual Machines**:
  - VMs require an operating system (OS)
  - Each OS requires a license ⇒ **CapEx**
  - Each OS needs maintenance, updates ⇒ **OpEx**
  - **VM Tax** = added CapEx + OpEx

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

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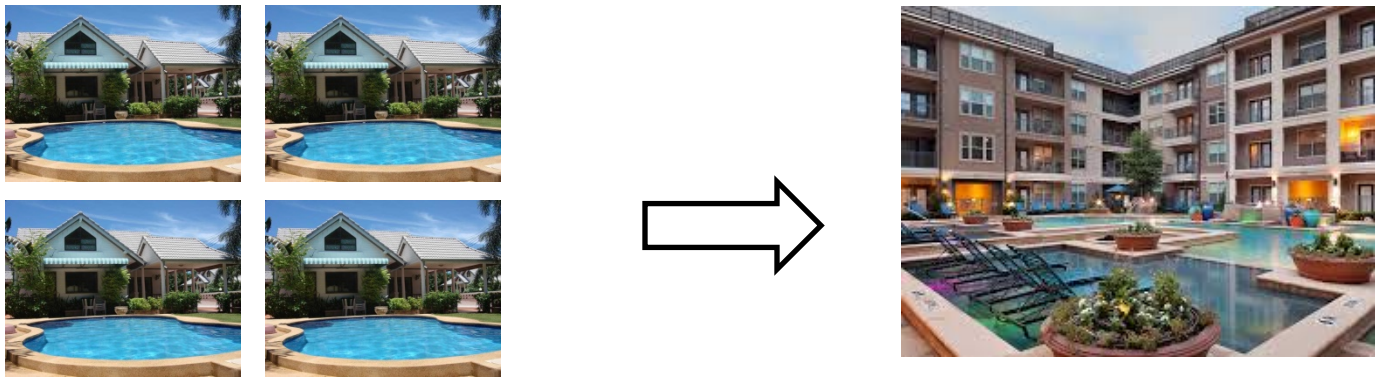
Trend 7: Virtualization to Containerization

- Run many apps in the same virtual machine
  - These apps share the OS and its overhead
  - Can't access each other's resources without permission
  - Like apartments in a complex ⇒ Containers
- **Cloud-Native** = Containerized micro-services
- **Kata Containers**: Performance like containers, isolation and security like VMs. Linux Foundation Project.



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

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Trend 8: Standards to Open Source

- Standard vs. Rough Consensus and Running Code
- Standards are slow Many standards 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, …
- Disaggregation ⇒ Open Source HW + Open Source SW
- # of networking projects at Linux Foundation
  > # of working groups at Internet Engineering Task Force
- **Open-Source Everything**:
  - Open Network Automation Platform (ONAP)
  - AI Developer Toolkits
  - Open-Source Blockchain

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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

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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 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

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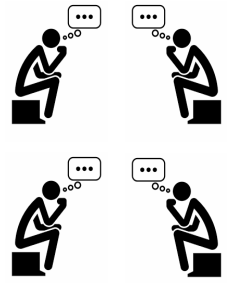
Probabilistic Blockchains



- Current blockchains allow only valid transactions
- Our Probabilistic Blockchains allow probabilistic statements:
  I think the attack is from Russia with 90% probability
  I am 80% confident that IBM stock will go up tomorrow 5%
- Allows risk assessment using a large number of opinions
  ⇒ Crowd sourcing of risk assessment
  ⇒ Particularly applicable to security risks
- Decisions are weighted by the reputation of the opinion makers
  Some people are experts on the topic ⇒ High Reputation
  Others are just bluffing ⇒ Low reputation after a few bluffs

Ref: T. Salman, M. Zolanvari, A. Erbad, R. Jain, and M, Samaka, "**Security Services Using Blockchains: A State of the Art Survey**" IEEE Communications Surveys and Tutorials, 2019, Volume 21, Issue 1, 858-880 pp., http://www.cse.wustl.edu/~jain/papers/bcs.htm

T. Salman, R. Jain, and L. Gupta, "**Probabilistic Blockchains: A Blockchain Paradigm for Collaborative Decision-Making**," 9th IEEE UEMCON 2018, http://www.cse.wustl.edu/~jain/papers/pbc_uem.htm

T. Salman, R. Jain, L. Gupta, "**A Reputation Management Framework for Knowledge-Based and Probabilistic Blockchains**," 2019 IEEE International Conference on Blockchain, July 14, 2019, http://www.cse.wustl.edu/~jain/papers/rpmcewa.htm

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Decisions with Risk

- Sell insurance
- Buy insurance
- Sell a stock
- Buy a stock
- Download a software application on your computer
- Update software

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Smart Everything

Smart Watch

Smart TV

Smart Car

Smart Health

Smart Home

Smart Kegs

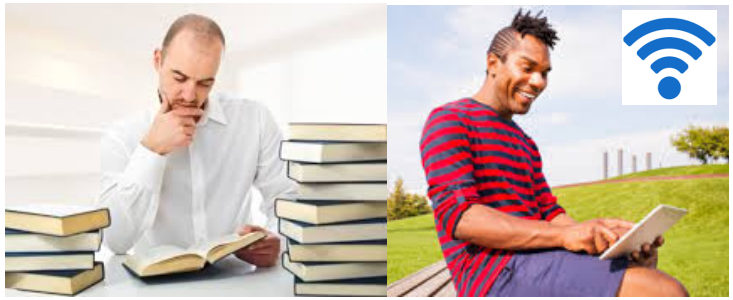
Smart Space

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

Trend 10: Smart to Intelligent

Intelligent Clock

Intelligent TV

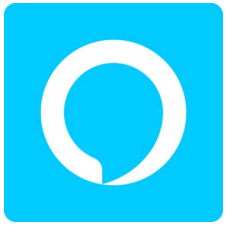
Intelligent Car

Intelligent Health

Intelligent Home Security

Intelligent Microwave

Intelligent Light

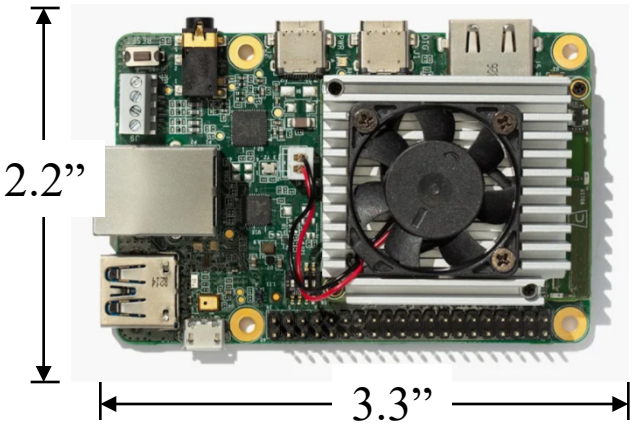


Amazon Alexa

Google Assistant

Edge AI

- Edge Computing + AI ⇒ AI in things
- Moving AI to the Edge
  ⇒ Data Compression and Anomaly Detection
- **Google Coral Development Board**
  - Edge Tensor Processing Unit (TPU)
  - Machine learning accelerator
  - Low cost: Below $150
- Similar offerings from Nvidia (Jetson nano) and others



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

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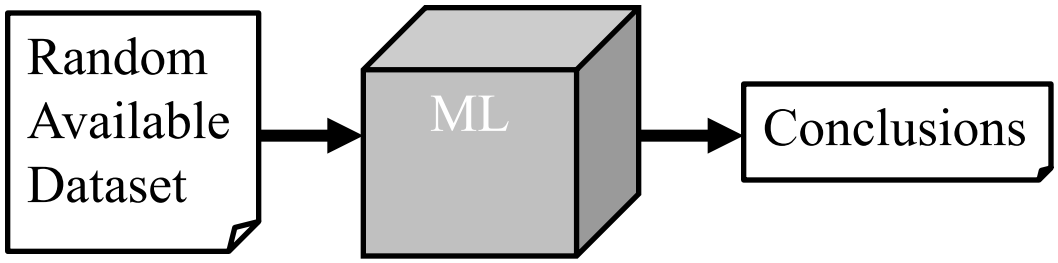
Machine Learning Challenges

- Machine learning is currently a black box
- 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.**

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Trend 12: SDN 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
- OpenDaylight is working on Network **Intent** Composition (NIC)

Network Manager

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

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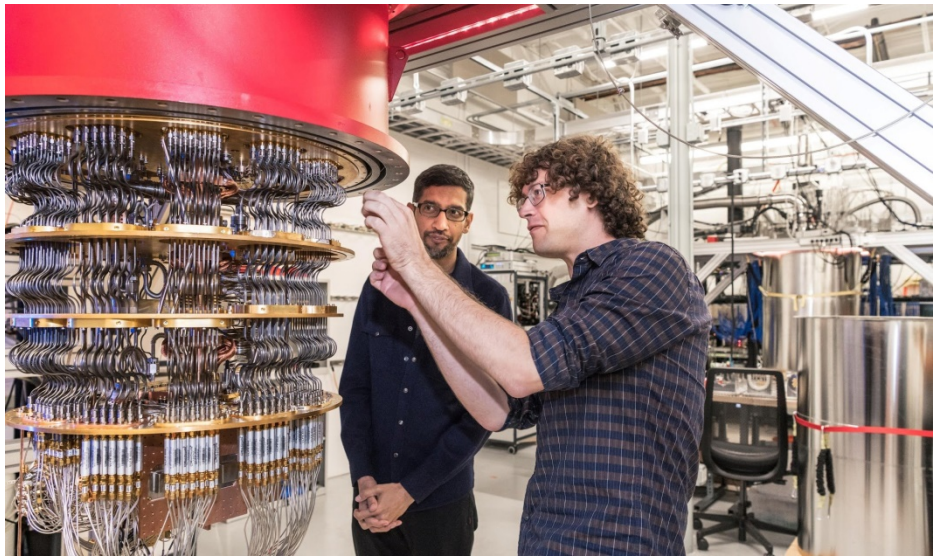
Quantum Hardware

- Google achieved **Quantum Supremacy** using a 54-bit superconducting quantum computer on October 23, 2019
- Global Competition: China, Japan, USA, EU are also competing



Ref: https://www.nbcnews.com/mach/science/google-claims-quantum-computing-breakthrough-ibm-pushes-back-ncna1070461

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Trend 13: Quantum Safe Cryptography

- Factoring large numbers is hard with conventional computing but much easier with quantum computing.
- It would be easy to break public key cryptography when quantum computing becomes feasible
- NIST started a competition for "Quantum Safe Cryptography" in December 2016
- 26 Algorithms have advanced to semifinal on January 30, 3019
- Several free Quantum Simulators are available to write quantum program

Ref: NIST, "Status Report on the First Round of the NIST Post-Quantum Cryptography Standardization Process," NSTIR 8240, https://csrc.nist.gov/publications/detail/nistir/8240/final

Raj Jain, "**Introduction to Quantum Computing and Its Applications to Networking**," WUSTL CSE 570S class lecture, Fall 2019, http://www.cse.wustl.edu/~jain/cse570-19/m_19qnt.htm

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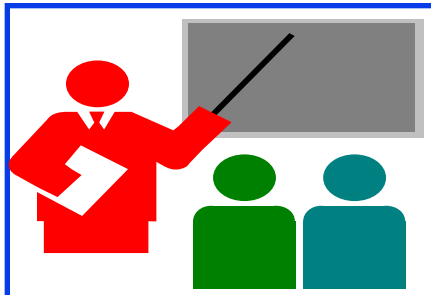

Summary

#	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
13	Classical	Quantum

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Summary (Cont)

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

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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

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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

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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

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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

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Related Papers (Cont)

AI for Networking (Cont):

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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

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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

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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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