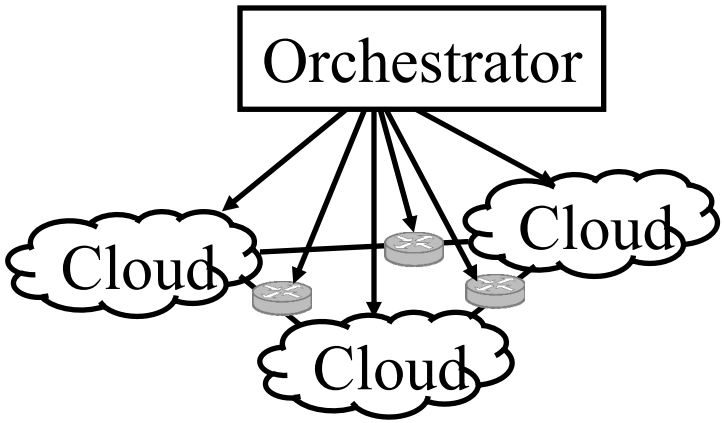
12 Trends in Networking: What's In, What's Out



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Keynote at International Conference on Computing, Networking and Communications (ICNC) 2019
Honolulu, Hawaii, February 20, 2019

These slides and recording of this talk are available on-line at:
http://www.cse.wustl.edu/~jain/talks/icnc19.htm

Overview

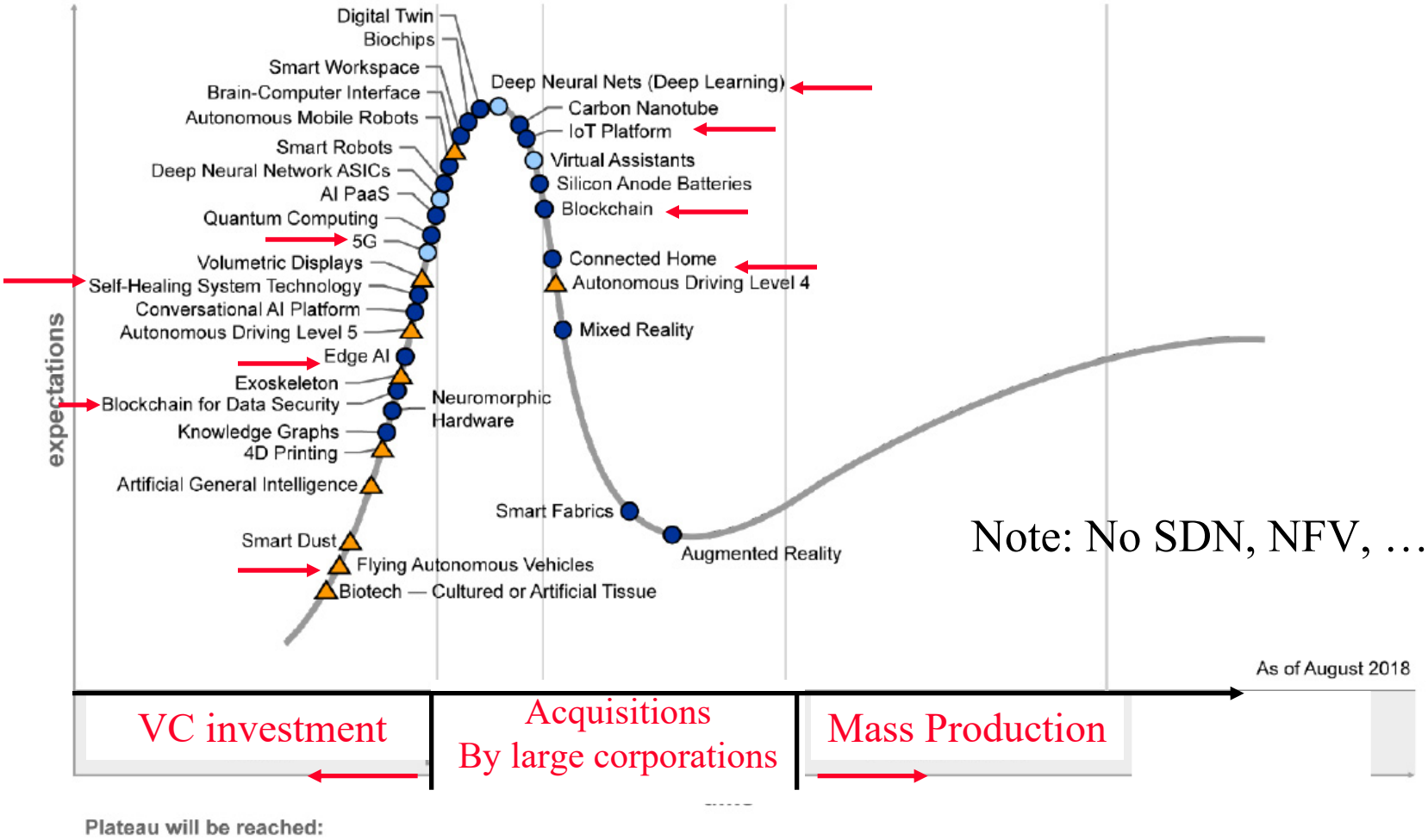
1. What has changed in the last five years?
2. What has happened to OpenFlow, SDN, and Clouds?
3. Twelve Trends ⇒ What's in, what's out?

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
  - 2010: Next Generation Internet/SDN
  - 2018: Whatever is being **hyped** this year?

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

Gartner Hype Cycle 2018

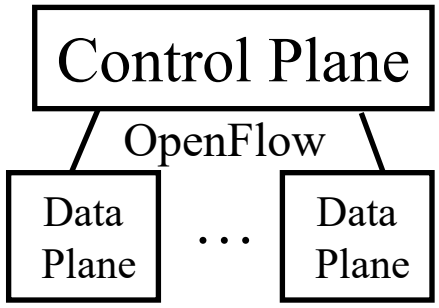


Note: No SDN, NFV, …

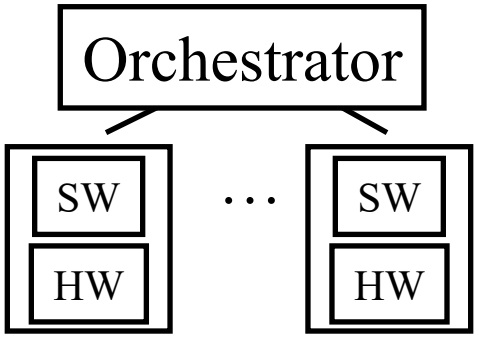
Ref: M. Walker, "Hype Cycle for Emerging Technologies, 2018," Gartner Report G00340159, 6 Aug. 2018, 73 pp.

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



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

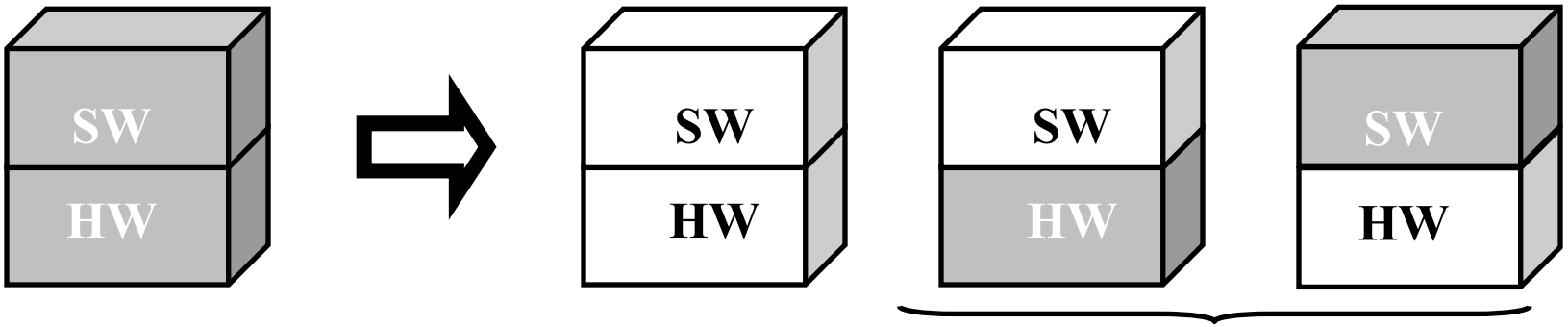


Ref: D. M Batista, G. Blair, F. Kon, R. Boutaba, D. Hutchison, R. Jain, R. Ramjee, C. Rothenberg, "Perspectives on software-defined networks: interviews with five leading scientists from the networking community" Journal of Internet Services and Applications 2015, 6:22, http://www.cse.wustl.edu/~jain/papers/jisa15.htm

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

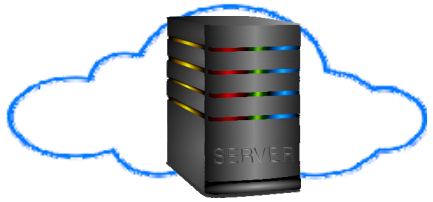
Separation and Centralization of Control Plane

Orchestration of Policies

Micromanagement is not scalable

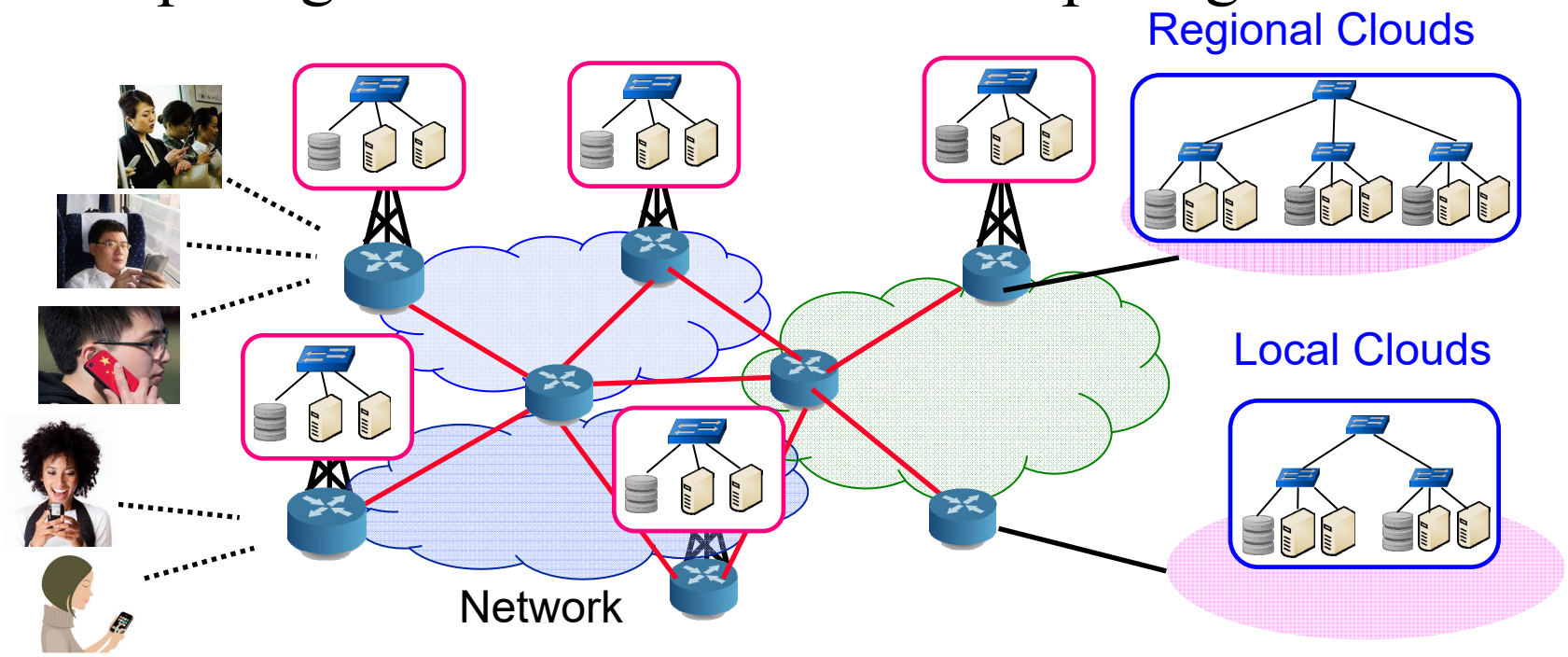
Trend 3: Clouds to Micro-Clouds

- 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

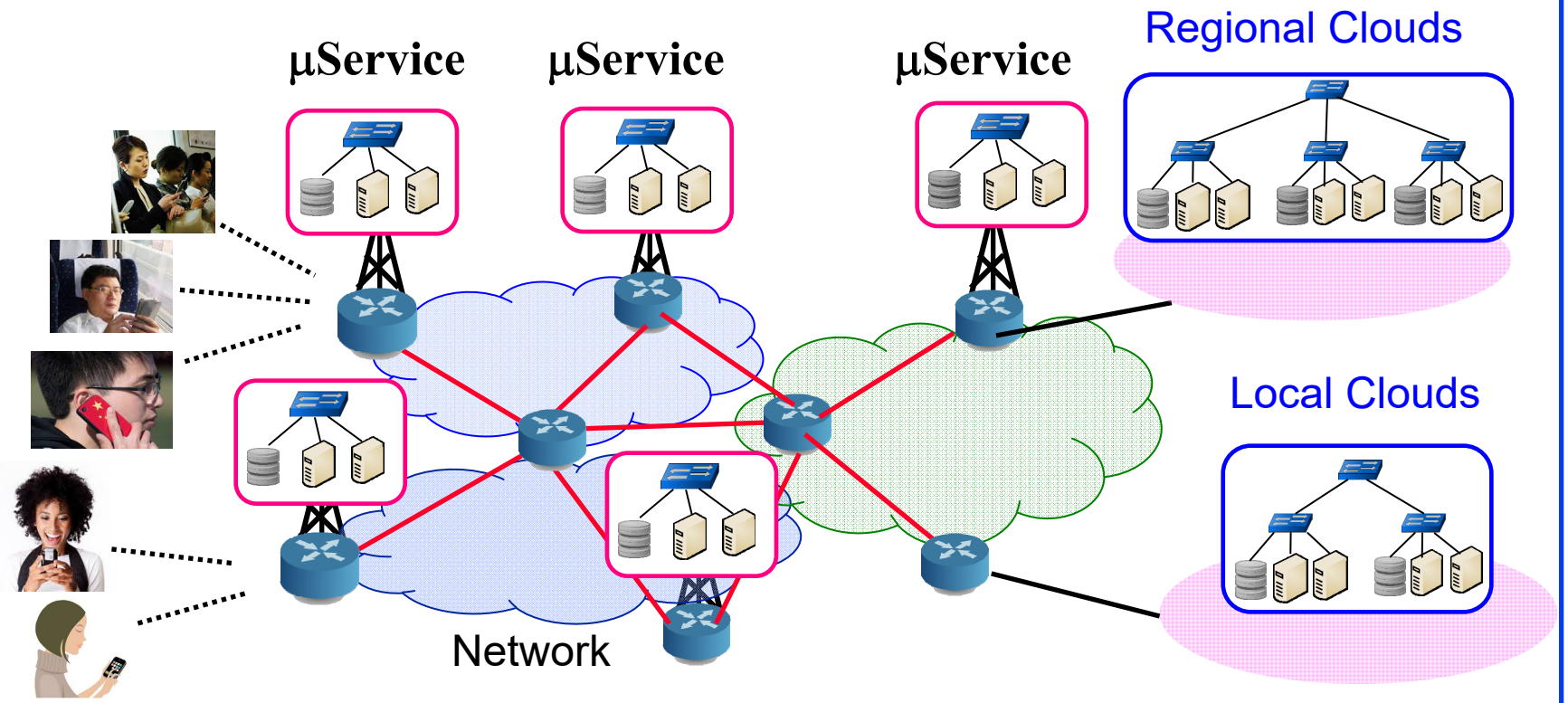
- To service mobile users/IoT, the computation needs to come to edge ⇒ Mobile Edge Computing. Edge computing = Distributed Cloud Computing



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

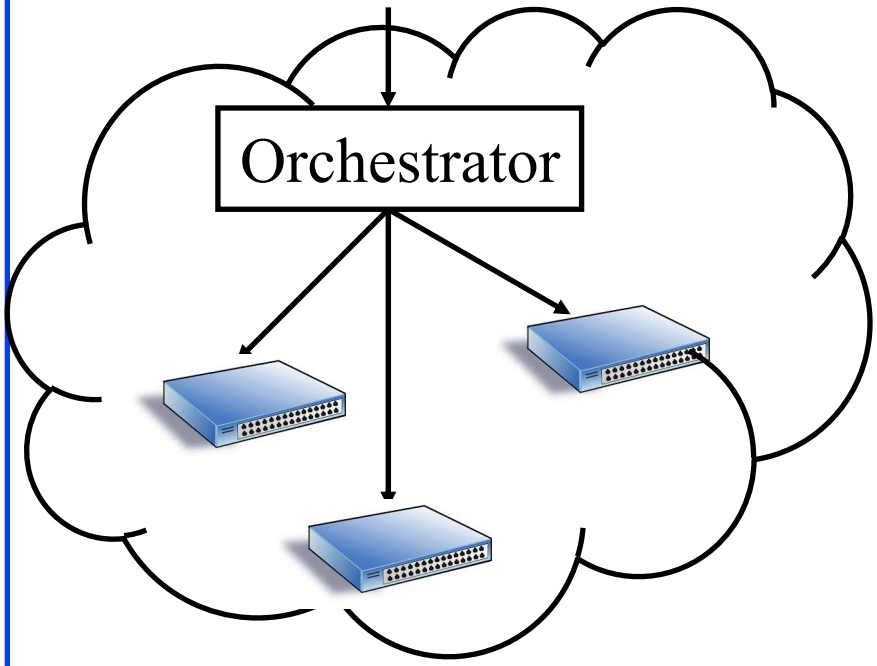


Ref: D. Bhamare, M. Samaka, A. Erbad, R. Jain, L. Gupta, H. A. Chan, "**Multi-Objective Scheduling of Micro-Services for Optimal Service Function Chains**," ICC 2017, May 21-25, 2017, http://www.cse.wustl.edu/~jain/papers/icc17.htm

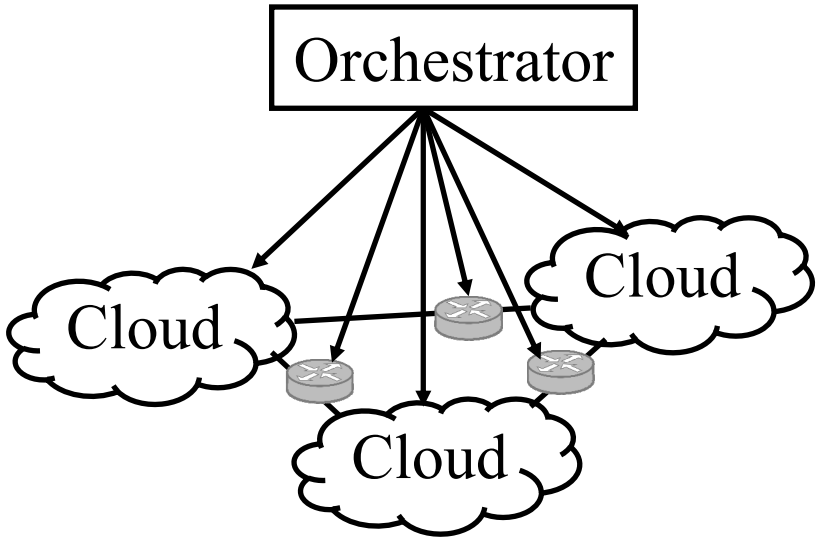
Trend 6: Orchestration of Switches to Orchestration of Multi-Cloud

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

Datacenter Applications

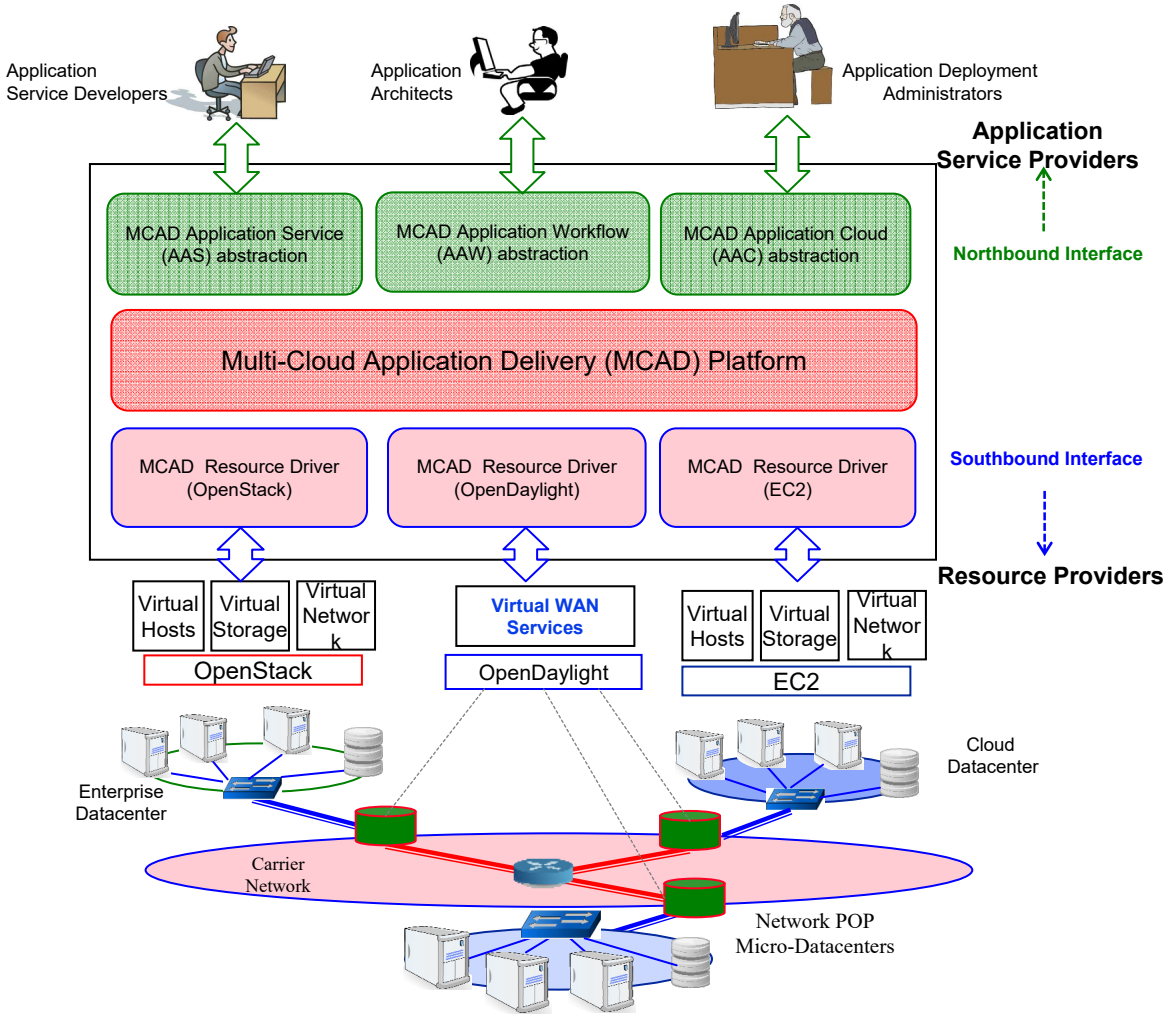


Global Applications



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

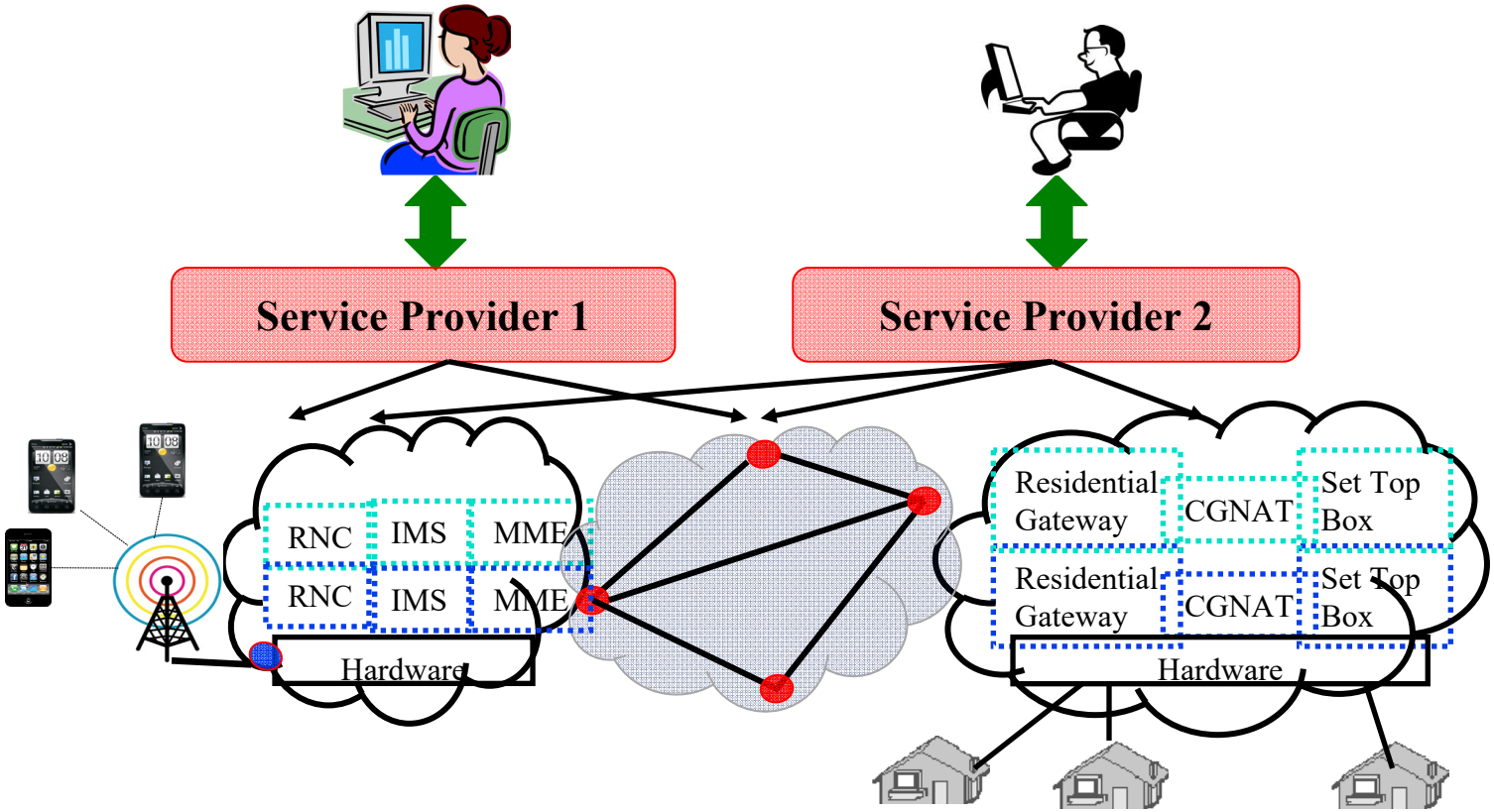
OpenADN Multi-Cloud Management



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

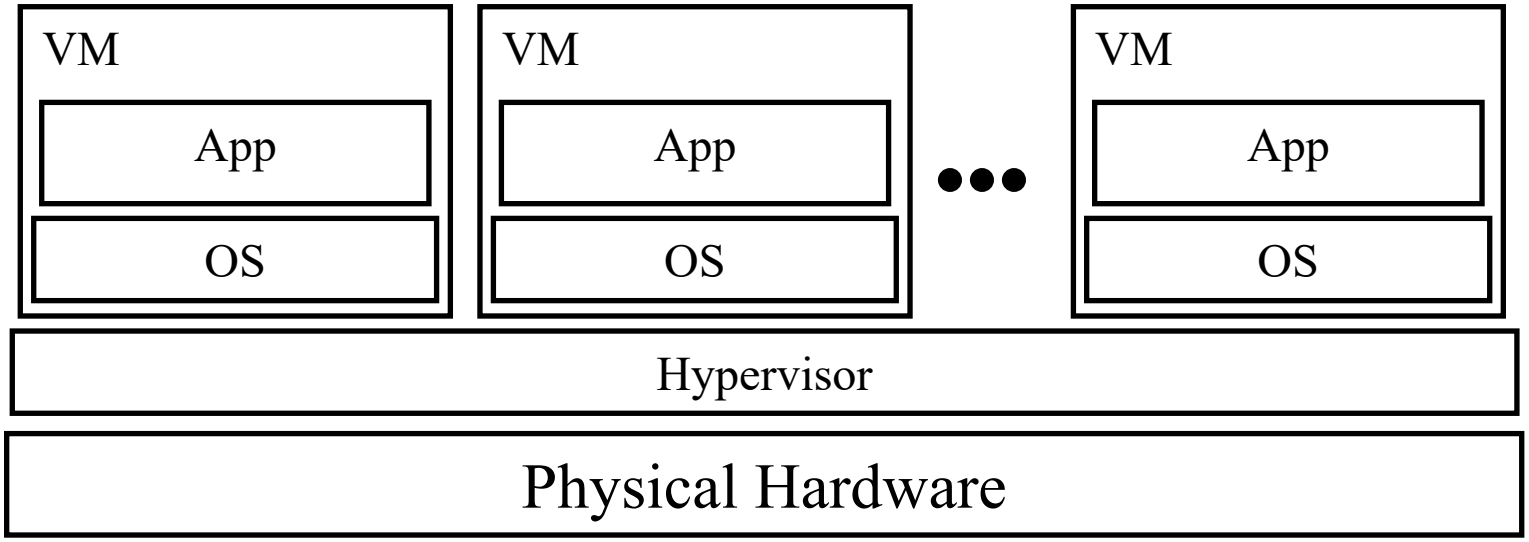
Network Function Virtualization (NFV)

- 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

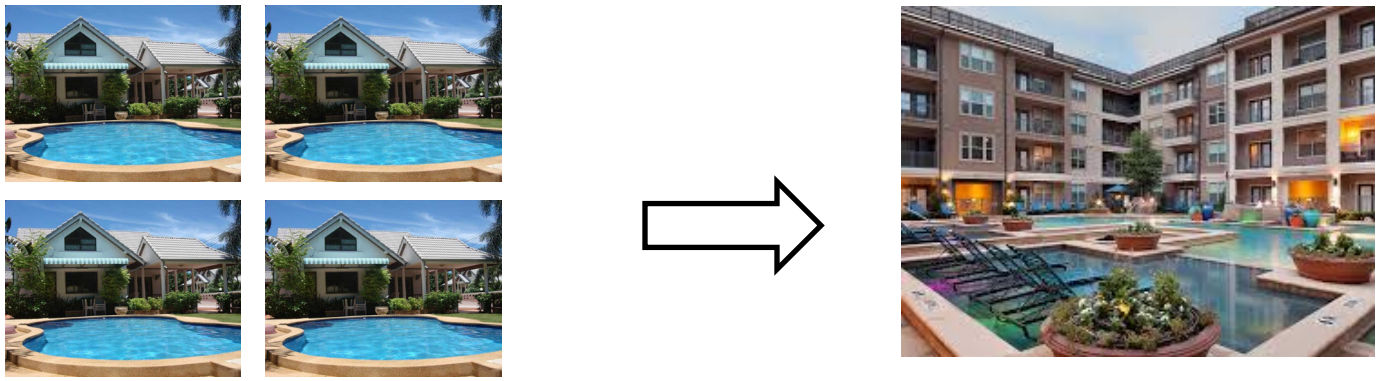
Problems with Virtual Machines



- 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
- 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

Examples of Centralized 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
     $\Rightarrow$ 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

Ideas to Enhance Blockchains

- Blockchain is just a distributed **data storage** of valid transactions
- All transactions are ***deterministic***
- What's Wrong?
  - Need to convert data to knowledge
  - Real life is probabilistic
  - Most decisions we make are probabilistic
    $\Rightarrow$ All decisions have some risk

Decisions with Risk

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

Can the Blockchains be Enhanced?

Limitation 1: Only facts are recorded

- Alice gave 20 coins to Bob

Limitation 2: Binary Validity

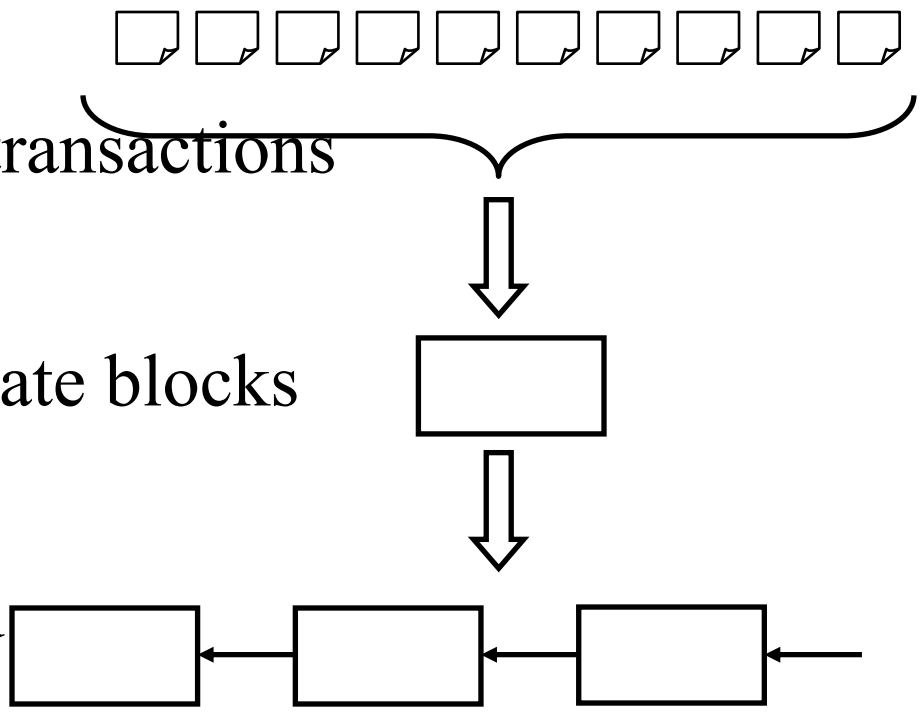
- All transactions/contracts recorded on the blocks that are committed are valid
- Those not on the committed blocks and old are invalid
- So the recording is binary: only 0 or 1.

Limitation 3: Deterministic Events only

- Can not record that I am only 90% sure that Alice gave 20 coins to Bob.

Current Blockchain Process

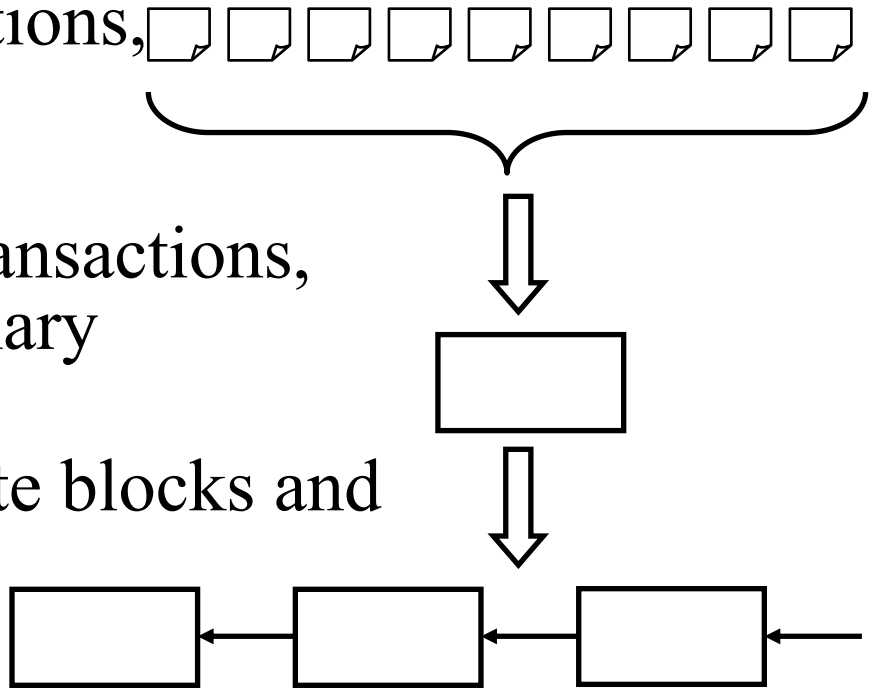
1. **Users** broadcast transactions or smart contracts
2. **Mining nodes** validate transactions and create blocks
3. **Blockchain nodes** validate blocks and construct a chain



- There are many users, many mining nodes, and many blockchain nodes.
- More nodes ⇒ Better.
  Less ⇒ Blockchain not required/useful.

Probabilistic Blockchain Process

1. **Agents** broadcast transactions,
   Transactions
   = Opinions/decisions
2. **Mining nodes** validate transactions,
   create a knowledge summary
   and create blocks
3. **Blockchain nodes** validate blocks and
   construct a chain
4. Two types of users:
   - **Agent nodes** provide their probabilistic decisions
   - **Management nodes** that inquire the blockchain
     and use it for group decisions



Blockchain 4.0: Database to Knowledge Base

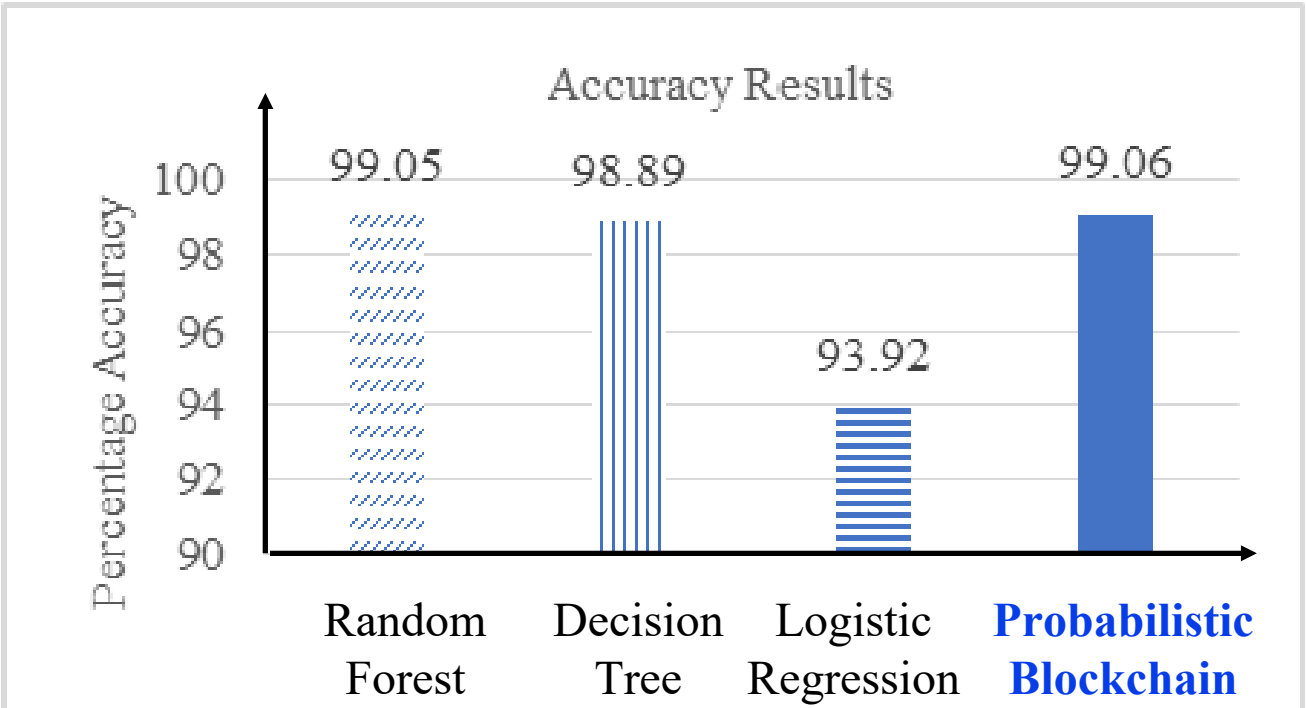
- Blockchain = Distributed database of smart contracts
- Probabilistic blockchain = Knowledge + database
- Database = Who bought, who sold, what quantity, what price, what time
- Knowledge =
  - Where the market is going?
  - Whether we should buy, sell, or hold?

Empirical Validation

- Issue: Whether a network traffic pattern represents intrusion
- 1000 Agents using different machine learning algorithms give their decisions: Yes or No
  - Agents randomly pick one of the 3 algorithms:
    - Random Forest, Decision Tree, Logistic Regression
- Mining nodes summarize these decisions using the majority function

Results

$$\text{Accuracy} = \frac{\text{Correct Predictions}}{\text{Overall Samples}} \times 100\%$$



Distributed decision making is better than any individual decision

Smart Everything

Smart Watch

Smart TV

Smart Car

Smart Health

Smart Home

Smart Kegs

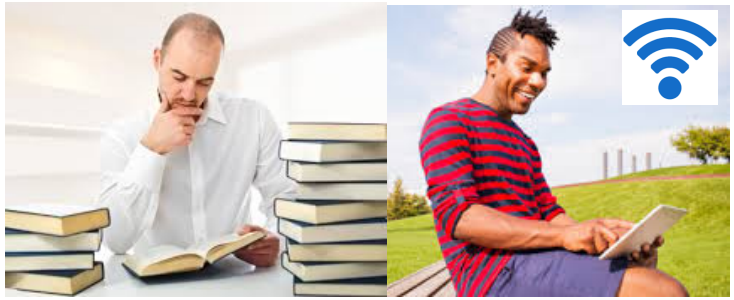
Smart Space

Smart Industries

Smart Cities

What's Smart?

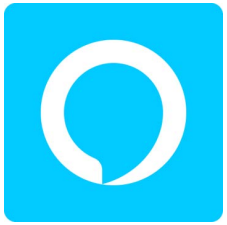
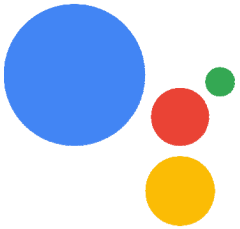
- Old: Smart = Can think ⇒ Computation
  = Can Recall ⇒ Storage
- Now: Smart = Can find quickly, Can Delegate
  ⇒ Communicate = Networking
- Smart Grid, Smart Meters, Smart Cars, Smart homes, Smart Cities, Smart Factories, Smart Smoke Detectors, …



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

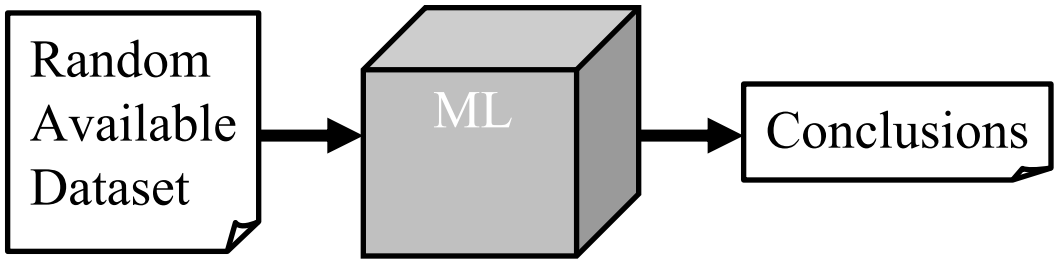
Edge AI

- Edge Computing + AI ⇒ AI in things
- 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 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

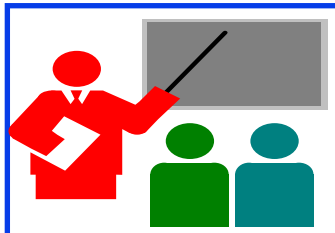
Network Manager

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

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)

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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

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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http://www.cse.wustl.edu/~jain/talks/icnc19.htm