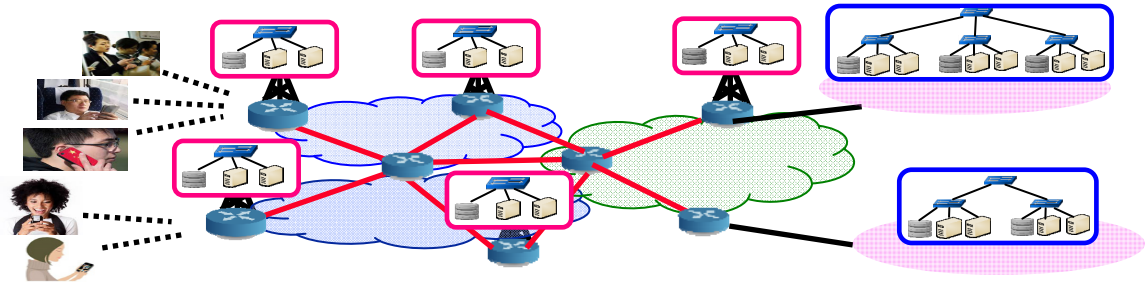
Multi-Cloud Global Application Delivery for Internet of Things and Smart Cities



RAJ JAIN

Washington University in Saint Louis
Saint Louis, MO 63130
Jain@wustl.edu

Cisco PI Meeting, San Jose, CA, May 26, 2016

These slides are available on-line at:

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

or **http://bit.ly/ciscopi**

Overview

- Why Multi-Cloud?
  - 1. Internet of Things and Smart Cities
  - 2. Mobile Traffic Explosion: NFV
  - 3. Any Function Virtualization
  - 4. Mobile Edge Computing
- OpenADN Multi-Cloud Management
- Service Function Placement Problem

1. Trend: Smart Everything

Smart Watch

Smart TV

Smart Car

Smart Health

Smart Home

Smart Kegs

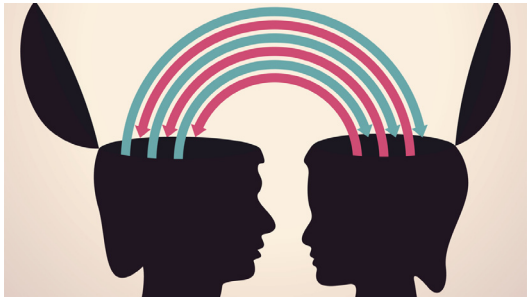
Smart Space

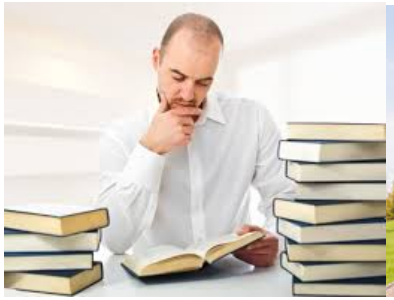
Smart Industries

Smart Cities

What's Smart?

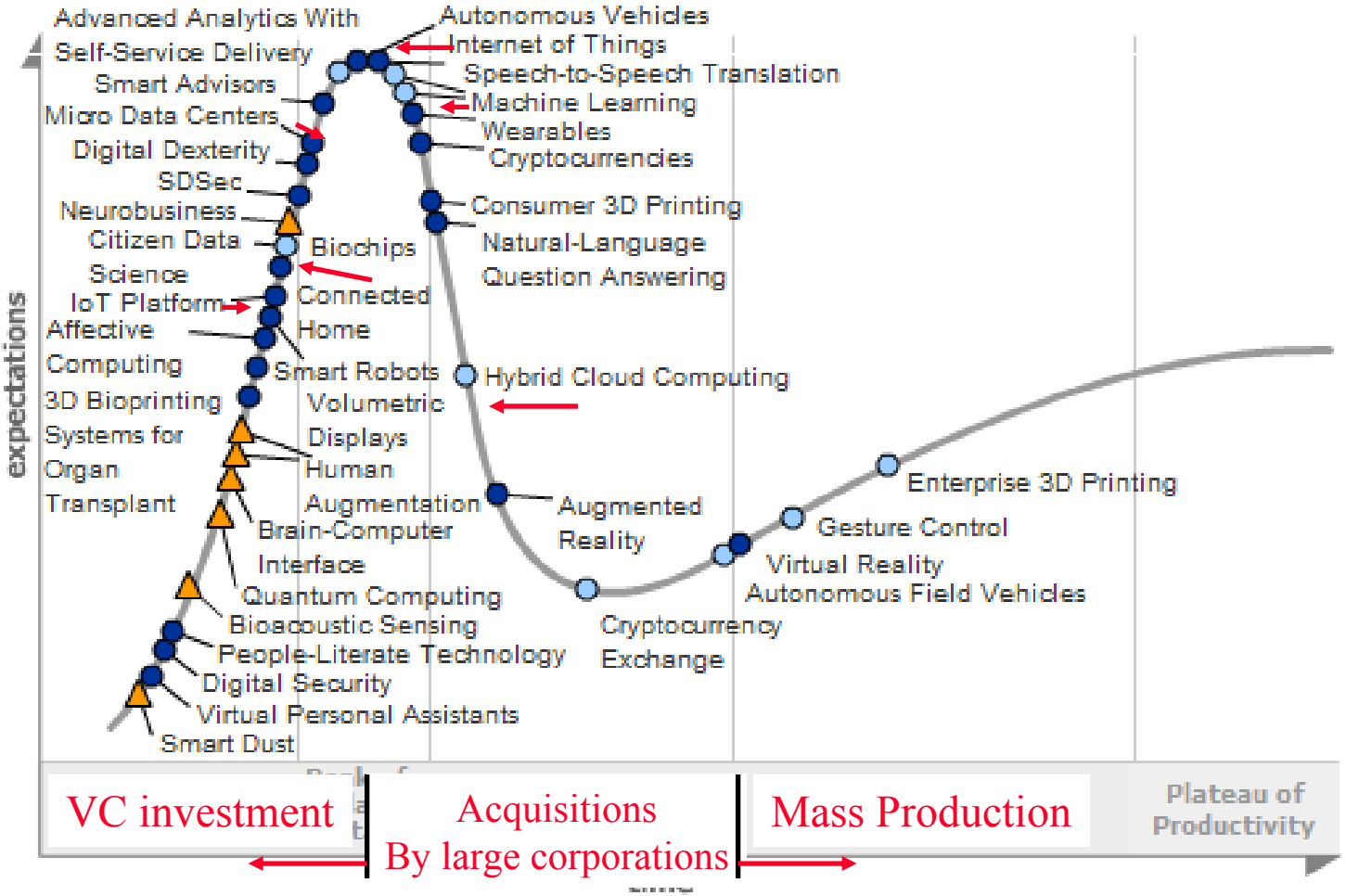
- Old: Smart = Can think ⇒ Computation
  = Can Recall ⇒ Storage
- Now: Smart = Can find quickly, Can Delegate
  ⇒ Communicate = Networking
- Smart Grid, Smart Meters, Smart Cars, Smart homes, Smart Cities, Smart Factories, Smart Smoke Detectors, …





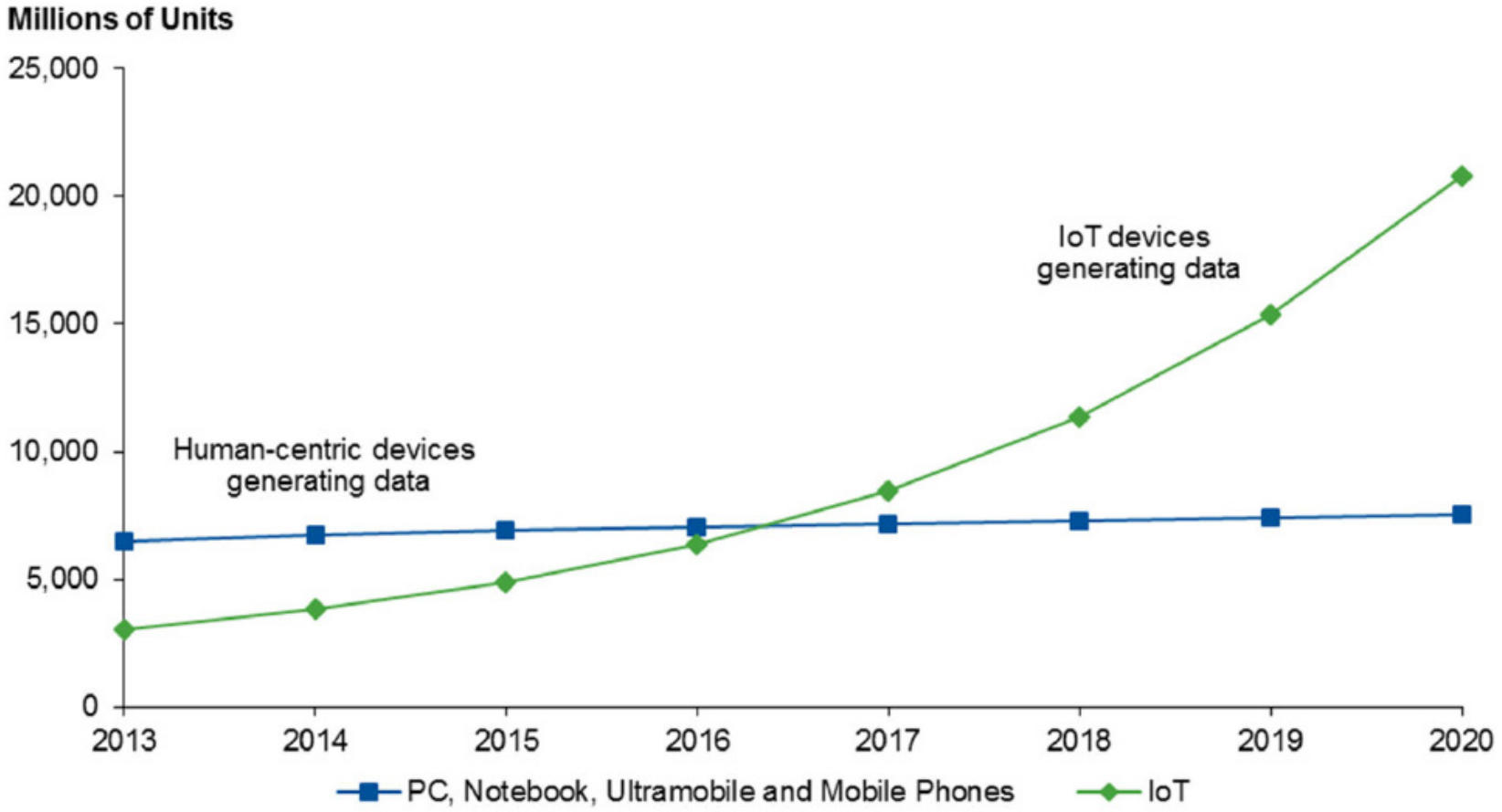
Not-Smart Smart

Gartner Hype Cycle 2015



Ref: Gartner, "Hype Cycle for Emerging Technologies, 2015," July 2015, [Available to subscribers only], http://www.gartner.com/document/3100227?ref=QuickSearch&sthkw=hype%20cycle%202015&refval=156919648&qid=fe61993355944ace1c8c01ec2df676d9

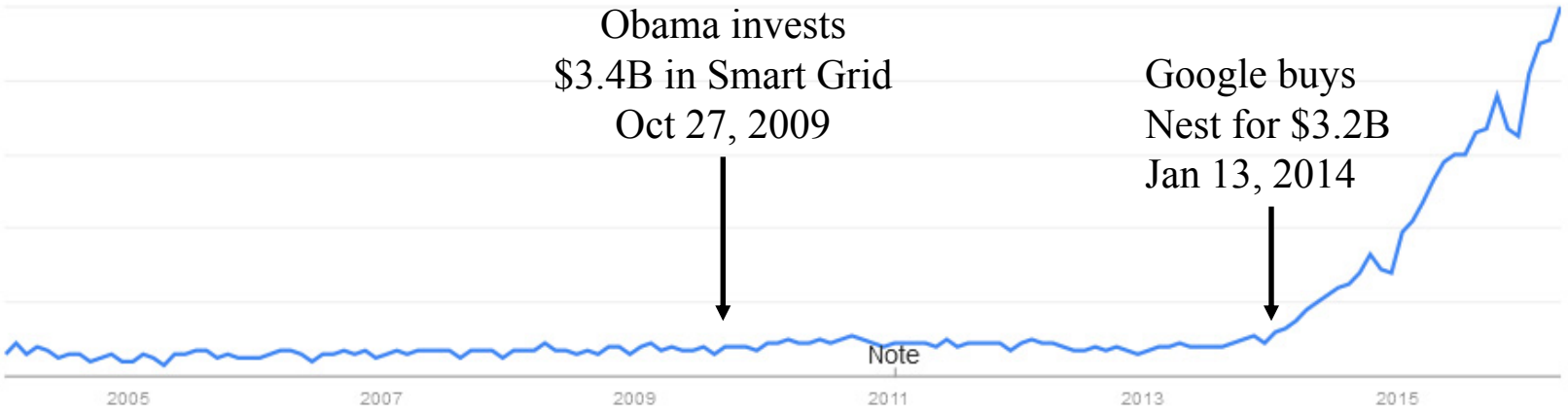
Computing vs. IoT



- 21 Billion devices by 2020

Ref: M. Moran, "Why the Internet of Things Will Dwarf Social (Big Data)," Gartner Report #G00289622, February 2016

Google Trends

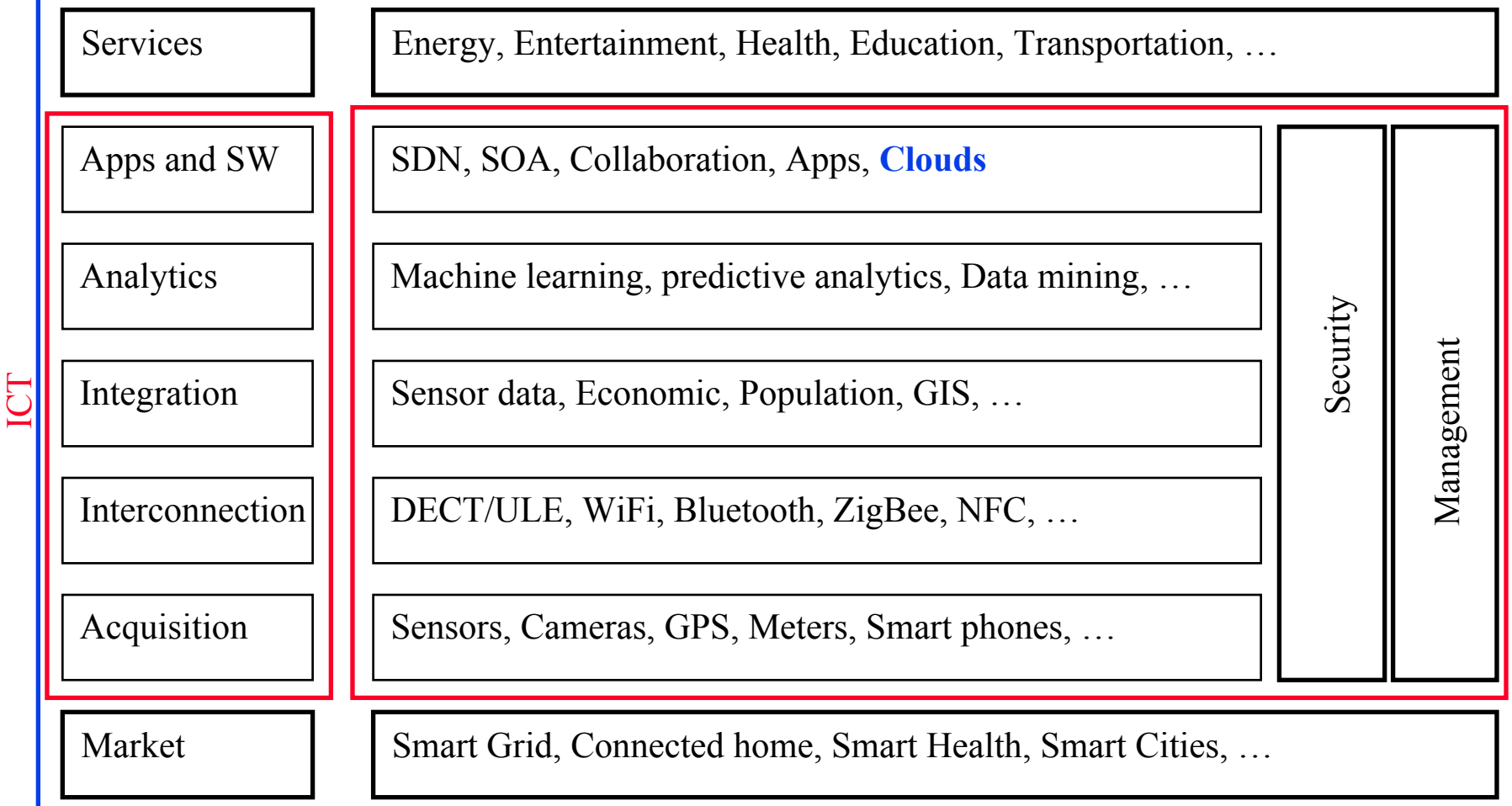


- Around for 10 years
- IERC-European Research Cluster on the Internet of Things funded under 7th Framework in 2009
  ⇒ "Internet of European Things"
- US interest started in 2009 w $3.4B funding for **smart grid** in American Recovery and Reinvestment Act of 2009

IoT is a Data ($) Mine

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

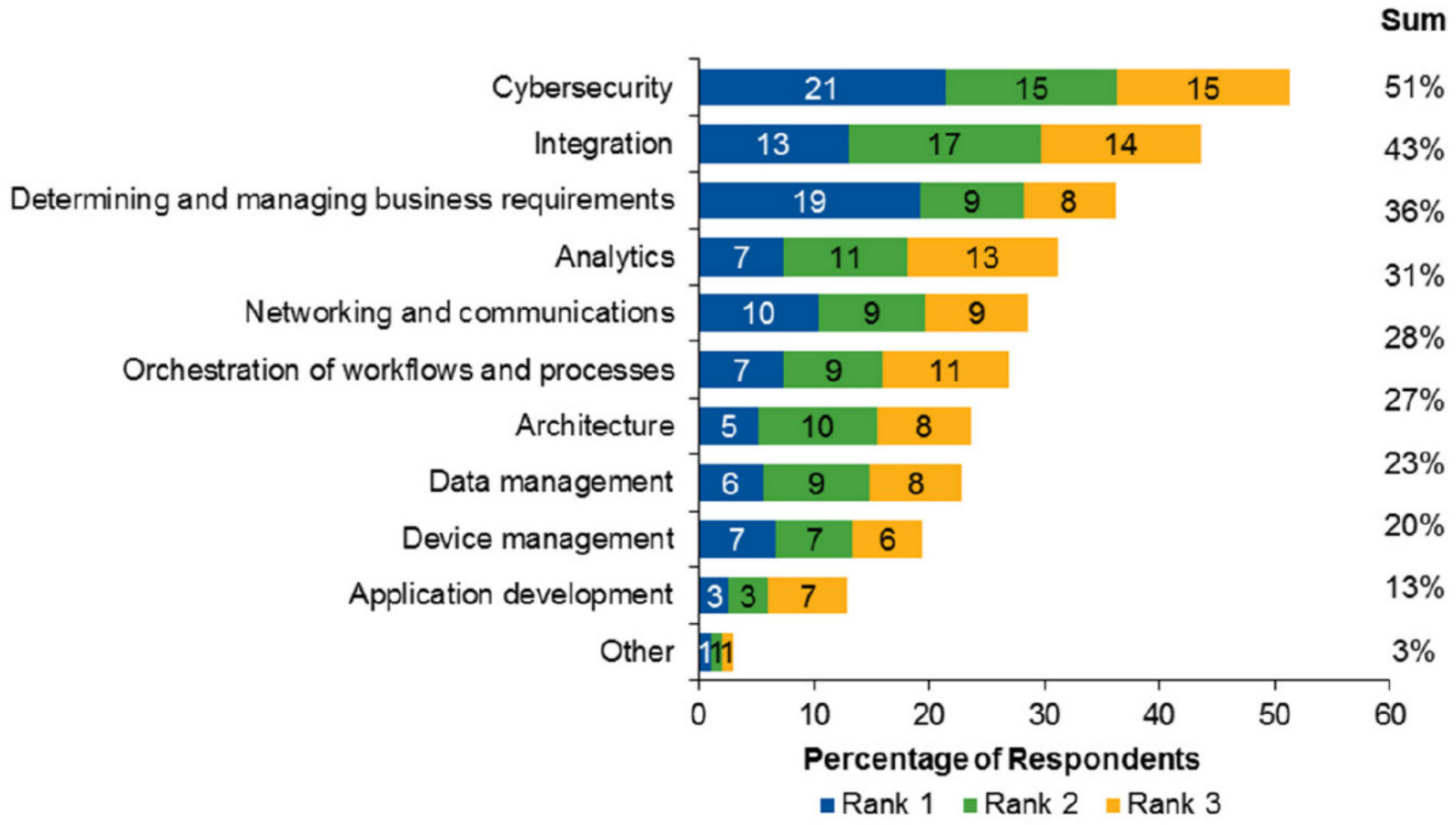
Layered Model of IoT/Smart Cities



Areas of Research for IoT/Smart Cities

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

Top Inhibitors to the Adoption of the IoT



Ref: B. Lheurex, et al, "Survey Analysis: Users Cite Ambitious Growth and formidable Technical Challenges in IoT Adoption," Gartner Report #G00300127, March 2016,

IoT Security: Popular Approach

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

Current IoT Security

- HP Study
  - 80% had privacy concerns
  - 70% lacked encryption
  - 60% had insecure updates
- Symantec Study:
  - 1/5th of Apps did not use SSL (Secure transfers)
  - None of the devices provided mutual (gateway) authentication
  - No lock-out/delaying measures against repeated attacks
  - Common web application vulnerabilities
  - Firmware upgrades were not encrypted

Ref: http://fortifyprotect.com/HP_IoT_Research_Study.pdf

Ref: M. Barcena and C. Wueest, "Insecurity in the Internet of Things," Symantec, March 2015,

Internet of Harmful Things

Imagine, as researchers did recently at Black Hat, someone hacking your connected toilet, making it flush incessantly and closing the lid repeatedly and unexpectedly.

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

Security ≠ AES-128

- CIA = Confidentiality, Integrity, Availability
  = Encryption + Message Authentication Code +
  Denial of Service Prevention
- Use of AES-128 does not guarantee security.
- Insecurity:
  - How strong is the key?
  - Where the key is stored?
  - Bugs in system code
  - Backdoors

DEFCON 2015

DEFCON 2015 (Cont)

- Hacking a Linux rifle
- Hacking smart safes
- Wirelessly steal cars
- Hack a Tesla
- Hack ZigBee
- Hacking IoT baby monitors
- Hacking FitBit Aria
- Cracking crypto currency
- Hack out of home detention
- Insteon's false security
- Hacking RFID, NFC
- DARPA Cyber Grand Challenge $2M

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

Door Locks Insecurity

- **Onity Door Locks**:
  - Used on hotel doors with magnetic strips
  - Information is encrypted using a hotel-specific secret key
  - **Programming port** on the bottom
  - Security Key can be read through programming port
  - Firmware update not possible ⇒ Replace hardware
- **Sigma Design's Z-Wave Door Locks**:
  - Z-Force tool can monitor traffic and have the lock accept a an arbitrary encryption key
- **Kwikset Kevo Door Locks**:
  - **Password** can be reset by email
  - Hijacked email addresses and phishing attack

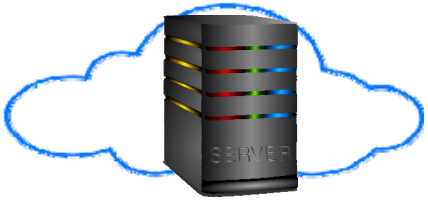
Ref: N. Dhanjani, "Abusing the Internet of Things: Blackouts, Freakouts, and Stakeouts," O'Reilly, 2015, ISBN: 978-1-491-90233-2

Attack Surface

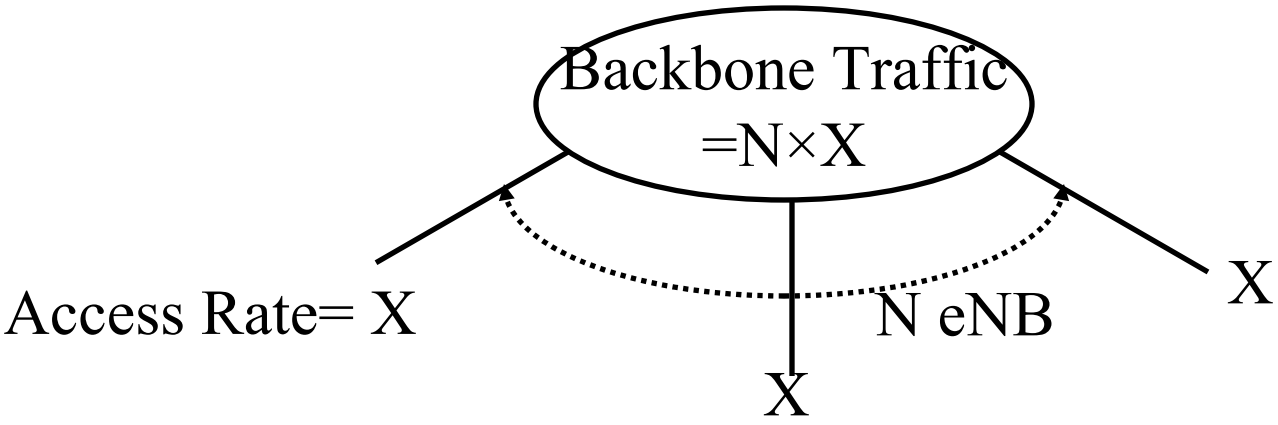
1. **Users**
2. **IoT Devices**
3. **IoT wireless access technology**: DECT, WiFi, Z-wave, …
4. **IoT Gateway**: Smart Phone
5. **Home LAN**: WiFi, Ethernet, Powerline, …
6. **IP and higher layer protocols**: DNS, Routers, …
7. **Cloud**
8. **Management Platform**: Web interface
9. **Life Cycle Management**: Booting, Pairing, Updating, …

Trend: Micro-Cloud Computing

- 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.
  - Each VM with Multiple Containers ⇒ Multiple Services

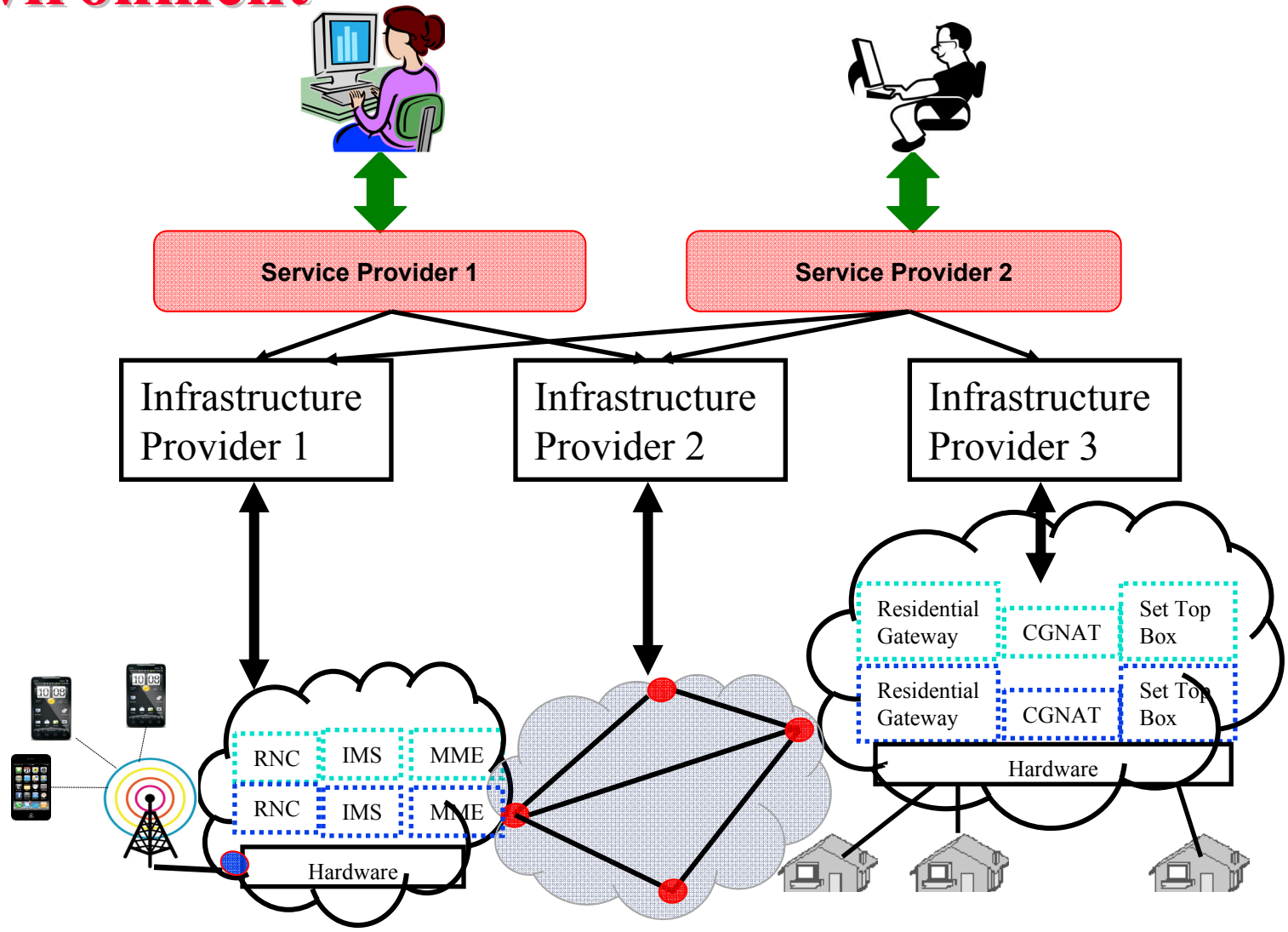


Trend: Mobile Traffic Explosion



- With **small cells**, N=# of edge points can be large
- While 5G radio access technologies may see only 1000× increase, backhaul may see much larger increase in capacity, highly dynamic, local
- Need dynamic capacity management
  ⇒ Network Function Virtualization (NFV)
- Need aggregation ⇒ Computing in the Edge

NFV in a Multi-Cloud Multi-Tenant Environment



Any Function Virtualization (FV)

- "Network" function virtualization of interest to Network service providers
- But the same concept can be used by any other industry, e.g., financial industry, banks, stock brokers, retailers, mobile games, …
- Everyone can benefit from:
  - Functional decomposition of there industry
  - Virtualization of those functions
  - Service chaining those virtual functions (VFs) or **Apps**

Networking App Market: Lower CapEx

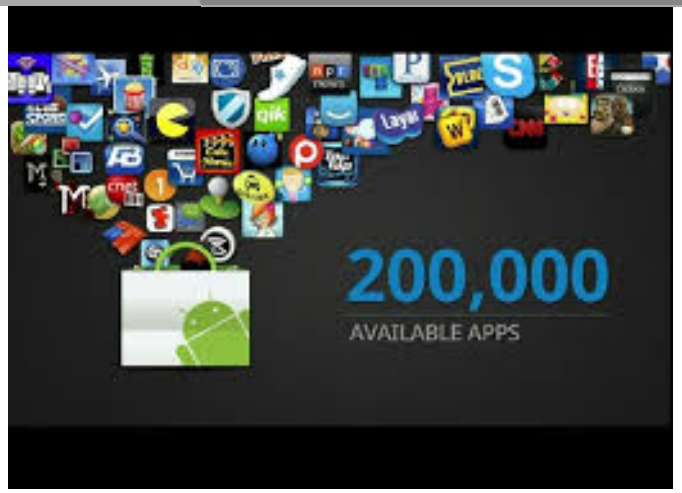
Virtual IP Multimedia System

Available on the App Store

CISCO

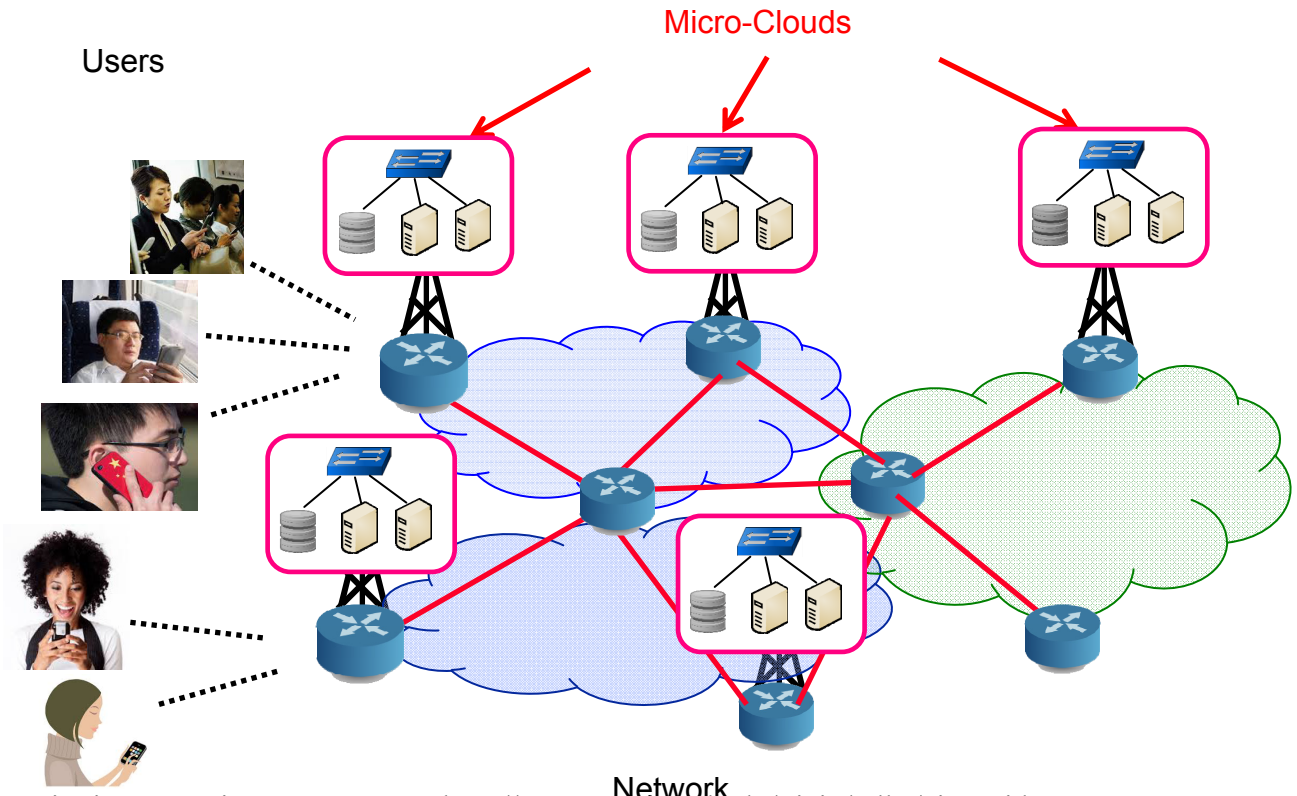
App Store

vRouter vRADIUS vVPN



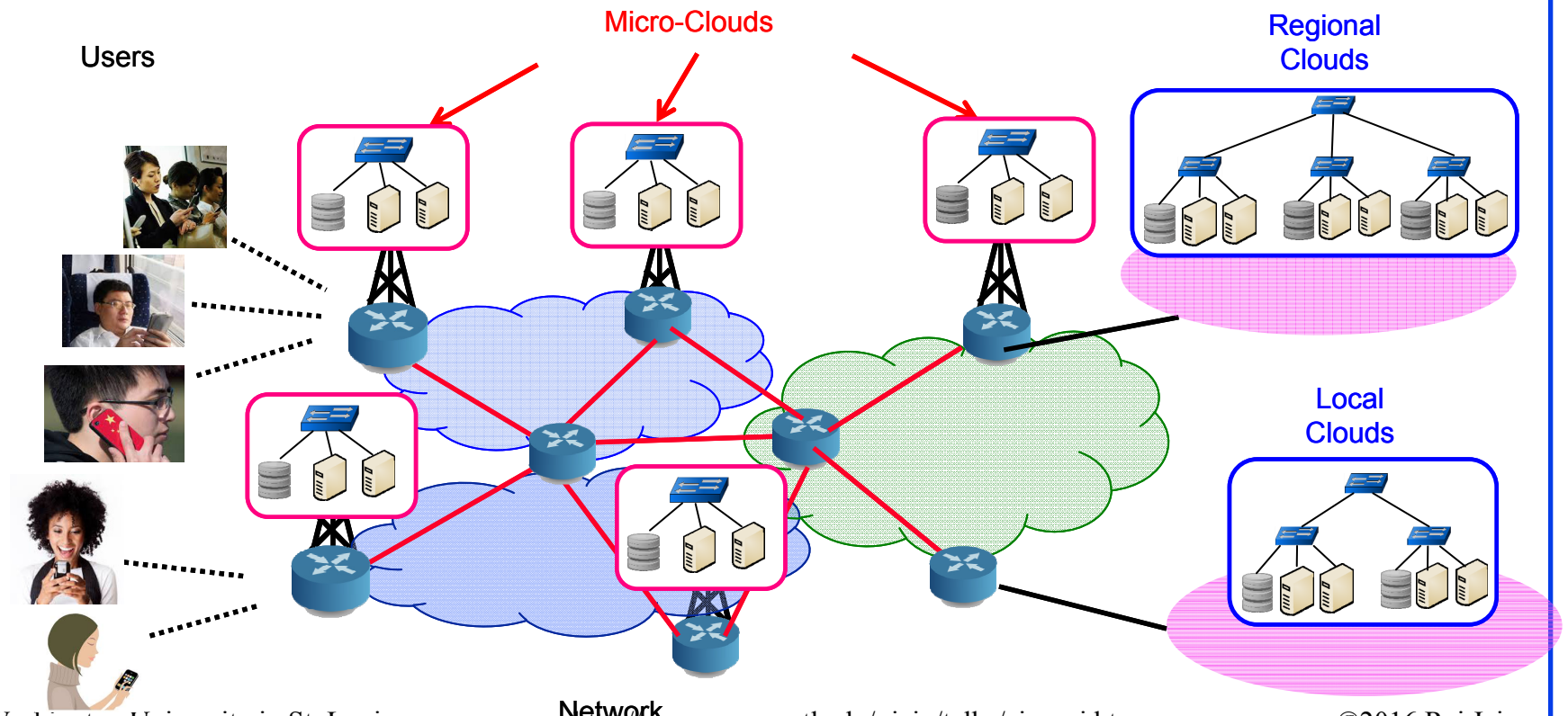
Trend: Mobile Edge Computing

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

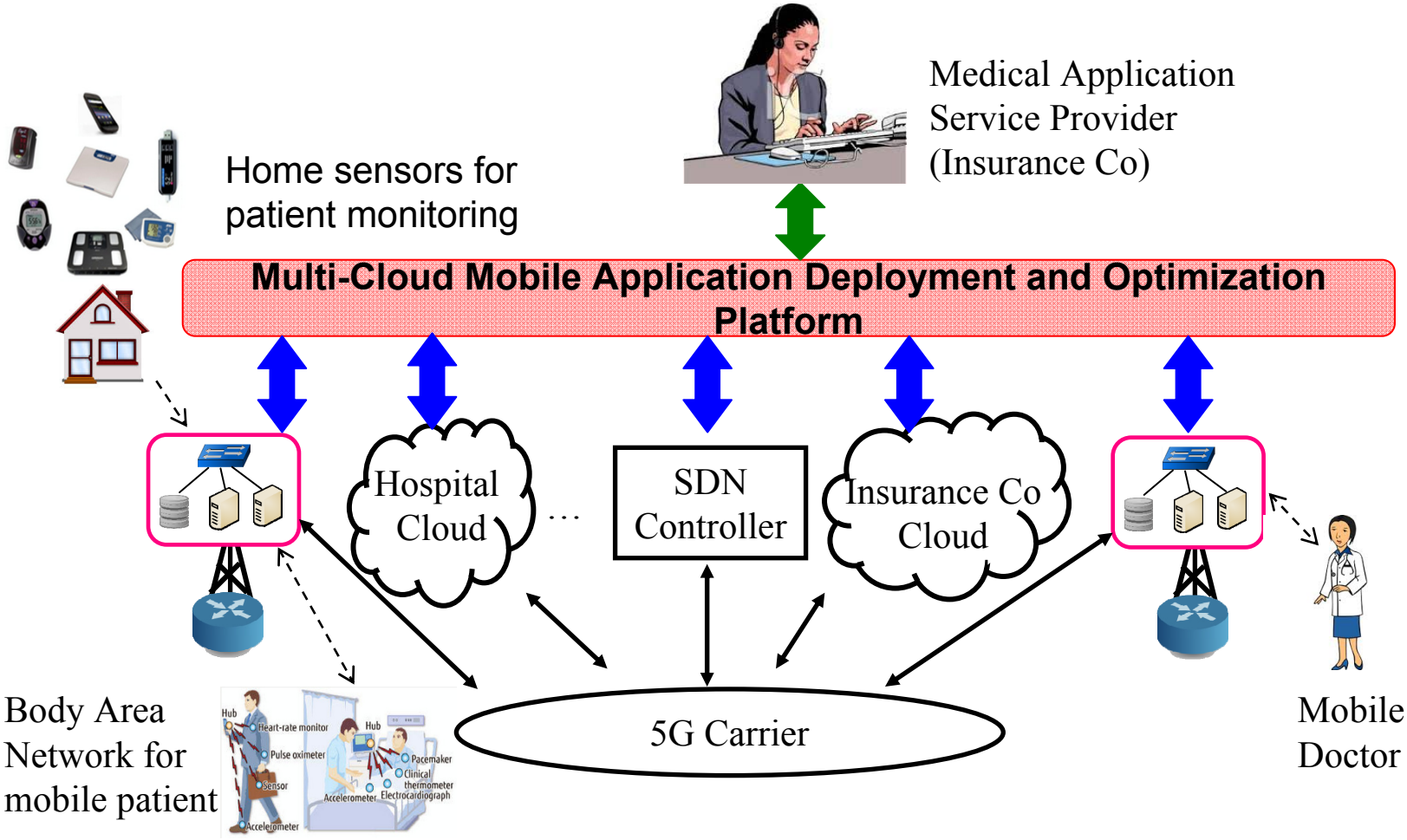


Multi-Cloud Hierarchy

- Wide area clouds, local area clouds (home routers with cloud features), Personal area clouds (cars), body area clouds (smart phone) ⇒ Fog Computing

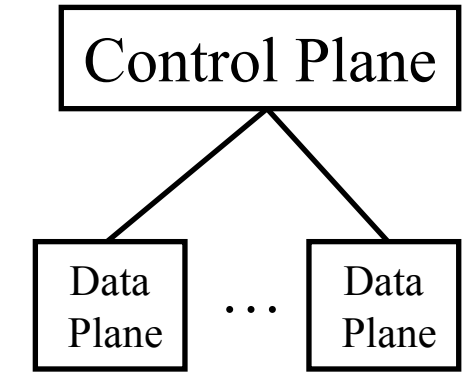


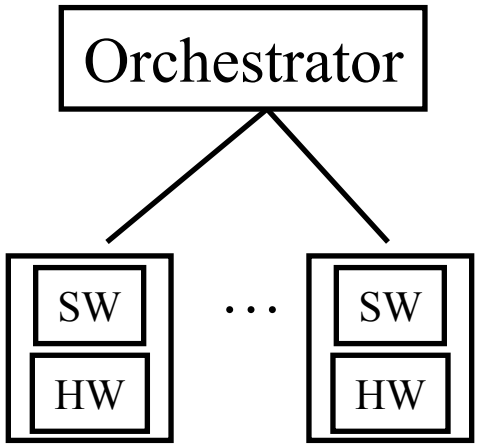
Mobile Healthcare Use Case



Software Defined Networking (SDN)

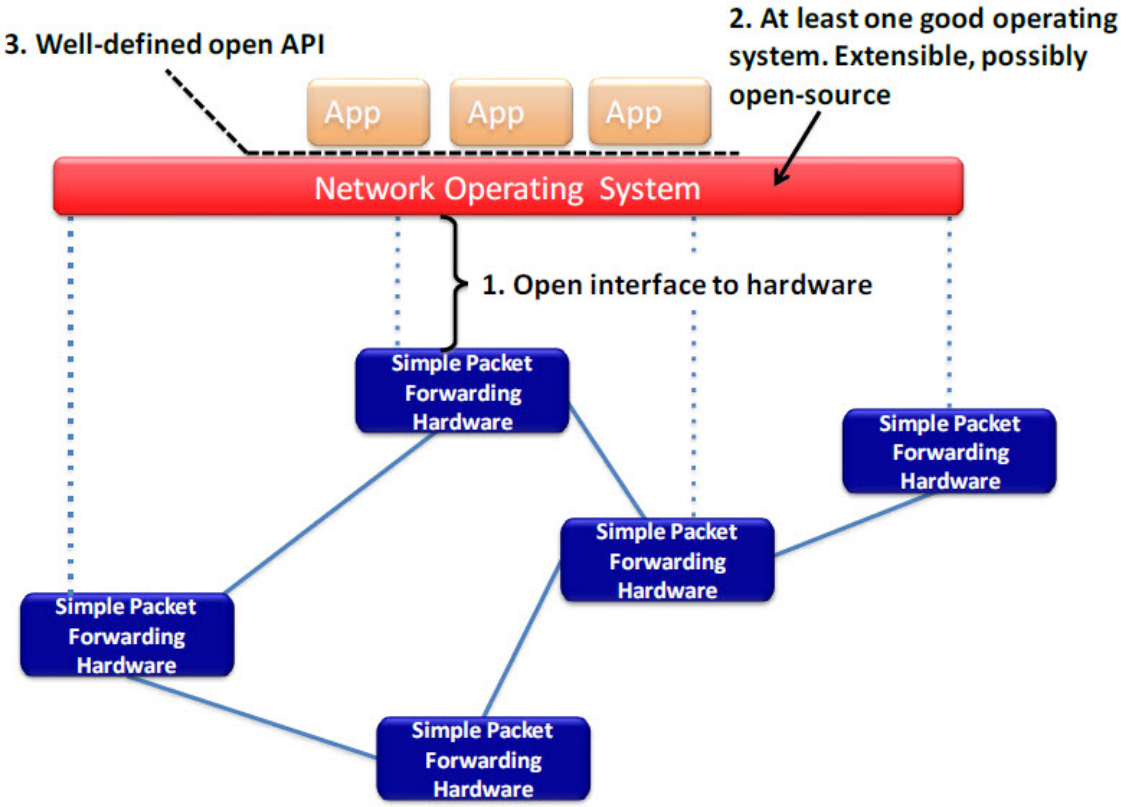
- SDN was invented in 2009
- Then: SDN:
  - OpenFlow Southbound
  - Separation of control and data planes
  - Centralization of Control
- Now: SDN = **Disaggregation** of hw/sw
  - Commodity hardware
  - Software that runs on commodity hw
  - Open Source Software
    ⇒ Service industry
  - Controller replaced by Orchestrator





Domain 2.0

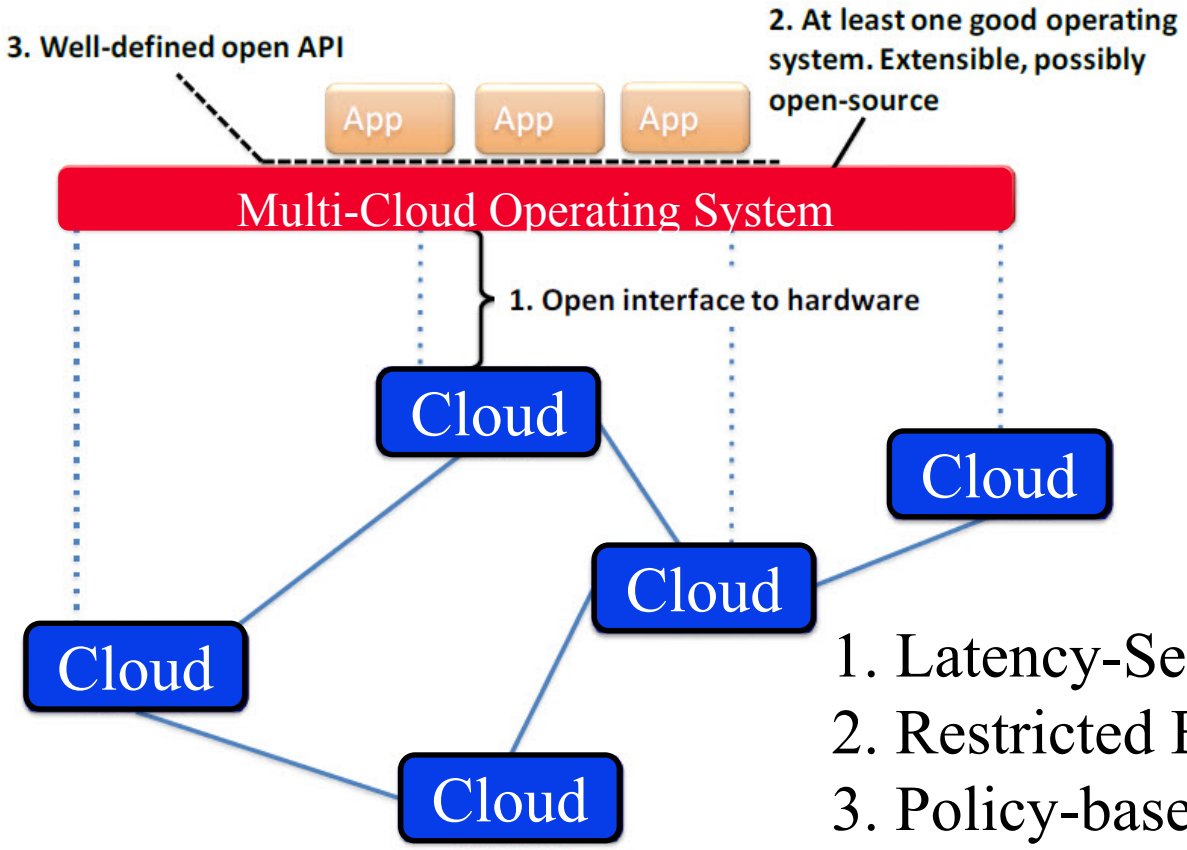
- Past: Virtualization of switches



Ref: AT&T, "Domain 2.0 White paper,"
https://www.att.com/Common/about_us/pdf/AT&T%20Domain%202.0%20Vision%20White%20Paper.pdf

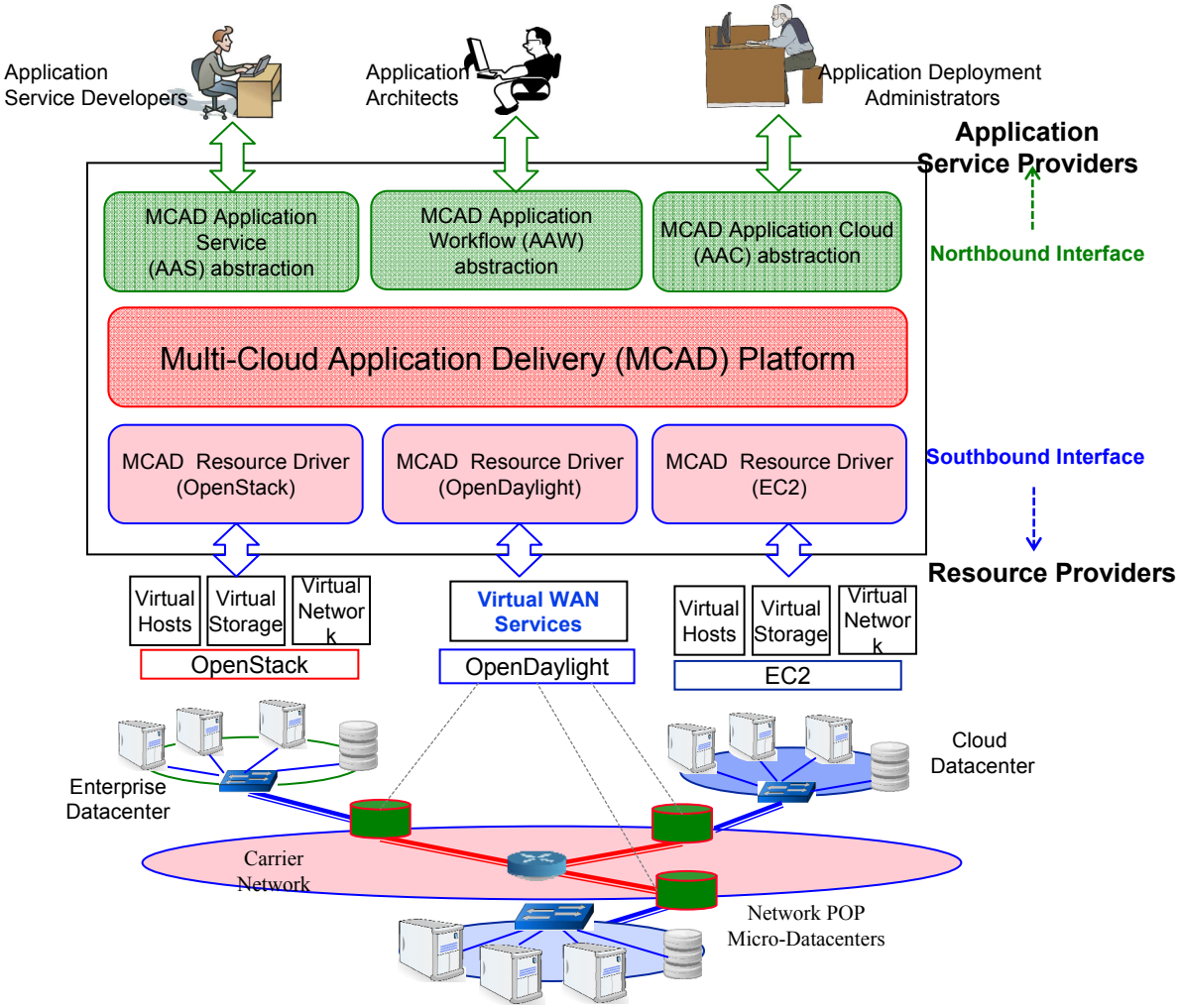
Domain 3.0

- Tomorrow: Virtualization of Clouds



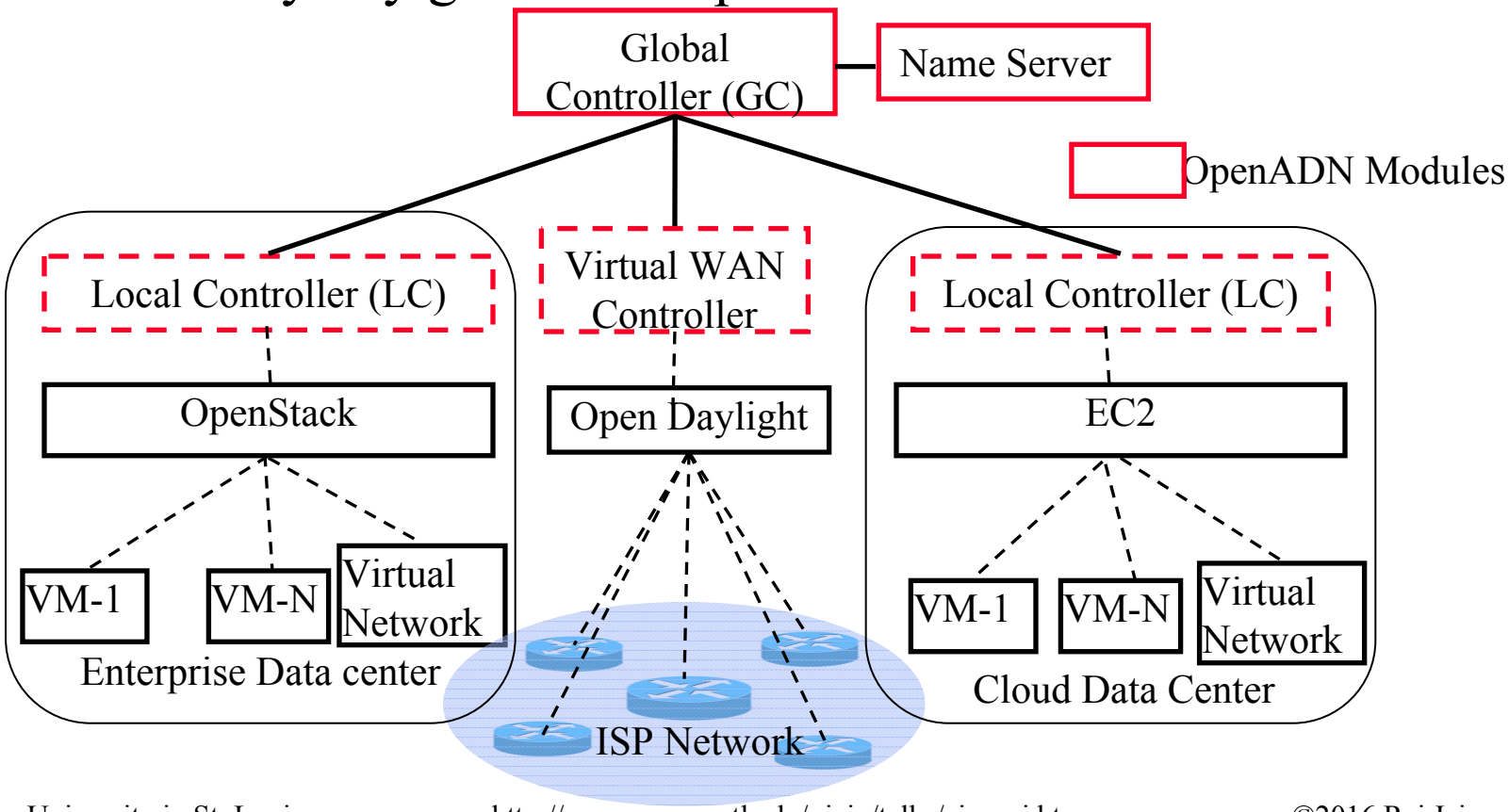
1. Latency-Sensitive
2. Restricted Bandwidth
3. Policy-based automation

OpenADN Multi-Cloud Management



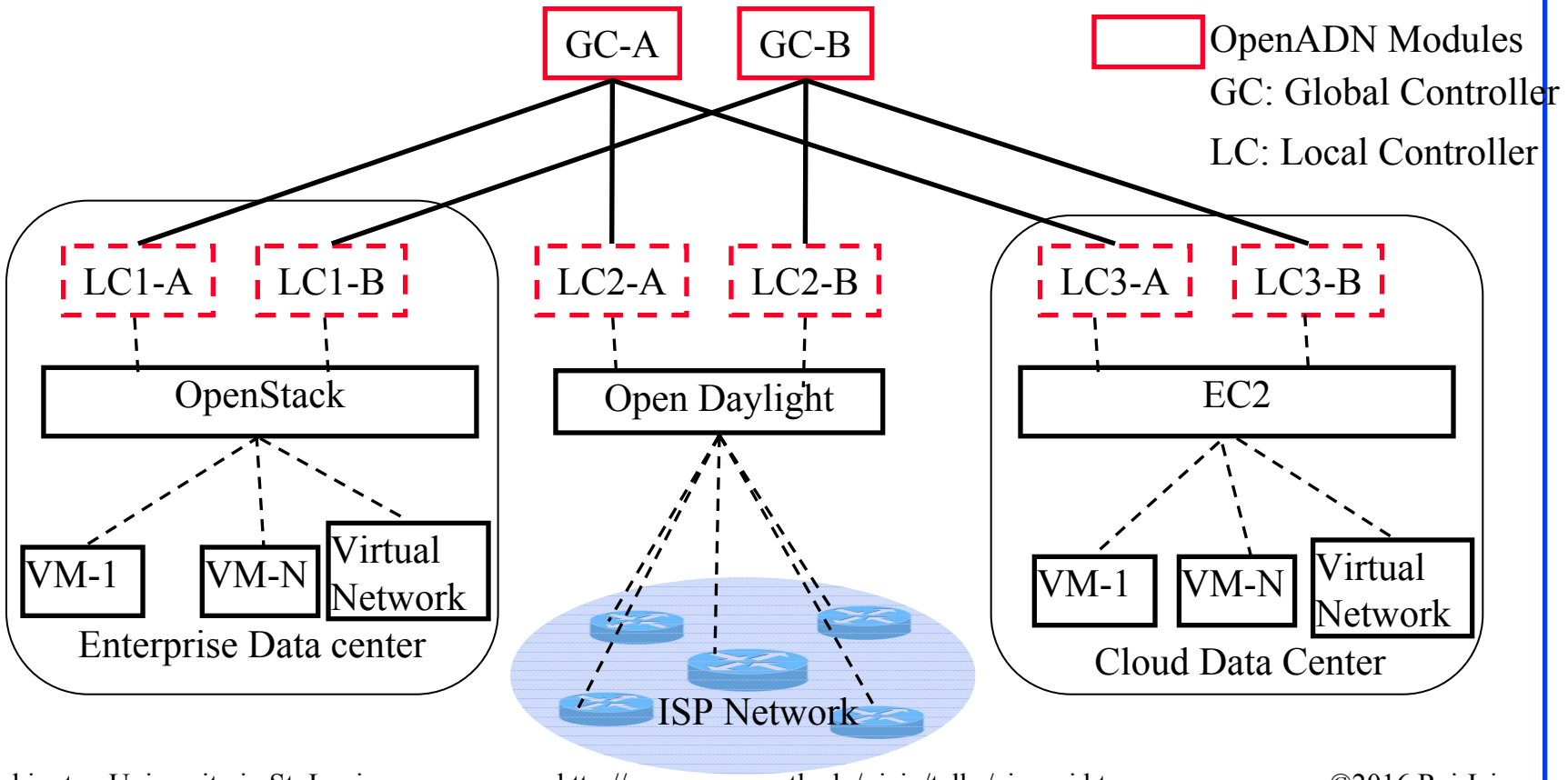
Key aspects of OpenADN Architecture

- Global and local controllers
- All services, servers, instances accessed by name
- Can be used by any global enterprise or carrier



Multiple Applications and Providers

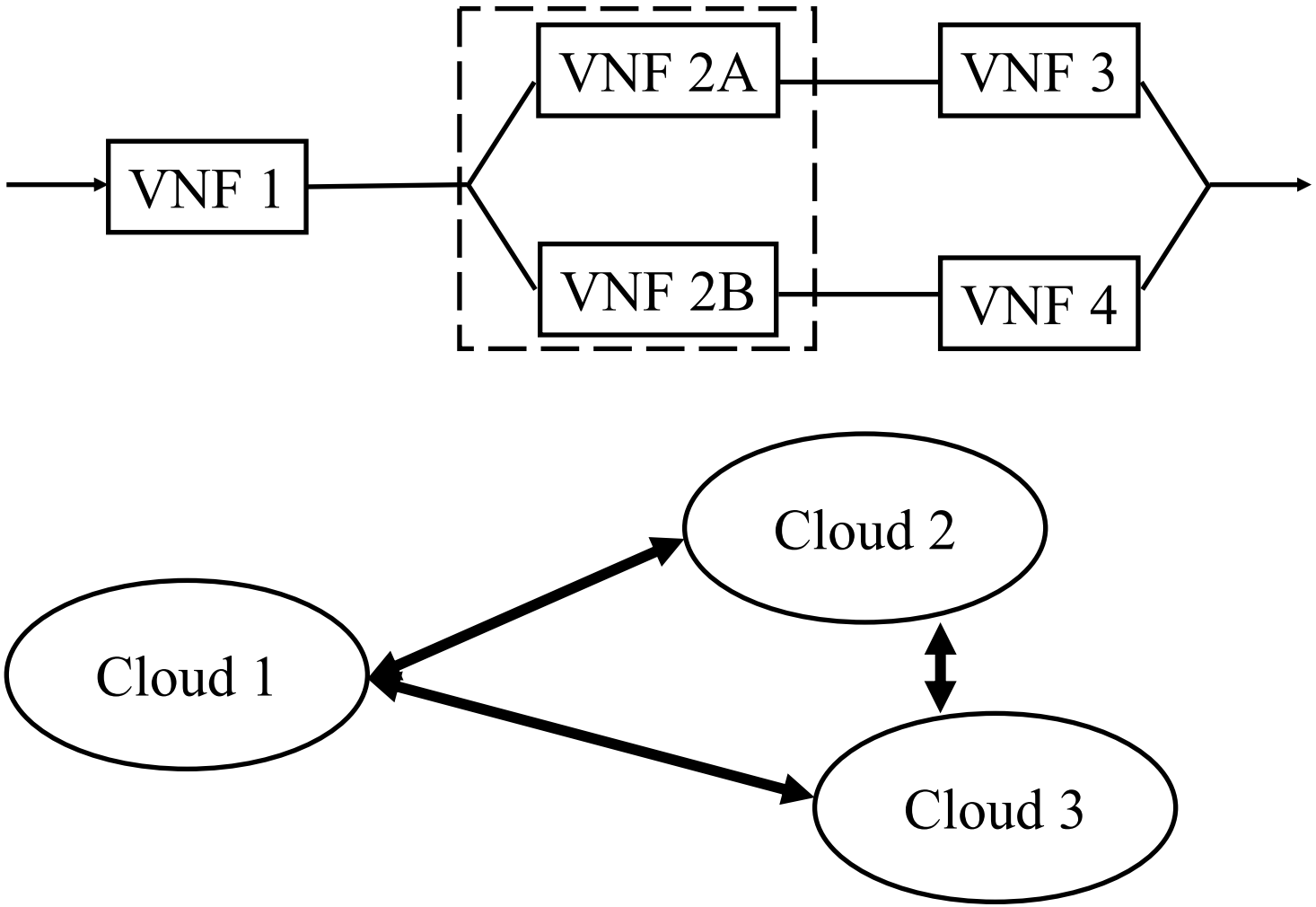
- Each Application service provider has its own Global controller and local controllers
- Every one has its own policies and set of providers



Challenges in Multi-Cloud Deployment

- **Dynamic**: Forwarding changes with state of the servers, links
- **Heterogeneous**: Different cloud providers, different services, different policies
- **Distributed Control**:
  - Equipment belongs to infrastructure provider
  - Data belongs to Tenants
- **Massive Scale**: Millions of enterprise applications sharing networks provided by many ISPs using cloud services from many CSPs

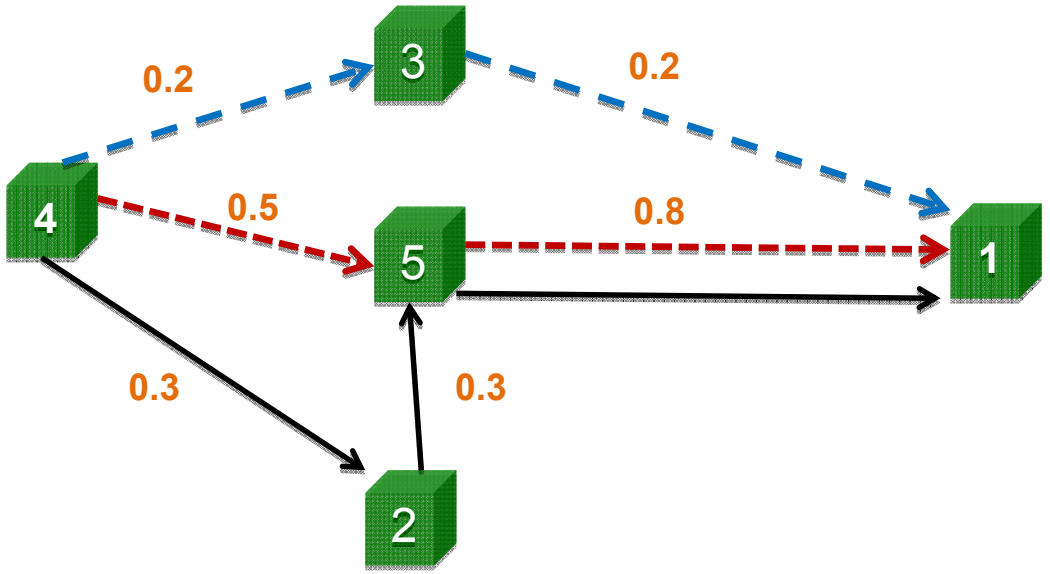
Service Function Placement Problem



Challenges in Service Placement

- **Delay constraints**
- **WAN links bottleneck:** Need to model link queues
- **Complexity**: NP-complete ⇒ Need efficient heuristics
- **Affinity:** VNF1 and VNF2 should be co-located
  - Significant communication exchanges
  - Duplicate memory pages in VMs (same OS and Libraries)
- **Anti-Affinity**: VNF1 and VNF2 should not be placed on the same physical server.
  - CPU-intensive applications
  - VMs belonging to different users in a cloud may cause security risk such as cross-VM attacks
  - Duplicate VMs used to improve fault tolerance and availability

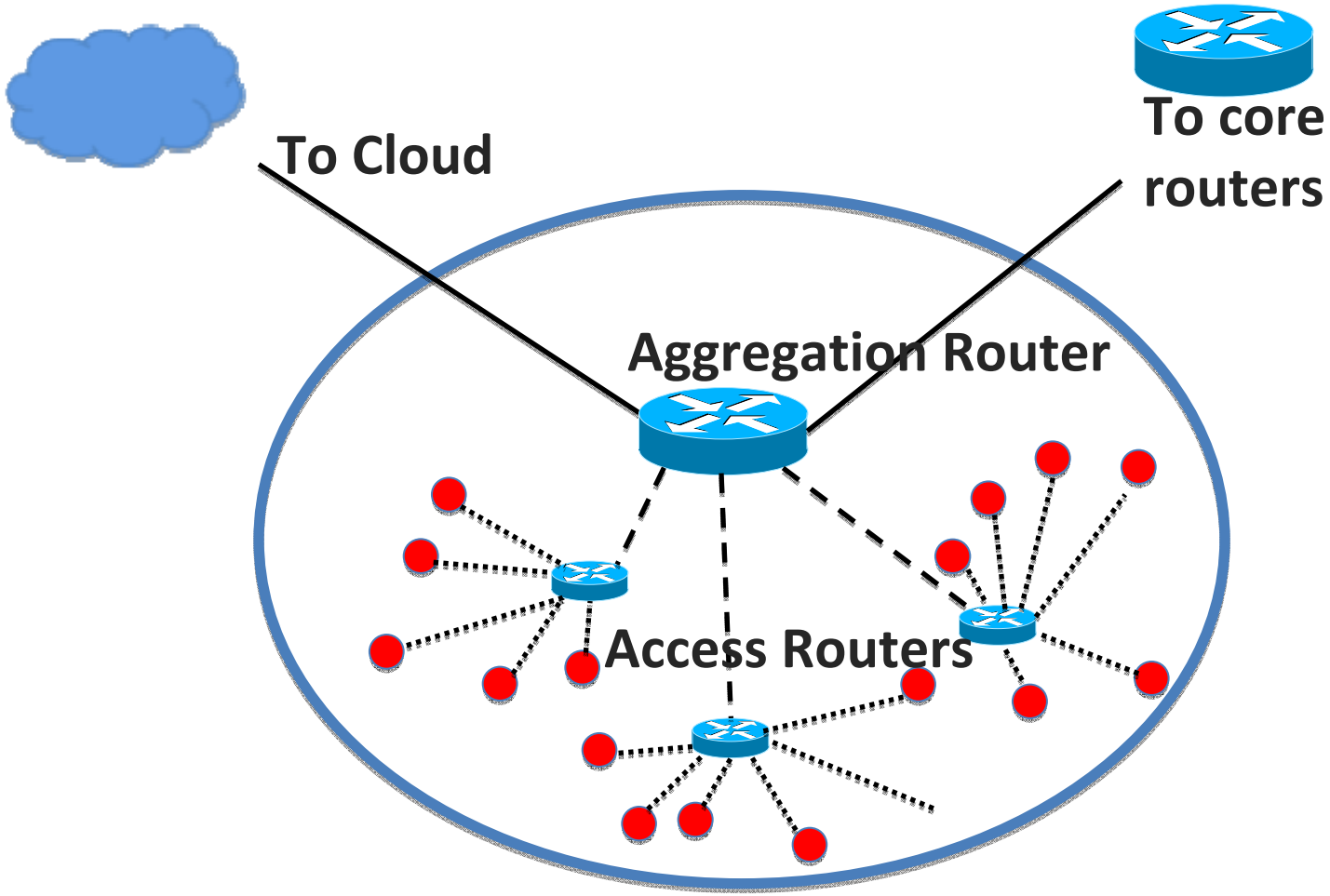
Sample Service Chains



- 5 VFs and 3 possible service chains based on business logic

User Clusters

- A cluster of end users are modeled as one

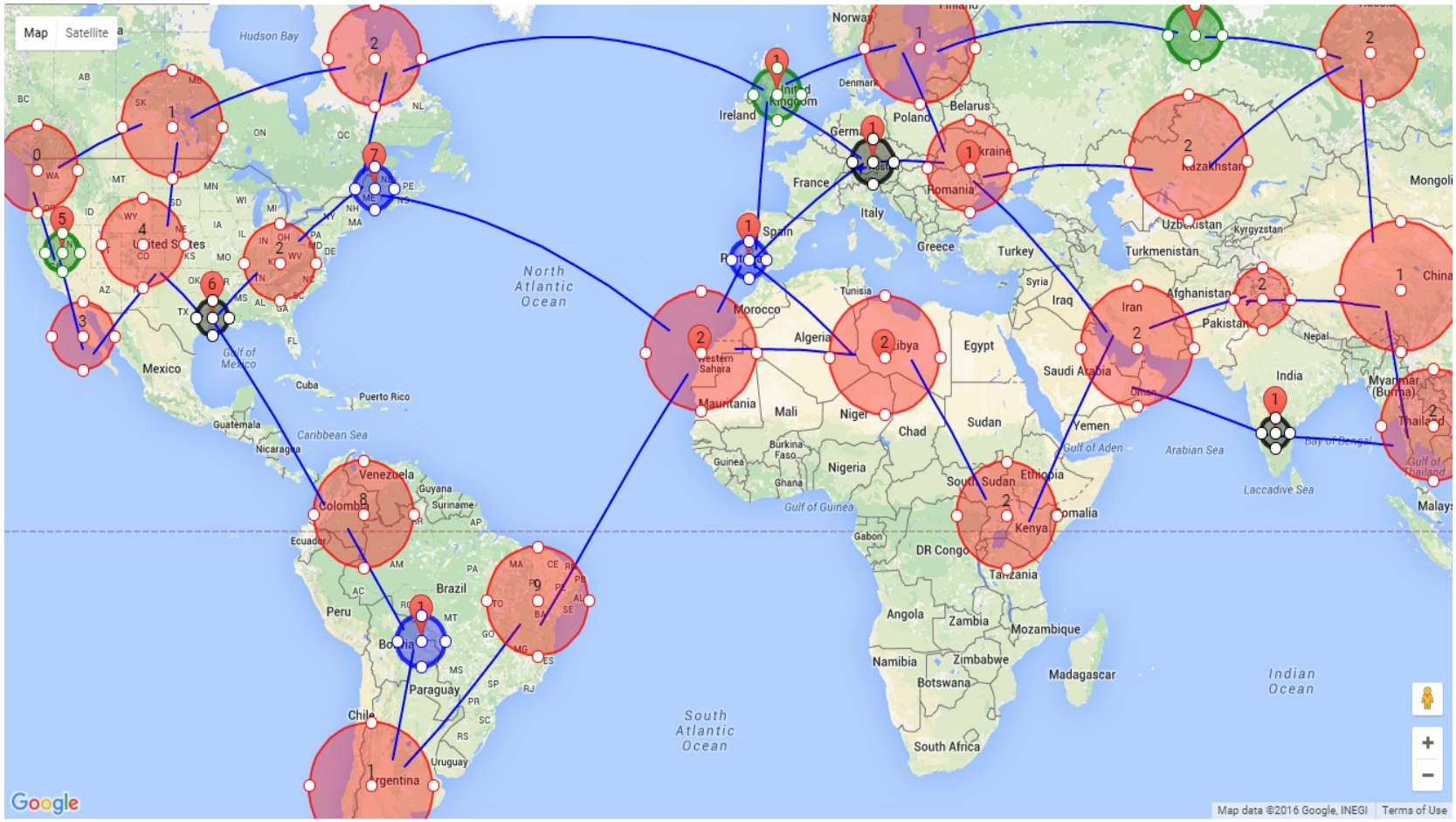


VM configurations

- **Resource configurations from Amazon EC2**

Configuration	Memory (GB)	Compute Unit	Disk (GB)	Platform (bit)	Cost ($/h)
m1.samll	1.7	1	160	32	0.1
m1.large	7.5	4	850	64	0.4
m1.xlarge	15	8	1690	64	0.8
c1.medium	1.7	5	350	32	0.2
c1.xlarge	7	20	1690	64	0.8

Topology UI


Map
Satellite
Hudson Bay
North Atlantic Ocean
South Atlantic Ocean
Indian Ocean
Caribbean Sea
Gulf of Mexico
Gulf of Guinea
Gulf of Aden
Arabian Sea
Laccadive Sea
Bay of Bengal
Mexico
Cuba
Puerto Rico
Guatemala
Nicaragua
Venezuela
Guyana
Suriname
Colombia
Ecuador
Peru
Brazil
Paraguay
Chile
Uruguay
Argentina
Ireland
France
Spain
Italy
Greece
Turkey
Poland
Belarus
Romania
Norway
Denmark
Morocco
Algeria
Tunisia
Libya
Egypt
Mauritania
Mali
Niger
Chad
Sudan
Nigeria
Ghana
Guinea
Burkina Faso
Western Sahara
South Sudan
Ethiopia
Kenya
Somalia
Gabon
DR Congo
Tanzania
Angola
Zambia
Mozambique
Namibia
Zimbabwe
Botswana
Madagascar
South Africa
Syria
Iraq
Iran
Afghanistan
Pakistan
Saudi Arabia
Yemen
Oman
India
Nepal
Myanmar (Burma)
Thailand
Malaysia
Kazakhstan
Uzbekistan
Turkmenistan
Kyrgyzstan
Mongolia
China
Google
Map data ©2016 Google, INEGI
Terms of Use

Analysis

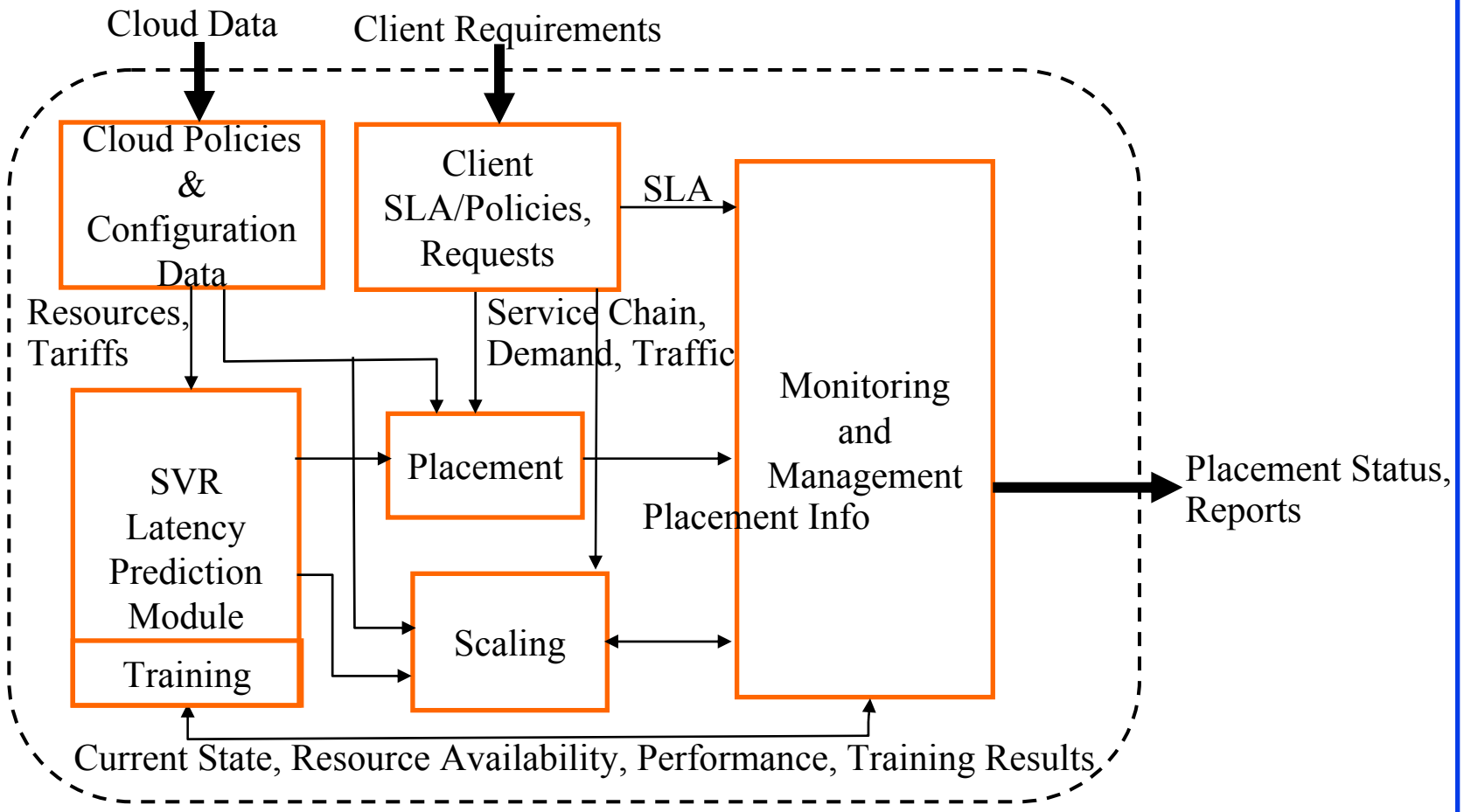
- Integer Linear Programming (ILP) to find the optimal solution
  - Exponential complexity (NP-Complete)
  - Takes days ⇒ Not usable in real-time deployment scenarios
- Heuristics:
  - Least-full first with First Finish (LFFF)
  - Most-full first with Decreasing time (MFDT)
  - Least-full first with Decreasing time (LFDT)
  - Most-full first with First Finish (MFFF)
  - **Fair-Weighted Affinity-based Scheduling (FWS)**

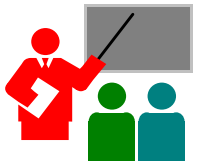
Machine Learning Based Placement

- Need to speed up placement and scaling so that latency could be maintained dynamically.
- ILP and exhaustive search may be slow for such a situation.
- Application of machine learning to learn from previous state to dynamically manage networks at future times could be a way to handle this problem.

CALOPE

- Cost Aware Latency Optimizing Placement Engine





Summary

1. Clouds getting smaller, Carriers and enterprises moving to clouds, Internet of things are leading to clouds everywhere $\Rightarrow$ multi-cloud applications.
2. Our multi-cloud application management system (MCAD) allows policy-based deployment and management of multi-cloud application. Handles heterogeneous clouds and respects resource ownerships
3. Service function placement problem is NP complete. Challenges included delay constraints, WAN Link bottlenecks, and affinity
4. We have developed efficient heuristics for placement and can be made faster with machine learning.

References

- Deval Bhamare, Raj Jain, Mohammed Samaka, Gabor Vaszkun, Aiman Erbad, "Multi-Cloud Distribution of Virtual Functions and Dynamic Service Deployment: OpenADN Perspective," Proceedings of 2nd IEEE International Workshop on Software Defined Systems (SDS 2015), Tempe, AZ, March 9-13, 2015, 6 pp. http://www.cse.wustl.edu/~jain/papers/vm_dist.htm
- Subharthi Paul, Raj Jain, Mohammed Samaka, Aiman Erbaud, "Service Chaining for NFV and Delivery of other Applications in a Global Multi-Cloud Environment," ADCOM 2015, Chennai, India, September 19, 2015, http://www.cse.wustl.edu/~jain/papers/adn_in15.htm
- Raj Jain, Mohammed Samaka, "Application Deployment in Future Global Multi-Cloud Environment," The 16th Annual Global Information Technology Management Association (GITMA) World Conference, Saint Louis, MO, June 23, 2015, http://www.cse.wustl.edu/~jain/papers/apf_gitp.htm

References (Cont)

- Subharthi Paul, Raj Jain, Mohammed Samaka, Jianli Pan, "Application Delivery in Multi-Cloud Environments using Software Defined Networking," Computer Networks Special Issue on cloud networking and communications, Available online 22 Feb 2014, http://www.cse.wustl.edu/~jain/papers/comnet14.htm
- Raj Jain and Subharthi Paul, "Network Virtualization and Software Defined Networking for Cloud Computing - A Survey," IEEE Communications Magazine, Nov 2013, pp. 24-31, http://www.cse.wustl.edu/~jain/papers/net_virt.htm

Acronyms

- ATM Asynchronous Transfer Mode
- ECN Explicit congestion notification
- EFCI Explicit Forward Congestion Indication
- FECN Forward Explicit Congestion Notification
- GB Gigabyte
- IEEE Institution of Electrical and Electronic Engineering
- IETF Internet Engineering Task Force
- IoT Internet of Things
- IP Internet Protocol
- IRTF Internet Research Task Force
- ITU International Telecommunications Union
- LAN Local Area Network
- LTE Long Term Evolution
- MHz Mega Hertz
- OpenADN Open Application Delivery Networking
- SDN Software Defined Networking

Acronyms (Cont)

- TCP Transmission Control Protocol
- TV Television
- VM Virtual Machine
- WAN Wide Area Network
- WiFi Wireless Fidelity
- WiMAX Worldwide Interoperability for Microwave Access

Scan This to Download These Slides

Raj Jain

http://bit.ly/ciscopi