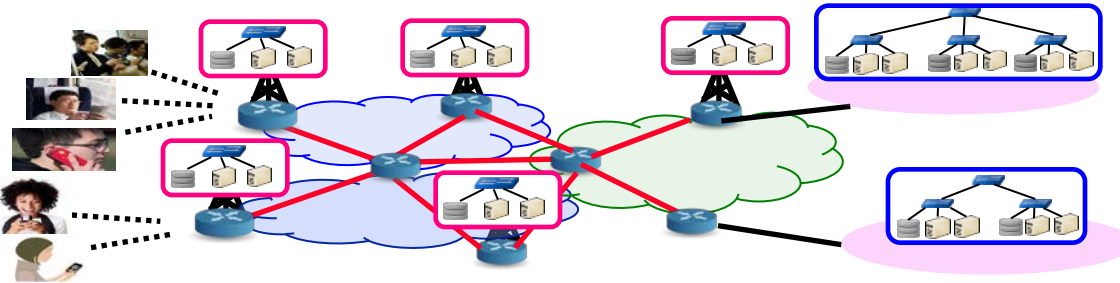


# Multi-Cloud Global Application Delivery for Internet of Things and Smart Cities



**RAJ JAIN**

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Keynote at The 2nd IEEE International Conference on  
Collaboration and Internet Computing (CIC),  
Pittsburgh, PA, Nov 1, 2016.

These slides and recording of this talk are available on-line at:

[http://www.cse.wustl.edu/~jain/talks/adn\\_cic.htm](http://www.cse.wustl.edu/~jain/talks/adn_cic.htm)

or [http://bit.ly/jain\\_cic](http://bit.ly/jain_cic)



- ❑ 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

# Trend: Smart Everything



Smart Watch



Smart TV



Smart Car



Smart Health



Smart Home



Smart Kegs



Smart Space



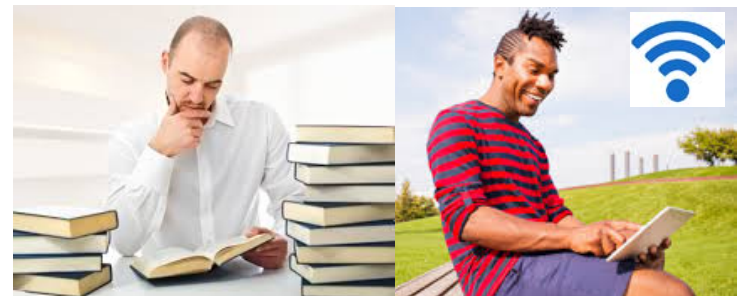
Smart Industries



Smart Cities

# What's Smart?

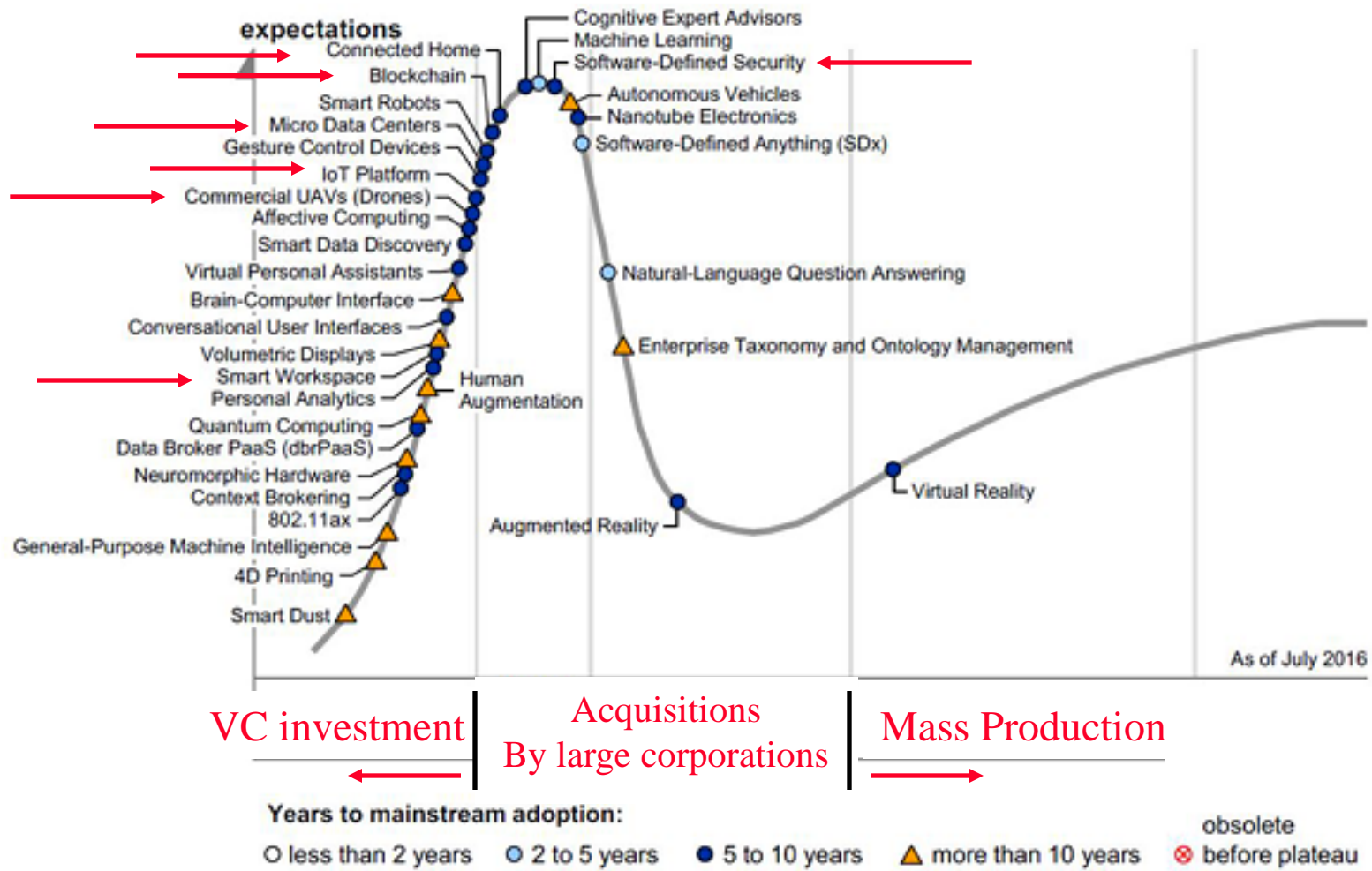
- ❑ Old: Smart = Can think  $\Rightarrow$  Computation  
= Can Recall  $\Rightarrow$  Storage
- ❑ Now: Smart = Can find quickly, Can Delegate  
 $\Rightarrow$  Communicate = Networking
- ❑ Smart Grid, Smart Meters, Smart Cars, Smart homes, Smart Cities, Smart Factories, Smart Smoke Detectors, ...



Not-Smart

Smart

# Gartner Hype Cycle 2016



Ref: Gartner, "Hype Cycle for Emerging Technologies, 2016," July 2016, [subscribers only], [gartner.com/document/3383817](http://gartner.com/document/3383817)

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[http://www.cse.wustl.edu/~jam/talks/adn\\_cic.htm](http://www.cse.wustl.edu/~jam/talks/adn_cic.htm)

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# IoT Business Opportunity

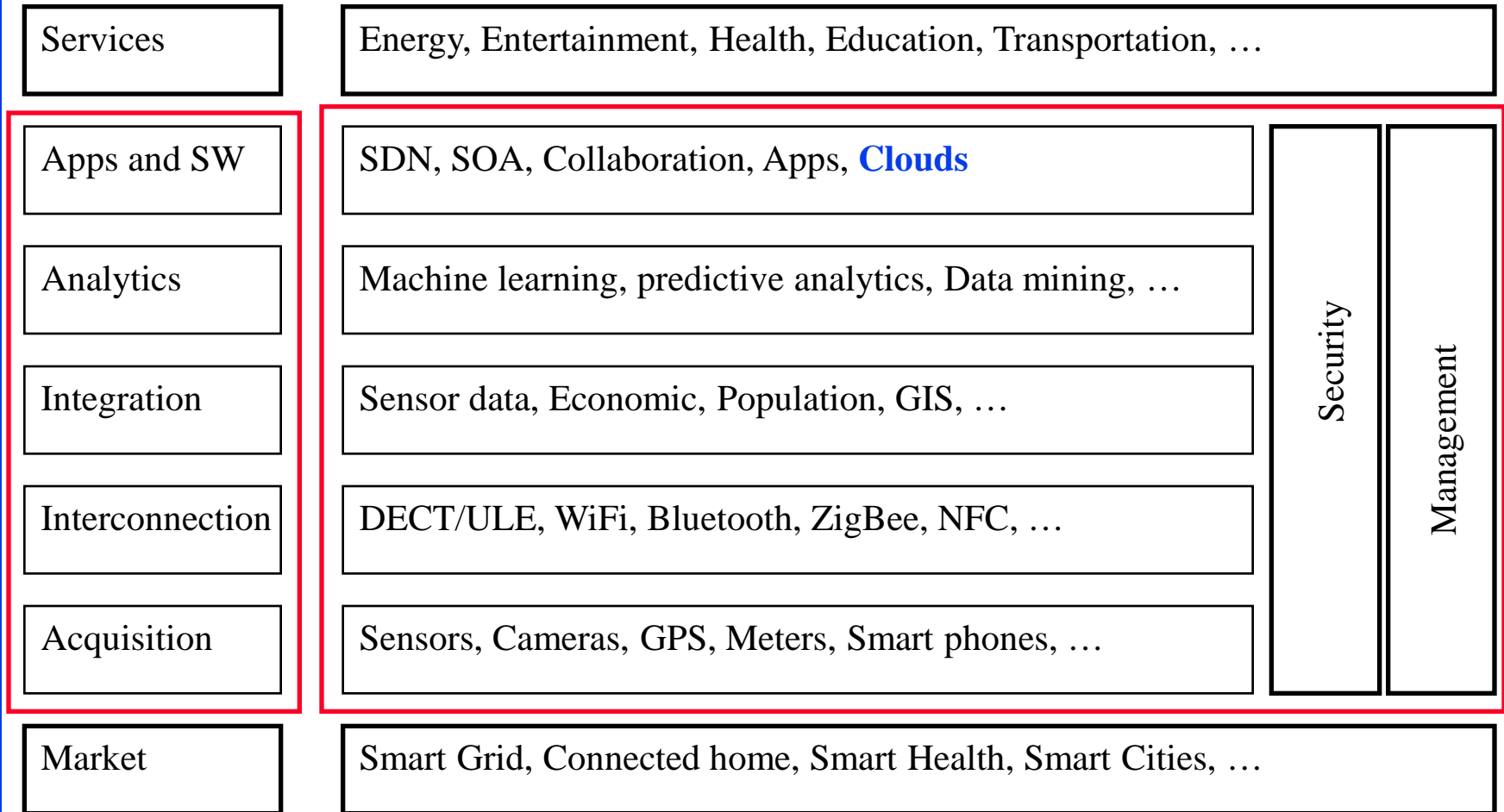


- ❑ \$1.7 Trillion by 2020 - IDC
- ❑ \$7.1 Trillion - Gartner
- ❑ \$10-15 Trillion just for Industrial Internet – GE
- ❑ \$19 Trillion – Internet of Everything - Cisco

Ref: <http://www.forbes.com/sites/gilpress/2014/08/22/internet-of-things-by-the-numbers-market-estimates-and-forecasts/>  
<http://www.forbes.com/sites/gilpress/2014/08/22/internet-of-things-by-the-numbers-market-estimates-and-forecasts/>

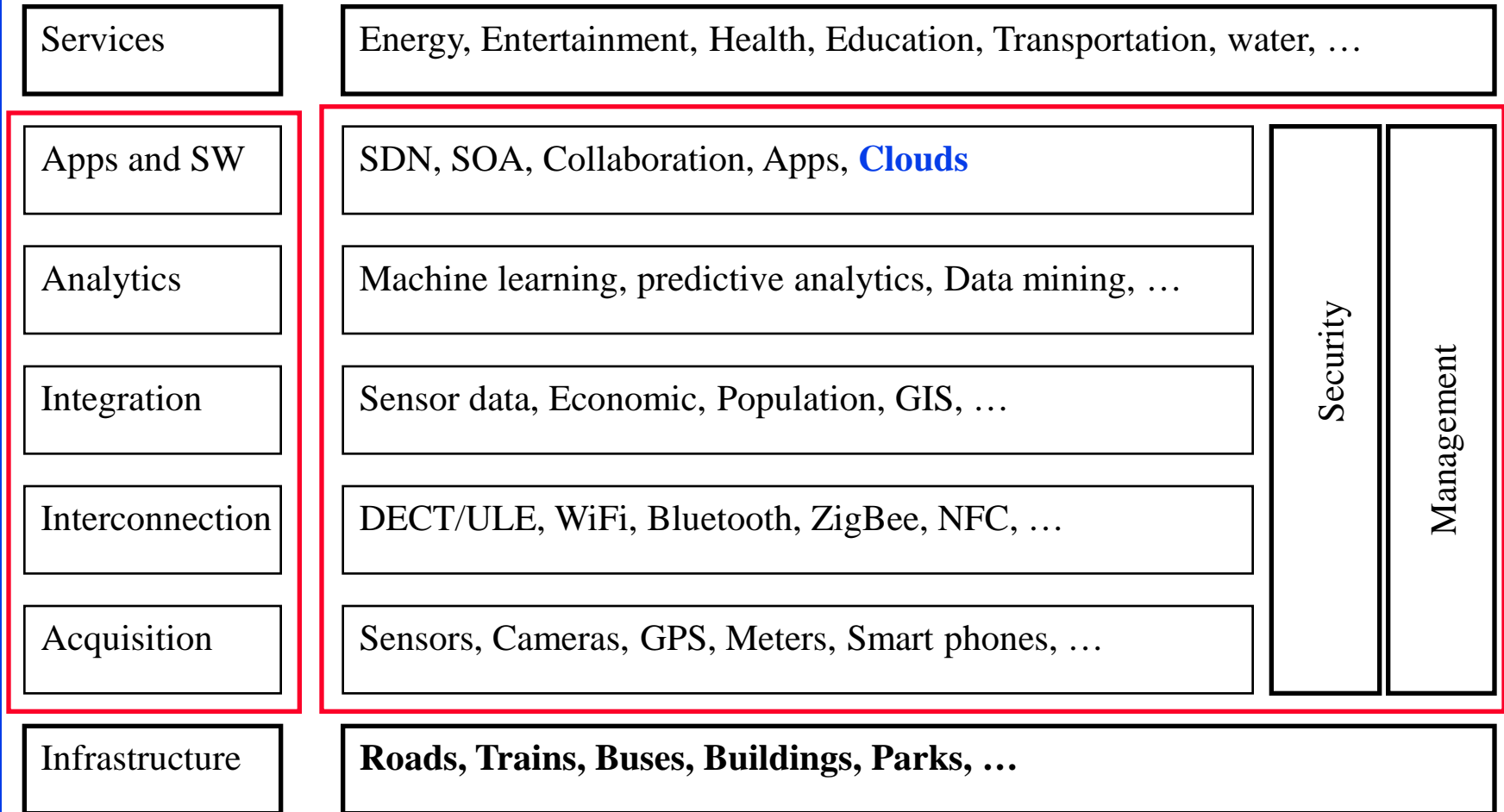
# A 7-Layer Model of IoT

ICT



# A 7-Layer Model of Smart Cities

ICT





# IoT is a Data (\$) Mine



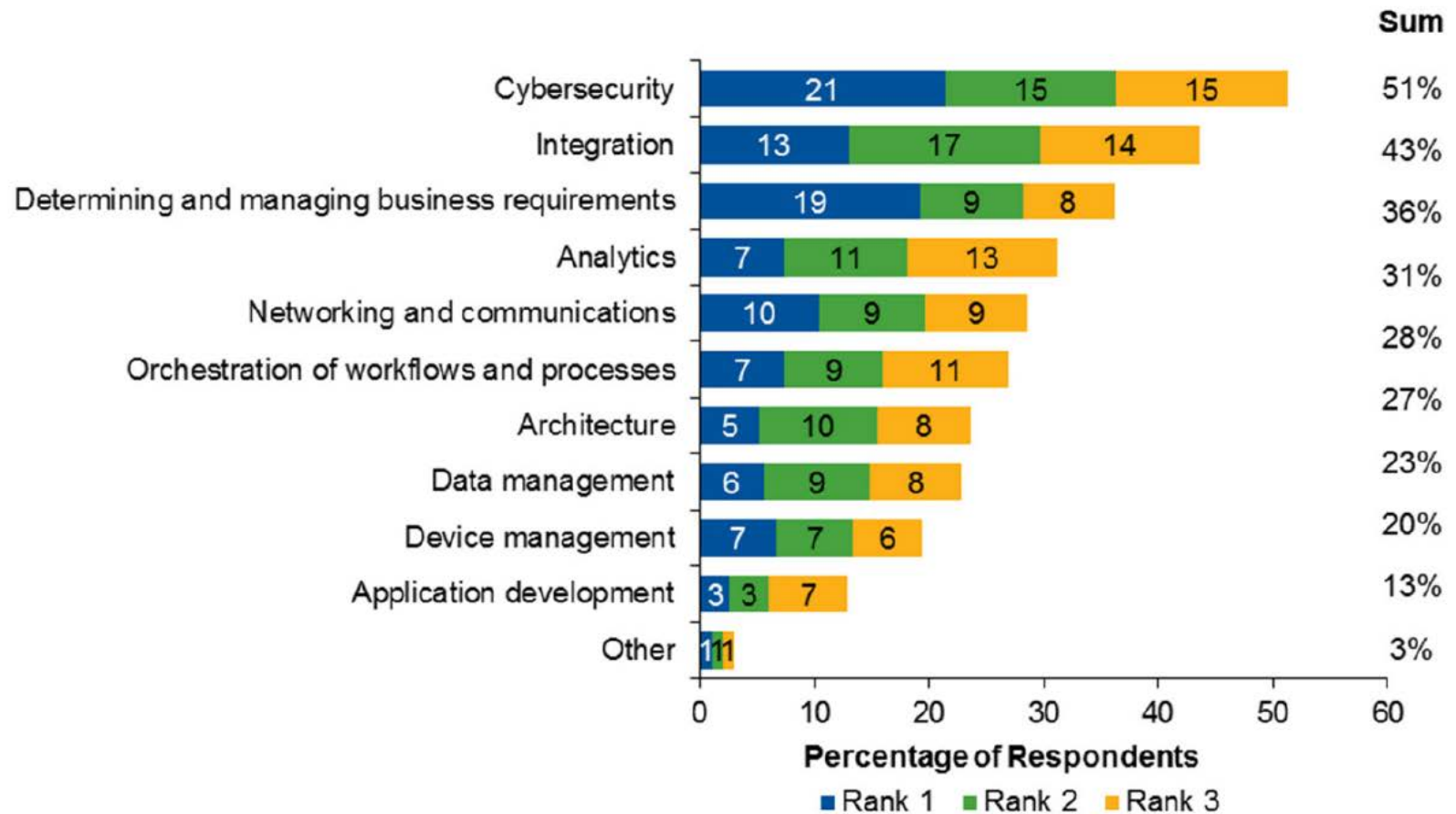
© marketoonist.com

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

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[http://www.cse.wustl.edu/~jain/talks/adn\\_cic.htm](http://www.cse.wustl.edu/~jain/talks/adn_cic.htm)

# 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,

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[http://www.cse.wustl.edu/~jain/talks/adn\\_cic.htm](http://www.cse.wustl.edu/~jain/talks/adn_cic.htm)

# IoT Security: Popular Approach

I have finished studying other companies' IoT Security strategies. "Close your eyes and hope for the best!" seems to be the most popular.



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

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# Current IoT Security

## ❑ HP Study

- 80% had privacy concerns
- 70% lacked encryption
- 60% had insecure updates

## ❑ Symantec Study:

- 1/5<sup>th</sup> 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](http://fortifyprotect.com/HP_IoT_Research_Study.pdf)

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

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[http://www.cse.wustl.edu/~jain/talks/adn\\_cic.htm](http://www.cse.wustl.edu/~jain/talks/adn_cic.htm)

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# 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>

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[http://www.cse.wustl.edu/~jain/talks/adn\\_cic.htm](http://www.cse.wustl.edu/~jain/talks/adn_cic.htm)

# 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>

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[http://www.cse.wustl.edu/~jain/talks/adn\\_cic.htm](http://www.cse.wustl.edu/~jain/talks/adn_cic.htm)

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# 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, ...



Users

Things

Access

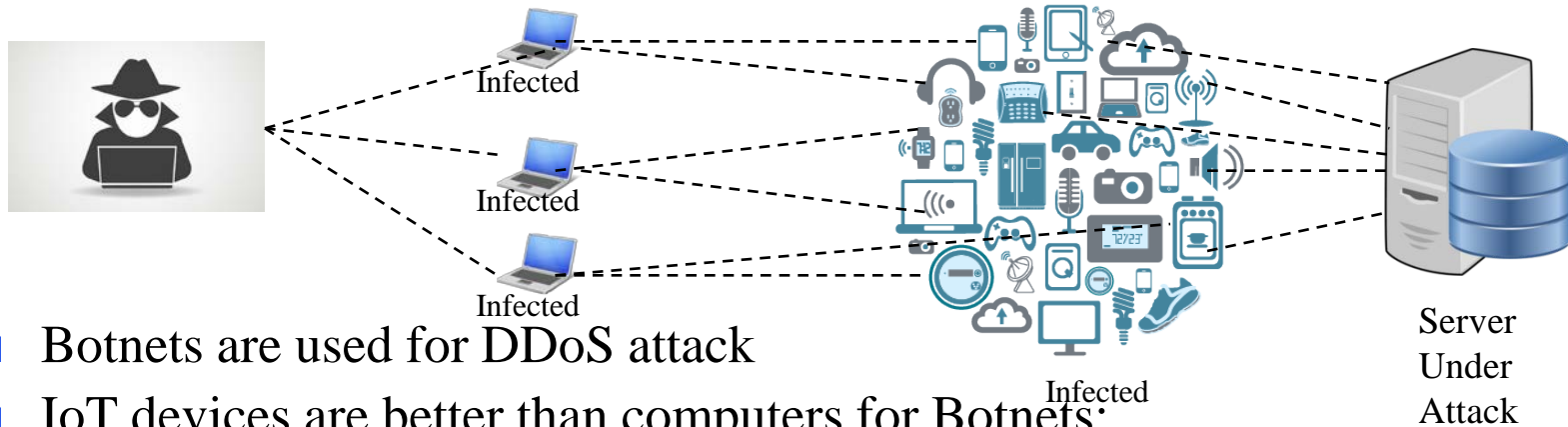
Gateway

WAN

Cloud



# IoT as an Attack Weapon



- ❑ Botnets are used for DDoS attack
- ❑ IoT devices are better than computers for Botnets:
  - Very high population compared to computers
  - Mostly unprotected with default passwords, open ports
  - Cameras, Routers, ...
- ❑ Oct 21, 2016: Mirai bot used 62 default usernames and passwords to infect 380,000 IoT devices and then caused a DDoS attack on a popular DNS service dyn.com
  - ⇒ Disabled many other sites for hours
- ❑ Mirai bot has made its source code public ⇒ Any kid can use it.
  - ⇒ Xiangmai has recalled 10,000 webcams.

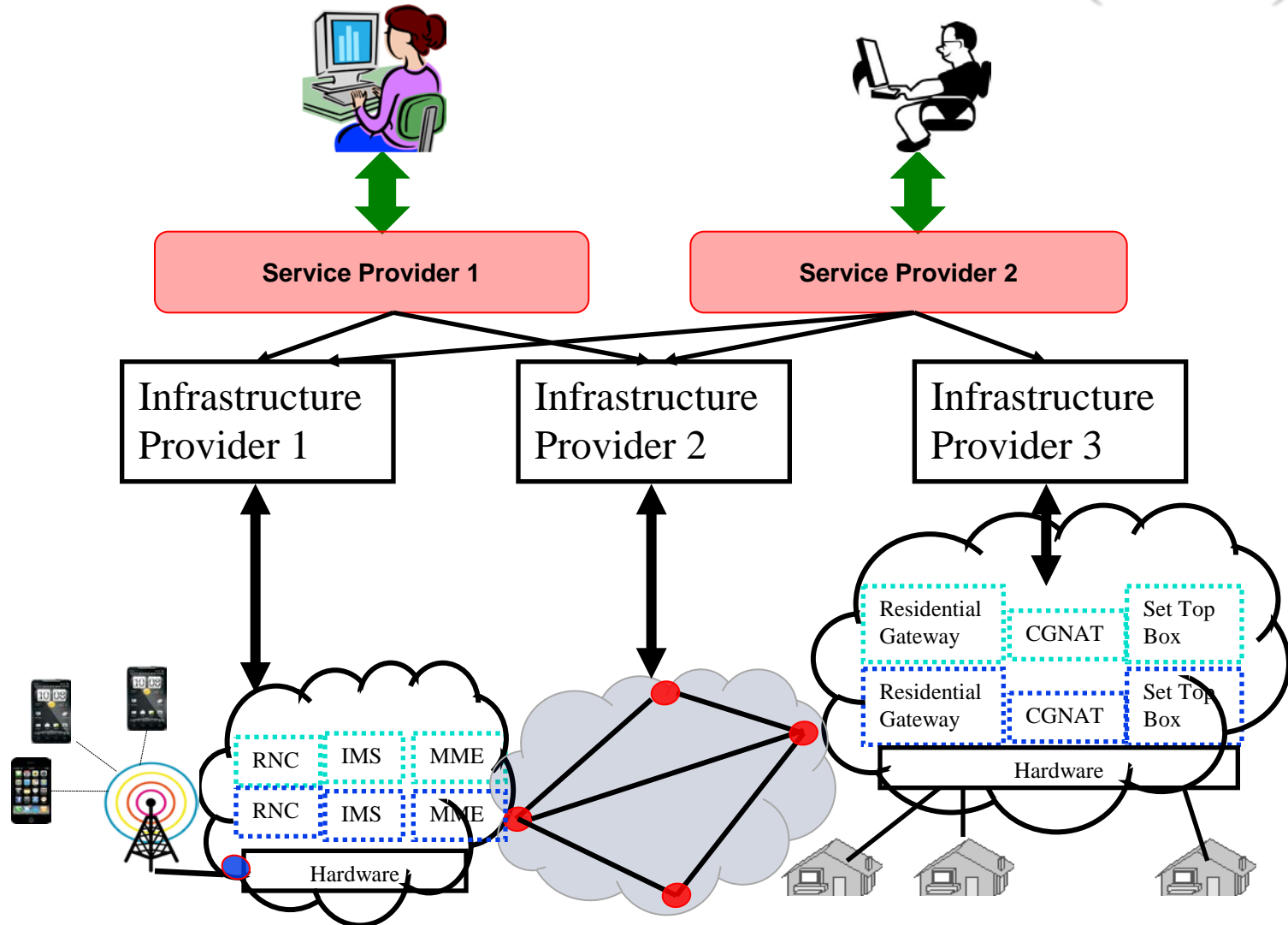
Ref: T. Green, "The secret behind the success of Mirai IoT botnets," Network World, Oct 27, 2016, <http://www.networkworld.com/article/3136314>

# 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
  - $\mu$ Cloud = Cloud in a server with multiple VMs.
  - Each VM with Multiple Containers  $\Rightarrow$  Multiple Services



# Network Function Virtualization (NFV)



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](http://www.cse.wustl.edu/~jain/papers/net_virt.htm)

# 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

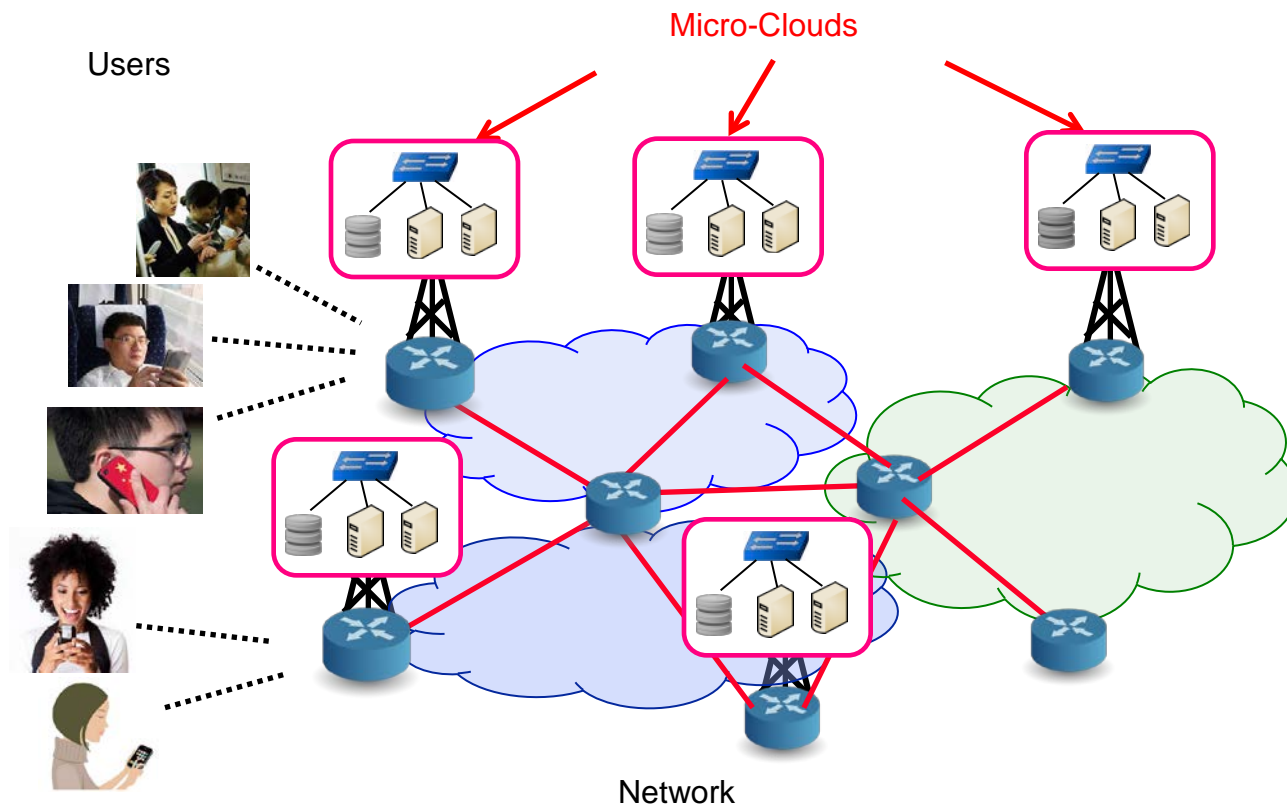
Virtual IP  
Multimedia  
System

Available on the  
**App Store**



# Trend: Mobile Edge Computing

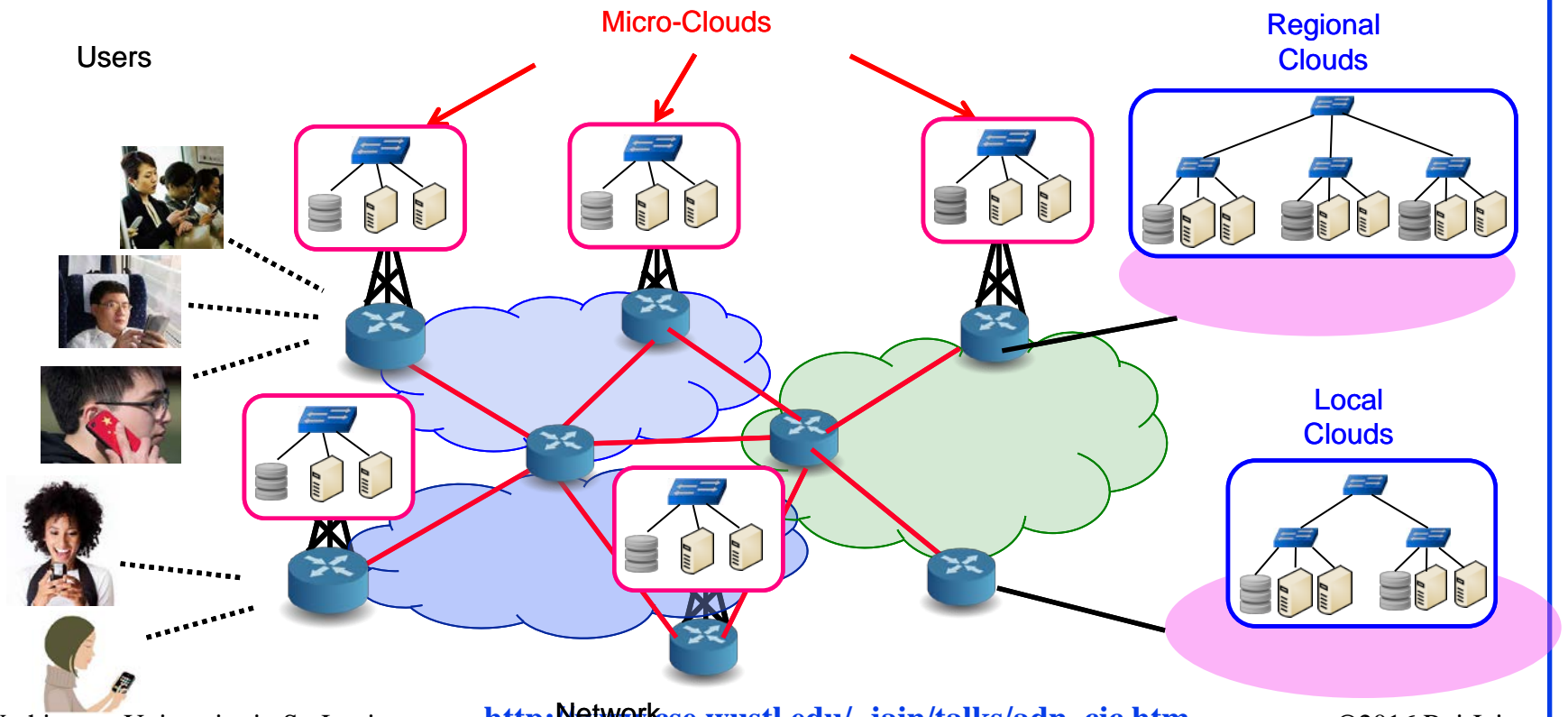
- To service mobile users/IoT, the computation needs to come to edge  $\Rightarrow$  Mobile Edge Computing



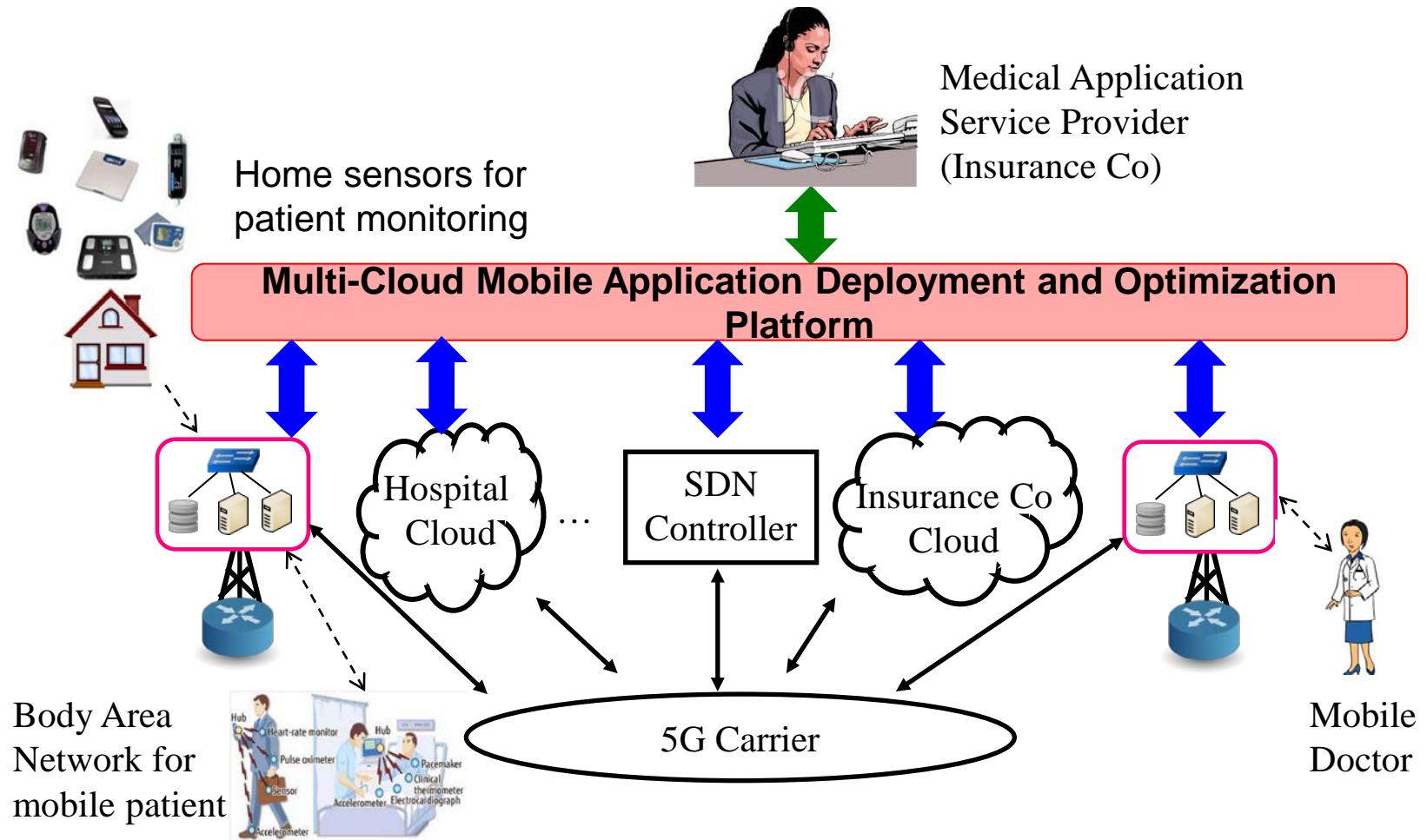
Ref: Lav Gupta, Raj Jain, H. Anthony Chan, "Mobile Edge Computing - an important ingredient of 5G Networks," IEEE Softwarization Newsletter, March 2016, <http://www.cse.wustl.edu/~jain/papers/mec16.htm>

# Trend: Micro-Services

- All major applications, such as, Facebook, Netflix, etc. consist of a number of micro-services that are instantiated on demand on virtual machines



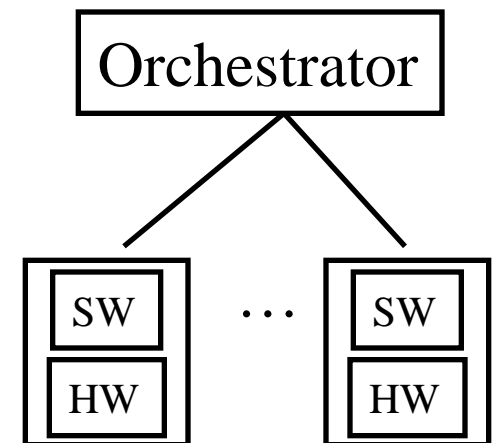
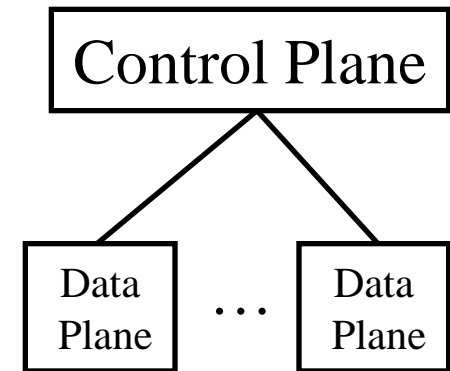
# Mobile Healthcare Use Case





# Software Defined Networking (SDN)

- ❑ SDN was invented in 2009
- ❑ Then: SDN:
  - Separation of control and data planes
  - Centralization of Control
  - Standard Protocol between the planes
- ❑ Now: Software Defined Everything (SDE) = **Disaggregation** of hw/sw
  - Commodity hardware
  - Software that runs on commodity hw
  - Open Source Software  
⇒ Service industry
  - Controller replaced by Orchestrator
  - Centralization of policies



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>

# Separation vs. Centralization

Separation of  
Control Plane



Centralization of  
Policies

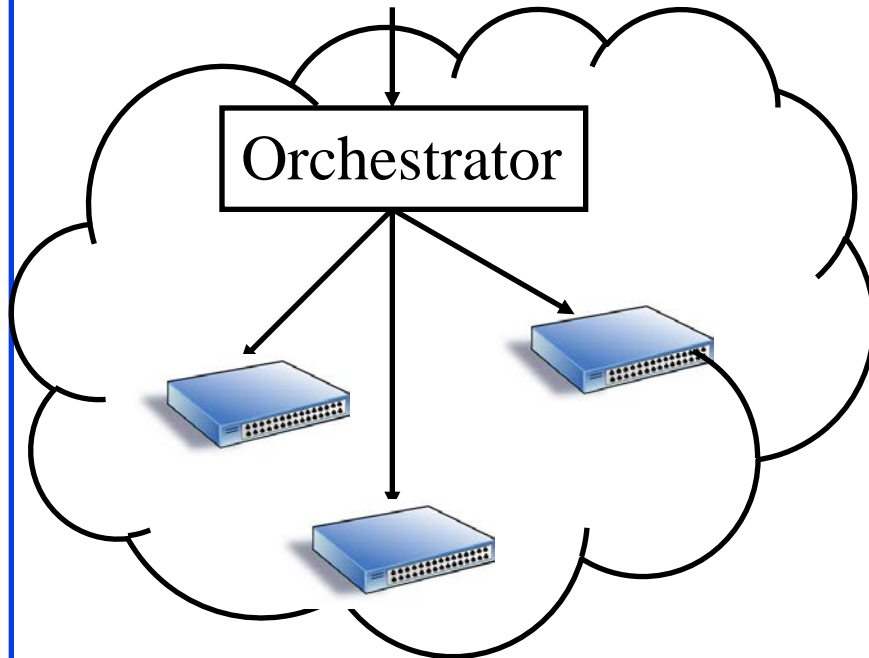


**Micromanagement is not scalable**

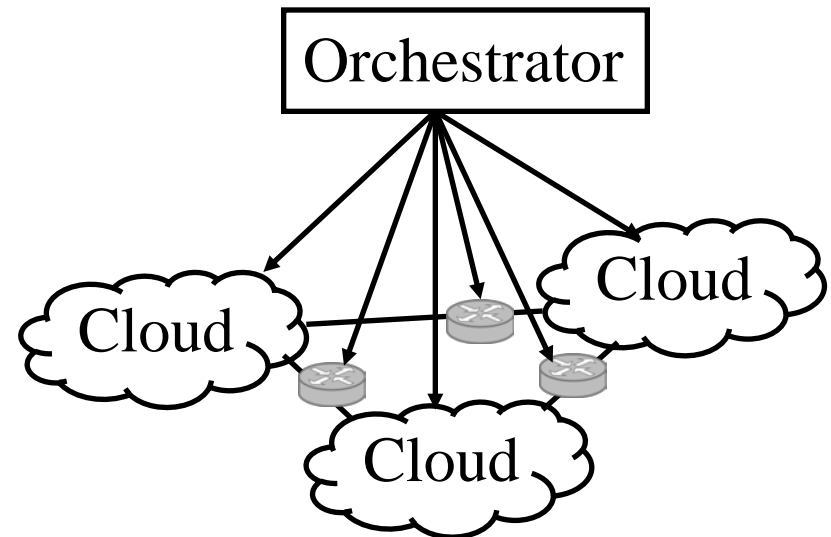
# Software Defined Multi-Cloud

- ❑ Orchestrating devices to Orchestrating Clouds

## Datacenter Applications



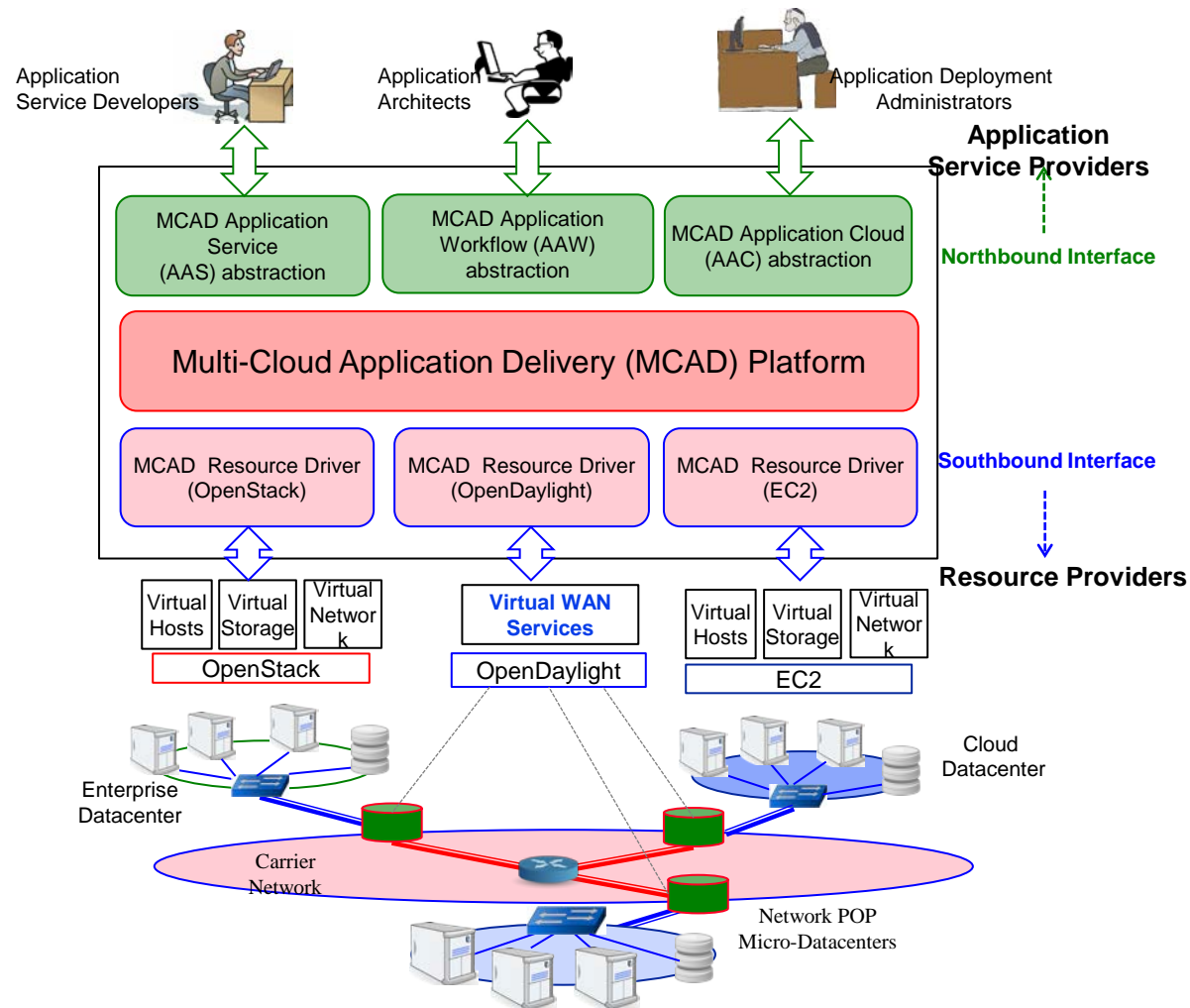
## Global Applications



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,

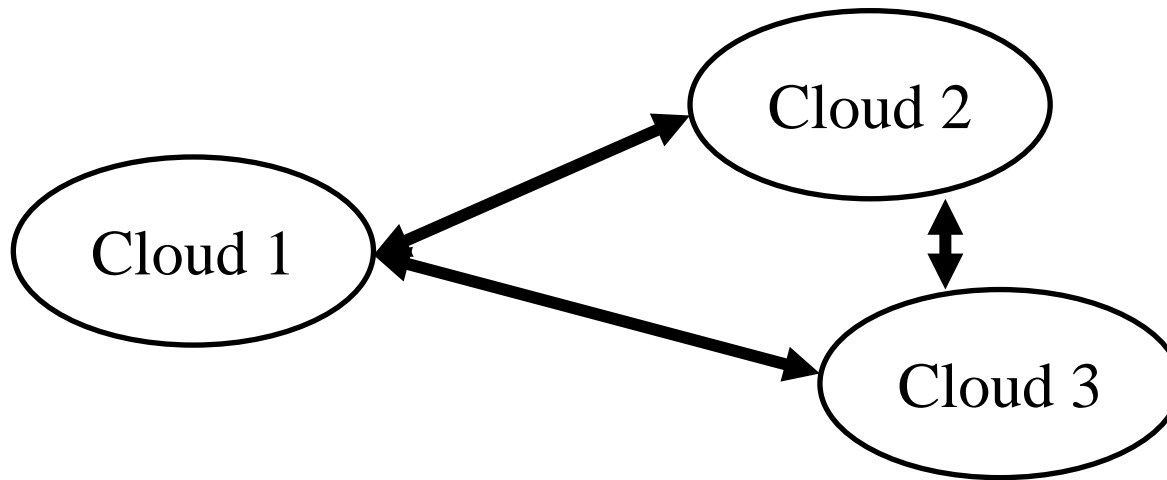
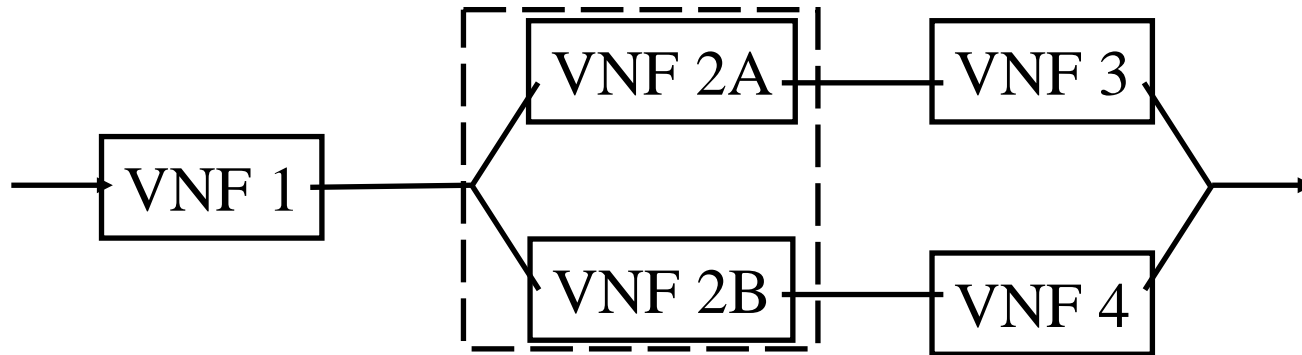
<http://www.cse.wustl.edu/~jain/papers/comnet14.htm>

# 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>

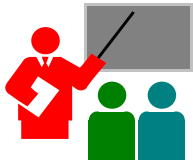
# Service Function Placement Problem



Ref: Deval Bhamare, Raj Jain, Mohammed Samaka, Aiman Erbad, "A Survey on Service Function Chaining," Journal of Network and Computer Applications, Sep 2016, 19 pp, <http://www.cse.wustl.edu/~jain/papers/jnca16.htm>

# Challenges in Service Placement

- ❑ **Delay constraints**
- ❑ **WAN links bottleneck:** Need to model link queues
- ❑ **Complexity:** NP-complete  $\Rightarrow$  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



# Summary

1. Value of IoT is in the data it produces. Privacy and Security are the key issues.
2. Clouds are getting smaller, Carriers and enterprises moving to clouds, Internet of things are leading to clouds everywhere ⇒ multi-cloud applications.
3. SDN is about orchestration and centralization of policy. Not about separation of control and data planes.
4. Software Defined Multi-Cloud Orchestration: Our Multi-cloud application management system (MCAD) allows policy-based deployment and management of multi-cloud applications.
5. Service function placement problem is NP complete. Challenges included delay constraints, WAN Link bottlenecks, and affinity

# 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

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