Internet of Things:
Research Challenges and Issues

RAJ JAIN

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

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These slides are available on-line at:
http://www.cse.wustl.edu/~jain/talks/iotwrld.htm

Overview

1. A Layered Model of IoT and Smart Cities

2. Areas of Research for IoT

3. IoT Security

4. Trend: Computation in the Edge, Multi-Cloud

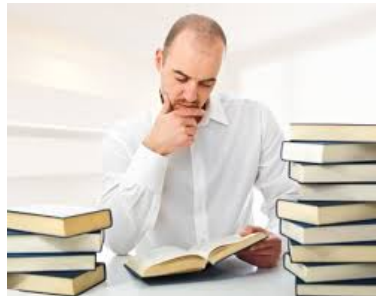5. Software Defined Multi-Cloud Application Management

What's Smart?

❑ Old: Smart = Can think ⇒ Can compute

❑ Now: Smart = Can find quickly, Can Delegate
⇒ Communicate = Networking

❑ Smart Grid, Smart Meters, Smart Cars, Smart homes, Smart Cities, Smart Factories, Smart Smoke Detectors, …
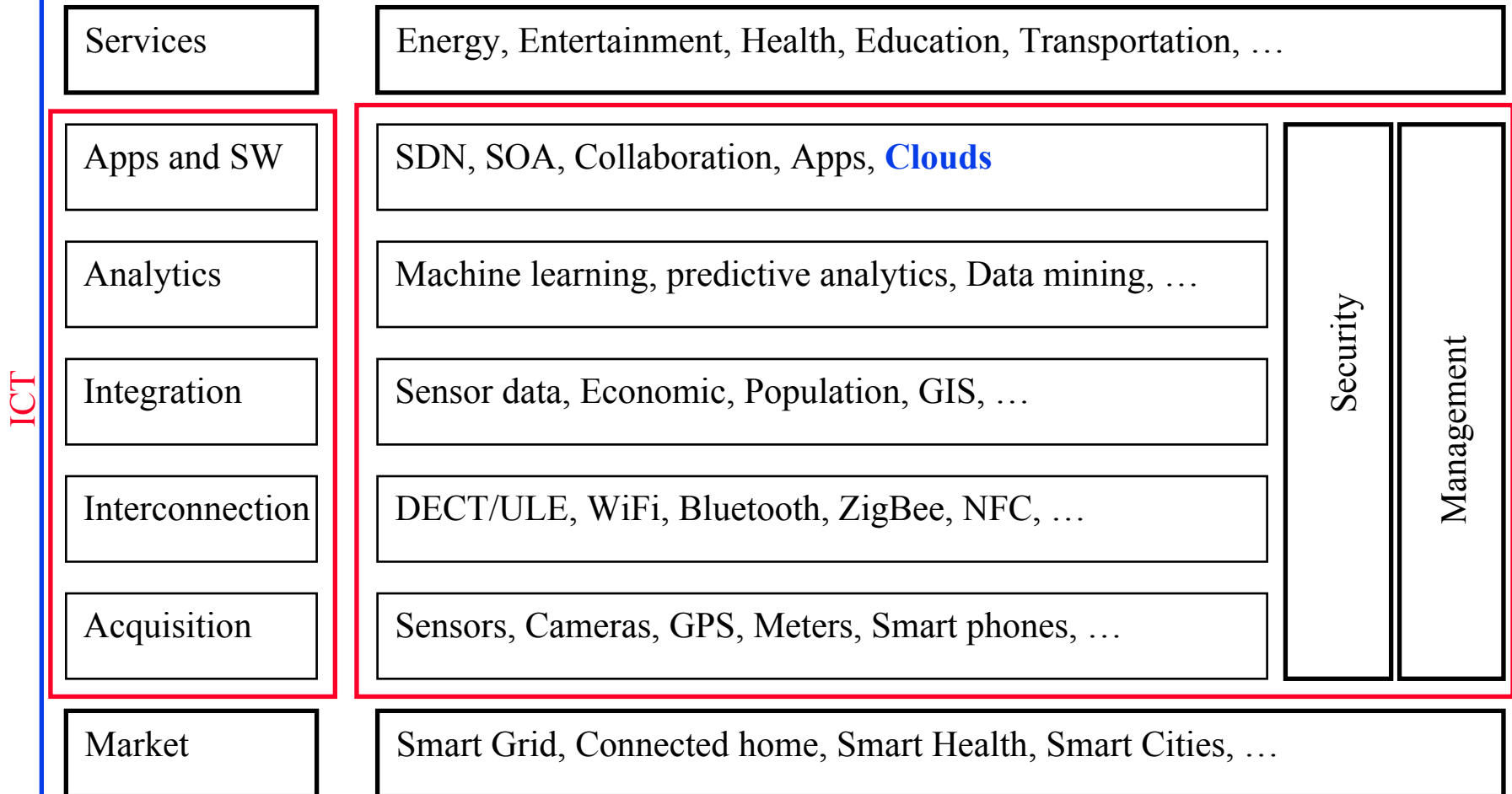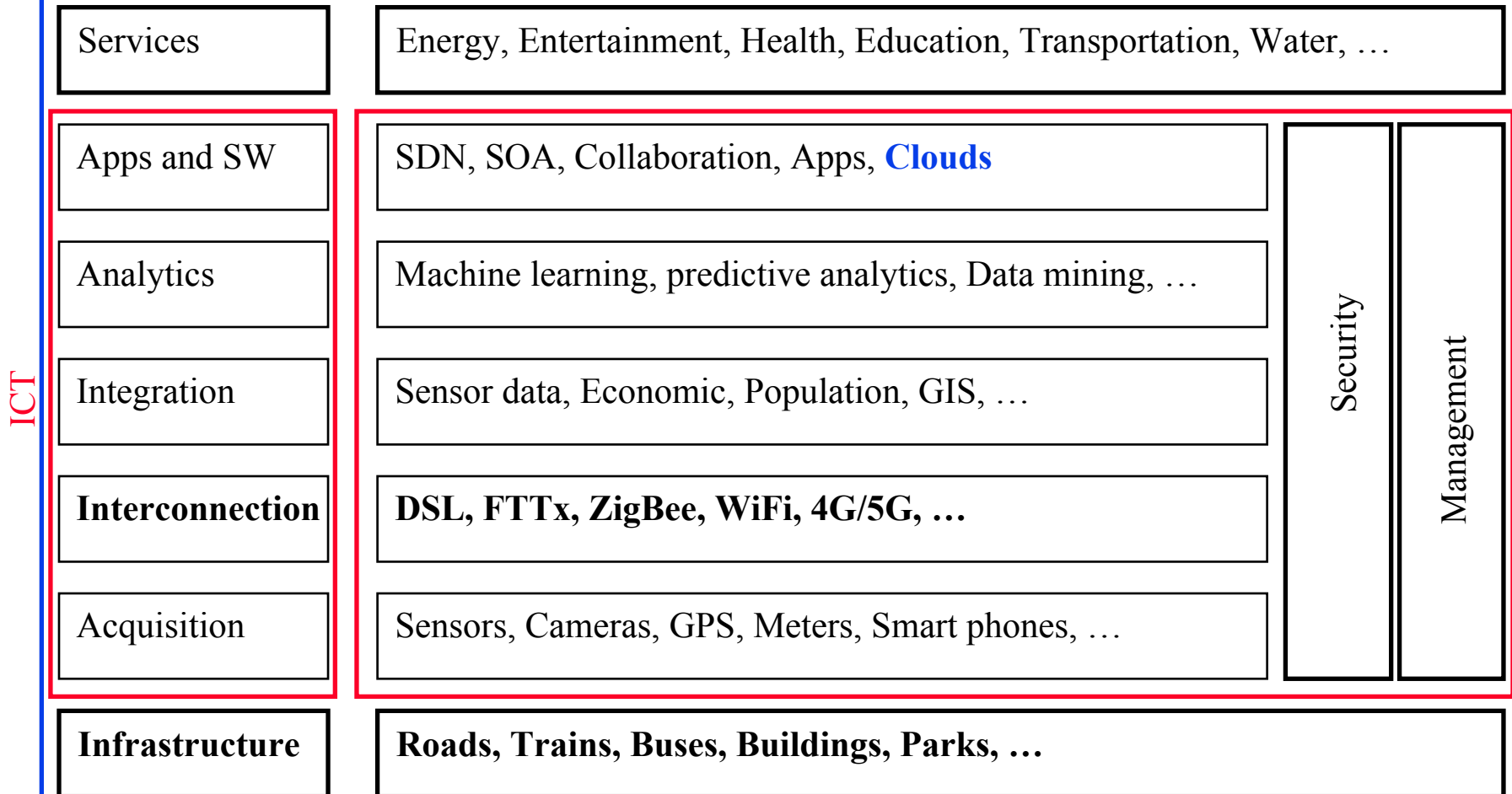

Think   Communicate   Not-Smart   Smart

A 7-Layer Model of IoT

Services	Energy, Entertainment, Health, Education, Transportation, …
Apps and SW	SDN, SOA, Collaboration, Apps, **Clouds**
Analytics	Machine learning, predictive analytics, Data mining, …
Integration	Sensor data, Economic, Population, GIS, …
Interconnection	DECT/ULE, WiFi, Bluetooth, ZigBee, NFC, …
Acquisition	Sensors, Cameras, GPS, Meters, Smart phones, …
Market	Smart Grid, Connected home, Smart Health, Smart Cities, …

ICT

Security

Management

A 7-Layer Model of Smart Cities

ICT

Services	Energy, Entertainment, Health, Education, Transportation, Water, …
Apps and SW	SDN, SOA, Collaboration, Apps, **Clouds**
Analytics	Machine learning, predictive analytics, Data mining, …
Integration	Sensor data, Economic, Population, GIS, …
Interconnection	**DSL, FTTx, ZigBee, WiFi, 4G/5G, …**
Acquisition	Sensors, Cameras, GPS, Meters, Smart phones, …
Infrastructure	**Roads, Trains, Buses, Buildings, Parks, …**

Security

Management

Ref: ISO/IEC JTC 1, "Smart Cities," 2014, http://www.iso.org/iso/smart_cities_report-jtc1.pdf

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Areas of Research for IoT

1. PHY: Smart devices, sensors giving real-time information
2. Datalink: WiFi, Bluetooth, ZigBee, IEEE 802.15.4, …
   Broadband: DSL, FTTH, Wi-Fi, 5G, …
3. Routing: Mesh networking, …
4. Analytics: Big-data, data mining, Machine learning, Predictive analytics, …
5. Apps & SW: SDN, SOA, Cloud computing, Web-based collaboration, Social networking, …
6. Applications: Remote health, On-line education, on-line laboratories, …
7. **Security: Privacy,** Trust, Identity, Anonymity, …

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,

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Attack Surface

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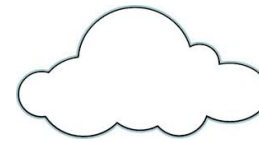9. **Life Cycle Management**: Booting, Pairing, Updating, …
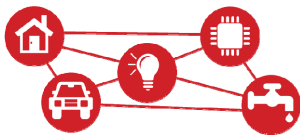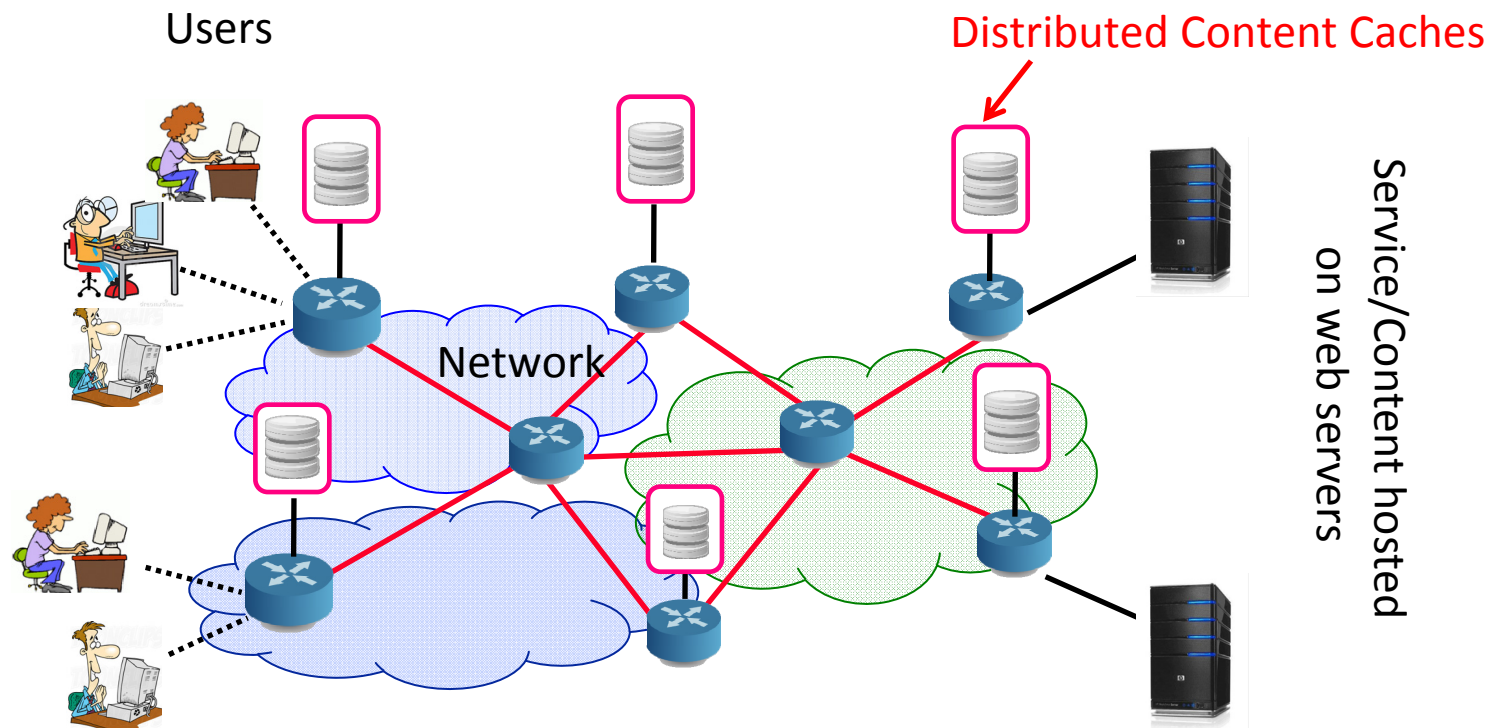
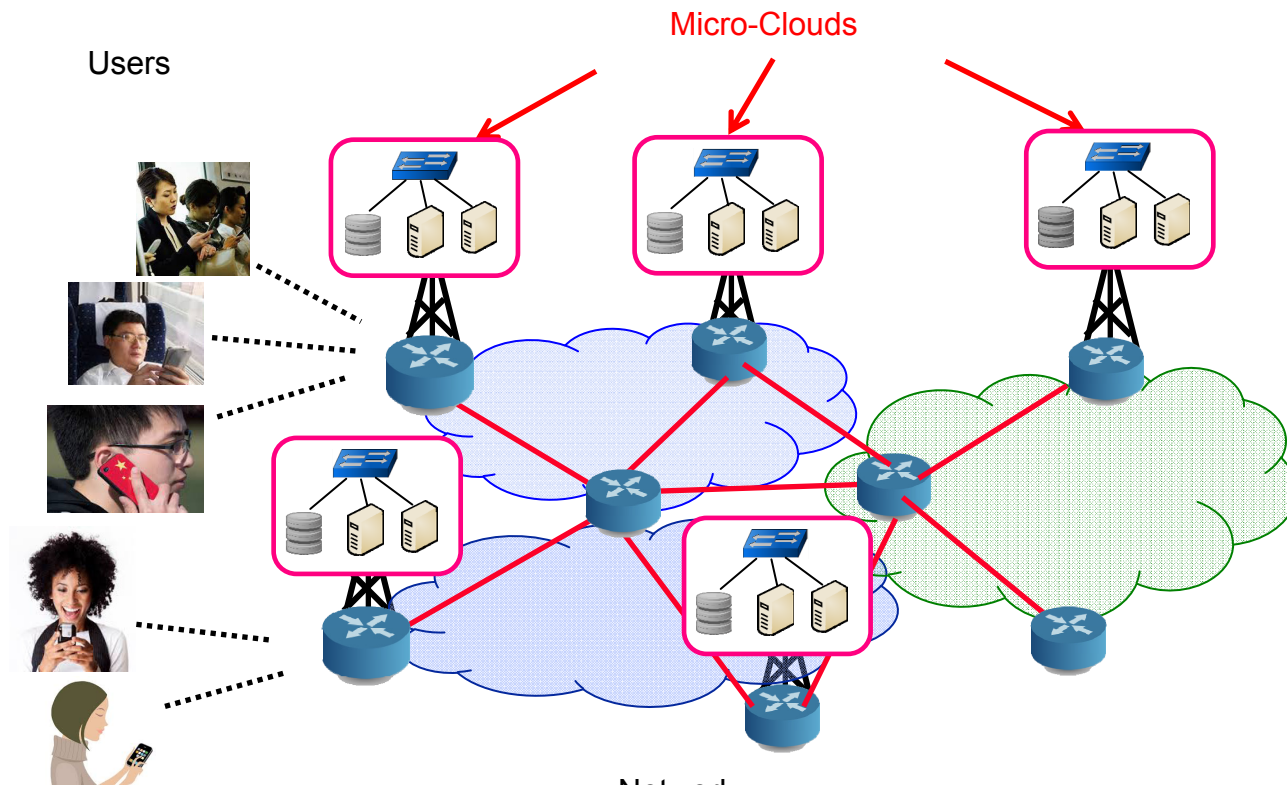| Things	Access	Gateway	WAN	Cloud	Users

Past: Data in the Edge

❑ To serve world-wide users, latency was critical and so the data was replicated and brought to edge

Users

Distributed Content Caches

Network

Service/Content hosted on web servers

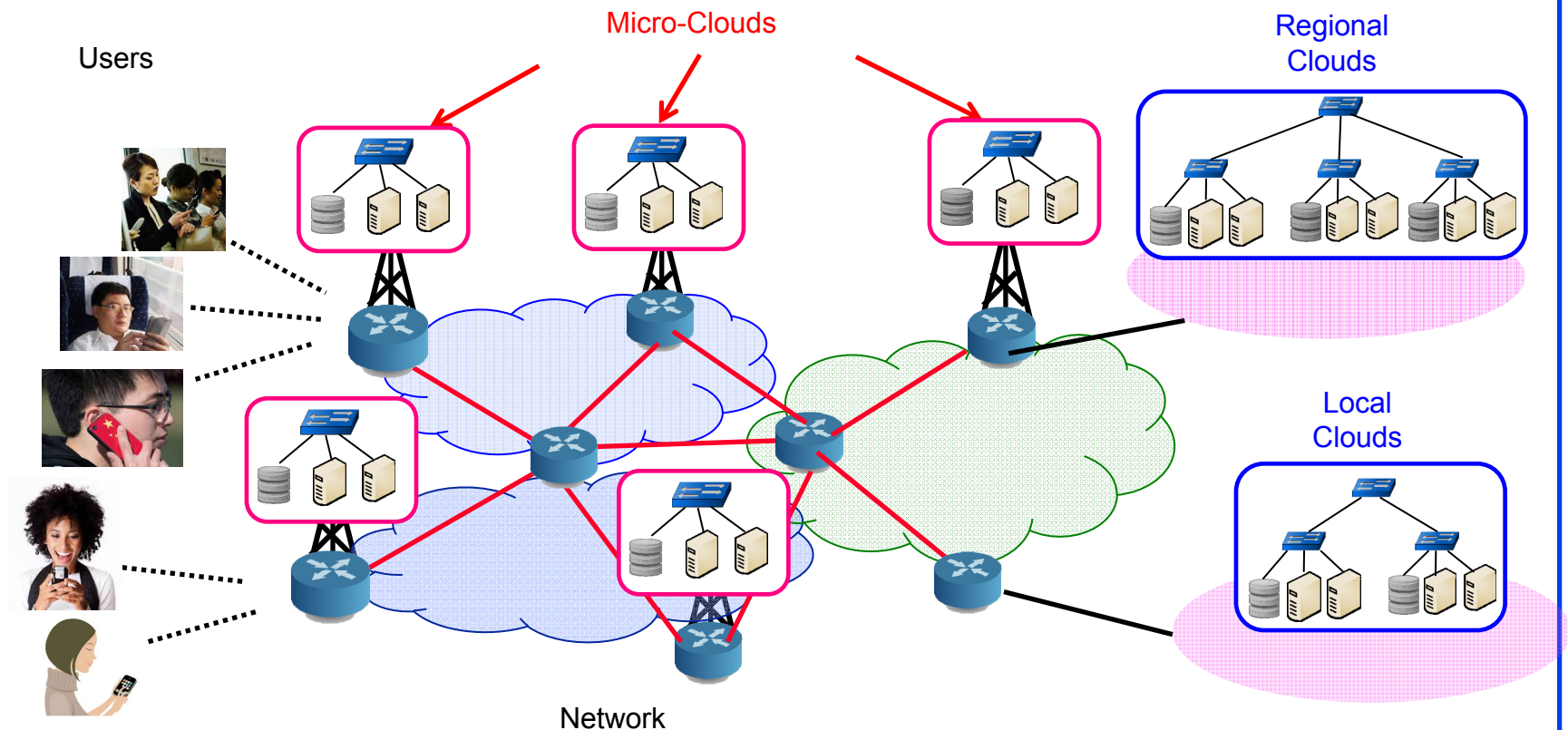# Trend: Computation in the Edge

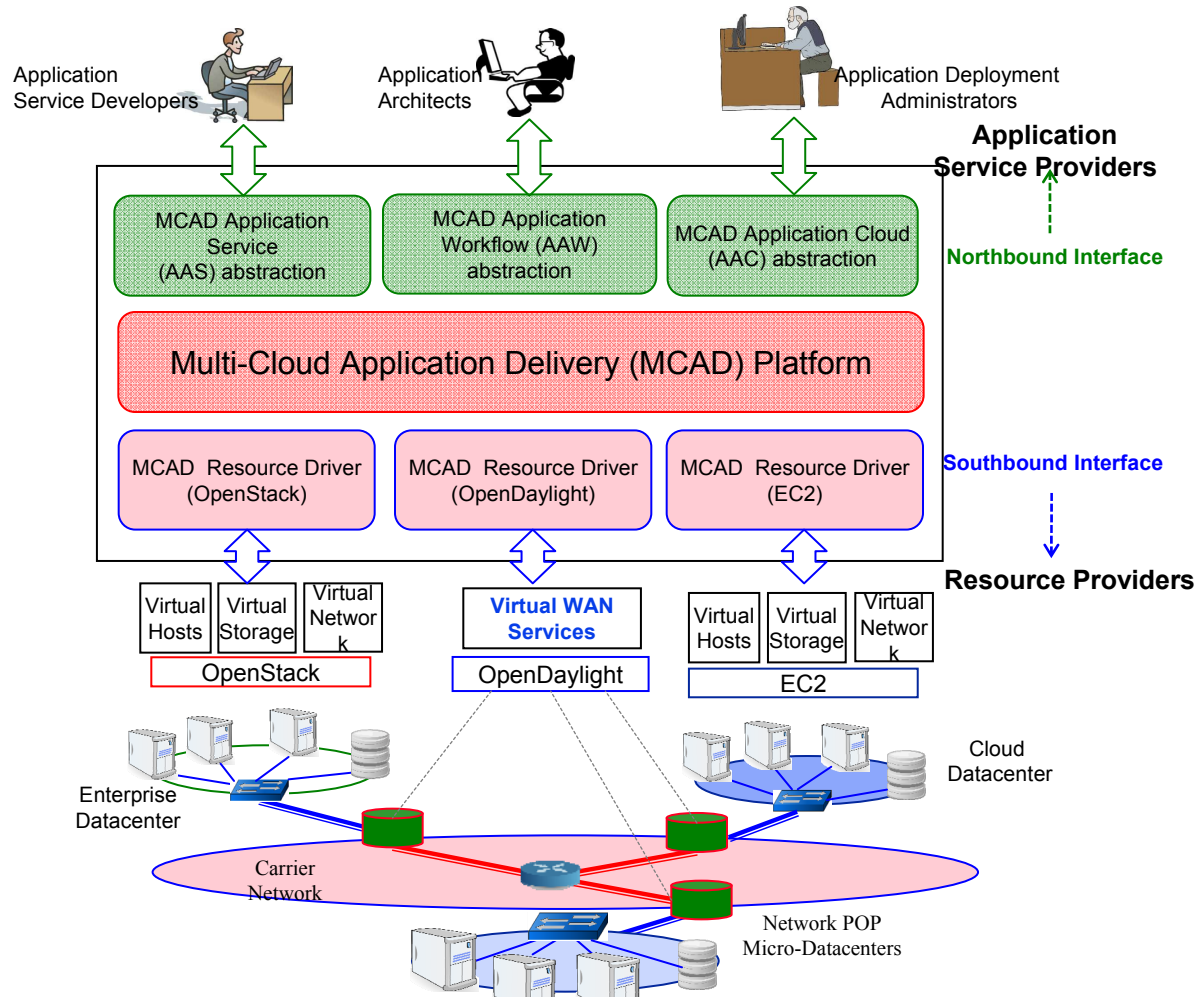❑ To service mobile users/IoT, the computation needs to come to edge ⇒ Micro-cloud on the tower

Trend: Multi-Cloud

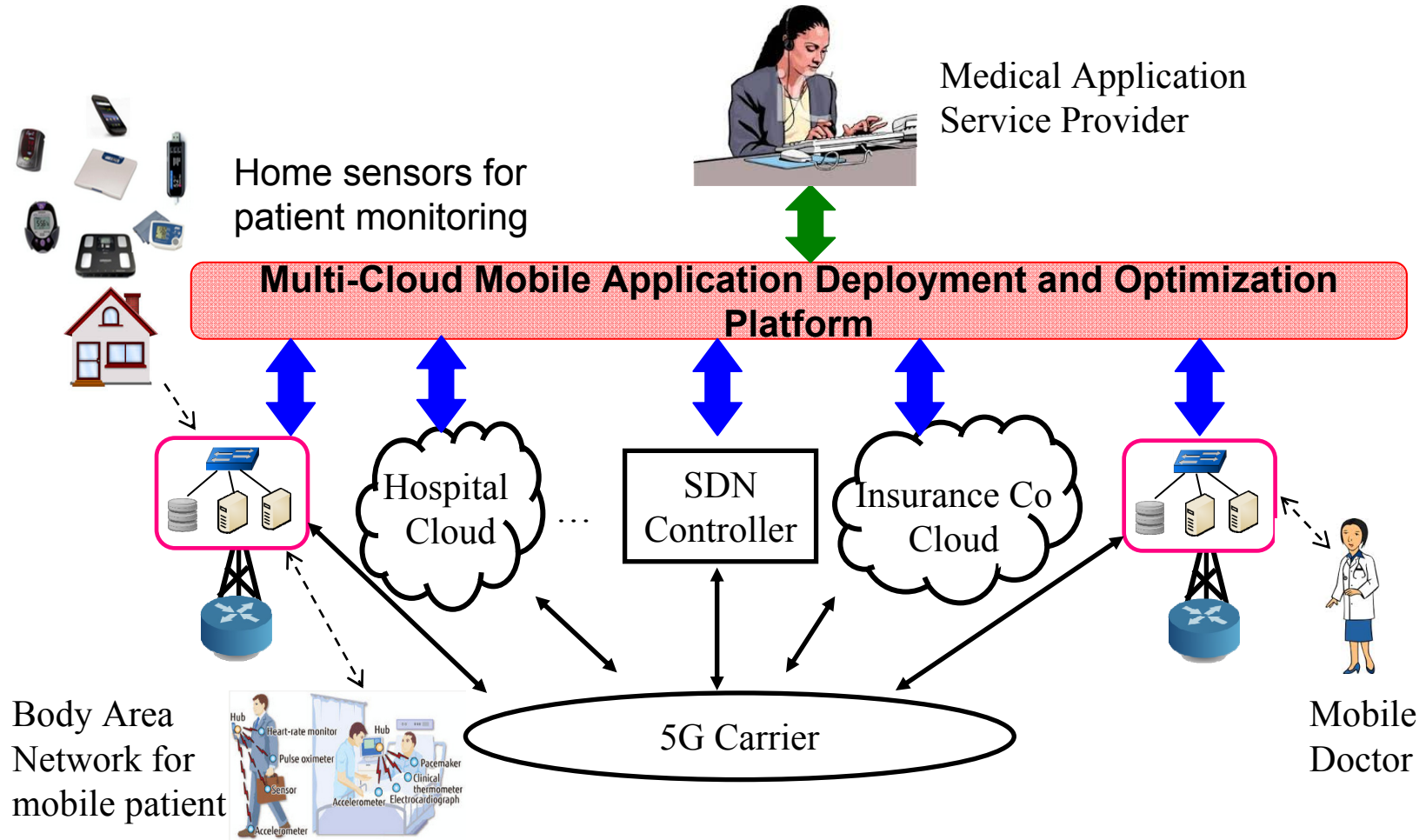❑ Larger and infrequent jobs serviced by local and regional clouds ⇒ Fog Computing

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

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Software Defined Multi-Cloud Application Management

Application Service Developers

Application Architects

Application Deployment Administrators

Application Service Providers

MCAD Application Service (AAS) abstraction

MCAD Application Workflow (AAW) abstraction

MCAD Application Cloud (AAC) abstraction

Northbound Interface

Multi-Cloud Application Delivery (MCAD) Platform

MCAD Resource Driver (OpenStack)

MCAD Resource Driver (OpenDaylight)

MCAD Resource Driver (EC2)

Southbound Interface

Resource Providers

Virtual Hosts | Virtual Storage | Virtual Network

OpenStack

Virtual WAN Services

OpenDaylight

Virtual Hosts | Virtual Storage | Virtual Network

EC2

Enterprise Datacenter

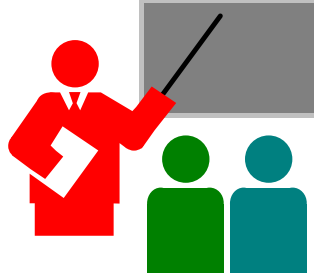Cloud Datacenter

Carrier Network

Network POP Micro-Datacenters

MCAD Features

❑ **Automate** the entire process of creating new workflows and installing them, managing them during runtime, uninstalling them as necessary
  ➢ Allow **Deployment Administrators** specify policies for quantity and location of resources inside various clouds.
❑ Workflow creation includes virtual networks, computers, storage inside the clouds as well as the network between the clouds
❑ **WAN bandwidth** and latency is the key to placement. Allows manual approval and override.
❑ Physical infrastructure owners keep complete control over their resources while the tenant service providers can deploy their applications according to their desired policies
❑ All communication is via APIs. All interfaces initially XML based. GUI based in future.

Mobile Healthcare Use Case

Medical Application
Service Provider

Home sensors for
patient monitoring

Multi-Cloud Mobile Application Deployment and Optimization Platform

Hospital
Cloud

…

SDN
Controller

Insurance Co
Cloud

Body Area
Network for
mobile patient

5G Carrier

Mobile
Doctor

Summary

1. IoT research areas are easy via the 7-layer model

2. Key challenges are: Sensors, access technologies, routing, data analytics, Cloud computing, SDN, …

3. Computation is moving to the Edge Þ Fog Computing $\Rightarrow$ Multi-Cloud/Inter-Cloud

4. Our MCAD abstracts/virtualizes the cloud interfaces and allows automated management of multi-cloud applications

Recent Papers

❑ 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

❑ 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

Recent Papers (Cont)

❑ 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

Recent Talks

❑ Raj Jain, **"Smart Cities: Technological Challenges and Issues**," IEEE CS Keynote at 21st Annual International Conference on Advanced Computing and Communications (ADCOM) 2015, Chennai, India, September 19, 2015, Chennai, India, September 18, 2015, http://www.cse.wustl.edu/~jain/talks/smrtcit.htm

❑ Raj Jain, **"Five Trends in Computing Leading to Multi-Cloud Applications and Their Management**," 2015 CMG Performance and Capacity Conference, San Antonio, TX, November 5, 2015, http://www.cse.wustl.edu/~jain/talks/apf_cmg.htm

❑ Raj Jain **"Application Deployment in Future Global Multi-Cloud Environment**," OIN Workshop, Saint Louis, MO, October 20, 2015, http://www.cse.wustl.edu/~jain/talks/apf_oin.htm

❑ Raj Jain, **"Internet of Things: Challenges and Issues**," **IEEE CS Keynote** at 20th Annual Conference on Advanced Computing and Communications (ADCOM 2014), Bangaluru, India, September 19, 2014, http://www.cse.wustl.edu/~jain/talks/iot_ad14.htm

Acronyms

- 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
- TCP   Transmission Control Protocol
- TV   Television
- VM   Virtual Machine
- WAN   Wide Area Network
- WiFi   Wireless Fidelity