

# Internet of Things: Research Issues



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These slides are available on-line at:

[http://www.cse.wustl.edu/~jain/talks/iot\\_nsf.htm](http://www.cse.wustl.edu/~jain/talks/iot_nsf.htm)



1. A Layered Model of IoT and Smart Cities
2. Areas of Research for IoT
3. IoT Security
4. Trends: Computation in the Edge, Multi-Cloud
5. Software Defined Multi-Cloud Application Mgmt

# Trend 1: 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  $\Rightarrow$  Can compute
- ❑ Now: Smart = Can Communicate = Networking
- ❑ Smart Grid, Smart Meters, Smart Cars, Smart homes, Smart Cities, Smart Factories, Smart Smoke Detectors, ...



Think



Communicate

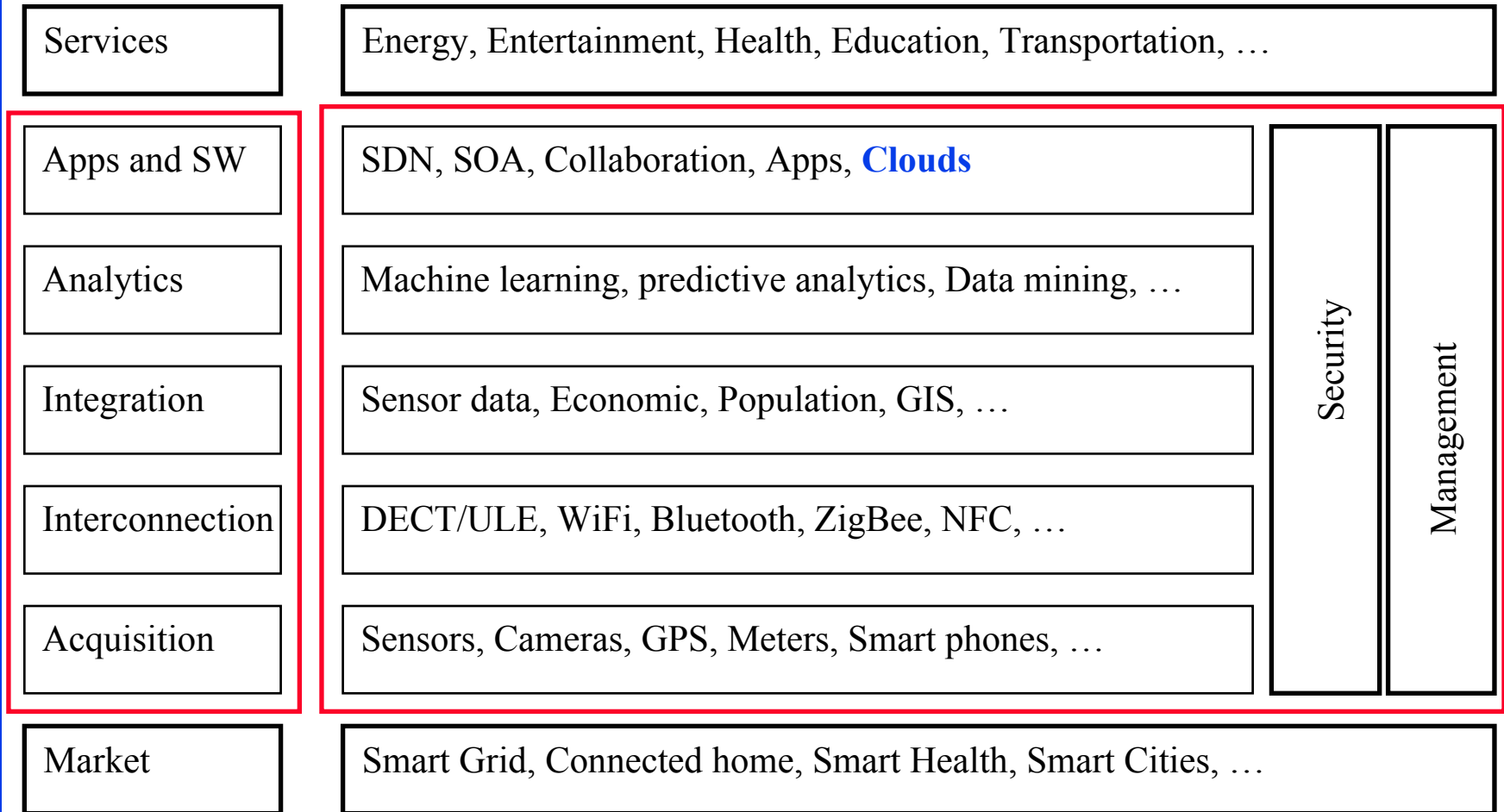


Not-Smart

Smart

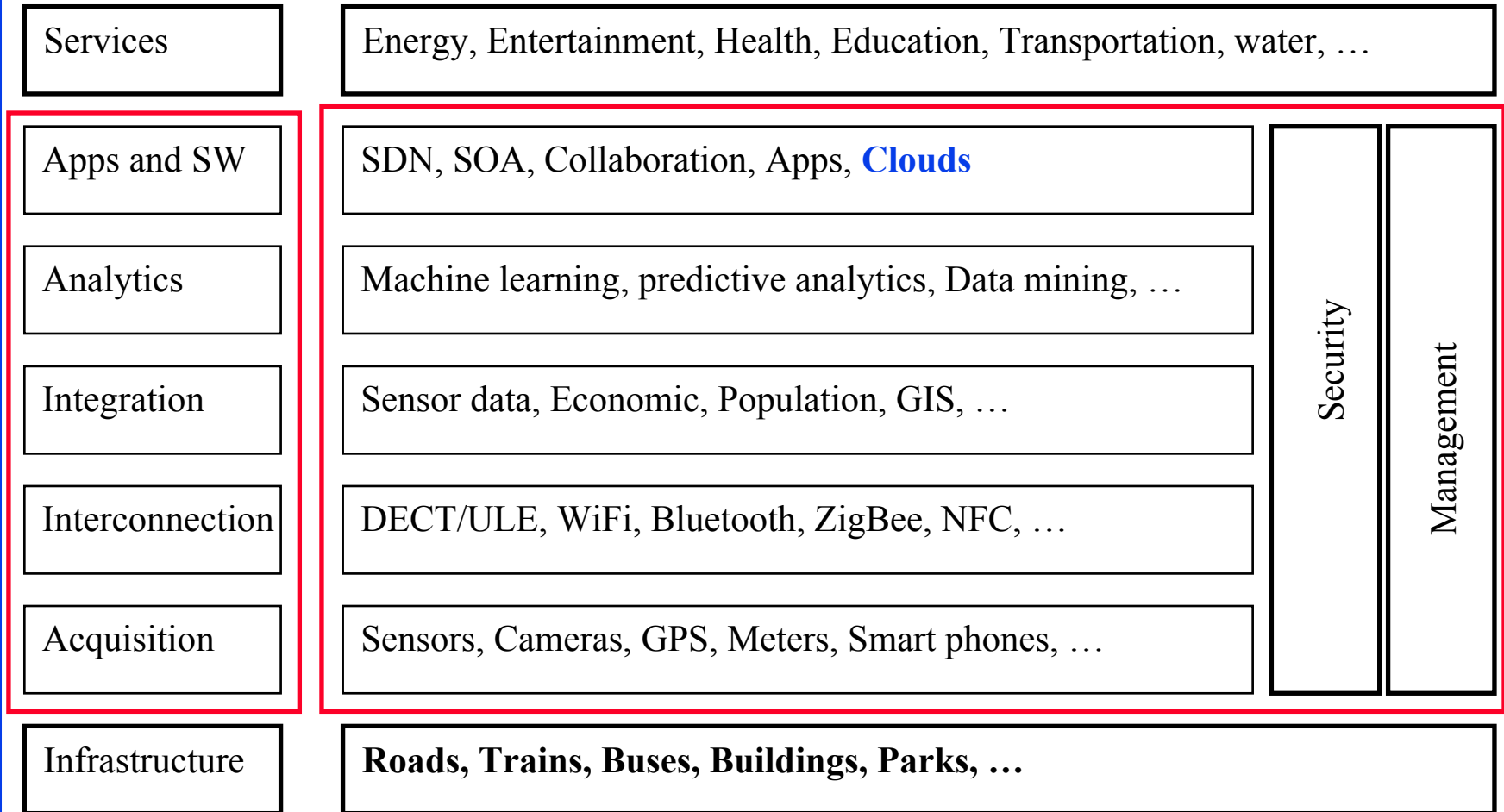
# A 7-Layer Model of IoT

ICT



# A 7-Layer Model of Smart Cities

ICT



# Areas of Research for IoT/Smart Cities

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, ...

# IoT is a Data (\$) Mine



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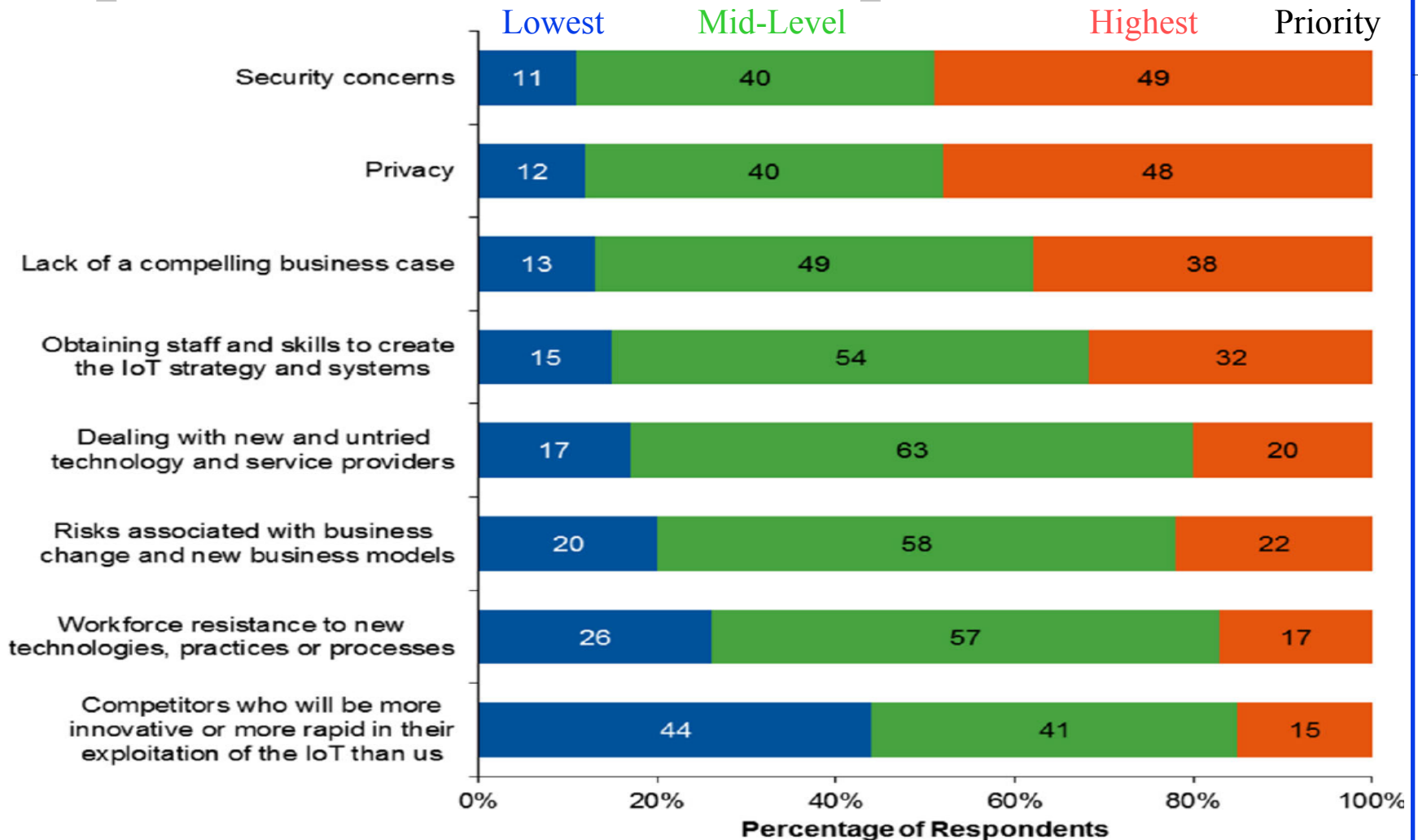
Ref: <https://www.pinterest.com/iofficecorp/humor/>

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# Top Inhibitors to the Adoption of the IoT



Ref: D. Mishra and E. Perkins, "Address Cybersecurity Challenges Proactively to Ensure Success With Outsourced IoT Initiatives," Gartner, May 2015, 10 pp.

# 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>

# 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,

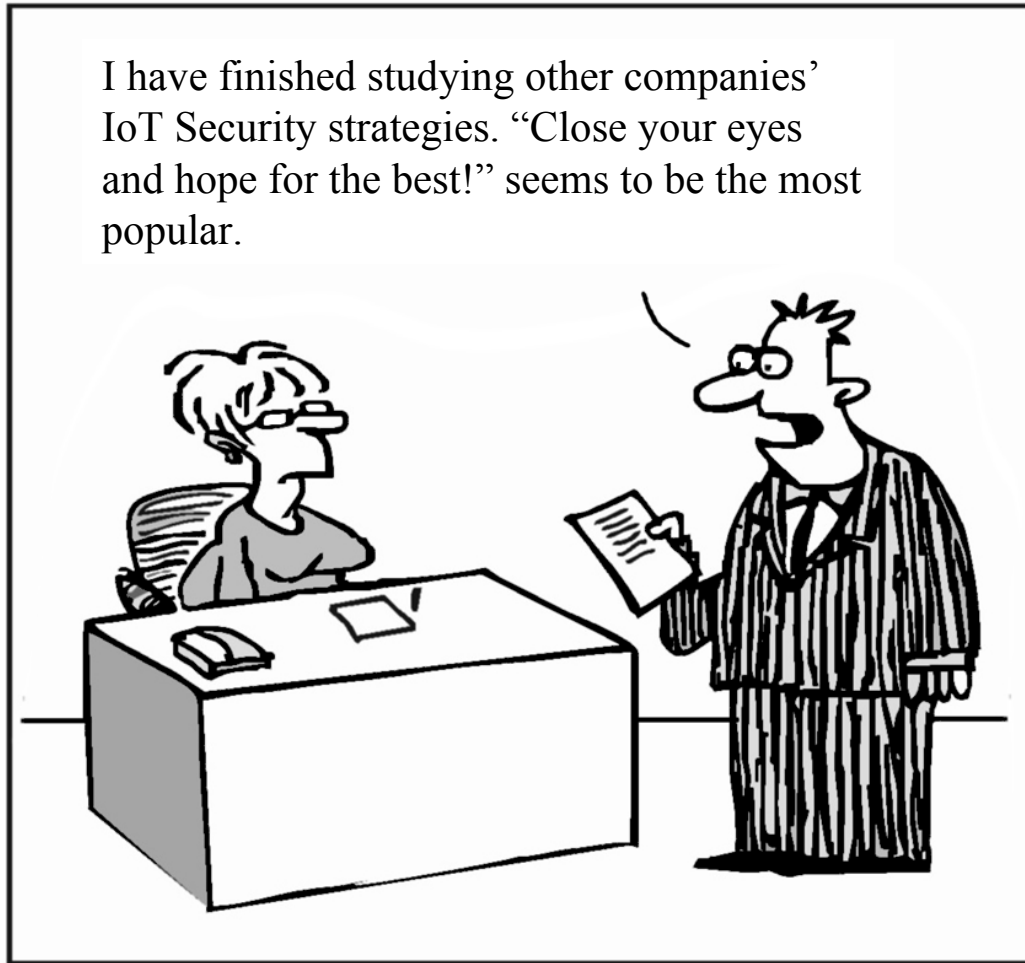
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# IoT Security: Popular Approach

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



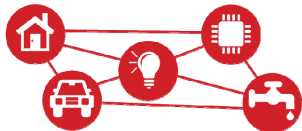
Ref: <http://cloudtweaks.com/2011/08/the-lighter-side-of-the-cloud-the-migration-strategy/>

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[http://www.cse.wustl.edu/~jain/talks/iot\\_nsf.htm](http://www.cse.wustl.edu/~jain/talks/iot_nsf.htm)

# 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

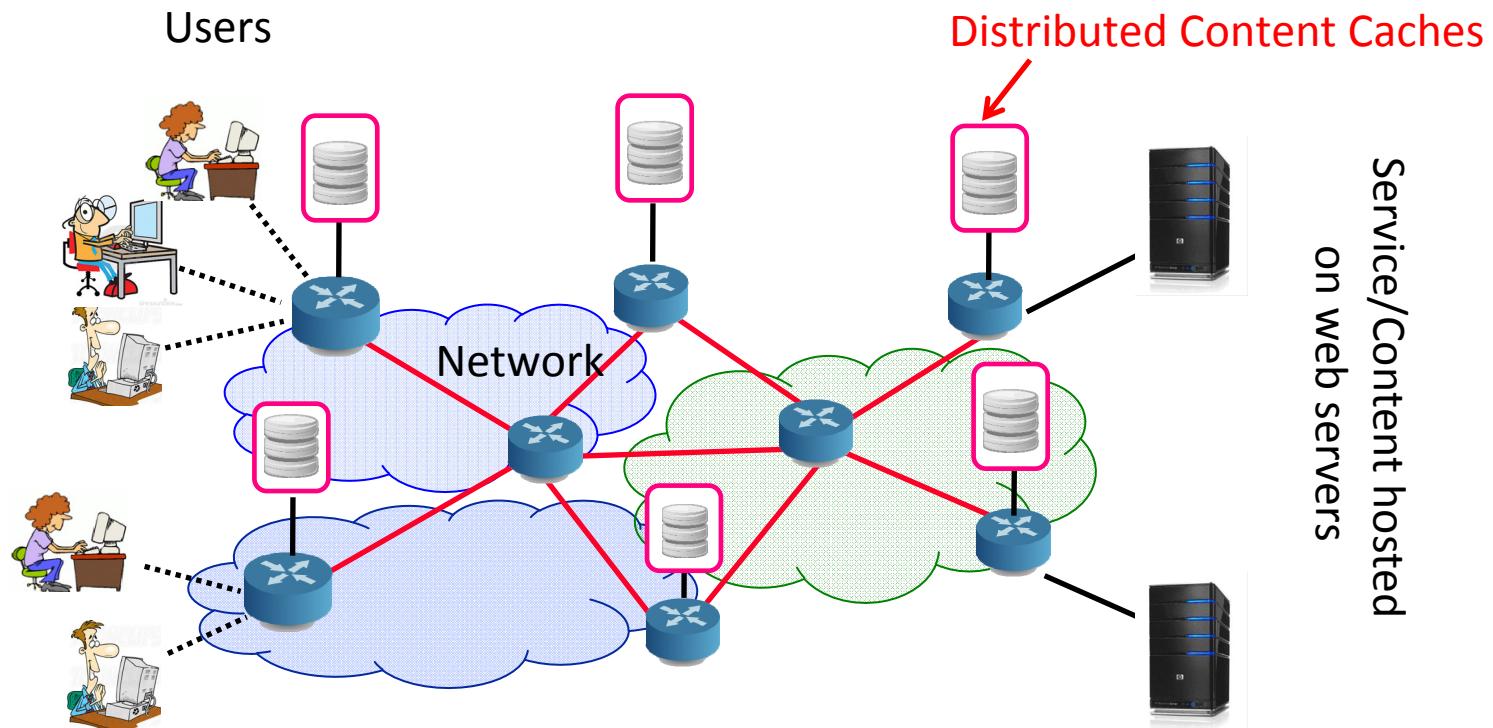
WAN

Cloud

Users

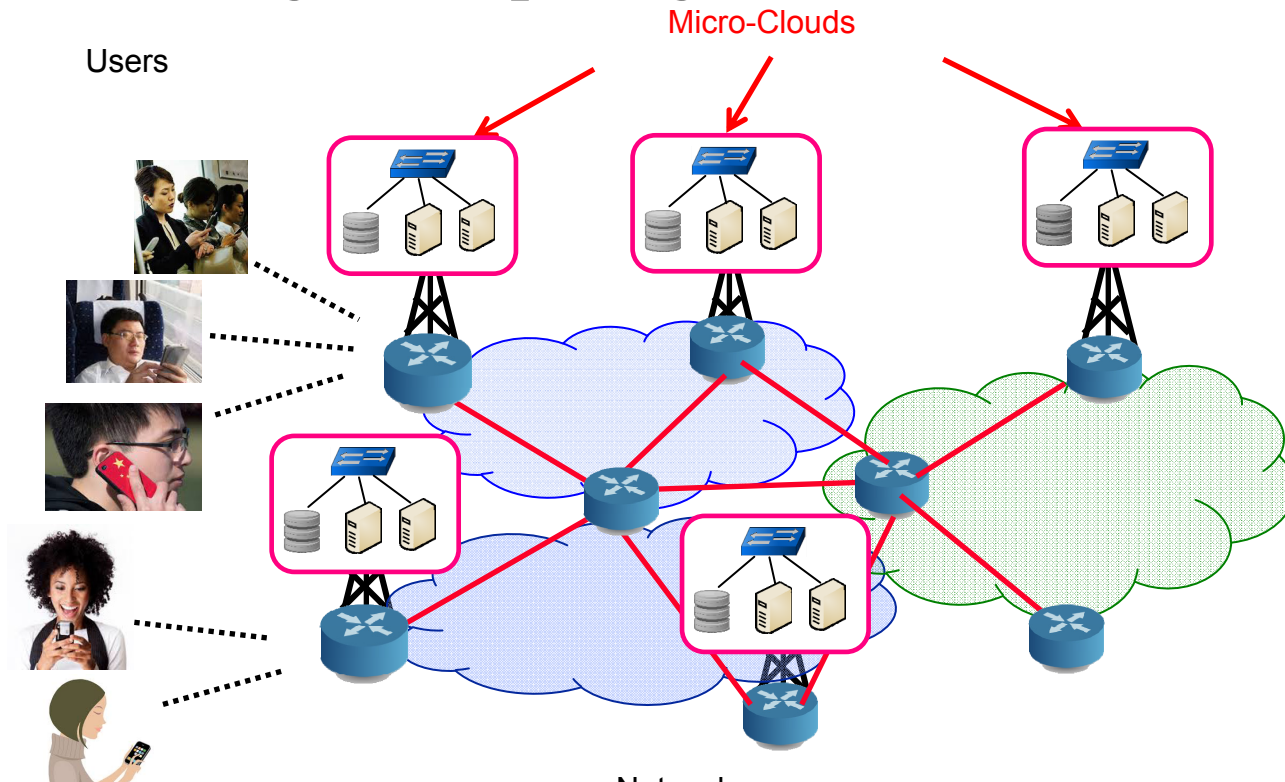
# Past: Data in the Edge

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



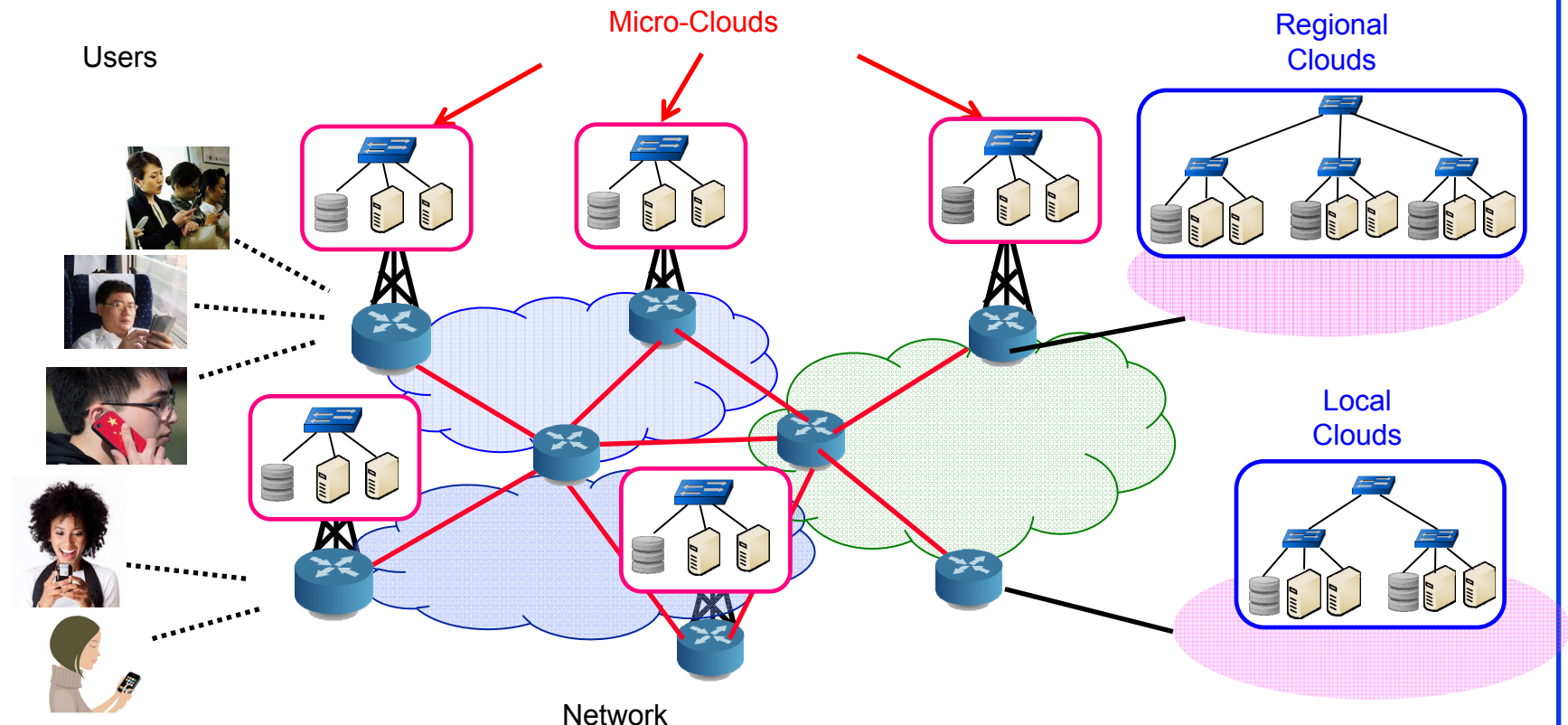
# Trend: Computation in the Edge

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



# Trend: Multi-Cloud

- Larger and infrequent jobs serviced by local and regional clouds  $\Rightarrow$  Fog Computing





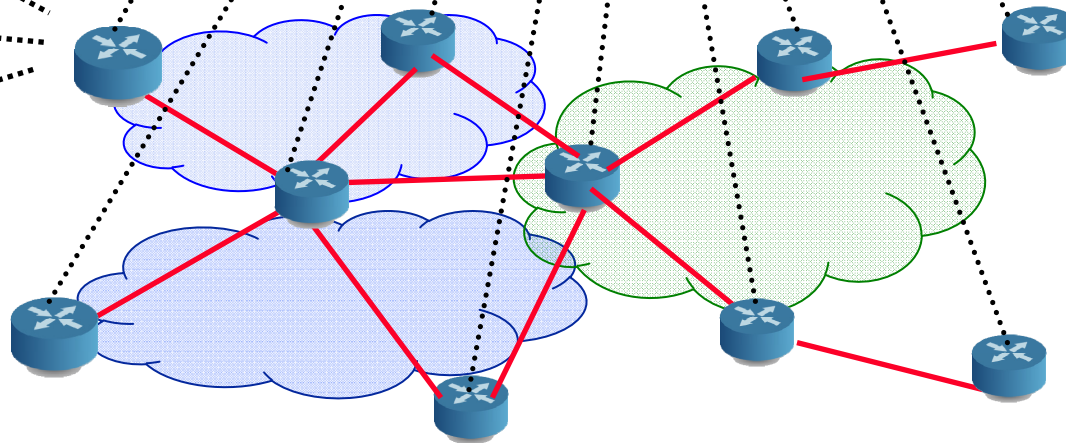
# Past: Software Defined Networking

- Network can be managed w/o worrying about individual device hardware



Network Manager

Users



Network

# Trend: Software Defined Multi-Cloud Application Delivery



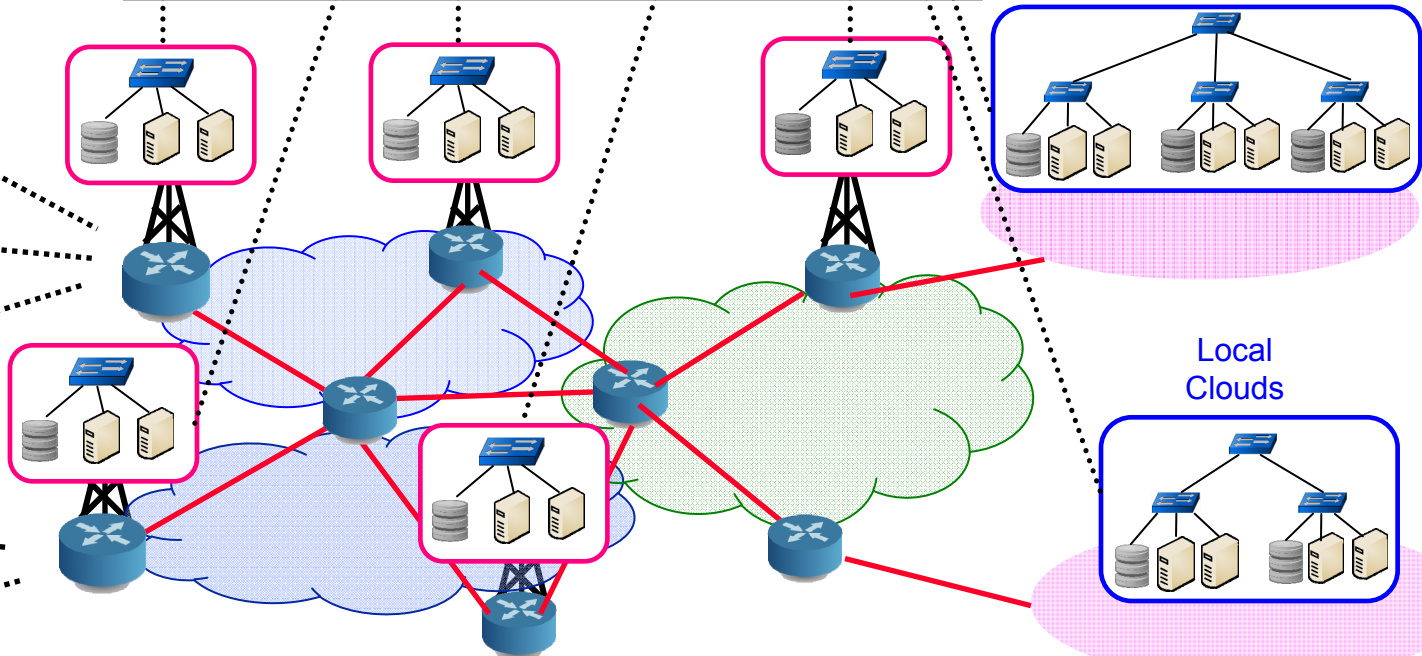
Application Developer/Manager/User

Users

Multi-Cloud Application Manager

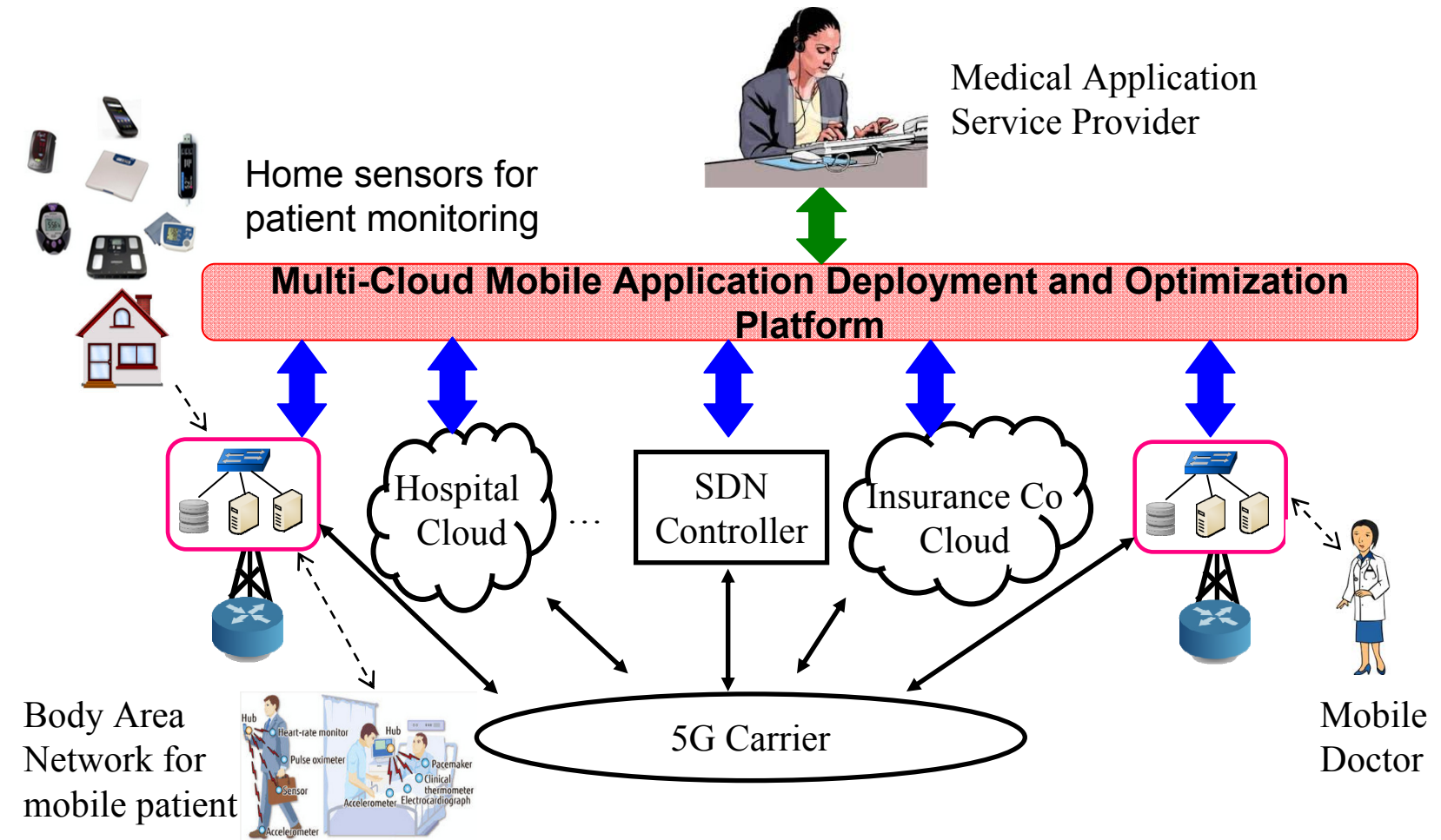
Regional Clouds

Local Clouds



Network

# Mobile Healthcare Use Case

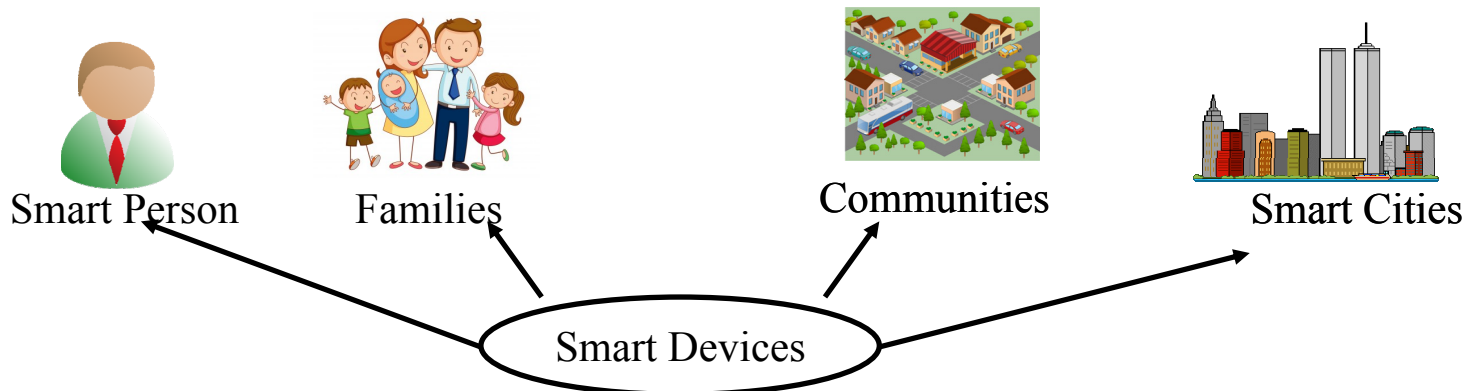


# Trend: Adaptive Everything

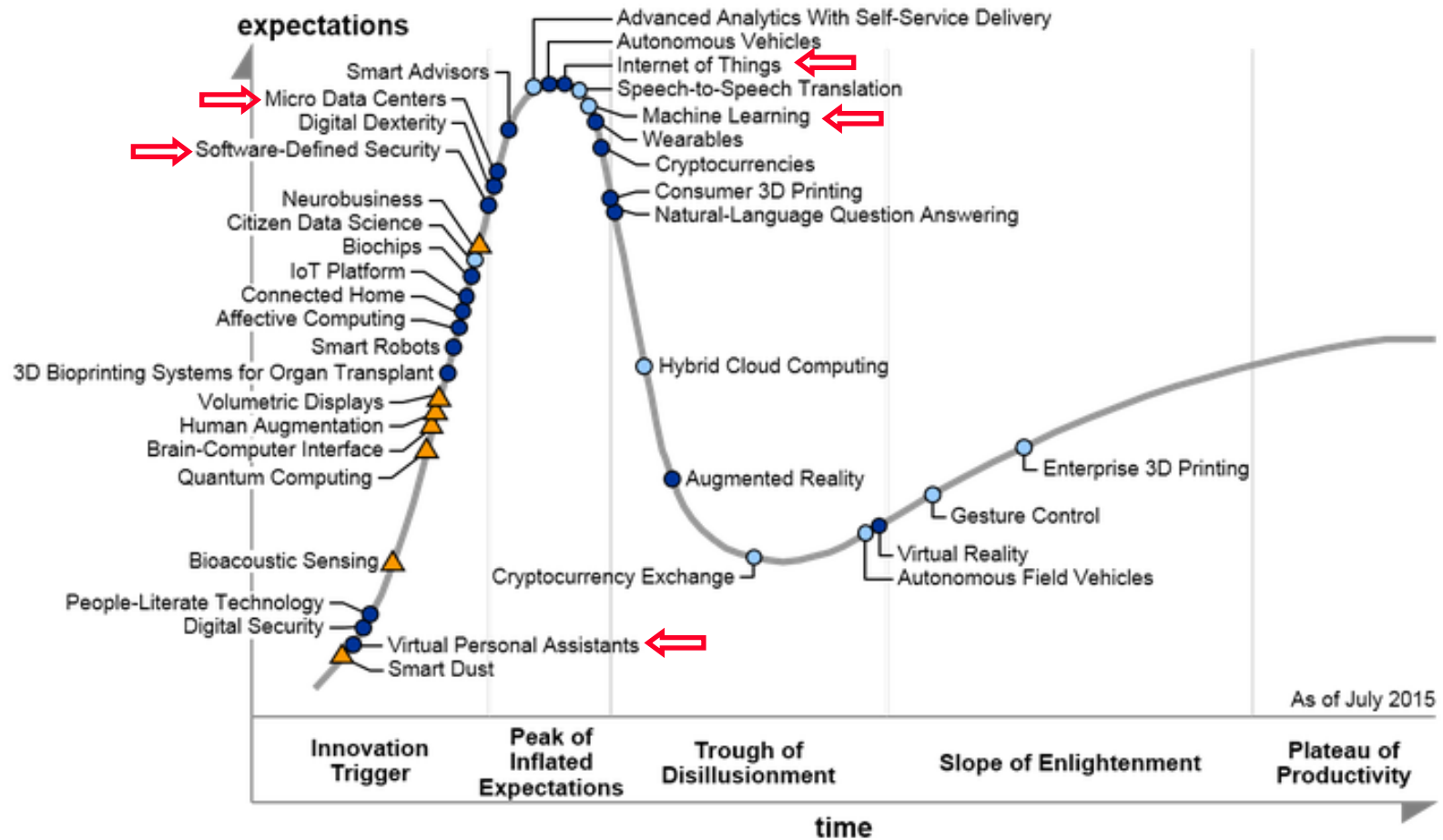
- ❑ Smart = Connected
- ❑ Adaptive = Machine Learning  
Aka “Intelligent”  
Aka “Autonomous”
- ❑ Adaptive Security
- ❑ Proactive fault diagnosis

# Trend: Personal Clouds

- ❑ **Digital Mesh**: All “Things” belonging to a person
  - Computing and communication, Wearables, transportation
  - Social interactions, Communities, Business, ...
- ❑ Analytics of information, machine learning
- ❑ **Personal Clouds** ⇒ “Smart” personal environments
- ❑ Autonomous Personal Assistants ⇒ Predicts personal needs
- ❑ Same applies to families, communities, and cities

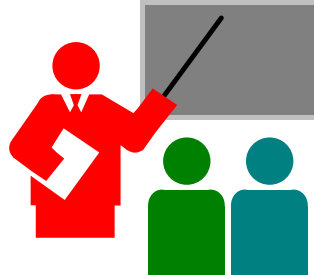


# Hype Cycle of Emerging Technologies 2015



Ref: Gartner, "Hype Cycle of Emerging Technologies 2015," July 2015, <http://www.gartner.com>

# Summary



1. IoT research areas are easy via the 7-layer model
2. IoT has brought in research issues in every layer: Sensors, datalink, routing, applications, analytics.
3. Security and privacy are most important
4. Computation is moving to the Edge  
⇒ Fog Computing ⇒ Mobile-Edge Computing
5. SDN concepts need to move up a layer –  
from Virtualizing routers to Virtualizing clouds

# 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](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](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](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](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](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](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](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