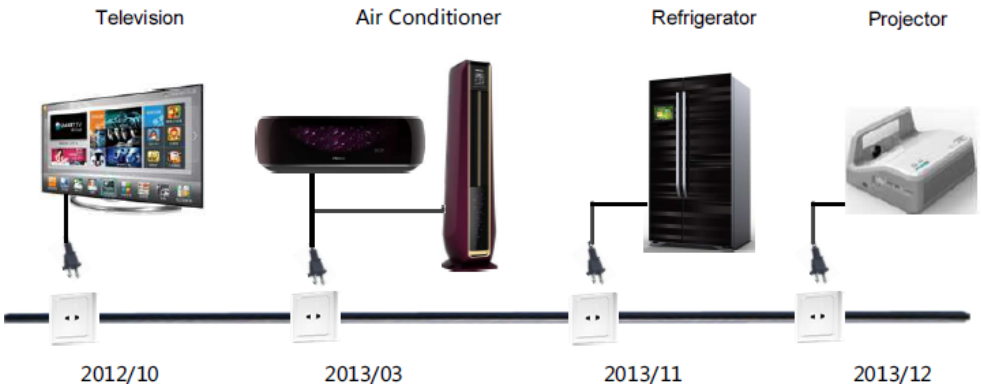
Internet of Things: Challenges and Issues



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IEEE CS Keynote at ADCOM 2014,
Bangaluru, India, September 19, 2014

These slides and video recording of this presentation are at:

http://www.cse.wustl.edu/~jain/talks/iot_ad14.htm

Overview

1. What are Things?
2. What's Smart?
3. Why IoT Now?
4. Business/Research Opportunities in IoT
5. Recent Protocols for IoT

What are Things?

- Thing = Not a computer
- Phone, watches, thermostats, cars, Electric Meters, sensors, clothing, band-aids, TV,…
- Anything, Anywhere, Anytime, Anyway, Anyhow (5 A's)

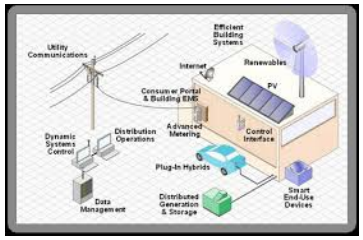
Ref: http://blog.smartthings.com/iot101/iot-adding-value-to-peoples-lives/

Internet of Things

- Less than 1% of things around us is connected.
  Refrigerator, car, washing machine, heater, a/c, garage door, should all be connected but are not.
- From 10 Billion today to 50 Billion in 2020
  Should include processes, data, things, and people.
- $14 Trillion over 10 years
  ⇒ Third in the list of top 10 strategic technologies by Gartner
  (After Mobile devices, Mobile Apps, but before Clouds, …)
- a.k.a. **Internet of Everything** by Cisco
  Smarter Planet by IBM

Ref: "Gartner Identifies Top 10 Strategic Technologies,"
http://www.cioinsight.com/it-news-trends/gartner-identifies-top-10-strategic-technologies.html
Ref: J. Bradley, "The Internet of Everything: Creating Better Experiences in Unimaginable Ways," Nov 21, 2013,
http://blogs.cisco.com/ioe/the-internet-of-everything-creating-better-experiences-in-unimaginable-ways/#more-131793

Sample IoT Applications



Smart Grid

Smart Health

Smart Home

Smart Cities

Smart Industries

Smart TV

Smart Watch

Smart Car

Smart Kegs

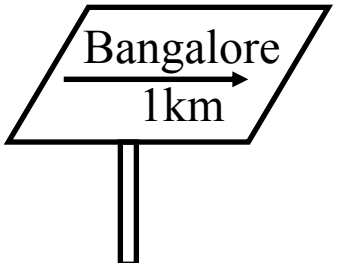
What's Smart?

- IoT = Instrument, Interconnect, Intelligently process (3 I's)
- 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

4 Levels of Smartness



1. **Passive**: Communicate only when queried. Passive RFID, QR codes (*Nirjeeva*)

2. **Active**: Communicate when needed. Sensors. Home automation (*1-4 sense*)

3. **Aware**: Action based on simple computation. E.g., tele-health (*5-sense*)

4. **Autonomous**: Can make decisions based on rules. E.g., autonomous cars, smart grid (*Human*)

Ref: http://go.gigaom.com/rs/gigaom/images/gigaomresearch_the_internet_of_things_report.pdf

Internet of Brains

- Brain-to-Brain Interface
- A person's brain can send signals to other person's brain
- Useful for handicap people to communicate with others

Ref: http://homes.cs.washington.edu/~rao/brain2brain/experiment.html

Why IoT Now?

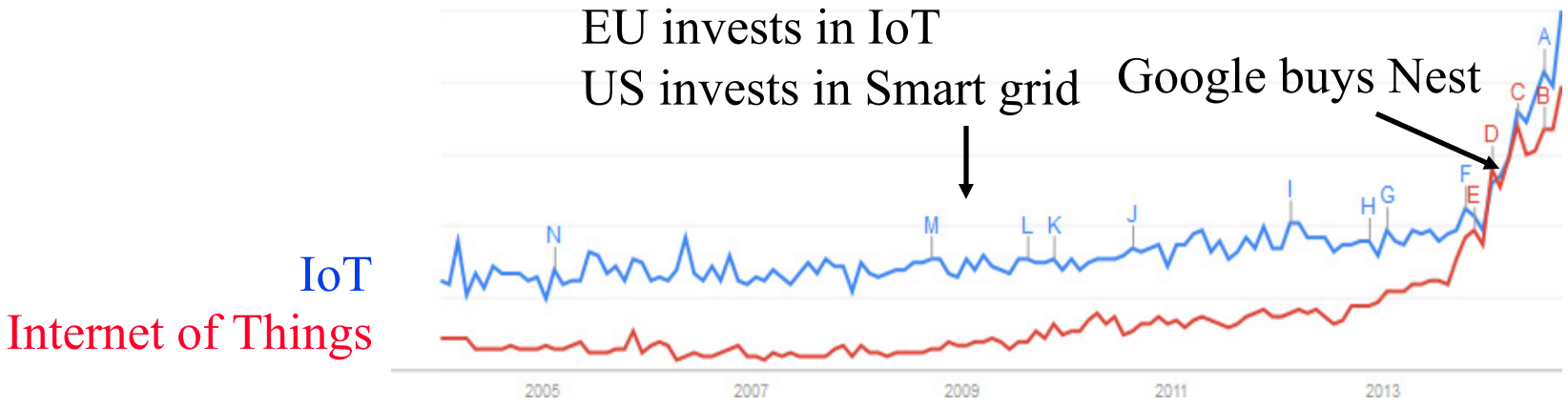
- IoT = Sensing + Communication + Computation

1. Micro-Sensors: Temperature, Moisture, Pressure, air quality, …
2. Tags: Radio Frequency Id (RFID), Quick Response (QR) Codes, …
3. Energy Efficient Communication: Small or no batteries, Personal area communication (PAN), Bluetooth, ZigBee, …
4. Micro-Computing: Micro multi-core chips, Raspberry Pi, Intel Galileo, Arduino, …
5. Cloud Computing: Little or no local computing
6. Open/Small operating systems: Linux

Ref: CTIA, "Mobile Cyber security and the Internet of Things,"
http://www.ctia.org/docs/default-source/default-document-library/ctia-iot-white-paper.pdf

Funding

Google Trends



- Around for 10 years
- IERC-European Research Cluster on the Internet of Things funded under 7th Framework in 2009

  $\Rightarrow$ "Internet of European Things"
- US interest started in 2009 w $4B funding for **smart grid** in American Recovery and Reinvestment Act of 2009

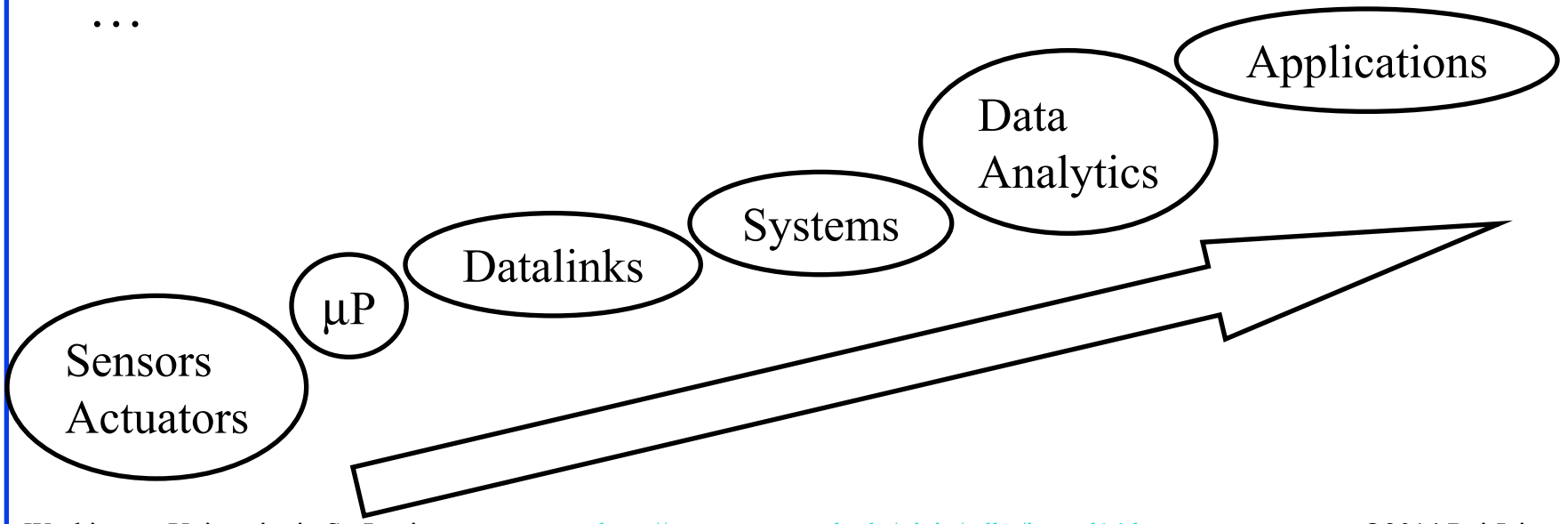
Research Funding for IoT

- 70 M € in European Research program FP7
  ⇒ Internet of European Things
- Networking and Information Technology Research and Development (NITRD)
  - Group of 15 Federal agencies: NSF, NIH, NASA, DOE, DARPA, ONR, …
  - Recommends supplement to the president's annual budget
  - CPS is one of the areas recommended by NITRD starting 2012 ⇒ Smart infrastructure
    - Smart Grid, Smart Bridges, Smart Cars, tele-operational surgical robots, Smart **Buildings**
- March 2014: £45M for IoT research in UK by David Cameron

Ref: NITRD, http://www.nitrd.gov/

Business Opportunities

- Components: Sensors, wireless radios, protocols,
- Smart Objects: Smart TV, Camera, Watch, …
- Systems: Buildings, Cars, Health, …
- Network service providers: ISP
- Application Service Providers: Monitoring, Analytics, Apps, …

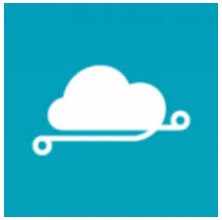
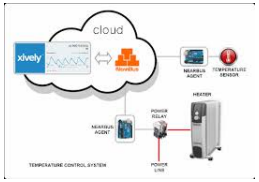
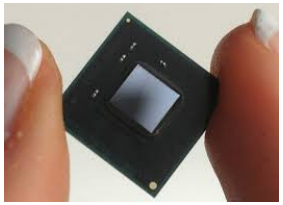
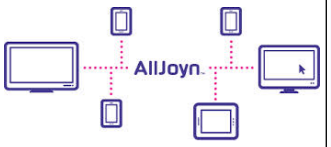


Venture Activities in IoT

- $1.1B invested in IoT startups by VCs in 153 deals in 2013
  - Quantified Self: Know your body and mind
  - Healthcare sensors: Wearable clock, sleep monitors
  - Energy management
  - Home Automation: Kitchenware, locks,
  - Environmental monitoring: Air Quality sensors, personal weather stations
- January 2014: Google buys NEST for 3.3B
- May 2014: $150M in VC investments in IoT by Cisco

Ref: http://www.cbinsights.com/blog/internet-of-things-investing-snapshot/
http://www.zdnet.com/cisco-invests-150m-in-internet-of-things-startups-7000028964/

Recent IoT Products

 NEST Thermostat	 Corventis: Wireless Cardiac Monitor	 WEMO Remote	 Tractive Pet Tracker
 Ninja Blocks	 Revolve Home Automation	 ThingWorx Application Platform	 Lings Cloud Platform
 Mbed Development Platform	 Xively Remote Access API	 Intel Quark Processor	 AllJoyn S/W Framework

IoT Research Challenges

1. **Naming and Addressing**: Advertising, Searching and Discovery
2. Service Orchestration
3. Power/Energy/Efficient resource management.
   Energy harvesting
4. **Things to Cloud**: Computation and Communication Gateways
5. **Miniaturization**: Sensors, CPU, network
6. **Big Data Analytics**: 35 ZB of data $2B in value by 2020
7. **Semantic technologies**: Information and data models for interoperability

8. **Virtualization**: Multiple sensors aggregated, or a sensor shared by multiple users
9. **Privacy/Security**/Trust/Identity/Anonymity
   Target Pregnancy Prediction
10. Heterogeneity/Dynamics/**Scale**

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.

News

Worm may create an Internet of Harmful Things, says Symantec (Take note, Amazon)

Security firm Symantec says it has found a Linux worm aimed at Internet of Things devices

By Patrick Thibodeau
December 3, 2013 01:22 PM ET Add a comment

Share 6 | 8+1 | Like 7 | More

Computerworld - Security researchers are gradually raising warnings that the Internet of Things will increase, by multitudes, the number of things that can be hacked and attacked.

The Hitchcockian plotlines are endless. Replace *The Birds* with flying Amazon delivery drones. Or imagine, as researchers did recently at Black Hat, someone hacking your connected toilet, making it flush incessantly and closing the lid repeatedly and unexpectedly.

Beacons

- Advertizing based on proximity
- Peripherals (your phone) broadcasts its presence if Bluetooth is turned on
- Primary aim of these broadcasts is to allow device discovery
- Advertising packets consist of a header and max 27B of payload with multiple TLV-encoded data items
  - May include signal strength ⇒ Distance
- iOS7 iPhones can send/received iBeacons
- Can be used for customized advertising, indoor location, geofencing
- PayPal uses this to identify you. You can pay using a PIN and your phone.

Power per MB

Type	Bit rate	TX Power	mJoules/MB
802.11b	11Mb	50mW	36.4
802.11g	54Mb	50mW	7.4
802.11a	54Mb	200mW	29.6
802.15.1 Bluetooth	1Mb	1mW	8.0
802.15.3	55Mb	200uW	0.03

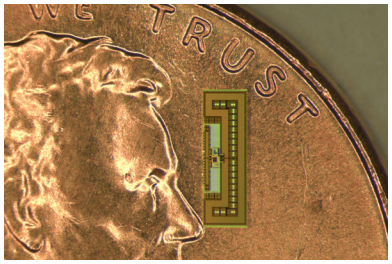
- Once connected, Bluetooth classic maintains connections even when there is no data. Low power but not low enough.

Datalink Issues

- Energy efficiency
  - ⇒ Need to decrease energy/bit by a factor of 1000
  - Energy/bit has gone down by a factor of 2 per year
  - Either wait ten years or design better protocols
- Small messages ⇒ Need low overhead
- Limited computing ⇒ Light weight protocols
  ⇒ lightweight Encryption, authentication, security
- Quality of Information (QoI)

Ant-Sized IoT Passive Radios

- Computer + Sensor + Radio in 3.7x1.2 mm from Stanford
- Can be added to dollar bills, band-aids, tools, …
- Monitor temperature, location
- 3 m range
- Extremely low power ⇒ No battery required (Similar to passive RFID
- Continuously monitor every part of the body of every patient



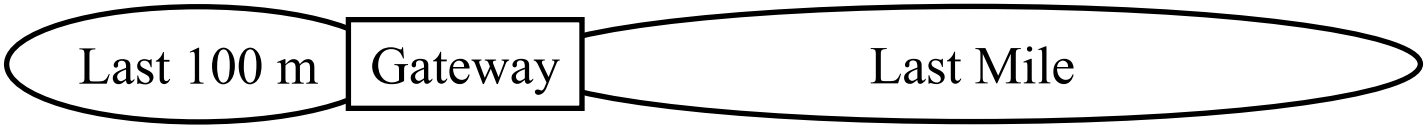
Ref: http://www.computerworld.com/article/2682854/stanfords-ant-sized-radios-could-connect-the-world.html?source=CTWNLE_nlt_pm_2014-09-12#tk.rss_all
http://web.stanford.edu/~arbabian/Home/Welcome.html

Networking Issues

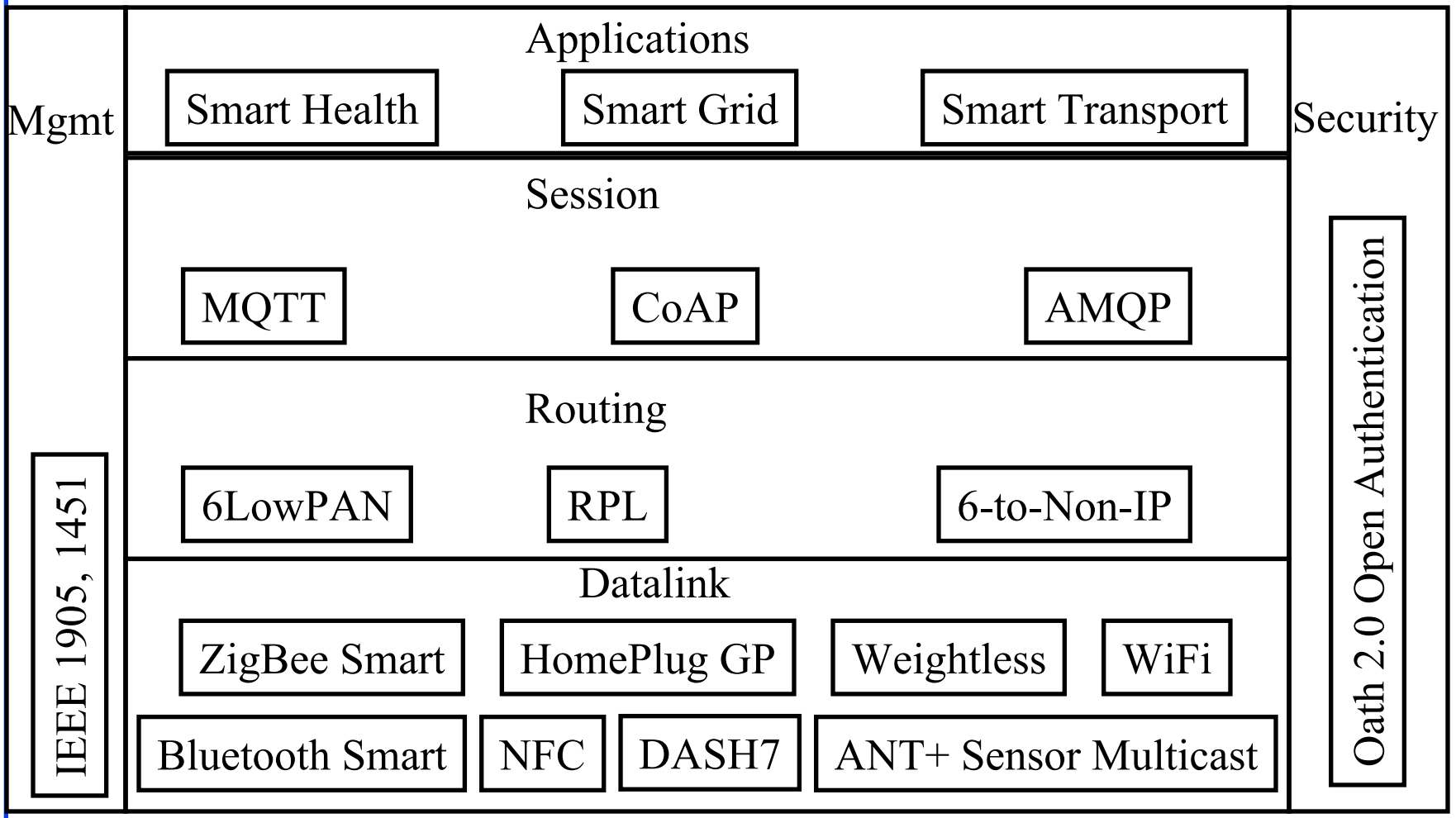
- Large number ⇒ 32-bit or 48-bit addressing not sufficient
- 32-bit IPv4 addresses too small
- 48-bit IEEE 802 too small
- 128-bit IPv6 addresses too large. Tiny things do not have energy to transmit such large addresses.
- 16-bit local addresses and 64-bit global addresses
- 6LowPAN, 6-to-NonIP

Last 100m Protocols

- The Last Mile: Mobile and Broadband Access revolution
  Smart Grid, Smart Cities, Smart Industries
- The last 100m: Smart home
- The last meter: Smart Healthcare, Smart Wearable's



Recent Protocols for IoT



Ref: http://tools.ietf.org/html/draft-rizzo-6lo-6legacy-00, http://en.wikipedia.org/wiki/OAuth, http://en.wikipedia.org/wiki/ANT%2B
http://en.wikipedia.org/wiki/Near_field_communication, http://en.wikipedia.org/wiki/Weightless_%28wireless_communications%29

Legacy IoT Protocols

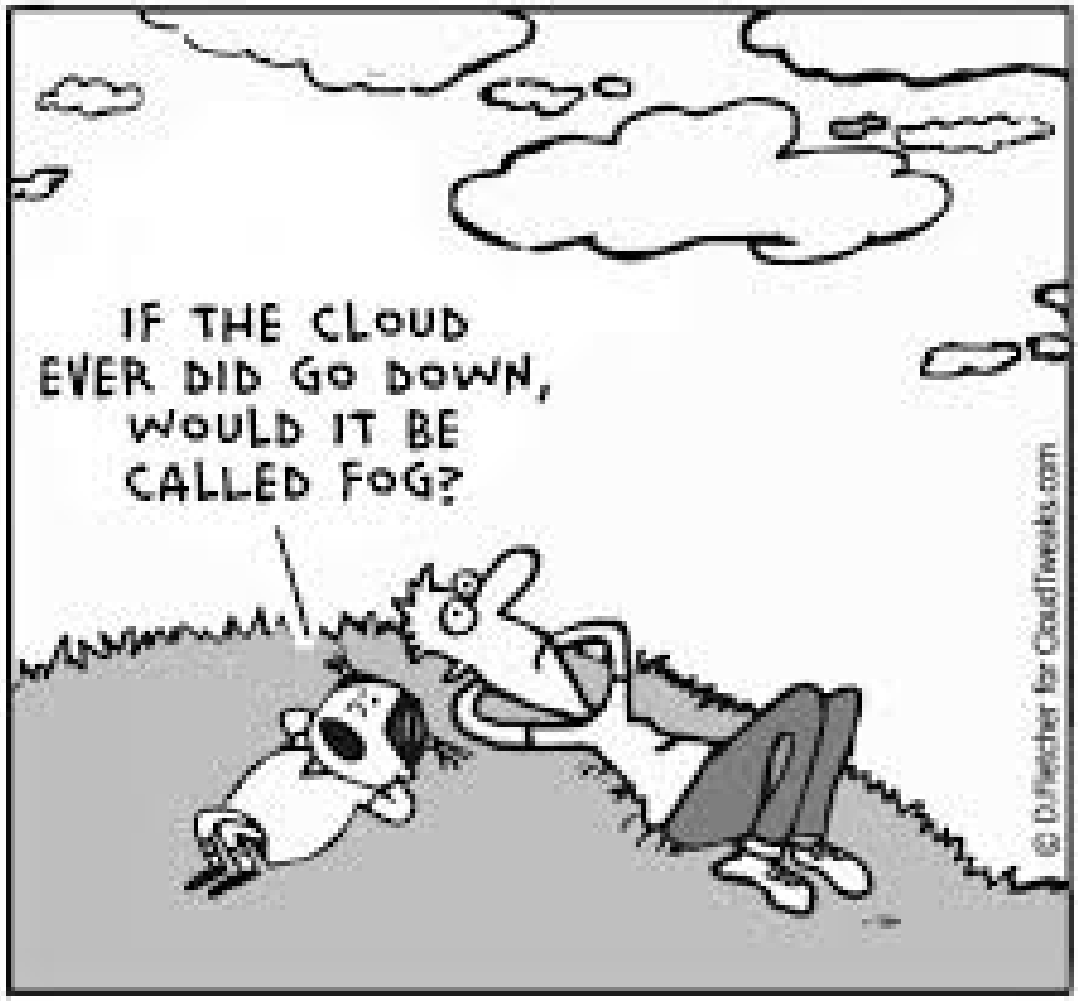
- **BACnet**: Building Automation and Control Network
- **LonWorks**: Local Operating Network (like BACnet)
- **ModBus**: Modicon (Schneider Electric)'s Serial Bus
- **KNX**: Home and Building Automation Standard
- **Z-Wave**: Wireless Communication for Home Automation
- **M-Bus**: Bus for remote reading of gas and electric meters
- **ANSI CI12.20**: Electric Meter Accuracy and Performance
- **DLMS**: Device Language Message Specification
- **COSEM**: Company Specification for Energy Metering

Standardization

- Almost every standards body is working on IoT: IEEE, IETF, ITU, ETSI, IPSO, …
- Seven organizations joined together to avoid duplication: ARIB, ATIS, CCSA, ETSI, TIA, TTA, TTC ⇒ oneM2M

Ref: http://www.onem2m.org

Fog Computing



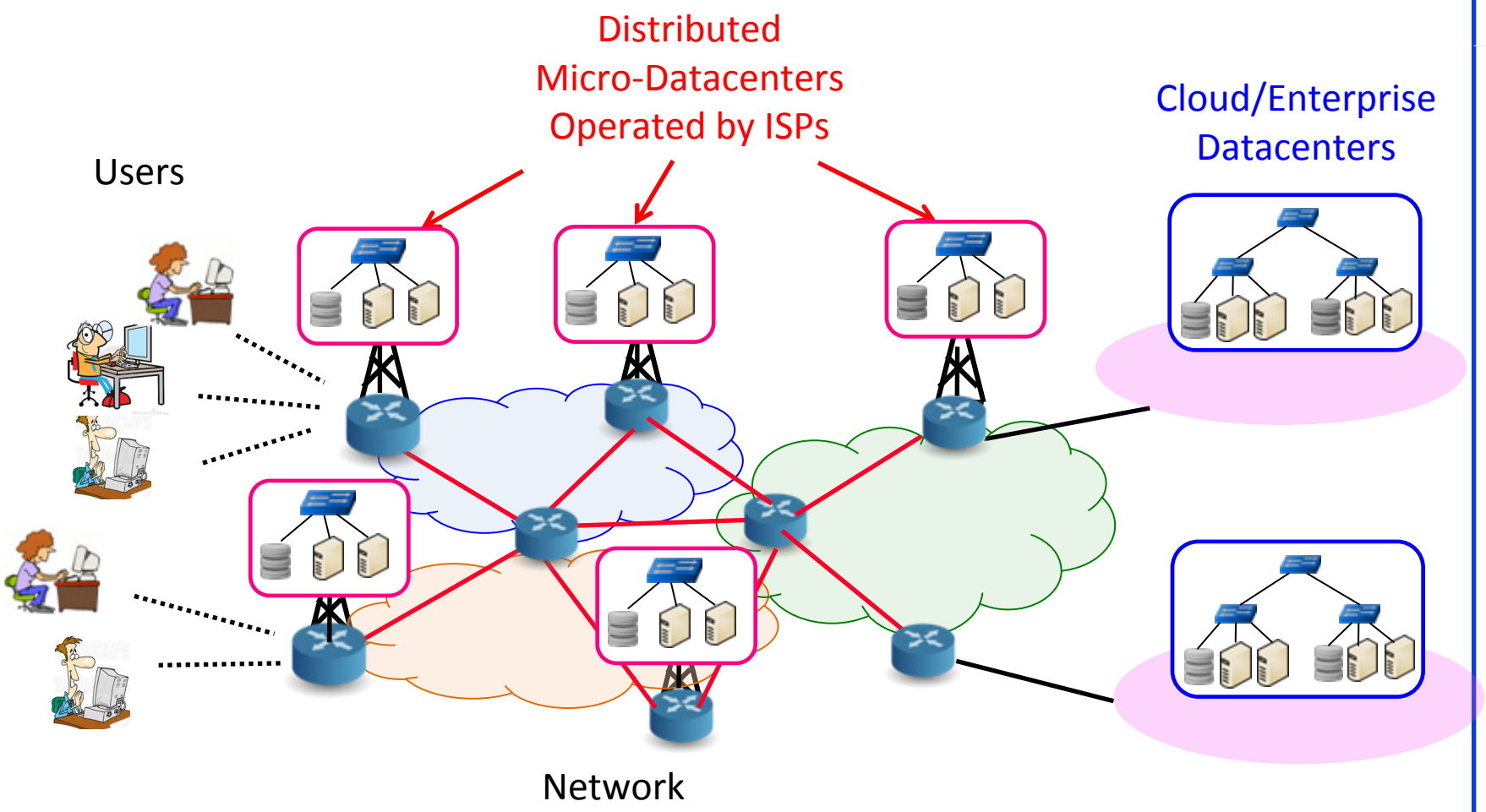
Ref: http://community.spiceworks.com/topic/254392-fog-computing-replaces-cloud-as-new-tech-buzzword

Fog Computing (Cont)

- Location Aware and Location Sensitive
  ⇒ Low latency ⇒ Computing in micro clouds
  ⇒ Computing in the edge ⇒ Computing everywhere
  ⇒ Fog
- Geographically distributed => Everywhere/Anywhere
- Large Scale
- Mobility
- Real-Time

Ref: F. Bonomi, et al., "Fog Computing and Its Role in the Internet of Things," ACM MCC'12, August 17, 2012, Helsinki, Finland

Micro-Clouds on Cell-Towers



New Business Opportunities: Domain 2.0,
Datacenters on Towers, IoT, NFV, FV, Elastic Networks

The Problem Statement

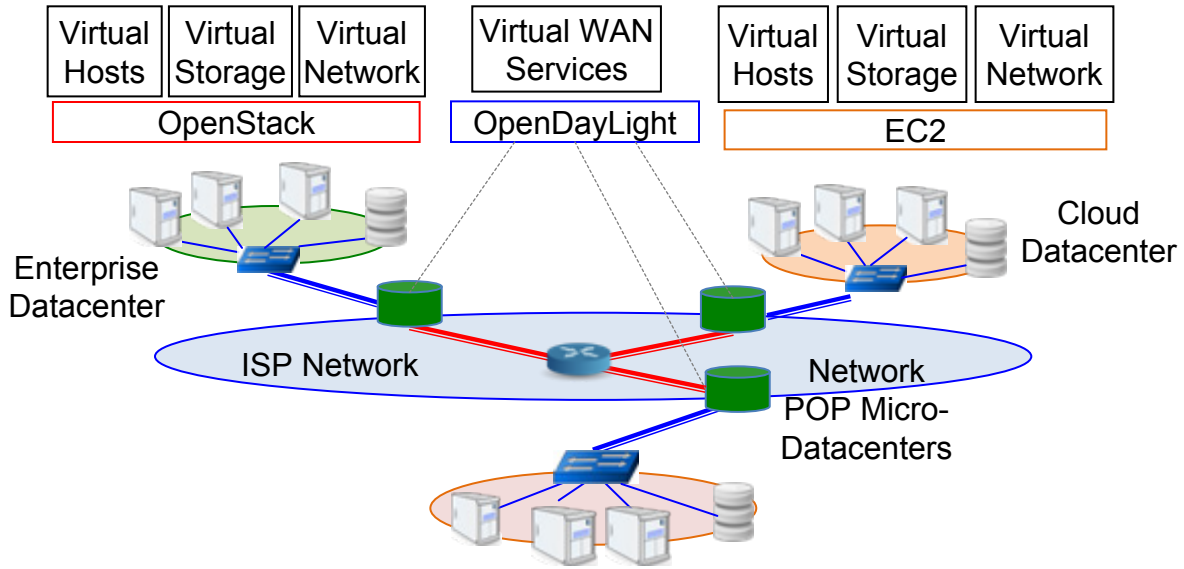
Massively Distributed Application Use Cases

Application Service Providers (ASPs)

Automatic Application Deployment and Delivery Platform

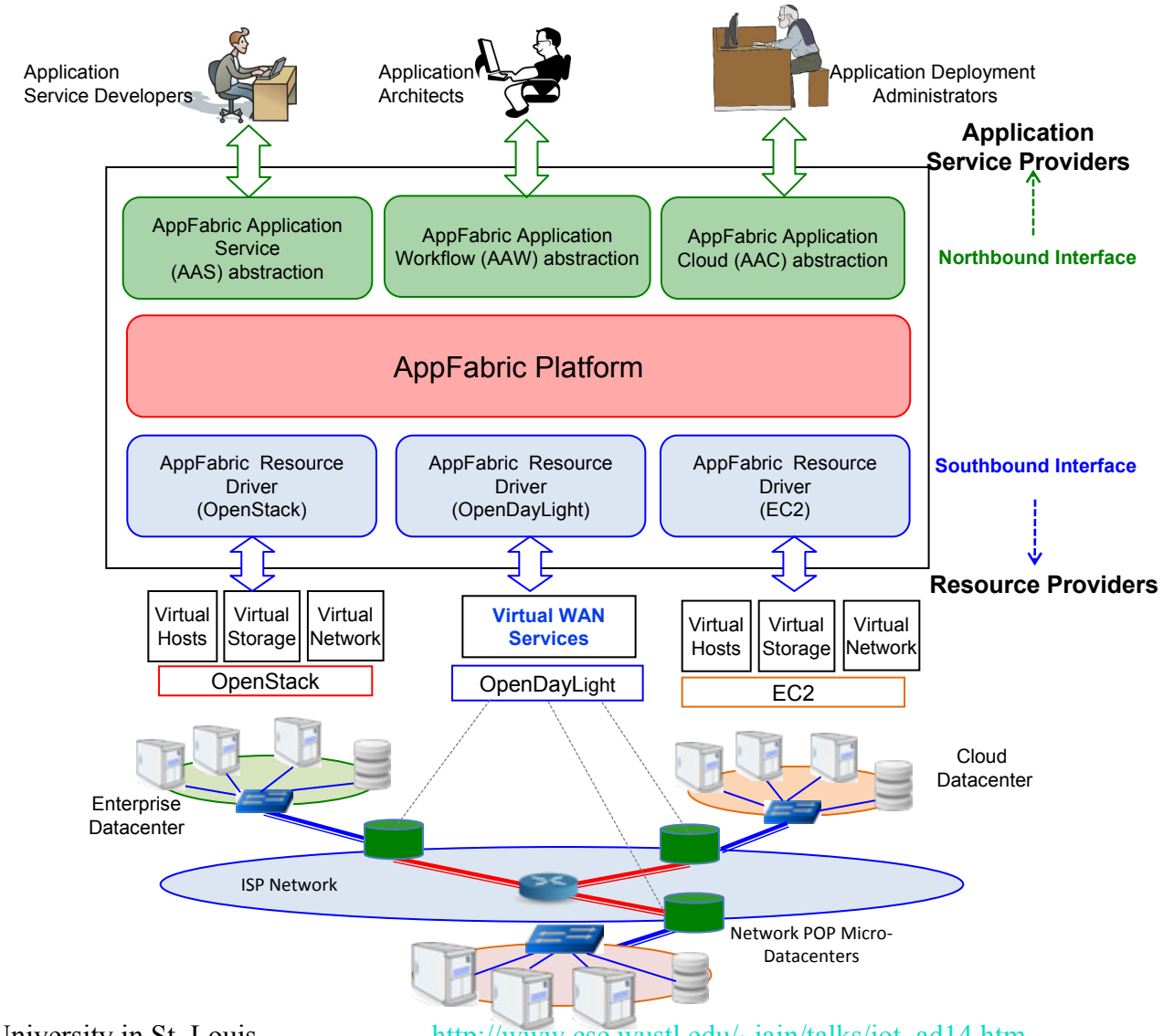
AppFabric

Distributed Virtual Infrastructure

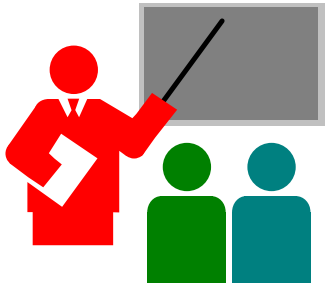


Resource Providers (ISPs, CSPs)

Services in a Cloud of Clouds



Summary



1. Less than 1% of things are connected
   ⇒ IoT is a big opportunity for academics and industry
2. Smart Grid and Energy management is leading the change.
3. Smartness comes from communication capability since the computation can be delegated
4. Right at the knee: Academic and Startup Research opportunities in almost subfields of computing including hardware development, data analytics, security, and networking.
5. Cloud computing everywhere leads to fog computing and multi-cloud computing ⇒ AppFabric

Acronyms

- 6LowPAN IPv6 over Low Powered Personal Area Network
- AMQP Advanced Message Queueing Protocol
- ANSI American National Standards Institute
- ANT A proprietary open access multicast wireless sensor network
- ANT+ Interoperability function added to ANT
- API Application Programming Interface
- ARIB Association of Radio Industries and Businesses (Japan)
- BACnet Building Automation and Control Network
- CI12.20 ANSI Standard for Electric Meter Accuracy and Performance
- CoAP Constrained Application Protocol
- COSEM Company Specification for Energy Metering
- CPS Cyber Physical Systems
- CPU Central Processing Unit
- CTIA Cellular Telecommunication Industries Association
- DARPA Defense Advance Research Project Agency
- DASH7 ISO 18000-7 RFID standard for sensor networks

Acronyms (Cont)

- DLMS Device Language Message Specification
- DoE Department of Energy
- ETSI European Telecommunications Standards Institute
- GreenPHY Green Physical Layer
- HomePlug-GP HomePlug Green PHY
- IEEE Institute for Electrical and Electronic Engineers
- IERC IoT-European Research Cluster
- IETF Internet Engineering Task Force
- IoT Internet of Things
- IP Internet Protocol
- IPSO IP for Smart Objects
- IPv4 Internet Protocol version 4
- IPv6 Internet Protocol version 6
- ISP Internet Service Provider
- ITU International Telecommunications Union

Acronyms (Cont)

- KNX Building automation protocol
- MQTT Message Queue Telemetry Transport
- NASA National Aeronautical and Space Administration
- NEST Name of a product
- NFC Near field communication
- NIH National Institute of Health
- NITRD Networking and Info Tech Research and Development
- NonIP Non-Internet Protocol
- NSF National Science Foundation
- OAuth Open Authorization protocol from IETF
- oneM2M One Machine to Machine
- ONR Office of Naval Research
- PAN Personal area network
- QoI Quality of information

Acronyms (Cont)

- QR Quick Response
- RFID Radio Frequency Identifier
- RPL Routing Protocol for Low Power and Lossy Networks
- TV Television
- UK United Kingdom
- US United States
- VC Venture Capital
- WiFi Wireless Fidelity
- ZB Ziga-Byte