Internet of Things: Challenges and Issues

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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,”
Ref: J. Bradley, “The Internet of Everything: Creating Better Experiences in Unimaginable Ways,” Nov 21, 2013,
### Sample IoT Applications

<table>
<thead>
<tr>
<th>Smart Grid</th>
<th>Smart Health</th>
<th>Smart Home</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Smart Grid Image" /></td>
<td><img src="image2.png" alt="Smart Health Image" /></td>
<td><img src="image3.png" alt="Smart Home Image" /></td>
</tr>
<tr>
<td>Smart Cities</td>
<td>Smart Industries</td>
<td>Smart TV</td>
</tr>
<tr>
<td><img src="image4.png" alt="Smart Cities Image" /></td>
<td><img src="image5.png" alt="Smart Industries Image" /></td>
<td><img src="image6.png" alt="Smart TV Image" /></td>
</tr>
<tr>
<td>Smart Watch</td>
<td>Smart Car</td>
<td>Smart Kegs</td>
</tr>
<tr>
<td><img src="image7.png" alt="Smart Watch Image" /></td>
<td><img src="image8.png" alt="Smart Car Image" /></td>
<td><img src="image9.png" alt="Smart Kegs Image" /></td>
</tr>
</tbody>
</table>
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, …
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*)

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

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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, ...
  5. Cloud Computing: Little or no local computing
  6. Open/Small operating systems: Linux

Ref: CTIA, “Mobile Cyber security and the Internet of Things,”
Funding
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”
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

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

## Recent IoT Products

<table>
<thead>
<tr>
<th>NEST Thermostat</th>
<th>Corventis: Wireless Cardiac Monitor</th>
<th>WEMO Remote</th>
<th>Tractive Pet Tracker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ninja Blocks</td>
<td>Revolve Home Automation</td>
<td>ThingWorx</td>
<td>Lings Cloud Platform</td>
</tr>
<tr>
<td>Mbed Development</td>
<td>Xively Remote Access API</td>
<td>Intel Quark</td>
<td>AllJoyn S/W Framework</td>
</tr>
<tr>
<td>Platform</td>
<td></td>
<td>Processor</td>
<td>Framework</td>
</tr>
</tbody>
</table>
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**
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.
Once connected, Bluetooth classic maintains connections even when there is no data. Low power but not low enough.

<table>
<thead>
<tr>
<th>Type</th>
<th>Bit rate</th>
<th>TX Power</th>
<th>mJoules/MB</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11b</td>
<td>11Mb</td>
<td>50mW</td>
<td>36.4</td>
</tr>
<tr>
<td>802.11g</td>
<td>54Mb</td>
<td>50mW</td>
<td>7.4</td>
</tr>
<tr>
<td>802.11a</td>
<td>54Mb</td>
<td>200mW</td>
<td>29.6</td>
</tr>
<tr>
<td>802.15.1 Bluetooth</td>
<td>1Mb</td>
<td>1mW</td>
<td>8.0</td>
</tr>
<tr>
<td>802.15.3</td>
<td>55Mb</td>
<td>200uW</td>
<td>0.03</td>
</tr>
</tbody>
</table>
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

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

- **Applications**
  - Smart Health
  - Smart Grid
  - Smart Transport

- **Session**
  - MQTT
  - CoAP
  - AMQP

- **Routing**
  - 6LowPAN
  - RPL
  - 6-to-Non-IP

- **Datalink**
  - ZigBee Smart
  - HomePlug GP
  - Weightless
  - WiFi
  - Bluetooth Smart
  - NFC
  - DASH7
  - ANT+ Sensor Multicast

- **Security**

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

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

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**Micro-Clouds on Cell-Towers**

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

[Diagram showing a network with distributed micro-datacenters operated by ISPs and cloud/enterprise datacenters.]
The Problem Statement

Massively Distributed Application Use Cases

Automatic Application Deployment and Delivery Platform

Distributed Virtual Infrastructure

Virtual Hosts | Virtual Storage | Virtual Network | Virtual WAN Services
---|---|---|---
OpenStack | OpenDayLight | EC2

Application Service Providers (ASPs)

AppFabric

Resource Providers (ISPs, CSPs)

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

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Services in a Cloud of Clouds

Application Service Providers

Application Architects

Application Deployment Administrators

Northbound Interface

Southbound Interface

Resource Providers

AppFabric Application Service (AAS) abstraction

AppFabric Application Workflow (AAW) abstraction

AppFabric Application Cloud (AAC) abstraction

AppFabric Platform

AppFabric Resource Driver (OpenStack)

AppFabric Resource Driver (OpenDayLight)

AppFabric Resource Driver (EC2)

Virtual Hosts

Virtual Storage

Virtual Network

OpenStack

Virtual WAN Services

OpenDayLight

EC2

Enterprises

Datacenter

ISP Network

Network POP Micro-Datacenters

Application Deployment Administrators

Application Architects

Application Service Providers

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