Mobile and Sensor Systems

Lecture 8: Internet of Things and Sensor Integration

Dr Andrea Gaglione
About Me

2009

2010

2011

2014

2016

2017

Things Connected
In this lecture

• We will introduce the Internet of Things (IoT) paradigm
• We will talk about the major challenges in the IoT ecosystem
• We will describe the 6LoWPAN and LPWAN architectures
The “classical” Internet

Router / access point

Static clients

Network infrastructure (Internet)

Base transceiver station (BTS)

Mobile clients
What is the IoT?

“A global infrastructure for the information society, enabling advanced services by interconnecting things based on existing and evolving interoperable information and communication technologies” [1].

“A system of physical objects that can be discovered, monitored, controlled, or interacted with by electronic devices that communicate over various networking interfaces and eventually can be connected to the wider internet” [2].

Hype cycle

Increased interest and investments in IoT technologies

50 billion IoT devices by 2020 - Cisco
Revised hype cycle (2016)

The focus on the development of IoT platforms
Recent IoT investments

Source: CB Insights


$768M in 2010 to over $1.9B in 2014
(Smart) Things

Physical objects digitally augmented with one or more of the following:

• Sensors (temperature, light, motion, etc.)
• Actuators (displays, sound, motors, etc.)
• Computation capabilities
• Communication interfaces

Blend the physical and the digital world in novel ways

New computing revolution

50 B devices will be connected by 2020 - Cisco
Enabling technologies

• Identification (e.g., RFID, NFC)
  – tag and track goods
  – smart logistics and supply chain
• Sensing
  – microelectromechanical systems (MEMS)
• Computation & communication
  – hardware platforms able to run embedded software
  – wireless communication technologies
  – operating systems, wireless sensor networks (WSN)
• Cloud computing & data analytics
  – smart object data combined to provide insight and recommendations
IoT landscape

**Tags** (RFID, NFC, QR codes)

**Devices** (sensor nodes, mobile and wearable devices)

**Machines** (home appliances, security systems, vehicles, etc.)

**Environments** (smart homes, buildings, cities)
Typical IoT system architecture

- **IoT Cloud**
  - Service hosting
  - Visualisations
  - Advanced analytics
  - Slow control
  - Data storage

- **IoT Gateway**
  - Edge analytics
  - Fast control
  - Short/wide comms
  - Local storage

- **IoT Device**
  - Basic processing
  - Short/wide comms
  - Sensing/actuation
IoT service pattern

**4As**
- **Acquire**: Capture real world information about entities and process(es) of interest.
- **Analyse**: Extract actionable insights from captured information.
- **Action**: Trigger action that impacts real world process(es) and entities.
- **Achieve**: Reach desired impact/goals through executed actions.

University of Cambridge
**IoT platform ecosystem**

<table>
<thead>
<tr>
<th>Source: CBInsights</th>
<th>Source: IOT Analytics</th>
<th>Source: Vision Mobile</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.9B in 2014</td>
<td>360+ IoT platform offerings</td>
<td>4.5M IoT developers</td>
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<td>$768M in 2010</td>
<td>200 startups</td>
<td>IoT developers use open source</td>
</tr>
<tr>
<td>221 deals in 2014</td>
<td>50+ Multinational</td>
<td>91% IoT developers use open source</td>
</tr>
<tr>
<td>91 deals in 2010</td>
<td>&lt; 20 Open Source</td>
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<tr>
<td>200 US based</td>
<td>100 European</td>
<td></td>
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<tr>
<td>200</td>
<td>30+ IoT platforms acquired</td>
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221 deals in 2014
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< 20 Open Source
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30+ IoT platforms acquired
91% IoT developers use open source
IoT platform scope

Source: IOT Analytics
Communication technologies

- Near field (<10 cm)
  - RFID
  - NFC
  - QR codes
- Personal area network (PAN)
  - Bluetooth / BLE
  - 802.15.4
  - Zigbee
- Local area network (LAN)
  - WiFi (802.11x)
- Wide area network (WAN)
  - GSM (2G) / 3G / 4G / 5G
  - LPWAN (LoRa, Sigfox, NB-IoT, ...)

Distance:
- Near field: < 10 cm
- Personal area network: 1 m – 50 m
- Local area network: 50 m – 1 km
- Wide area network: 1 km – 50 km
Interoperability

- Ability for devices from different manufacturers to exchange data
- Problem of complex nature
  - heterogeneity of devices, communication technologies
  - existence of many data formats
  - dynamic landscape

Extremely difficult to define a widely accepted specification
Addressing issues

• Incredibly high number of nodes

• IPv4 uses 32-bit addresses
  – \(2^{32} = 4,294,967,296\) unique addresses
  – IPv4 exhaustion occurred in 2011!

\[\downarrow\]

IPv6

– 128-bit addresses \(\rightarrow 2^{128}\) unique address

Is it enough? Can we just run the Internet Protocol on smart devices?
IPv6 main challenges

• Frame size and bandwidth
  – 1280 Bytes → reflects the advances in link layer technologies the Internet uses
  – low power wireless embedded radio technology has limited frame size (400 – 200 Bytes) and bandwidth (20 – 250 Kbit/s)
  – Limited buffering and processing capabilities of embedded devices

• Power and duty cycle
  – the basic assumption of IP is that a device is always connected

• Security
  – Security mechanisms (e.g., IPsec) too complex for embedded devices

• Reliability
  – Transport layer not designed (and optimized) for low power wireless networks
6LoWPAN

- IPv6 over Low power Wireless Personal Area Networks
- Enable the use of IPv6 over 802.15.4 radio links
- Efficient adaptation layer between 802.15.4 link layer and TCP/IP stack

<table>
<thead>
<tr>
<th>HTTP</th>
<th>TCP/UDP</th>
<th>IPv4/IPv6</th>
<th>Ethernet/WiFi MAC</th>
<th>Ethernet/WiFi PHY</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Application</td>
<td>Physical</td>
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<td>Transport</td>
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<td>Network</td>
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<td>Data Link</td>
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<td>Application protocols (e.g., CoAP)</td>
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<td>UDP/ICMP</td>
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<td></td>
<td>IPv6, RPL</td>
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<td>6LoWPAN</td>
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<td></td>
<td>802.15.4 MAC</td>
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<td></td>
<td></td>
<td></td>
<td>802.15.4 PHY</td>
</tr>
</tbody>
</table>
IPv6/6LoWPAN architecture

- Route traffic in and out of the LoWPAN
- IPv6 - LoWPAN adaptation
  - header compression (40 B → 2, 12, 20 B)
  - fragmentation
- Management of the LoWPAN
- IPv4 support (tunneling)
Security and Privacy

• Wide scale of IoT systems expected to magnify security threats
  – how could encryption and authentication technologies be implemented within IoT devices?
  – tradeoffs, e.g., what will motivate device designers and manufacturers to accept additional product design cost to make devices more secure?

• Privacy challenges have implications on basic rights and our collective ability to trust the Internet and the devices that connect to it
  – users have no knowledge or control over the way in which their personal data is being collected and used
  – marketplace relationship between data sources and data collectors
Low Power Wide Area Networks (LPWAN)

- Long range, low bandwidth
- Deep indoor penetration
- Very cheap radio modules
- High latency
LPWAN architecture

- **Single hop** communication (star topology) between end nodes and gateways
- Gateways are connected to the network infrastructure via standard IP connections
- Application servers allow for the development of complex services over IoT data
## LPWAN technologies

<table>
<thead>
<tr>
<th></th>
<th>LoRaWAN</th>
<th>Neul</th>
<th>NWave</th>
<th>SigFox</th>
<th>Weightless-N</th>
<th>Weightless-P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Range (km)</strong></td>
<td>2-5 urban 45 rural</td>
<td>Up to 10</td>
<td>Up to 10</td>
<td>&lt;10 urban, 50 rural</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td><strong>Deep Indoor performance</strong></td>
<td>yes</td>
<td>ISM yes, WS no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Freq band</strong></td>
<td>Varies, subGHz</td>
<td>ISM or WS</td>
<td>SubGHz</td>
<td>Freq indep 868/902</td>
<td>SubGHz</td>
<td>SubGHz</td>
</tr>
<tr>
<td><strong>ISM</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Fully bi-directional</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Uplink</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Data rate</strong></td>
<td>0.3-50 kbps</td>
<td>10-100 kbps</td>
<td>100 bps</td>
<td>10-1000 bps</td>
<td>30-100 kbps</td>
<td>Up 100 kbps</td>
</tr>
<tr>
<td><strong>Power profile</strong></td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Authentication</strong></td>
<td>Yes</td>
<td>-</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>E2E encryption</strong></td>
<td>Yes</td>
<td>-</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>OTA SW upgrade</strong></td>
<td>Yes</td>
<td>-</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
LPWAN market share by sector

Source: Infoholic Research, 2016
Public LPWAN networks

- Footprint in 24 countries
- Extensive coverage in Spain and France

SIGFOX

LoRaWAN

- France (Orange, Bouygues)
- Belgium (Proximus)
- Netherlands (KPN)
- Swiss (Swisscom)
- US (Senet)
- India (Tata Communications)
- Korea (SK Telecom)
Things Connected

• Jumpstart the UK low power wide area network (LPWAN) eco-system through a innovation support programme

• Establish an open low power wide area network (LPWAN) in London to be used as innovation testbed for the IoT community

• Empower UK businesses, innovators and communities with the knowledge and skills to become quickly productive on top of LPWANs
Things Connected

First London-wide LoRaWAN

- Open, free to use network for experiments and innovation
- First phase roll out to cover central London
- Second phase Demand based extensions within M25 boundary
- Up to 50 LoRaWAN gateways to cover greater London area in 2017

22 GWs operational today

www.thingsconnected.net
Key take aways

- IoT is past its hype as it moves into real commercial reality

- The hype has created a lot of market uncertainty and due to oversupply of proprietary solutions and fragmentation

- Both IoT data platforms and LPWANs are key technology enablers for the IoT and will have a significant role to play in future

- There are plenty of challenges to solve and exciting opportunities, so it’s worth to work in this space
Suggested readings


