Internet of Things
2015/2016

The Things

Johan Lukkien

John Carpenter, 1982
Guiding questions

• What makes up the IoT?
• IoT versus WSN
• What are examples?
Some definitions of IoT (march 2015)

• **Whatis.com:** a scenario in which objects, animals or people are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. IoT has evolved from the convergence of wireless technologies, micro-electromechanical systems (MEMS) and the Internet.

• **Wikipedia:** … is the network of physical objects or "things" embedded with electronics, software, sensors and connectivity to enable it to achieve greater value and service by exchanging data with the manufacturer, operator and/or other connected devices. Each thing is uniquely identifiable through its embedded computing system but is able to interoperate within the existing Internet infrastructure.

• **Techopedia:** … is a computing concept that describes a future where everyday physical objects will be connected to the Internet and be able to identify themselves to other devices.
Some definitions of IoT (March 2015)

- IERC:

  - A dynamic global network infrastructure
  - with self configuring capabilities
  - based on standard and interoperable communication protocols
  - where physical and virtual "things"

  - have identities, physical attributes, and virtual personalities
  - use intelligent interfaces,
  - and are seamlessly integrated
  - into the information network.
The hour glass of IP

- The essence of IP, and its success
  - a unified protocol and naming (addressing) scheme to enable communication between any pair of devices
  - all ‘layer breaking’ or application knowledge is banned from lower layers until the transport layer
  - semantics only at endpoints

![Diagram of OSI model with HTTP/UDP, HTTP/TCP at the transport layer (UDP,TCP/IP)](diverse applications)
Is IoT so much different?

• The essence of IoT
  — *a unified protocol and naming (addressing) scheme to enable communication between any pair of devices* things
  • … *that contain embedded networked electronics, of course*
What’s new with IoT?

- There are **many** things
  - #things / person >> 1 (50B in 2020)
  - hence, things need to talk to *each other*
    - about …..
  - self-* properties, autonomy
    - self management, self healing, …
  - scalability, at access networks
    - many things sharing your wireless LAN

- Things have **limitations**
  - low processing power, memory, network capacity
    - size IP packet comparable to available memory
  - sometimes battery operated

- Their numbers and locations enable **entirely new applications**
  - large-scale data collection
  - data-based applications
  - manufacturers probing into the deployed systems

- Their penetration comes with **complex concerns**
  - data handling, ownership
  - security, safety, application reliability
  - at a compelling scale
  - application development, deployment, management
Scope

• Literature mentions converging elements:
  – Internet, IP protocols
  – WSN
    • low resource communication standards
  – Cyber Physical Systems
    • tight integration of communication, computation, physical world
  – Cloud Computing

• Using cloud computing:
  – build power services and applications on top of massive amounts of data
  – … collected through the embedded devices
  – however, there are more operational views

But we had already WSN?

IoT

- **System**
  - is platform: concurrent applications at endpoints
- **Protocol**
  - IP to endpoints
  - ... on top of low resource networks
- **Applications**
  - use standard IP protocols
  - developed separately
- **Management**
  - IP management protocols
  - explicit, requires interfaces

WSN

- **System**
  - ... is the application
- **Protocol**
  - application oriented
  - cross-layer optimization
- **Applications**
  - developed and optimized along with the entire system
- **Management**
  - implicit, part of the application
Which (IP) protocols are we talking about?

- **Connectivity:**
  - uIP, IP/X, with X = Zigbee, 802.15.4, and others
  - 6lowpan (= IP/802.15.4), UDP, TCP [sometimes]
  - RPL, RIP, MPL: routing
  - DTLS: security
  - Trickle: dissemination

- **Application**
  - RESTful style (REST plus HTTP methods)
    - CoAP – constrained application protocol
  - DSN-SD using mDNS, CoAP directory: for service discovery
  - M2M protocols, e.g. MQTT
What makes up the IoT?

• ‘Things’ are constrained devices…
  – memory: static background (flash) and dynamic (RAM)
  – processing power: #instructions / second
  – available energy
  – accessibility, uptime (duty cycling)
• …connected into constrained networks (typically deriving from node constraints)…
  – low bitrate
  – duty cycle limits [may not use network more than x%]
  – high packet loss, and variability
  – asymmetric links
  – small packet size
  – limited group communication primitives
• …but then, united with regular Internet devices
RFC 7228

- Three classes
- C0: dependent on proxies for secure Internet inclusion
- C1: only low resource protocols
- C2: can run most Internet protocols

<table>
<thead>
<tr>
<th>Name</th>
<th>data size (e.g., RAM)</th>
<th>code size (e.g., Flash)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 0, C0</td>
<td>&lt;&lt; 10 KiB</td>
<td>&lt;&lt; 100 KiB</td>
</tr>
<tr>
<td>Class 1, C1</td>
<td>~ 10 KiB</td>
<td>~ 100 KiB</td>
</tr>
<tr>
<td>Class 2, C2</td>
<td>~ 50 KiB</td>
<td>~ 250 KiB</td>
</tr>
</tbody>
</table>
## Some taxonomy

<table>
<thead>
<tr>
<th></th>
<th>Flash</th>
<th>RAM</th>
<th>Address space</th>
<th>Processor (type)</th>
<th>OS</th>
<th>Energy</th>
<th>Operation</th>
<th>Actively reachable</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>small code memory</td>
<td>several bytes</td>
<td>&lt;= 8bits</td>
<td>~100Hz</td>
<td>no</td>
<td>External, or battery + wakeup</td>
<td>Externally activated, simple read/write</td>
<td>not designed</td>
<td>RFID tag, ISO 18000-6c</td>
</tr>
<tr>
<td>B</td>
<td>&lt;= 32K</td>
<td>Few hundreds</td>
<td>&lt;=16 bits</td>
<td>~1MHz TMS430</td>
<td>no, or simple executive</td>
<td>mechanical</td>
<td>mechanically activated, just generates some data</td>
<td>no; needs proxy</td>
<td>TMS430</td>
</tr>
<tr>
<td>C</td>
<td>&lt;=32K</td>
<td>Few hundreds</td>
<td>&lt;=16 bits</td>
<td>~1MHz TMS430</td>
<td>Contiki, TinyOS</td>
<td>battery</td>
<td>simple, fixed external behavior, needs proxy, simple sensing</td>
<td>duty cycled, needs proxy</td>
<td>simple sensor mote</td>
</tr>
<tr>
<td>D</td>
<td>&lt;=32K</td>
<td>~10K</td>
<td>&lt;=16 bits</td>
<td>~1MHz TMS430</td>
<td>Contiki, TinyOS</td>
<td>battery + recharge</td>
<td>capable of managing most constrained IP protocols, sensing, actuating, processing</td>
<td>self-managed</td>
<td>Crossbow</td>
</tr>
<tr>
<td>E</td>
<td>&lt;=256K</td>
<td>~32K</td>
<td>&lt;=32 bits</td>
<td>~1-10Mhz ARM</td>
<td>Contiki, TinyOS</td>
<td>battery + recharge, mains</td>
<td>complete IP endpoint behavior, limited storage</td>
<td>yes</td>
<td>Jennic mote</td>
</tr>
<tr>
<td>F</td>
<td>~GB</td>
<td>~500Mb</td>
<td>32 bits</td>
<td>battery + recharge, mains</td>
<td>Linux</td>
<td>~Ghz ARM</td>
<td>full fledged embedded computer system</td>
<td>yes</td>
<td>Raspberry PI</td>
</tr>
<tr>
<td>G</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>phones, laptops, servers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Every Thing?

• IP connectivity comes with hidden assumptions
  – endpoints are active, reachable
  – … by IP packets

• Devices cannot always guarantee this
  – passive nodes, when there is no reader
  – battery-less nodes
  – duty cycling, or off-time planning
  – incapability to process IP

• Legacy may prevent IP to endpoints
  – existing networks, without capability to use IP
Example applications

Some Things

Consumer & Home  Smart Infrastructure  Security & Surveillance

Healthcare  Transportation

Retail  Industrial  Others

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Conclusion, and concerns

- IoT networks: devices and topology
- IoT protocols: typical operation
- IoT applications: patterns and life cycles
- IoT platform
  - reliability
  - security
  - data management
- IoT trends