Outline

• Introduction to IoT
• Enabling technologies
• Open problems and future challenges
• Applications
What is IoT?

• A phenomenon which connects a variety of *things*
  – Everything that has the ability to communicate
Connection of Multiple Visions

Source: Atzori et al. 2010
IoT Definitions

• The Internet of Things, also called The Internet of Objects, refers to a wireless network between objects, usually the network will be wireless and self-configuring, such as household appliances. *(Wikipedia)*

• The term "Internet of Things" has come to describe a number of technologies and research disciplines that enable the Internet to reach out into the real world of physical objects. *(IoT 2008)*

• “Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts”. *(IoT in 2020)*
• Starts with only network and evolves into everything that can be connected with a *network*

Source: Perera et al. 2014
Any-X Point of View

- The Internet of Things allows people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service.

Source: Perera et al. 2014
Characteristics of IoT

1. Intelligence
   – Knowledge extraction from the generated data
2. Architecture
   – A hybrid architecture supporting many others
3. Complex system
   – A diverse set of dynamically changing objects
4. Size considerations
   – Scalability
5. Time considerations
   – Billions of parallel and simultaneous events
6. Space considerations
   – Localization
7. Everything-as-a-service
   – Consuming resources as a service
IoT Layered Architecture

Middleware and Applications

Sensing And Communication

Source: ZTE
• RFID to smallest enabling technologies, such as chips, etc.

Source: Qian Zhang. Lecture notes. 2013
RFIDs

• The reduction in terms of size, weight, energy consumption, and cost of the radio takes us to a new era
  – This allows us to integrate radios in almost all objects and thus, to add the world “anything” to the above vision which leads to the IoT concept
• Composed of one or more readers and tags
• RFID tag is a small microchip attached to an antenna
• Can be seen as one of the main, smallest components of IoT, that collects data
Wireless Technologies

- Telecommunication systems
  - Initial/primary service: mobile voice telephony
  - Large coverage per access point (100s of meters – 10s of kilometers)
  - Low/moderate data rate (10s of kbit/s – 10s of Mbits/s)
  - Examples: GSM, UMTS, LTE

- WLAN
  - Initial service: Wireless Ethernet extension
  - Moderate coverage per access point (10s – 100s meters)
  - Moderate/high data rate (Mbits/s – 100s)
  - Examples: IEEE 802.11(a-g), WiMax

Wireless Technologies

• Short range:
  – Direct connection between devices – sensor networks
  – Typical low power usage
  – Examples: Bluetooth, Zigbee, Z-wave (house products)

• Other examples:
  – Satellite systems
    • Global coverage
    • Applications: audio/TV broadcast, positioning, personal communications
  – Broadcast systems
    • Satellite/terrestrial
    • Support for high speed mobiles
  – Fixed wireless access
    • Several technologies including DECT, WLAN, IEEE802.16, etc.

Sensor Networks (SNs)

• Consist of a certain number (which can be very high) of sensing nodes (generally wireless) communicating in a wireless multi-hop fashion.

Source: Perera et al. 2014
Sensor Networks (SNs)

• SNs generally exist without IoT but IoT cannot exist without SNs

• SNs have been designed, developed, and used for specific application purposes
  – Environmental monitoring, agriculture, medical care, event detection etc.

• For IoT purposes, SNs need to have a middleware addressing these issues:
  – Abstraction support, data fusion, resource constraints, dynamic topology, application knowledge, programming paradigm, adaptability, scalability, security, and QoS support
Example: Indoor Localization

• An indoor positioning system (IPS) is a solution to locate objects or people inside a building using radio waves, magnetic fields, acoustic signals, or other sensory information collected by mobile devices.

• For indoor localization:
  – Any wireless technology can be used for locating
  – GPS, WiFi, Bluetooth, RFID, Ultrawide band, Infrared, Visible light communication, Ultrasound
Middleware

- Middleware is a software layer that stands between the networked operating system and the application and provides well known reusable solutions to frequently encountered problems like heterogeneity, interoperability, security, dependability [Issarny, 2008]

- IoT requires stable and scalable middleware solutions to process the data coming from the networking layers
Service Oriented Architecture (SOA)

- Middleware solutions for IoT usually follow SOA approaches
- Allows SW/HW reuse
  - Doesn’t impose specific technology
- A layered system model addressing previous issues
  - Abstraction, common services, composition

Source: Atzori et al. 2010
Other Middleware Examples

• Fosstrak Project
  – Data dissemination/aggregation/filtering/interpretation
  – Fault and configuration management, lookup and directory service, tag ID management, privacy

• Welbourne et al.
  – Tag an object/create-edit location info/combine events collected by antennas

• e-Sense Project
  – Middleware only collects data in a distributed fashion and transmits to actuators

• UbiSec&Sens Project
  – Focuses on security → secure data collection, data store in memory, etc.
Open Problems and Challenges

• Lack of standardization
• Scalability
  – Addressing issues
  – Understanding the big data
• Support for mobility
• Address acquisition
• New network traffic patterns to handle
• Security/Privacy issues
Standardization

- Several standardization efforts but not integrated in a comprehensive framework
- Open Interconnect Consortium: Atmell, Dell, Intel, Samsung and Wind River
- Industrial Internet Consortium: Intel, Cisco, GE, IBM
- AllSeen Alliance: Led by Qualcomm, many others

<table>
<thead>
<tr>
<th>Standard</th>
<th>Objective</th>
<th>Status</th>
<th>Comm. range (m)</th>
<th>Data rate (kbps)</th>
<th>Unitary cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPCglobal</td>
<td>Integration of RFID technology into the electronic product code (EPC) framework, which allows for sharing of information related to products</td>
<td>Advanced</td>
<td>~1</td>
<td>~10^2</td>
<td>~0.01</td>
</tr>
<tr>
<td>GRIFS</td>
<td>European Coordinated Action aimed at defining RFID standards supporting the transition from localized RFID applications to the Internet of Things</td>
<td>Ongoing</td>
<td>~1</td>
<td>~10^2</td>
<td>~0.01</td>
</tr>
<tr>
<td>M2M</td>
<td>Definition of cost-effective solutions for machine-to-machine (M2M) communications, which should allow the related market to take off</td>
<td>Ongoing</td>
<td>N.S.</td>
<td>N.S.</td>
<td>N.S.</td>
</tr>
<tr>
<td>6LoWPAN</td>
<td>Integration of low-power IEEE 802.15.4 devices into IPv6 networks</td>
<td>Ongoing</td>
<td>10–100</td>
<td>~10^2</td>
<td>~1</td>
</tr>
<tr>
<td>ROLL</td>
<td>Definition of routing protocols for heterogeneous low-power and lossy networks</td>
<td>Ongoing</td>
<td>N.S.</td>
<td>N.S.</td>
<td>N.S.</td>
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</tbody>
</table>

Other relevant standardization activities
- NFC: Definition of a set of protocols for low-range and bidirectional communications
- Wireless: Definition of protocols for self-organizing, self-healing and mesh architectures over IEEE 802.15.4 devices
- ZigBee: Enabling reliable, cost-effective, low-power, wirelessly networked, monitoring and control products
Scalability

THE INTERNET OF THINGS
AN EXPLOSION OF CONNECTED POSSIBILITY

- Number of devices increasing exponentially
  - How can they uniquely be tagged/named?
  - How can the data generated by these devices be managed?
Addressing Issues

• Incredibly high number of nodes, each of which will produce content that should be retrievable by any authorized user
  – This requires effective addressing policies
  – IPv4 protocol may already reached its limit. Alternatives?
  – IPv6 addressing has been proposed for low-power wireless communication nodes within the 6LoWPAN context

• IPv6 addresses are expressed by means of 128 bits → 1038 addresses, enough to identify objects worth to be addressed

• RFID tags use 64–96 bit identifiers, as standardized by EPCglobal, solutions to enable the addressing of RFID tags into IPv6 networks

Encapsulation of RFID message into an IPv6 packet.
Source: Atzori et al. (2010)
New Traffic to Handle

• The characteristics of the smart objects traffic in the IoT is still not known
  – Important → basis for the design of the network infrastructures and protocols

• Wireless sensor networks (WSNs) traffic characterization
  – Strongly depend on the application scenario
  – Problems arise when WSNs become part of the overall Internet
  – The Internet will be traversed by a large amount of data generated by sensor networks deployed for heterogeneous purposes → extremely different traffic characteristics
  – Required to devise good solutions for supporting quality of service
Security

• The components spend most of the time unattended
  – It is easy to physically attack them
• IoT components are characterized by low capabilities in terms of both energy and computing resources
  – They can’t implement complex schemes supporting security
• Authentication problem
  – Proxy attack, a.k.a. man in the middle attack problem

• Data integrity
  – Data should not be modified without the system detecting it
  – Attacks on the node
    • Memory protection
  – Attacks over the network
    • Keyed-Hash Message Auth. Code

Man in the middle attack Source: Atzori et al. (2010)
Privacy

• How is it different than traditional privacy?
  – Legislative issues
  – Ethics issues

• Easy for a person to get involved in IoT even if he/she does not know

• Data can be stored indefinitely

• Current solutions are not enough
  – Encryption, pseudo-noise signal, privacy broker
Applications

- Several different domains
  - Transportation and logistics
  - Healthcare
  - Smart environment (home, office, etc.)
  - Personal and social domain
Application Domains and Scenarios

Transportation and logistics:
- Logistics
- Assisted driving
- Mobile ticketing
- Environment monitoring
- Augmented maps

Healthcare:
- Tracking
- Identification, authentication
- Data collection
- Sensing

Smart environments:
- Comfortable homes/offices
- Industrial plants
- Smart museum and gym

Personal and social:
- Social networking
- Historical queries
- Losses
- Thefts

Futuristic:
- Robot taxi
- City information model
- Enhanced game room

Source: Atzori et al. 2010
Healthcare Applications

- Various sensors for various conditions
- Example ICP sensor: Short or long term monitoring of pressure in the brain cavity
- Implanted in the brain cavity and senses the increase of pressure
- Sensor and associated electronics encapsulated in safe and biodegradable material
- External RF reader powers the unit and receives the signal
- Stability over 30 days so far

Source: Qian Zhang. Lecture notes. 2013
Healthcare Applications

• Other applications:
  – National Health Information Network
  – Electronic Patient Record
  – Home monitoring and control
    • Pulse oximeters, blood glucose monitors, infusion pumps, accelerometers
  – Bioinformatics
    • Gene/protein expression
    • Systems biology
    • Disease dynamics

Source: Qian Zhang. Lecture notes. 2013
Environmental Application: CitiSense

- Air quality monitoring project in UCSD CSE

- Environmental application

- Electrochemical **sensors**, **microcontroller** for data collection and transmission to an **Android** app

- **Actuation**: air quality is immediately reported, as well as retransmitted to a backend for larger-scale analysis
Transportation Applications

- **Vehicle control**: Airplanes, automobiles, autonomous vehicles
  - All kinds of sensors to provide accurate, redundant view of the world
  - Several processors in cars (Engine control, break system, airbag deployment system, windshield wiper, door locks, entertainment system, etc.)
  - Actuation is maintaining control of the vehicle
  - Very tight timing constraints and requirements enforced by the platforms
Example Transportation Scenarios

1. A network of sensors in a vehicle can interact with its surroundings to provide information
   - Local roads, weather and traffic conditions to the car driver
   - Adaptive drive systems to respond accordingly

2. Automatic activation of braking systems or speed control via fuel management systems.
   - Condition and event detection sensors can activate systems to maintain driver and passenger comfort and safety through the use of airbags and seatbelt pre-tensioning

3. Sensors for fatigue and mood monitoring based on driving conditions, driver behavior and facial indicators
   - Ensuring safe driving by activating warning systems or directly controlling the vehicle

Source: Qian Zhang. Lecture notes. 2013
Smart Home Applications

- Smart meters, heating/cooling, motion/temperature/lighting sensors, smart appliances, security, etc.
A Futuristic Application: Shopping

- When entering the doors, scanners will identify the tags on her clothing.
- When shopping in the market, the goods will introduce themselves.
- When paying for the goods, the microchip of the credit card will communicate with checkout reader.
- When moving the goods, the reader will tell the staff to put a new one.

Source: Qian Zhang. Lecture notes. 2013
An exciting future!

The Internet of Things

CONNECT THE WORLD

CONNECTED OBJECTS

3km range