INTRODUCTION TO WIRELESS SENSOR NETWORKS

Marco Zennaro, ICTP Trieste-Italy
A Wireless Sensor Network is a self-configuring network of small sensor nodes communicating among themselves using radio signals, and deployed in quantity to sense, monitor and understand the physical world.

Wireless Sensor nodes are called *motes*.
Wireless sensor networks

Introduction to Wireless Sensor Networks - October 2012

[Culler:2004]
Mote Anatomy

- These motes are highly constrained in terms of
  - Physical size
  - CPU power
  - Memory (few tens of kilobytes)
  - Bandwidth (Maximum of 250 KB/s, lower rates the norm)
- Power consumption is critical
  - If battery powered then energy efficiency is paramount
- May operate in harsh environments
  - Challenging physical environment (heat, dust, moisture, interference)
A World of Sensors

Enable New Knowledge

Predictive Maintenance

Energy Saving Smart Grid

High-Confidence Transport and Asset Tracking

Enhanced Safety & Security

Improve Food and H₂O

Improved Productivity

Intelligent Buildings

Enhanced Safety & Security

Energy Saving Smart Grid

Smart Home

Improved Productivity
Intelligent buildings (or bridges)

- Reduce energy wastage by proper humidity, ventilation, air conditioning (HVAC) control
- Needs measurements about room occupancy, temperature, air flow, ...
- Monitor mechanical stress after earthquakes
WSN application examples

- Disaster relief operations
  - Drop sensor nodes from an aircraft over a wildfire
  - Each node measures temperature
  - Derive a “temperature map”

- Biodiversity mapping
  - Use sensor nodes to observe wildlife
Wireless communication

- The two 5 alternatives when it comes to wireless communications:
  - 802.15.4 or Zigbee
  - Low power WiFi
  - GPRS or SMS
  - Satellite
  - Bluetooth LE
The two main alternatives when it comes to wireless communications:

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Distance</th>
<th>Gateway</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.15.4/Zigbee</td>
<td>100m</td>
<td>Yes</td>
</tr>
<tr>
<td>Low Power WiFi</td>
<td>100m</td>
<td>Yes (AP)</td>
</tr>
<tr>
<td>GPRS/SMS</td>
<td>infinite</td>
<td>No</td>
</tr>
<tr>
<td>Satellite</td>
<td>infinite</td>
<td>No</td>
</tr>
<tr>
<td>Bluetooth LE</td>
<td>50m</td>
<td>No</td>
</tr>
</tbody>
</table>
Wireless communication

- The two main wireless standards used by WNS are 802.15.4 and Zigbee
- They are low-power protocols
- Performance is an issue
- Max distance is around 100 m
IEEE Wireless Standards

- **802.11** – Wireless Local Area Networks (WiFi)
  - 802.11a, 802.11b, 802.11g, 802.11n

- **802.15** – Wireless Personal Access Networks (WPAN)
  - Task Group 1 – Bluetooth (802.15.1)
  - Task Group 2 – Co-existence (802.15.2)
  - Task Group 3 – High Rate WPAN (802.15.3)
  - Task Group 4 – Low Rate WPAN (802.15.4 or 802.15 TG4)
  - Task Group 5 – Mesh Networking (802.15.5)

- **802.16** – Wireless Metropolitan Area Networks (WiMax)

- **802.20** – Mobile Broadband Wireless Access (Mobile-Fi) - Defunct

- **802.22** – Wireless Regional Access Network (WRAN)
  - Utilise free space in the allocated TV spectrum
Wireless communication: 802.15.4

- **Channels:**
  - 868.0 - 868.6MHz → 1 channel (Europe)
  - 902.0-928.0MHz → 10 channels (EEUU)
  - 2.40-2.48GHz → 16 channels (Worldwide)

- **Bit Rates:**
  - 868.0 - 868.6MHz → 20/100/250 Kb/s
  - 902.0-928.0MHz → 40/250 Kb/s
  - 2.40-2.48GHz → 250 Kb/s
WiFi based WSN

- Advantage: use existing WiFi networks.
- High power Wi-Fi chips are optimized for fast response, low latency, and high data rates.
- Low power Wi-Fi chips are optimized for low power consumption, particularly when the device is in Standby mode.
WiFi based WSN

- Configuration trap
- App-specific (e.g. send sensor data)
- Linkup trap or keep-alive packet
- Associate with WLAN
- Cold boot

Duration:
- 12 hours
- 2.5 minutes
- 1 minute

Activity types:
- one time
- tens of thousands of times
## WiFi based WSN

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional Wi-Fi</th>
<th>Low-Power Wi-Fi</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standby / Idle</td>
<td>NA*</td>
<td>&lt;4</td>
<td>μW</td>
</tr>
<tr>
<td>Processor + clock sleep</td>
<td>13</td>
<td>0.2</td>
<td>mW</td>
</tr>
<tr>
<td>Data processing</td>
<td>115</td>
<td>56</td>
<td>mW</td>
</tr>
<tr>
<td>Receive sensitivity, 1 Mbps</td>
<td>-91</td>
<td>-91</td>
<td>dBm</td>
</tr>
<tr>
<td>Time to wake from Standby</td>
<td>NA*</td>
<td>10</td>
<td>ms</td>
</tr>
<tr>
<td>Time to wake from processor+clock sleep</td>
<td>75</td>
<td>5</td>
<td>ms</td>
</tr>
</tbody>
</table>
WiFi based WSN

Examples

- The **XBee Wi-Fi** modules from Digi International come in 1mW and 2mW versions.
- The **Flyport** provides the following services: Webserver (even Ajax apps can be run), TCP Socket, UDP Socket, SMTP Client.
- The **Gainspan** modules.
What is a Smart Object?

- A tiny and low cost computer that may contain:
  - A **sensor** that can measure physical data (e.g., temperature, vibration, pollution)
  - An **actuator** capable of performing a task (e.g., change traffic lights, rotate a mirror)
  - A **communication device** to receive instructions, send data or possibly route information

- **This device is embedded into objects**
  - For example, thermometers, car engines, light switches, gas meters

- We now talk about **Internet of Things**
All Our Lightbulbs Will Have IP Addresses

By Adrian Covert on May 20, 2011 at 12:00 PM

When we remarked that home automation technology was a reason we needed IPv6 technology, we weren’t kidding. If Netherlands-based NXP has it their way, we’ll all be using networked LED lightbulbs, each with their own IPv6 address.

According to Fast Company, this GreenChip technology operates on the 802.15.4 wireless protocol, which means it doesn’t use the same bandwidth as 802.11 wi-fi gadgets. Cool.

But what do you do with networked bulbs? Automate your home, of course.

“...You’ll also be able to control mood lighting “states” with a remote control, or via your iPad, as if you were a theatre lighting designer; you’ll be able to quickly and easily incorporate movement sensing automated lighting, that could even turn on dimly if it detects you’re stumbling to the bathroom at midnight; and you’ll be able to download apps to hone and polish your home’s lighting energy needs so that you end up with a smaller power bill.
Internet of Things

Ambient Umbrella

Glowing intelligence lets you know that there’s rain in today’s forecast.
IPv4 or IPv6

- Smart Objects will add tens of billions of additional devices
- There is no scope for IPv4 to support Smart Object Networks
- IPv6 is the only viable way forward
  - Solution to address exhaustion
  - Stateless Auto-configuration thanks to Neighbor Discovery Protocol
  - Each embedded node can be individually addressed/accessed
## Smart Objects

<table>
<thead>
<tr>
<th>Year</th>
<th>World Population</th>
<th>Connected Devices</th>
<th>Connected Devices Per Person</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>6.3 Billion</td>
<td>500 Million</td>
<td>0.08</td>
</tr>
<tr>
<td>2008</td>
<td>6.8 Billion</td>
<td>12.5 Billion</td>
<td>1.84</td>
</tr>
<tr>
<td>2010</td>
<td>7.2 Billion</td>
<td>25 Billion</td>
<td>3.47</td>
</tr>
<tr>
<td>2015</td>
<td>7.6 Billion</td>
<td>50 Billion</td>
<td>6.58</td>
</tr>
</tbody>
</table>

Based on what we know is true today (Conservative)

More connected devices than people
Recommended reading

- Covers the trends in Smart Objects
- Detailed application scenarios
- Written by
  - JP Vasseur (Cisco DE)
  - Adam Dunkels (Inventor of Contiki O/S, uIPv6)
Market: Sun SPOT

- Sun SPOT Processor Board
- 180 MHz **32 bit** ARM920T core - 512K RAM/4M Flash
- 2.4 GHz IEEE 802.15.4 radio with integrated antenna
- USB interface
- 32 uA deep sleep mode
- 2G/6G 3-axis accelerometer, Temperature sensor, Light sensor, 8 tri-color LEDs, 6 analog inputs, 2 momentary switches, 5 general purpose I/O pins and 4 high current output pins
Market: Sun SPOT
Market: Sun SPOT
Market: Sun SPOT

- Pros:
  - Java based!
  - You can use NetBeans to develop your software
  - Good community base
  - Open Software and Hardware
  - Discount for Research Institutions

- Cons:
  - Price: 399$ (educational discount available)
Market: Sun SPOT

http://www.sunspotworld.com
Market: Zolertia Z1

- **Zolertia Z1**
- Backwards compatibility with motes based on MSP430+CC2420
- Can run TinyOS and Contiki
- Out of the box support for Phidgets
- 95 euros each (75 euros in +50)

http://www.zolertia.com/
Market: Zolertia Z1
Market: Zolertia Z1
Thanks

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