Low Power Wireless Session Overview

- Review industry standards and wireless evolution with a focus on IEEE 802.15.4 radios
- Wireless compatibility with energy harvesting power supplies
- Wireless power profiles and design techniques
- Energy harvesting-based wireless demo to highlight key concepts
The Wireless Evolution

- Standards-based wireless systems become pervasive:
  - New standards catalyze market growth

<table>
<thead>
<tr>
<th>Technology</th>
<th>Implementation Price</th>
<th>Power</th>
<th>Co-existence with other networks</th>
<th>Large-scale networking stack</th>
<th>Small-scale networking stack</th>
<th>Wireless Microcontroller design</th>
<th>Interoperability</th>
<th>Encryption</th>
<th>Datarate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluetooth</td>
<td>Low</td>
<td>High</td>
<td>Poor</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Med</td>
<td>High</td>
</tr>
<tr>
<td>WiBree</td>
<td>Low</td>
<td>Low</td>
<td>Poor</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Med</td>
<td>Low</td>
</tr>
<tr>
<td>Proprietary</td>
<td>Low</td>
<td>Low</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Med</td>
<td>Low</td>
</tr>
<tr>
<td>802.15.4</td>
<td>Low</td>
<td>Low</td>
<td>Good</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Good</td>
<td>Low</td>
</tr>
<tr>
<td>WiFi</td>
<td>High</td>
<td>High</td>
<td>Good</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Good</td>
<td>High</td>
</tr>
</tbody>
</table>

- IEEE802.15.4 offers optimal solution
  - Designed to operate in large networks of devices
  - Lowest cost. Flexible design solution for many different applications
  - No ‘application-profiles’ ensures design flexibility
  - Lowest power with prospect of interoperability
  - Co-existence with other wireless networks (e.g. Wi-Fi)

RF Comparison Usage and Scenarios

Increasing priority

Technology for a Changing World
IEEE 802.15.4 offers an optimal solution
- Designed to operate in large networks of devices
- Lowest cost. Flexible design solution for many different applications
- Lowest power with prospect of interoperability
- Co-existence with other wireless networks (e.g. Wi-Fi)
- Offset Phase Shift Keying is superior to Bluetooth and WiFi modulation in high noise environments
Bluetooth versus 802.15.4

When to use Bluetooth

• When connecting to a device that already has Bluetooth
  » PDA or cell phone connections
  » Why add another radio, use what already exists
  » Use the standard profiles if they work well

• Stereo audio
  » High data rate
  » Excellent CD quality audio

• Co-existence is not an issue
  » Interference with WiFi channels that cause missed packets
  » Interference with large number of Bluetooth users in one area
  » If these are not a concern, then Bluetooth is a good solution

Bluetooth versus 802.15.4

Problems with Bluetooth that 802.15.4 solves

• Bluetooth devices change every 18 months
  » It is a consumer electronics driven specification which requires new product introductions and improvements
  » New specification issued and so new devices replace old ones
  » 802.15.4 is an industrial standard which has not changed the hardware specification for 10 years.

• Low immunity to noise interference.
  • Bluetooth hops channels and was intended for consumer grade communication.
  • 802.15.4 devices stay locked into a channel and switch only if noise level gets too high.

• Networking of devices
  • 802.15.4 can be networked through a variety of configurations.
  • Bluetooth is really intended only for point to point communication.
Bluetooth versus 802.15.4

Problems with Bluetooth that 802.15.4 solves (continued)

- Fast connect times
  - Bluetooth pairing with a new device takes several seconds
  - 802.15.4 is 6mS or less connect time
  - Faster connect times means lower power consumption
- Co-existence
  » Stay locked in one channel
  » Blacklist channels where WiFi is being used
  » Prevents interfering with WiFi data
  » Have 10+ 802.15.4 devices per channel without an issue

**IEEE802.11 vs IEEE802.15.4 Module Solutions**

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Technology</th>
<th>Frequency</th>
<th>World Wide Acceptance for All Channels</th>
<th>Active Power</th>
<th>Sleep Current</th>
<th>Data Rate</th>
<th>Distance</th>
<th>Dimensions</th>
<th>Pricing at 1pc / 10K pcs</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF Monolithics WSN802G</td>
<td>IEEE 802.11 b/g</td>
<td>2.4GHz</td>
<td>No. Country specific</td>
<td>200mA</td>
<td>8uA</td>
<td>11Mbps / 54Mbps</td>
<td>250m / 820ft line of sight</td>
<td>25.4mm x 26.7mm</td>
<td>Roughly 3X of standard power 802.15.4 module</td>
</tr>
<tr>
<td>NXP JN5148-001-M00</td>
<td>IEEE 802.15.4</td>
<td>2.4GHz</td>
<td>Yes</td>
<td>17mA</td>
<td>2.8uA</td>
<td>250 Kbps</td>
<td>400m / 1,300ft line of sight</td>
<td>16mm x 32mm</td>
<td>$X</td>
</tr>
<tr>
<td>NXP JN5148-001-M04</td>
<td>IEEE 802.15.4</td>
<td>2.4GHz</td>
<td>Yes</td>
<td>110mA / 23mA</td>
<td>2.8uA</td>
<td>250 Kbps</td>
<td>6Km / 19.685ft line of sight</td>
<td>18mm x 41mm</td>
<td>20 percent more than std power</td>
</tr>
</tbody>
</table>

- Data rate is one advantage for WiFi

Technology for a Changing World
### Wireless Networking Standards Comparison

<table>
<thead>
<tr>
<th></th>
<th>JenNet-IP</th>
<th>ZigBee SL</th>
<th>ZigBee HA</th>
<th>Wi-Fi</th>
<th>ZigBee-IP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routing Topology</td>
<td>Mesh</td>
<td>Mesh</td>
<td>Mesh</td>
<td>Mesh Over Mesh</td>
<td>Mesh Over Mesh</td>
</tr>
<tr>
<td>Max. Nodes</td>
<td>500</td>
<td>1000</td>
<td>500</td>
<td>254</td>
<td>50</td>
</tr>
<tr>
<td>Availability</td>
<td>Now</td>
<td>Q1/2012</td>
<td>Now</td>
<td>Now</td>
<td>2012</td>
</tr>
<tr>
<td>IP Based</td>
<td>Yes (6LoWPAN)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Stack Size (excl. application)</td>
<td>&lt;85kB</td>
<td>&lt;128KB</td>
<td>&lt;96kB</td>
<td>&gt;256kB</td>
<td>&lt;200kB</td>
</tr>
<tr>
<td>Cost</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$$$</td>
</tr>
<tr>
<td>Frequency</td>
<td>2.4GHz</td>
<td>2.4GHz</td>
<td>2.4GHz</td>
<td>2.4-5GHz</td>
<td>2.4GHz</td>
</tr>
<tr>
<td>Standby power</td>
<td>Medium &gt;150mA</td>
<td>Medium &gt;150mA</td>
<td>Medium &gt;150mA</td>
<td>High</td>
<td>Medium &gt;150mA</td>
</tr>
<tr>
<td>Operating Power</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Optimized commissioning</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes, but no simple commissioning</td>
<td>No</td>
<td>Designed for Smart Energy apps</td>
</tr>
<tr>
<td>Licensing Cost</td>
<td>Free</td>
<td>ZB Alliance membership &amp; product cert. fees, potential 3rd party IP costs</td>
<td>ZB Alliance membership &amp; product cert. fees, potential 3rd party IP costs</td>
<td>Wi-Fi Alliance membership &amp; product cert. fees, potential 3rd party IP costs</td>
<td>ZB Alliance membership &amp; product cert. fees, potential 3rd party IP costs</td>
</tr>
<tr>
<td>Interoperability</td>
<td>IPv4 and IPv6</td>
<td>ZSL only</td>
<td>ZHA Only</td>
<td>any IP Device</td>
<td>ZB SE 2.0 and IPv6</td>
</tr>
<tr>
<td>Development Complexity</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

### ZigBee Roadmaps

![ZigBee Roadmaps](Image)

**Technology for a Changing World**
Sending Data from Energy Harvesting Node

- Energy harvester generates an energy pulse
  - From the physical action of pressing the switch, light, etc
  - ZigBee Green Power requires 200uJ of energy
  - No stored energy available between switch presses
- Receiver
  - Requires battery or AC voltage
  - Receiver always on to receive packet
- Sending a packet
  - Not enough time to send a fully acknowledged packet
  - Not enough energy to join the network
- Transmitting with minimal amount of energy
  - Send stream of data with three packets
  - Redundancy assures that one of the three packets gets through
  - Acceptable for most applications, such as lighting
- Where should it **not** be used
  - Life critical applications, such as emergency door exit
  - Any application which requires acknowledgement of data

Packet Format

- Low power operation
  - Wake, load program code, calibrate radio
  - Transmit 3 packets at full output power (2.5dBm) using just 15.5mA
  - Sleep with RAM held between transmissions
- Boot code size just 1kbyte
  - Fast bootup
  - Conserves battery life
- 19byte total transmitted packet (13 bytes MAC frame plus 6 byte header)
  - Standard IEEE802.15.4 frame
  - Sequence number stored in external EEPROM when packet is sent
    - Ensures each packet has unique sequence number
- Must be fixed channel
Demo Block Diagrams

Energy Harvester

802.15.4 radio

Switch

Switch harvester and pcb

Light with custom pcb

802.15.4 radio

LED driver

LEDs

Light Fixture

802.15.4 Current Profile (Minimum Required)

- Very low overall energy consumption due to very low TX current
- Significantly lower energy usage than competing single chip products

Full solution is achieved using just 50uC of charge (100uJ at 2v)

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Current Profile (Supplied by Energy Harvester)

- More than enough current is supplied
- Might be capable of transmit and receive operations

Wireless Network Software

- Configured to support intermittent end device transmission
  - Ready to service requests when the end device needs
- Uses a Proxy Server
  - Powered Routers – always ready to receive from E/H end devices

Interoperate with ZigBee or IP (6LoWPAN) Nodes

Technology for a Changing World
**Wireless Proxy Server**

- Differentiates from other Energy Harvesting technologies
- Receives E/H data and sends it along the network
- Remote device can be operated by E/H activity

![Diagram of Wireless Proxy Server](image)

Interoperate with ZigBee or JenNet IP (6LoWPAN) Nodes

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**Networking stack important for Energy Harvesting**

- Light can operate from energy harvesting switch or from network command
- At the end of the day, light switch can turn all lights off without having to activate all the energy harvesting switches individually
- Operational commands can be sent to lamps out of radio range

![Diagram of Networking stack](image)

EH Light & proxy

Energy Harvesting Switch

EH Light (routes messages)

Normal light (routes messages)

Wireless switch turns off all lights

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**Technology for a Changing World**
Commissioning the Network

How to setup the network is important

• Assign the right switch to the right lamps
• Assign channels
• Pick a PAN id

Needs to be easy to do

• Limit the software required
• Better if flash programming is not required

Commissioning Methods

- Flash programming
- Open Window
- Button Press
- Serial port programming
- NFC RFID
- Receive PAN id at power up
- Verification at Coordinator
- RF Signal Strength
- Operates this light
- Channel H, B, H, B, L01
- Lamp 1 Node Tree

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Summary

• Energy harvesting technology is an important technology for powering wireless communications
• Wireless technology choices are determined by the amount of energy harvested and the tasks to be accomplished
• There are several ultra-low power wireless choices
• Optimizing the wireless network initialization, device registration process, and communication message duration is essential for proper network operation of Energy Harvesting powered wireless devices.

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Conclusion

- Any Questions?