Low-Power RF and MCU Technology
Enabling the IoT

Embedded World 2014

Matt Saunders
Marketing Manager - MCU and Wireless
Matt.saunders@silabs.com
Preparing for What’s Next

“…the Internet of Things is a game changer…”

- **For consumers**
  Enables new levels of intelligence, safety, convenience, comfort and cost savings

- **For industry**
  Provides efficiencies, energy savings and lower cost

- **For semiconductor companies**
  Opens the door to smaller players and broad-based companies

- **For the supply chain**
  Opportunities to add value through innovation to reduce costs
More Connected Devices Than People

Source: Silicon Labs, Thomson Reuters, Morgan Stanley
Questions

- Where is the IoT opportunity?
  - Which applications / segments?

- Which wireless technology will win?
  - Will it be Bluetooth? Wi-Fi? ZigBee? Sub-GHz?
Where is the IoT Opportunity?

- When thinking about microcontroller-based solutions:
  - Sensors
    - Energy management, security, monitoring
  - Motors
    - Preventative maintenance, performance monitoring
  - Medical Monitoring
    - Chronic disease management, on-body wellness tracking
  - Asset/Goods Tracking
    - Hospital equipment, RFID “from a distance”
  - The Previously Unconnected
    - Streetlights, traffic signs/lights, parking meters, vending machines
IoT Wireless Node Design Challenges

- **Must consume lowest possible amount of power when active**
  - MCU active modes need to be very efficient
  - RF Tx and Rx modes designed to give best energy / bit transmitted

- **Must be able to switch modes extremely quickly**
  - Between active and standby / low power modes
  - This minimizes the amount of wasted power during these transition states

- **Must offer analog capabilities to interface with sensors and take measurements**
  - Collecting and processing data locally to minimise RF traffic

- **Must be able to operate at extremely low voltage levels**
  - Especially relevant in battery operated or energy harvesting systems
  - Prolongs useable life
MCU could be 8-bit or 32-bit but must be low power

Wireless link could be one of many choices:
- Wi-Fi, Bluetooth, ZigBee, Sub-GHz proprietary

MCU + RF could be implemented as SoC / SiP
Which wireless technology will win?

- **Bluetooth**
- **WiFi**
- **ZigBee**
- **Sub-GHz**

**Cable Replacement**
- Bluetooth
- WiFi
- ZigBee
- Sub-GHz

**Web, Email, Video**
- Bluetooth
- WiFi
- ZigBee
- Sub-GHz

**Monitoring & Control**
- Bluetooth
- WiFi
- ZigBee
- Sub-GHz

**Cable Replacement**

**Web, Email, Video**

**Monitoring & Control**
The IoT Requires Networking Coexistence
Wireless Design Challenges

1. **Architecture**
   - Range and regional coverage
   - Network topology
   - Interoperability
   - Cost

2. **Hardware Design**
   - System partitioning
   - RF layout / configuration
   - Antenna design

3. **Software Design**
   - Networking software
   - Application development
   - Networking debug

4. **Compliance Testing**
   - Regulatory
   - Standards (ie. ZigBee)
Network Topology

- **Point to Point**
  - 1-way
  - Two-Way – Acks can assure data gets through and allows for status responses.

- **Star**
  - Central data collector. Network size is limited by node to node range. Can be extended with repeaters.

- **Mesh**
  - Complex but reliable networks. Network can cover large distances through routing.

- **Proprietary vs. Standard**
  - Proprietary – Typically lower cost but closed networks.
Wireless Applications by Topology

Point-to-Point One-Way
- Garage Door Openers
- RKE
- Weather Stations
- Toys

Point-to-Point Two-Way
- Remote Control
- Simple Lighting
- Monitoring/Control
- Metering

Star
- Security
- Metering
- Electronic tags
- Some detectors

Mesh
- Smart Energy
- Home Automation
- Building Control
The leading wireless mesh networking standard for monitoring and control

- Low-power (mains or battery)
- Simple (self-configuring)
- Reliable and robust (self-healing)
- Flexible (mesh topology)
- Secure (built-in cryptography)
- Cost effective

<table>
<thead>
<tr>
<th></th>
<th>ZigBee</th>
<th>Sub-GHz</th>
<th>Wi-Fi</th>
<th>Bluetooth</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical Layer Standard</strong></td>
<td>802.15.4</td>
<td>Proprietary / 802.15.4g</td>
<td>802.11</td>
<td>802.15.1</td>
</tr>
<tr>
<td><strong>Application Focus</strong></td>
<td>Monitoring &amp; control</td>
<td>Monitoring &amp; control</td>
<td>Web, email, video</td>
<td>Cable replacement</td>
</tr>
<tr>
<td><strong>Battery Life (days)</strong></td>
<td>100 – 1,000+</td>
<td>1,000+</td>
<td>0.5 - 5</td>
<td>1 - 7</td>
</tr>
<tr>
<td><strong>Network Size</strong></td>
<td>100s to 1,000s</td>
<td>10s to 100s</td>
<td>32</td>
<td>7</td>
</tr>
<tr>
<td><strong>Bandwidth (Kbits/s)</strong></td>
<td>20 - 250</td>
<td>0.5 – 1,000</td>
<td>11,000+</td>
<td>720</td>
</tr>
<tr>
<td><strong>Range (meters)</strong></td>
<td>1 – 100+</td>
<td>1 – 7,000+</td>
<td>1 – 30+</td>
<td>1 – 10+</td>
</tr>
<tr>
<td><strong>Network Architecture</strong></td>
<td>Mesh</td>
<td>Point-to-point, star</td>
<td>Star</td>
<td>Star</td>
</tr>
<tr>
<td><strong>Optimized For</strong></td>
<td>Reliability, low power, low cost, scalability</td>
<td>Long range, low power, low cost</td>
<td>Speed</td>
<td>Low cost, convenience</td>
</tr>
<tr>
<td><strong>Silicon Labs Products</strong></td>
<td>Ember® ZigBee® EM35x Series</td>
<td>EZRadio®, EZRadioPRO®, Si10xx wireless MCUs</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Evolution of the ZigBee Market

**Total Addressable Market**

**2010**
- **Smart Meter**
  - First large app for ZigBee
  - 30-35M units per year
  - 1 device per install

**2011**
- **Security, Monitoring & Automation**
  - 115M households (US only)
  - 8-12 devices per install

**2012**
- **Home Area Network**
  - White goods, smart appliances, controller, smart plugs

**2013**
- **Retail / Consumer**
  - In-home display and remote control

**2014**
- **Building Automation**
  - HVAC and lighting control systems

**2015**
- **Lighting Control**
  - Street, residential and commercial
  - LED a key area of interest

- **Healthcare**
  - Patient alarm monitoring
  - Senior activity monitoring
ZigBee Smart Buildings

Aria Hotel
4000 Rooms

➤ One simple remote in the hotel room can control:
  • Lighting levels
  • Room temperature
  • Shades
  • Locks
  • Music
  • TV / Video systems
World’s Most Deployed ZigBee PRO Stack

EmberZNet PRO Protocol Stack – Field-Proven Advantages

- **Larger networks** – scales to thousands of nodes in a single network
- **Denser networks** – intelligent table management ensures network stability even when many routing nodes are within close proximity
- **“Greener” networks** – longer end-device battery life through enhancements such as configurable deep-sleep timeouts
- **More mobile networks** – identifies and optimizes mobile ZigBee End Devices within networks
- **More secure networks** – enabled by optional ZigBee PRO security extensions for advanced network encryption and device security
- **More resilient networks** – enables the entire network to change channels in the face of interference
Making ZigBee Development Simple

- Visualize the mesh network to ease development and testing
  - Silicon with Packet Trace Port
    - Monitors packet data without impact on CPU
    - Understand exactly what is being sent on the mesh
  - App Builder Tool
    - Generate application profiles that are known to work
    - Minimise debug time

Packet Trace Port reaches deep inside the silicon to trace packets and to monitor and control the application.

Desktop Network Analyzer provides a macroscopic view of the entire network from a single console.

Debug Adapter provides a high-speed back-channel link between Desktop Network Analyzer and node.

Ember AppBuilder generates complete, ready for ZigBee certification, template application.
Wireless Applications by Topology

**Point-to-Point One-Way**
- Garage Door Openers
- RKE
- Weather Stations
- Toys

**Point-to-Point Two-Way**
- Remote Control
- Simple Lighting
- Monitoring/Control
- Metering

**Star**
- Security
- Metering
- Electronic tags
- Some detectors

**Mesh**
- Smart Energy
- Home Automation
- Building Control
Si446x – Next-Generation EZRadioPRO®

Features

- Frequency bands from 119 to 1050 MHz
  - Si4464: 119-960 MHz
  - Si4460/1/3: 142-175, 284-350, 425-525, 850-1050 MHz
- Up to +20dBm output power
- -126dBm sensitivity (GFSK @ 500bps)
- Antenna diversity
- (G)FSK / 4(G)FSK / (G)MSK / OOK / ASK modulation
- Low current consumption
  - Standby Current = 50nA
  - Tx Active Current = 85mA (@+20dBm)
  - Rx Active Current = 10mA
- Max Data Rate = 1Mbps
- Advanced modem features

Benefits

- Low current consumption (long battery life)
- High sensitivity (long range)
- High output power (long range)
- Small size, low external BOM
Configure – Generate - Test

- RF developments can be time consuming
  - Many options / registers to configure

- Good development tools ease this process
  - Simple to use GUI tools to configure the radio to the application requirements
  - Source code generators to simplify the development on the microcontroller
Prototyping an IoT node – easily!

- Modular System
  - Choose the required Microcontroller and Radio boards
  - Attached the relevant antenna
  - Plug them together!
  - Download a reference implementation from the development tools
  - Test…
MCU could be 8-bit or 32-bit but always must be low power

- Lower processing requirements can be met by 8-bit
- More complicated stacks may demand a 32-bit MCU
- Localised processing of data on a 32-bit MCU could reduce network traffic
EFM32 – Energy-Friendly MCUs

CPU and Memory
- ARM Cortex-M4 processor
- Memory Protection Unit
- Embedded Trace Macrocell
- Flash Program Memory
- RAM Memory
- Debug Interface
- DMA

Clock Management
- High Freq Crystal Osc
- High Freq RC Osc
- Low Freq Crystal Osc
- Low Freq RC Osc
- Ultra Low Freq RC Osc
- Auxiliary RC Osc

Energy Management
- Voltage Regulator
- Voltage Comparator
- Brown-out Detector
- Power-on Reset
- Back-up Power Domain

Peripheral Reflex System
- 32-bit bus

Serial Interfaces
- USART
- UART
- Low Energy UART
- I2C
- USB

I/O Ports
- External Bus Interface
- TFT Driver
- General Purpose I/O
- External Interrupt
- GPIO Wake-up
- Pin Reset

Timers and Triggers
- Timer/Counter
- Low Energy Timer
- Pulse Counter
- Backup RTC
- Real Time Counter
- Watchdog Timer

Analog Modules
- ADC
- DAC
- LCD Controller
- Operational Amplifier
- Analog Comparator

Security
- AES Accelerator

Available down to:
- EM0 (Run Mode)
- EM1 (Sleep)
- EM2 (Deep Sleep)
- EM3 (Stop Mode)
- EM4 (Shutoff Mode)
Benefits of Local Digital Signal Processing

- Example: Kalmann-Filter (e.g. for noise detection and elimination in sensor data)

- 10x10 matrix calculation with floating point (f32) and fix point operations (q15) on ARM Cortex M3 vs. M4F

- 4x better energy consumption with ARM Cortex M4F vs. M3
  Example: average current consumption was reduced from 550 μA to 170 μA (Wonder Gecko)
LESENSE – Low Energy Sensor Interface

Analog events
Capacitive, inductive or resistive sensors

Generic MCU
Wake-up periodically to detect the events
Analog events
Capacitive, inductive or resistive sensors

Generic MCU
Wake-up periodically to detect the events

Gecko MCU
Wake-up only on the events
Analog events
Capacitive, inductive or resistive sensors

Generic MCU
Wake-up periodically to detect the events

Gecko MCU
Wake-up only on the events

Gecko MCU
Conditional wake-up (e.g. on every 2nd event)
LESENSE Example 1: Resistive/General Measurement

Implemented for MCU power budget of <2 µA
- Using onboard comparators, LESENSE, Peripheral Reflex System
LESENSE Example: Counting Propulsions in Deep Sleep

EFM32 MCU

- Implemented for MCU power budget of <1.5 µA
  - Using onboard comparators, LESENSE, Peripheral Reflex System
Low-Power ADC strategies on EFM32

Three possible approaches:

1. Standard approach, ADC + PRS + DMA
   - 270 µA
   - Wake up and start conversion with interrupt
   - Fetch result

   Average:
   - 165 µA @ 1 ksamples/s
   - 350 µA @ 32 ksamples/s

2. New approach, EM2 + interrupt
   - 2 mA
   - 270 uA
   - Wake up and start conversion with optimized loop, no interrupt latency.

   Average:
   - 60 µA @ 1 ksamples/s
   - 32 ksamples/s not possible

3. Optimized new approach, EM2 + wait for event, no interrupt latency
   - 2 mA
   - 270 uA
   - Wake up and start conversion with optimized loop, no interrupt latency.

   Average:
   - 20 µA @ 1 ksamples/s
   - 550 µA @ 32 ksamples/s
Low-Power ADC strategies on EFM32

See Silicon Labs Application Note AN0021
Energy-Efficient Signal Processing/Capture

- Signal monitoring can be realized at about 1.5μA
- Signal acquisition is possible from 14μA (12Bit, 1ksps) to maximum 350μA (12Bit, 1Mspss)
- Integrated DSP command set helps applications with digital signal processing functions like FFT or Kalman-Filter decreasing their average current consumption to about 100μA

Local signal processing in an IoT node can be used to:
- Gain battery life times up to 4x higher or
- Avoid using batteries at all (energy harvesting)
- Reduce network traffic and overall power budget
The IoT is still far from reaching a point of standardisation

- The number of emerging ‘standards’ is growing all the time
- The number of applications entering the IoT bracket is also growing

The technology to build IoT nodes exists today

- ZigBee SoC for mesh networks
- Sub-GHz for star and point-to-point
- Ultra-low-power microcontrollers
- An array of sensor options

Silicon Labs offers much more than silicon

- Development kits (RF and MCU)
- Reference implementations
- Software examples
- Certified stacks
Low Power RF and MCU Technology
Enabling the IoT

Embedded World 2014

Matt Saunders
Marketing Manager - MCU and Wireless
Matt.saunders@silabs.com