MSP430 Goes Zigbee/802.15.4

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**Agenda**

- About 802.15.4 and ZigBee
- Introduction to ZigBee
- MSP430 802.15.4/ZigBee solutions
- Demonstration: 4-node ZigBee network application
- Application Design Considerations
- Facts, statistics & other information
Wireless Solution Spaces

Wireless Solution Spaces

- ZigBee/802.15.4
  - Building Automation
  - Residential Control
  - Industrial
  - Tracking
  - Sensors
  - Home Automation / Security
  - Meter Reading

- Proprietary Low Power Radio
  - Gaming
  - PC Peripherals
  - Audio
  - Meter Reading
  - Building Mgt.
  - Automotive

- Wi-Fi/802.11
  - PC Networking
  - Home Networking
  - Video Distribution

- UWB
  - Wireless USB
  - Video/audio links

Frequencies for free

- 2.4GHz
- 433/868MHz
- 315/315MHz
- 433MHz
- 433/915MHz

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What is IEEE 802.15.4?

- IEEE standard for low data rate wireless
  - First version in October 2003
  - New version since June IEEE 802.15.4-2006 (Rev B) approved, going through final editing before being published shortly
  - New version usually free after 6 months
  - http://standards.ieee.org/getieee802/
- Personal Area Network (PAN)
- Defines the Physical (PHY) and Medium Access Control (MAC) communication layers
- Focus on low power, low cost and robust
- Battery life extension by selectable latency
- 4 packet frame types:
  - Data, Acknowledgement, MAC Command, and Beacon.
- Typical range for IEEE 802.15.4:
  - Indoor 10 - 30 meters;
  - Outdoor 100 – 150 meters w/o PA; w/ PA 540 meters outdoor

IEEE 802.15.4 Frequency Allocation

Europe, Asia, Pacific, Worldwide

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Europe 868 MHz, 1 channel</th>
<th>Americas 915 MHz, 10 channels</th>
<th>Worldwide 2.4 GHz, 16 channels</th>
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<tr>
<td>Data Rate</td>
<td>20kbps ... 100kbps</td>
<td>40kbps ... 250kbps</td>
<td>250kbps</td>
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<tr>
<td></td>
<td></td>
<td></td>
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BPSK modulation
RC pulse shaping $\alpha=1$
rx sensitivity -92 dBm

Source: Dr. Heinz Mathis
### IEEE 802.15.4 PHY

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<tr>
<th>Nibble</th>
<th>Correct chip sequence for nibble = 5</th>
<th>Incoming chip sequence (value is 5, but with 8 faulty chips)</th>
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</tr>
</tbody>
</table>

- DSSS (Direct Sequencing Spread Spectrum)
- 4 bits are coded into 32 chips using a look up table
- OSI model architectured (Open System Interconnect)

### What is ZigBee?

- **Software Stack on top of IEEE 802.15.4**
- **Standard specifications for LR-WPAN/Sensor and Control wireless mesh networking**
- **Low cost**
- **Low power consumption, Long battery life**
- **Low data rate**
- **No band cost (Unlicensed) - ISM band**
- **Secure data**
- **Standard and custom application profiles**
ZigBee™ – ZigBee Alliance

• “The ZigBee Alliance is an association of companies working together to enable reliable, cost-effective, low-power, wirelessly networked monitoring and control products based on an open global standard”
• Source: ZigBee Alliance homepage

• Through the Chipcon acquisition, TI is now central in the alliance
• Promoters of the ZigBee alliance are: BM Spa, TI/Chipcon, Ember, Freescale, Honeywell, Mitsubishi Electric, Motorola, Philips, Samsung, Schneider Electric, ST, Siemens and Huawei
• The alliance has over 200 members
• For further information please see: http://www.zigbee.org/

ZigBee Promoter Companies
ZigBee Example Applications

ZigBee – Main Application Areas

• Home Automation
  - Automatic Meter Reading (AMR),
  - Lighting, Heating, Alarm, Security
  - White Goods health status monitoring

• Commercial Building Automation
  - Heating Ventilation & Air Condition (HVAC)
  - Energy management
  - Alarm, Security

• Industrial Automation

• Hospital and Patient Care

• Asset tracking / Active RFID
  - With CC2431 location technology

• Wireless Sensor Networks
ZigBee Products – Key Features

- Very long battery life
- Low node cost
- Easy to deploy (low installation cost and simple network commissioning)
- Self healing in Mesh networks
- Supports large networks
- Low data rate (intended for monitoring & control)
- Standardized protocol (interoperability)
- Profiles to enable interoperability of products from different vendors

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ZigBee Feature Set

• Logical Device Types
  ▪ Coordinator, Router and End Device

• Ad-hoc self forming networks
  ▪ Mesh, Cluster Tree and Star Topologies
    (Star Topology for max 14 devices; no stack profiles available for >14 devices)
  ▪ Reliable broadcast messaging
  ▪ Non-guaranteed message delivery

• Applications
  ▪ Device and Service Discovery
  ▪ Optional acknowledged service
  ▪ Messaging with optional responses
  ▪ Mechanism to support mix of Public and Private profiles in the same network.

• Security
  ▪ Symmetric Key with AES-128
  ▪ Authentication and Encryption at MAC, NWK and Application levels.
  ▪ Key Hierarchy: Master Keys, Network Keys and Link Keys

• Conformance Certification (Platform and Logo)

ZigBee Device Types

• PAN Coordinator
  ▪ One PAN Coordinator per WPAN
  ▪ Forms the network by allowing joining all other forms of ZigBee devices

• Router
  ▪ Scans to find an active channel to join a PAN
  ▪ Permits other devices to join
  ▪ Routes data

• End Device
  ▪ Joins either Coordinator or Router
  ▪ Sends data to the associated device only
  ▪ Incapable of joining other devices to itself
  ▪ Does not route data
  ▪ Reduced Function Device
  ▪ Is typically battery operated
ZigBee Network Topologies (Star)

- ZigBee Coordinator (FFD)
- ZigBee End Device (RFD or FFD)

ZigBee Network Topologies (Tree)

- ZigBee Coordinator (FFD)
- ZigBee Router (FFD)
- ZigBee End Device (RFD or FFD)
ZigBee Network Topologies (Mesh)

- ZigBee Coordinator (FFD)
- ZigBee Router (FFD)
- ZigBee End Device (RFD or FFD)
- Mesh Link

ZigBee Network Topologies

- **Star networks** support a single ZigBee coordinator with one or more ZigBee End Devices (up to 65,536 in theory, < 2000 is realistic)
- **Mesh** network routing permits path formation from any source device to any destination device
  - Radio Receivers on coordinator and routers must be on at all times.
  - Employs both, tree and table driven routing.
  - Table routing employs a simplified version of Ad Hoc On Demand Distance Vector Routing (AODV). This is an Internet Engineering Task Force (IETF) Mobile Ad Hoc Networking (MANET) submission.
- **Cluster tree networks** provide for a beaconing multi-hop network
  - Beaconing permits battery management of coordinator and routers.
  - Must tolerate high latency due to beacon collision avoidance.
  - Must use "netmask" type tree routing.

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Addressing

- All IEEE 802.15.4 devices have a unique, 64-bit address, assigned during production.
  - This long address is similar to the well-known MAC address used in an 802.11 wireless card or 802.3 Ethernet NIC card.
- Each ZigBee device gets a short 16-Bit ZigBee address assigned during network formation.
  - Similar the IP address in Ethernet
  - Makes in-network communications more efficient and substantially shortens the packet length. The PAN Coordinator is tasked with handing out the short address when a device joins its network.
- CSkip based address assignment
  - Assigns block of addresses to router to enable joining without intervention of Coordinator
  - Block size depends on max network depth

ZigBee™ – “One Stop Shop”

- Hardware
  IEEE 802.15.4 compliant radios CC2420/CC2430/CC2431
- Software
  ZigBee stack “Z-Stack” (Figure 8 Wireless)
- Tools
  Development tools
  Commissioning
  Testing
ZigBee Stack Architecture

ZigBee compatibility

- **ZigBee with Standard Profile**
  - Compatible with other vendor’s devices (Vendor A “switch” works with vendor B “lamp”)
  - Already defined standard profiles:
    - “Home Automation” (since September 2006, not backwards compatible to former ‘Home Controls – Lighting’)
    - “Industrial Plant Monitoring” (since Q4 2006)
    - “Commercial Building Automation” incl. HVAC (expected Q1 2007)
    - Much more in discussion (Automatic Meter Reading, Health Care, etc.)

- **ZigBee with Proprietary Profile**
  - Incompatible with other vendor’s device
  - Still can use infrastructure of an existing ZigBee network to transmit data packets (hopping)
  - Has to be registered by ZigBee Alliance (already > 450 registered)

- **Conformance Certification (Platform and Logo)**
Endpoints

- Endpoints are a logical extension added to a single ZigBee radio which permits support for multiple applications, addressed by the Endpoint number (1-240)

- Key Relationships:
  - Maximum of 240 Endpoints per ZigBee Device (0 is reserved and used by ZDO (ZigBee Device Object) to describe the generic device capabilities. 255 is reserved for broadcasting to all endpoints, 241-254 are reserved for future use)
  - One Profile described per Endpoint

1 radio for 2 switches

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ZigBee Device Block Diagram

- Sensors
- RF Transceiver
- Output Devices
- Device Driver
- MCU
  - Application Software
  - Network Layer
  - MAC Layer
  - PHY Layer
  - Operating System
  - Device Driver
  - Device Driver
  - Application Software
  - Operating System
  - Network Layer
  - MAC Layer
  - PHY Layer
  - Device Driver

MSP430F161x: Good ZigBee Choice

- MSP430 48K or 55K Flash
- SCoC with ADC12, DAC12
- Maximum 10K RAM
- USART supports SPI, UART, and I2C
- ZigBee End Device
- Maybe ZigBee Router, application dependant
MSP430FG461x: Good ZigBee Choice

- 1st MSP430 with >60KB Flash
- Maximum 8K RAM
- SC0C with ADC12, DAC12 and OpAmps
- LCD_A with integrated charge pump
- USCI supports SPI, UART, I2C, LIN and IrDA

ZigBee PAN coordinator
ZigBee Router
Complex ZigBee End Device

MSP430F261x: Good ZigBee Choice

- MSP430 with >60KB Flash
- Maximum 8K RAM
- SC0C with ADC12, DAC12 and OpAmps
- USCI supports SPI, UART, I2C, LIN and IrDA
- Planned for 2007

ZigBee PAN coordinator
ZigBee Router
Complex ZigBee End Device
**TI / Chipcon Solutions**

- **Actual offerings**
  - CC2420 – Z-Stack (1.4.0), 2.4GHz Transceiver
  - CC2430 SoC – Z-Stack (1.4.0)  
    SoC with 8051 core, CC2420 radio and Z-Stack SW  
  - CC2431 SoC, is a CC2430 with location detection.
  - IEEE 802.15.4 TIMAC
  - MSP430/CC2430 ZigBee Stack – Z-Stack (1.5) – End of 2006  
    ZigBee software in CC2430 SoC, only application on MSP430  
    Low cost development kit, ideal to start with ZigBee.

- **Upcoming Releases:**
  - CC2520 IEEE 802.15.4 transceiver – 1H07  
    Similar to CC2420
    Improved performance / feature set  
    Smaller package (5x5 mm QFN-28)
    Reduced cost (TBD %) compared to CC2420
  - CC2530 & CC2531 SoC  
    Next generation to CC2430 & CC2431
3 Ways to your ZigBee Application

1. Cost & Simplicity
   - CC2430 SoC for Application and ZigBee

2. Flexibility & Analog
   - MSP430 for Appl.
   - CC2430 for ZigBee

3. ULP ZigBee
   - MSP430 for Appl. & ZigBee
   - CC2420 for RF

Develop a product for an existing Profile

1. Buy a development kit or module
2. Develop the application from existing profile demo software
3. Join ZigBee.org as Adopter
4. Pay Conformance Certification house for logo certification
5. Do FCC or CE certification
6. Produce and ship product
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**Demo: 4-Node Network Application**

- **Coordinator**
- **Lamp 1**
- **Router 1**
- **Switch 2**
- **End Device**
- **Switch 1**
- **Router 2**
- **Lamp 2**
4-Nodes salient Features

- ZigBee Network formation
- Devices association
- Application Binding
- Routing communication between devices
- “Sensing-and-acting” wirelessly (On / Off control of a lamp using a switch)
- Self-healing / route repair

Demo: Network Formation

- **Power up PAN Coordinator (P)**
  - PAN/C (P) sends beacon and starts network

- **Power up Router1 (R1)**
  - Router1 (R1) joins PAN Coordinator
  - PAN/C assigns R1 the ZigBee address 0x0001
  - R1 also gets a block of addresses (0x0001…0x071D) for further children to join R1

- **Power up Router2 (R2)**
  - Router2 (R2) joins PAN Coordinator
  - PAN/C assigns R2 the ZigBee address 0x071E
  - R2 also gets a block of addresses for further children to join R2

- **Power up EndDevice (E)**
  - EndDevice (E) joins Router1 (R1)
  - R1 assigns E the ZigBee address 0x0002
Demo: Network Formation

- Coordinator 0x0000
- Router 1 0x0001...
- Router 2 0x071E...
- End Device 0x0002
- Switch 1
- Switch 2
- Lamp 1
- Lamp 2

Demo: Application Binding

- Switch 1 will be bound to Lamp 1
- Switch 2 will be bound to Lamp 2
- Binding is done in this demo during network formation
Demo: Application Binding

Communication between Switch 1 and Lamp 1 routed through Router 1

Demo: Communication (1)
Demo: Communication (2)

Communication between Switch 2 and Lamp 2 routed through PAN/C Hopping

Switch 2

Router 1
0x0001…0x071D

Coordinator
0x0000

End Device
0x0002

Router 2
0x071E…

Lamp 2

Demo: Self healing (scenario 1)

Automatically takes alternative route.
Switch 1 communicates direct to Lamp 1, if it’s within range.

Switch 2

Router 1
0x0001…0x071D

Coordinaoter
0x0000

End Device
0x0002

Disabled
Power Off

Switch 1

Lamp 1

Router 2
0x071E…

Lamp 2
**Demo: Self healing (scenario 2)**

Automatically takes alternative route.
Switch 1 communicates through Router 2 (hopping), if Lamp 1 is out of range.

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Application Design Considerations

Network Formation Management

- Permit Join can be enabled/disabled on routers and the coordinator (network wide)
- Permit Join can be managed by an application to allow devices to enter the network upon:
  - Button press on a designated device or any other application defined action
  - Security keys may be exchanged upon managed network formation

- Deployment examples:
  - No commissioning tool
    - Example: Bubble pack purchased at a home improvement store
  - Commissioning tool
    - Example: Professional installation

Commissioning without Tool

- Three networks: Suite 101, Suite 102, Fire Safety for the floor
- Coordinators are the green dots
- Question: How to commission appropriate devices to their proper coordinators
Commissioning without Tool

- Some approaches to the previous commissioning problem (without a dedicated commissioning tool):
  - Button press sequences to permit joining for a set amount of time and then a second set of button presses to identify the joining devices
  - Low power output
    - Reduces RF transmission distance to ‘one suite’
    - Though this may affect the topology if the end device children are too far away from their parent
  - Remote control device selection
    - Choose all neighbors and then iterate through deducing which device is which
    - Construct the list and permit the user to add/eliminate devices
  - Pre-manufactured with information on devices in the pack

Commissioning with Tool

- Same network topologies as before with addition of commissioning tools
- Commissioning tool works by identifying neighbors and networks, joining appropriate network, populating a list of devices on the network and permitting the installer to identify which one is which
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ZigBee cost

• IEEE Addresses for 802.15.4
  ▪ 240 addresses ~1800 $

• ZigBee Alliance
  ▪ Promoter 40.000$/year
  ▪ Member 9.500$/year
  ▪ Adopter 3.500$/year

• ZigBee Logo
  ▪ Conformance Certification (Platform and Logo)
    e.g. TUV (world wide: http://www.tuv.com/)
    NTS = National Testing Systems
    (world wide: http://www.ntscorp.com/about/locations.html)

• RF Compliance Tests
  ▪ FCC
  ▪ ETSI
  ▪ CE
Z-Stack for MSP430 + CC2420

- **Coordinator**
  - .... k bytes of CODE memory – Flash program memory
  - ......... bytes of DATA memory – RAM
  - ........ bytes of CONST memory – Flash memory

- **Router**
  - .... k bytes of CODE memory – Flash program memory
  - ......... bytes of DATA memory – RAM
  - ........ bytes of CONST memory – Flash memory

- **End Device (Reduced Function)**
  - .... bytes of CODE memory – Flash program memory
  - ......... bytes of DATA memory – RAM
  - ........ bytes of CONST memory – Flash memory

**Summary**

ZigBee:
- Software Stack on top of IEEE 802.15.4
- Standardized
- Low cost
- Low power consumption
- Long battery life
- Low data rate
- Easy installation
- Available today from Texas Instruments