Selecting the Right RF Protocol for your MSP430 Application

Miguel Morales

Agenda

- Introduction to ultra-low power wireless networking
- Low power protocol selection criteria
- In-depth look @ TI offerings
  - 802.15.4
  - ZigBee
  - SimpliciTI
- Application examples
Agenda

- Introduction to ultra-low power wireless networking
- Low power protocol selection criteria
- In-depth look @ TI offerings
  - 802.15.4
  - ZigBee
  - SimpliciTI
- Application examples

Fundamentals of low-power wireless networks
Low-power wireless application space

- Others not shown:
  - ULP Bluetooth
  - RFID
  - SimpliciTI
  - ANT
  - Blue Robin
  - Wireless KNX
  - Z-wave
  - Wireless HART

---

**Low-power protocol selection criteria**

**Application Considerations**
- *Robustness & Reliability*
- *Ease of Use*

**Hardware & RF Considerations**
[1] Application considerations

• What does your application require?
  – Network topology
  – Reliability of communications
  – Security concerns
  – Customization → design freedom
  – Development time → protocol complexity
  – Interoperability

• What drawbacks can you accept?
  – Protocol complexity → development time
  – Standard-defined limitations or restrictions
  → sible royalty fees

[1] Application considerations

• Network Topologies

  Peer to Peer  Tree  Star

  M E S H

  Coordinator
  Start the network
  Routes packets
  Routers
  Routes packets
  Extend network range
  Sink Device
  Sleep most of the time
  Can be battery powered
  No routing function
[2] Robustness and reliability

• Messaging Protocol
  – Synchronous Communication
    • Periodic beacon from the coordinator
    • Timeslots for communication → Time division multiple access (TDMA)
  – Asynchronous Communication
    • Nodes contend for the channel using listen-before-talk
      – Channel sense multiple access (CSMA)

• Message Delivery
  – Routing schemes
  – [N]ACK communication
  – Message retries

• Message Security
  – Message integrity/authentication
  – Security keys and encryption
    • AES-128 encryption
  – Trust center

ATC 2008
[2] Robustness and reliability

- Physical Layer Reliability
  - All channels and RF devices are subject to:
    - Noise
    - Transmission environment
    - Product Encasing
    - Physical relation to other nodes (height, orientation)
  - How does one mitigate its effects on the application?
    - Channel Scanning
      - RSSI & LQI values
    - Frequency Agility
    - Antenna Selection & Design
  - Power and Frequency Restrictions / Certifications
    - ETSI in Europe
    - FCC in America
    - ARIB in Japan

[3] Ease of use

OSI Network Model
- Application
  - Application Services
- Presentation
  - Data Encryption
- Session
  - Link Management
- Transport
  - End-to-End Reliability
- Network
  - Routing & Protocol
- Data Link
  - Peer-to-Peer Reliability
- Physical
  - HW Interface

ALSO CONSIDER:
TOOLS
- Evaluation
- Debugging
- 3rd Party

DOCUMENTATION

SUPPORT
[4] Hardware & RF considerations

• Link Budget
  – Transmit Power
  – Receiver Sensitivity
  – Antenna Technology

• Coexistence
  – Receiver Selectivity
  – Clear Channel Assessment / Listen-Before Talk

• Low Power
  – Wake On Radio
  – Low Power Modes
  – Startup Time (Off → Active)
  – Switching time between modes
  – Smart, flexible peripherals

• Misc / System
  – Integrated encryption
  – Integrated analog
  – Physical hardware size
  – Memory size in support of the protocol

Agenda

• Introduction to ultra-low power wireless networking
• Low power protocol selection criteria

• In-depth look at TI offerings
  – 802.15.4
  – ZigBee
  – SimpliciTI

• Application examples
IEEE 802.15.4 Standard → TIMAC

- IEEE PAN wireless standard
- Design considerations
  - Data rate
  - Frame overhead
  - Complexity
  - Range
  - Power Management
- Applications
  - Home Automation
  - Industrial Controls
  - Agriculture
  - Security

ATC 2008

TIMAC Application Considerations

- If the application requires:
  - Faith in a standardized physical layer and lower-layer protocol
  - Freedom to design own higher layer protocol
  - Free choice of different HW and lower layer SW vendors
  - Interoperability on the physical and lower protocol layer
  - Support and maintenance by other vendors/providers

- And can accept drawbacks like:
  - Design and development of higher layer protocol and application
  - Radio channel restrictions
TIMAC Topologies

Peer to Peer  Star  Combined

FFD  RFD  Communication Flow

TIMAC Robustness & Reliability

- **Messaging protocol**
  - Synchronous or asynchronous

- **Message delivery**
  - P2P ACKs
  - Reprogrammable message retries

- **Physical layer considerations**
  - Energy Detection Scan (EDS) on network init

- **Security**
  - PAN ID
  - Configurable join logic
TIMAC Ease of Use

Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical Layer

Ease of Use Meter

IEEE 802.15.4 MAC
868/915 MHz 2400 MHz

802.15.4 Standard

ATC 2008
MSP430 Advanced Technical Conference

TIMAC Hardware & RF Considerations

**EXP461x + CC2420**
SMARTRF04
Code Size
- 26 KB Flash/ROM
- 2.3 KB RAM

**MSP430F2618 + CC2520**
SMARTRF05
Code Size
- 27 KB Flash/ROM
- 2.3 KB RAM

HW Resource Requirements
Radio Interface:
- 4 x GPIO
- 4-wire SPI
Peripherals:
- Timer_A CCR0 & CCR1
- Timer_B CCR0 & CCR1

ATC 2008
MSP430 Advanced Technical Conference
Agenda

- Introduction to ultra-low power wireless networking
- Low power protocol selection criteria
- In-depth look at TI offerings
  - 802.15.4
  - ZigBee
    - SimpliciTI
- Application examples

ZigBee 2006 & 2007 (Pro) → Z-Stack 2.0

- Built “on” 802.15.4
- Target applications
  - Energy Management
  - Home Automation
  - Building Automation
  - Industrial Automation
- Most functionality
  - Application-level implementation
  - Extremely reliable communications
- INTEROPERABILITY
  - IEEE 802.15.4 MAC
  - 868/915 MHz
  - 2400 MHz
Z-Stack Application Considerations

• If the application requires:
  – Faith in a standardized physical layer and lower layer protocol (IEEE 802.15.4)
  – Standardized higher layer protocol (providing e.g. mesh topology, multi-hop)
  – Full interoperability; even up to the application layer (public profiles)
  – Minimal design and development effort (focusing on application only)
  – High competition due to support and maintenance between vendors/providers

• and can accept drawbacks like:
  – Code size (overhead of functionality one might not use)
  – Cost for ZigBee Alliance membership
  – Certification costs (not needed if not targeting a ZigBee certified product)
  – Radio channel restrictions (to the channels specified in 802.15.4)
Z-Stack Robustness & Reliability

- **Messaging Protocol**
  - Typically asynchronous
  - Optional synchronous mode
- **Message Delivery**
  - P2P ACKs
  - End-to-end ACKs
  - Reprogrammable message retries
  - Route Discovery → Self-healing mesh
- **Physical Layer Considerations**
  - Energy Detection Scan (EDS) on NWK startup
  - Frequency Agility

- **Security**
  - PAN ID
  - Levels of security keys
  - Mandatory AES 128-bit & MIC 128-bit encoding

Z-Stack Robustness & Reliability

- **Application-Level Abstractions**
  - Endpoints
    - Multiple end points per network node
  - Clusters
    - 1 x data in & 1 x data out
  - Device descriptors
    - Endpoint + Clusters
  - Binding
  - Group Addressing

- **Application Profiles**
  - e.g. - Home Automation, Smart Energy
  - Private Profiles available
### Z-Stack Ease of Use

#### Application Layer

- Presentation Layer
- Session Layer
- Transport Layer
- Network Layer
- Data Link Layer
- Physical Layer

#### IEEE 802.15.4 Standard

- 868/915 MHz
- 2.400 MHz

#### Z-Stack HW & RF Considerations

**MSP430 + CC2520**

- **Code Size**
  - Coordinator: 57 KB Flash/ROM, 6.6 KB RAM
  - End Device: 41 KB Flash/ROM, 4.4 KB RAM
- **Radio Interface**
  - 4 GPIO
  - 4-wire SPI
- **Timers**
  - Timer_A CCR0 & CCR1
  - Timer_B CCR0 & CCR1
- **Debugging Peripherals**
  - USCI_A <-> ZTool
  - LCD_A <-> LCD

**CC2430 / CC2431**

- **Code Size**
  - Coordinator: 97 KB Flash/ROM, 6.7 KB RAM
  - End Device: 76 KB Flash/ROM, 3.7 KB RAM

Run on the GenericApp application provided with the Z-Stack

- Excluding pre-compiler definitions for LCD and ZTool debugging
- IAR MSP430 v4.10 compiler optimizations: Size → High
- IAR 8051 v7.09B compiler optimizations: Size → High
Z-Stack Hardware & RF Considerations

- Free-up MCU resources
- Small memory footprint
- Configure CC2480 from the MCU
- Simplify ZigBee API calls

Agenda

- Introduction to ultra-low power wireless networking
- Low power protocol selection criteria
- In-depth look at TI offerings
  - 802.15.4
  - ZigBee
    - SimpliciTI
- Application examples
Texas Instruments’ SimpliciTI

- **SimpliciTI Key Features**
  - **Low Power**
    - Supports sleeping devices for low power consumption
  - **Low Cost**:
    - Uses < 8K FLASH & < 1K RAM in most applications
  - **Flexible**:
    - Simple star w/ extender and/or p2p communication
  - **Simple**:
    - Utilizes a very basic 6-instruction API
- **NWK Topologies**
  - P2P
  - Simple Star
- **FREE source code**
- **No license and royalty fees**

SimpliciTI Application Considerations

- If the application requires:
  - Freedom to design own higher layer protocol
  - Lower cost on design & development than the purely proprietary solution
  - Usage of available lower layer protocol to obtain easy implementation and deployment out-of-the-box.
- and can accept drawbacks like:
  - Design and development of higher layer protocol and application
SimpliciTI: Robustness & Reliability | Ease of Use

- Messaging Protocol
  - Asynchronous communication

- Message Delivery
  - Network management capabilities
    - Initialization (NWK join)
    - Ping
    - Link / link listen
    - Security*
    - Freq agility
    - Rx / Tx
    - I/O

- Physical-layer Considerations
  - No formal PHY or data-link layer
  - Simple HAL
  - No OSAL

ATC 2008

SimpliciTI HW Considerations

- Example Compilation and Resource Requirements:
  - Access Point
  - End Device
  - ~9KB ROM
  - ~6.5KB ROM
  - ~700B RAM
  - ~400B RAM

- Out-of-the-box support for:
  - CC2430DB  CC2430 Demonstration Board
  - EXP461x  ATC 2006 eval kit
  - EZ430RF  MSP430 + RF eval kit
  - RFUSB  RF evaluation kit
  - SRF04EB  Smart RF board
### LPW Product Summary

<table>
<thead>
<tr>
<th>Product / Kit</th>
<th>Protocol</th>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC2430DB / CC2430EB</td>
<td>SimpliciTI</td>
<td>SimpliciTI 1.0.4</td>
</tr>
<tr>
<td>11xx, 25xx, 2430</td>
<td>SimpliciTI</td>
<td>SimpliciTI 1.1.0</td>
</tr>
<tr>
<td>CC2420+MSP430F4618</td>
<td>IEEE 802.15.4 MAC/PHY</td>
<td>TIMAC 2420 1.2.1</td>
</tr>
<tr>
<td>CC2520+MSP430F2618</td>
<td>IEEE 802.15.4 MAC/PHY</td>
<td>TIMAC 2520 1.2.1</td>
</tr>
<tr>
<td>CC2430DK</td>
<td>IEEE 802.15.4 MAC/PHY</td>
<td>TIMAC 1.2.1</td>
</tr>
<tr>
<td>CC2530DK</td>
<td>IEEE 802.15.4 MAC/PHY</td>
<td>TIMAC 1.x.x</td>
</tr>
<tr>
<td>CC2420+MSP430F4618</td>
<td>ZigBee-2006</td>
<td>Z-Stack 1.4.3</td>
</tr>
<tr>
<td>CC2430ZDK</td>
<td>ZigBee-2006</td>
<td>Z-Stack 1.4.3</td>
</tr>
<tr>
<td>CC2431ZDK</td>
<td>ZigBee-2006 w/ Location</td>
<td>Z-Stack 1.4.3</td>
</tr>
<tr>
<td>CC2480</td>
<td>ZigBee-2006 Network Processor</td>
<td>Z-Stack &amp; ZASA</td>
</tr>
<tr>
<td>CC2420+MSP430F4618</td>
<td>ZigBee-2007 (PRO)</td>
<td>Z-Stack 2.0.0</td>
</tr>
<tr>
<td>CC2520+MSP430F2618</td>
<td>ZigBee-2007 (PRO)</td>
<td>Z-Stack 2.0.0</td>
</tr>
<tr>
<td>CC2530ZDK</td>
<td>ZigBee-2007 (PRO) + AMI</td>
<td>Z-Stack 2.1.0</td>
</tr>
</tbody>
</table>

---

### DIY Proprietary Solution

- **If the application requires:**
  - High design freedom
  - Proprietary ‘private’ solution
  - Low complexity
  - Low code overhead (implement only what is needed)

- **and can accept drawbacks like:**
  - Cost on design and development of protocol and application
  - No interoperability
  - Lack of support & maintenance by other vendors/providers

- **Examples:**
  - MSP430 Interface to CC100/2500 Code Library (siaa325) [Ultra-low-power]
  - MSP430 + CC2500 / CC1100 Examples and Function Library (swra141) [Abstraction and ease of porting]
  - Slingshot IDE by Sentilla → embedded programming in Java

---

**ATC 2008**

MSP430 Advanced Technical Conference
Questions?

Agenda

• Introduction to ultra-low power wireless networking
• Low power protocol selection criteria
• In-depth look at TI offerings
  – 802.15.4
  – ZigBee
  – SimpliciTI
• Application examples
Customer Examples

• Data logger
• Medical Sensor Network
• AMR
• Home security

Data Logger Example

• Applications considerations
  – System is designed to capture humidity, air pressure data every 5 minutes
  – Up to five sensing stations
  – Base station must communicate data to PC network
  – System is for retrofitting factories, replaces mechanical logging methods
• Robustness & Reliability
  – Factory data should remain confidential
  – Not critical but data logged during factory processing must be maintained per regulatory requirements for five years
• Ease of Use
  – System released to market in six months
• Hardware & RF Considerations
  – Battery operated—must last minimum of two years

Recommendation: Use SimpliciTI
Medical Sensor Network

- **Application Considerations**
  - Modular, wireless health monitoring system next to the hospital bed.
    - EKG, Glucose meter, Body temperature, Blood pressure monitor, etc.
  - Alarm + warning signals exist as End Devices on the network and serve as gateways to the hospital’s alarm system.
  - A standard physical and P2P communication may benefit multiple medical end-equipment vendors from a support and design perspective.

- **Robustness & Reliability**
  - Data must be received and recorded accurately with near zero dropouts
  - Patient medical data should remain confidential
    - Can tradeoff with real-time system performance
  - Need highly reliable P2P communications and a Star network topology with limited application-level development
    - Base station redundancy
  - Application-level sensor implementation Ease of Use
  - Need faith in an industry standard to market the products successfully

- **Hardware & RF Considerations**
  - Batteries need to last for weeks, maybe months

**Recommendation:** Use 802.15.4

Automatic Meter Reading

- **Application Considerations**
  - Wireless collection of utility meter data
  - Remove the need for the utility vendor to drive around to each home, checking utility meters.

- **Robustness & Reliability**
  - System must remain secure against tampering, eavesdropping
  - Data must be received and recorded accurately with zero dropouts

- **Ease of Use**
  - Promoting and industry standard would increase competitive advantage.
  - Need high levels of complexity and reliability without the time it takes to implement in-house.

- **Hardware & RF Considerations**
  - No size restrictions
  - Batteries need to last for years
  - Base station will need considerably more memory than end devices

**Recommendation:** Use ZigBee; consider SimpliciTI
Home Security Network

- **Application Considerations**
  - Home security network
  - Smoke, glass breakage, motion, occupancy detection development
  - Base station must communicate data to home security company
  - User interface must be intuitive
  - Only interoperable with home security products from own company

- **Robustness & Reliability**
  - A key design criteria
  - System must remain secure against tampering, eavesdropping

- **Ease of Use**
  - Desire quick, easy integration of wireless communications to existing applications.
  - Willing to possibly implement methods of reliability and security.

- **Hardware & RF Considerations**
  - Most network devices are battery powered

Recommendation: SimpliciTI

---

Home Security Network

- **Application Considerations**
  - Home security network
  - Smoke, glass breakage, motion, occupancy detection development
  - Base station must communicate data to home security company
  - User interface must be intuitive
  - Require faith in an industry standard

- **Robustness & Reliability**
  - A key design criteria
  - System must remain secure against tampering, eavesdropping

- **Ease of Use**
  - Require a standardized P2P reliability protocol

- **Hardware & RF Considerations**
  - Most network devices are battery powered

Recommendation: Use 802.15.4
Home Security Network

- Application Considerations
  - Home security network
  - Smoke, glass breakage, motion, occupancy detection development
  - Base station must communicate data to home security company
  - User interface must be intuitive
  - Should benefit from interoperability with and support from different vendors
- Robustness & Reliability
  - A key design criteria
  - System must remain secure against tampering, eavesdropping
- Ease of Use
  - Require standardized, implemented schemes for reliability and security
  - Plan to integrate home security applications into an overall home automation network
  - Willing to take the time to learn and leverage a more complex API
- Hardware & RF Considerations
  - Most network devices are battery powered

Recommendation: Use ZigBee