Bluetooth® Low Energy & Zigbee
Multi-protocol Concurrency
- Fundamentals and hands-on Practice

Texas Instruments Senior Wireless FAE
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SimpleLink™ MCU platform

Wired Microcontrollers
- Host Ethernet MCU
  MSP432E4
- Host MCU
  MSP432P4

Wireless Microcontrollers
- Bluetooth® low energy
  CC264x
- Sub-1 GHz
  CC131x CC135x
- Multi-standard
  CC135x CC265x
- WiFi®
  CC3220 CC3235
- WiFi®
  CC3235
- Zigbee
  CC1352 CC2652

Wireless Network Processors
- WiFi®
  CC3135
- WiFi®
  CC3120

100% code reuse

SDK

Common software
The SimpleLink™ SDK

The SimpleLink SDK is designed for simplified development within one environment using industry standard APIs, TI Drivers, and TI RTOS to provide a robust foundation for application development

- 100% application code compatibility across SimpleLink MCU portfolio
- TI Drivers offers standardized set of functional APIs for integrated peripherals
- Integrated TI-RTOS, a robust, intelligent kernel for complete, out-of-the-box development
- POSIX-compatible APIs offer flexible OS/kernels support
- Encryption-enabled security features
- IoT stacks and plugins to add functionality to your design
Invest once, reuse effortlessly

Learn more about SimpleLink code portability
SimpleLink™ Portfolio redefining scalability

Key Features
- 2.4 GHz support
- Sub-1 GHz support
- Low power operation
- Security accelerators
- Wi-Fi support
- 5GHz-Dual Band
- Ethernet MAC & PHY
- 14 bit ADC
- Integrated ADC
- 105 deg. C
- Display support
- 12 bit ADC

More memory
- Multi-step approach from 32kB to 2MB

More integration
- Sensor controller, precision ADC, PA, coexistence and multiple wired/wireless

Easier to use
- Comprehensive software, complete reference designs, and SimpleLink Academy training
Why TI SimpleLink™ MCUs?

**Scale**
- Breadth of wireless technologies
- Concurrent multi-protocol
- Multi-band SD radio for LP IoT
- Dual-band Wi-Fi

**Conserve**
- Low energy radios
- Extended range
- ULP Sensor Controller
- Wi-Fi LP IoT
- Best-in-class standby

**Secure**
- FIPS 140-Level 1
- Offload CPU bandwidth – HW crypto accelerators
- Secure boot

**Innovate**
- BAW: First crystal-less wireless SoC
- Future-proof with 5GHz Wi-Fi
SimpleLink™ CC26xx hardware platform
SimpleLink™ Multi-standard CC26x2R
Key features and benefits

Connect the building, home and grid
with the lowest-power, multi-standard devices for Bluetooth 5, Thread and Zigbee

Consistently the lowest power in the industry – 10-year operation on a coin cell battery

✓ Ultra-low power sensor controller
✓ 0.8uA standby current

Expanded applications - enhanced features and more memory

✓ Multi-standard support for Bluetooth® 5, Thread, and Zigbee
✓ 608 KB of non-volatile memory including 352KB flash, 256KB ROM (with BLE stack embedded), 80KB RAM
✓ Hardware security accelerators – AES-256, ECC and RSA public key, SHA2-512, True Random Number Generator (TRNG)

Fast time to market - comprehensive software offerings and training

✓ SimpleLink SDK with code portability to the SimpleLink platform devices
✓ SimpleLink Academy training environment
SimpleLink CC26x2R
One architecture, several technologies

Application MCU
- Application
- Profiles/services
- TI RTOS
- Peripheral drivers and libraries
- Royalty free protocol stacks

Peripherals/modules
- DC/DC converter
- Temp/battery monitor
- AES
- GPIO
- Timers
- UART/SPI
- I2C/I2S
- DMA

Radio
- Strong Sensitivity
- Power output:
  - +5dBm/+20dBm @ 2.4 GHz
  - +15dBm/+20dBm @ Sub-1 GHz
- LinkLayer in ROM

Sensor controller engine
- ADC and comparators
- Digital sensor readings
- Capacitive sensing

Memory
- 608 KB non-volatile memory
- 352 KB Flash + 256 KB ROM
- 80 KB SRAM + 8 KB cache

ARM® Cortex®-M4F

QFN package: 7x7mm

TI RTOS
Peripheral drivers and libraries
Royalty free protocol stacks

Bluetooth
Low Energy

Zigbee

Texas Instruments
**Key Features**

**More memory**
- 608 KB non-volatile memory
- 352kB kB Flash memory for application code + 256 KB ROM
- 80kB SRAM
- Device is equivalent to a 512kB device (including BLE5 stack, TI-RTOS, 15.4 High layer MAC in ROM)

**More peripherals**
- Enhanced security (hardware acceleration, AES-128/256, SHA2-512, ECC, RSA-2048)
- 1 Additional UART

**Lower power**
- Faster start-up times
- Standby current as low as 0.9uA
- Ultra-low power sensor controller with current consumption as low as 1 uA during operation

**More processing power**
- ARM Cortex M4F core (1-cycle MAC, SIMD, floating-point)
- 7x7mm pin compatible with CC2640R2F
SimpleLink CC26x2R

Sensor controller

**SPI reading - Wake ups per second**

<table>
<thead>
<tr>
<th></th>
<th>Cortex-M4, 48 MHz</th>
<th>Sensor controller, 24 MHz</th>
<th>Sensor controller, 2 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.4 μA</td>
<td>1.5</td>
<td>1.0 μA</td>
</tr>
<tr>
<td>20</td>
<td>25.4 μA</td>
<td>4.0 μA</td>
<td>1.4 μA</td>
</tr>
<tr>
<td>100</td>
<td>119 μA</td>
<td>15.6 μA</td>
<td>3.0 μA</td>
</tr>
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</table>

**Example application**

<table>
<thead>
<tr>
<th>Power consumption</th>
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<tbody>
<tr>
<td>Flow metering</td>
</tr>
<tr>
<td>Motion detector</td>
</tr>
<tr>
<td>Thermostat</td>
</tr>
</tbody>
</table>

**Additional information**

- **Power consumption**: 119 μA
- **Current**: 15.6 μA
- **Sensor controller, 2 MHz**: 3.0 μA
- **Flow metering**: 16-Hz: 1.7 μA
- **Motion detector**: Reading Comp A @ 100 Hz: 1.9 μA
- **Thermostat**: ADC sampling @ 1Hz: 1 μA

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**Diagram**

- Main CPU: ARM Cortex-M4F
- Up to 48 MHz: 79 μA/Hz
- 2.4 GHz: Sensor controller:
  - SPI reading: Wake ups per second
  - ADC reading: Giga-bit/s
- Cortex-M4, 48 MHz:
  - 1: 2.4 μA
  - 20: 25.4 μA
  - 100: 119 μA
- Sensor controller, 24 MHz:
  - 1: 1.5 μA
  - 20: 4.0 μA
  - 100: 15.6 μA
- Sensor controller, 2 MHz:
  - 1: 1.0 μA
  - 20: 1.4 μA
  - 100: 3.0 μA

**Additional components**

- Digital PLL
- D3P Modem
- ARM Cortex-M0
- 16-KB SRAM
- General Hardware Peripherals and Modules
- I2C and I2S
- 4x 32-Bit Timers
- 2x UART
- 32 ch. μDMA
- 26 GPIOs
- AE3-256, SHA2-512
- ECC, RSA
- RTC

**Texas Instruments**
## TI BAW – Crystal-less wireless MCU

### Current obstacles

**Limitations of current clocking and quartz crystal devices**

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<tbody>
<tr>
<td>Going crystal-less is the next step in IoT evolution</td>
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</table>

### Advancements in BAW technology propel us to the future

- ✓ Increased performance
- ✓ Simpler
- ✓ Lower cost
- ✓ Smaller size
TI BAW – Crystal-less wireless MCU

Design with crystal

Design with BAW technology

12% area savings with TI's BAW technology
ti.com/simplelink-baw
Featured Technologies

Bluetooth® 5
What’s new with Bluetooth® 5?
Longer range, higher speed, more data, diverse applications.

**Longer range**

- 6 dB improved sensitivity through coding – same TX/RX current
- Whole-house coverage (1.5km range)

**Higher speeds**

- 500% increase in data throughput vs. Bluetooth 4.0 (2Mbps mode)
- CC2640R2F supports even higher throughput up to 5Mbps (proprietary)

**Increased broadcasting capacity**

- Transmit more intelligent data over a beacon (up to 248 bytes)
- Enable rich location/navigation applications

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**Home / building automation**
- Door locks, beacons
- Smoke detectors, door bells, lights

**Health / medical**
- Glucose monitors, patient monitors, drug delivery

**Appliances**
- Coffee-maker, vacuum, HVAC

**Retail**
- EPOS card readers
- EPOS printers
- Handheld transaction terminals

**Logistics**
- Anti-lost tags, asset tracking personnel locator

**Automotive**
- Remote keyless entry (RKE), passive-entry passive-start (PEPS), wire replacement

**Industrial**
- Power tools, e-meters, sensors
Bluetooth® 5: higher speed

- Double symbol rate compared to 1M
- Almost half the energy consumption per frame
- Twice as fast?
  - Still inter-frame spacing of 150µs contributing to overhead
    - On the other hand, can use data-length extension

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**“Empty PDU” connection event**

1M

<table>
<thead>
<tr>
<th>Master (Samsung S8)</th>
<th>Slave (CC2642)</th>
</tr>
</thead>
<tbody>
<tr>
<td>229.125 us (0.4 slots)</td>
<td>149.125 us (0.2 slots)</td>
</tr>
<tr>
<td>149.125 us (0.2 slots)</td>
<td>149.375 us (0.2 slots)</td>
</tr>
</tbody>
</table>

2M
**Bluetooth® 5: higher speed**

**New 2Mbps LE PHY mode**

- 2x throughput compared to BT4.x LE
  - 2 MSymbol/s rate un-coded
  - Backwards compatible with BLE4.x 1Mbps devices since LE Controllers negotiate link speed

<table>
<thead>
<tr>
<th>BLE 4.0/4.1</th>
<th>BLE 4.2</th>
<th>BLE 5.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 1Mbps PHY</td>
<td>• 1Mbps PHY</td>
<td>• 2Mbps PHY</td>
</tr>
<tr>
<td>• 27 byte PDU</td>
<td>• 27-255 byte PDU with Data Length Extension</td>
<td>• 27-255 byte PDU with Data Length Extension</td>
</tr>
<tr>
<td>305 kbps</td>
<td>780 kbps</td>
<td>1.4 Mbps</td>
</tr>
</tbody>
</table>

Maximum throughput (LE) by specification
**Bluetooth® 5: longer range**

**Increased receiver performance with LE-coded PHY**

- Bluetooth Low Energy 4.x uses 1Mbps un-coded PHY
  - 1:1 ratio between transmitted data bits and over-the-air modulated symbols
  - Single bit error in transmission requires re-transmission of entire PDU (CRC error)
  - Good for low-noise or shorter range communication

- Bluetooth 5 introduces *Coded PHY* rates of 500kbps and 125kbps
  - Uses Forward Error Correction (FEC) to code the payload data bits 1:2
  - This can be used as is with a data rate of 500 kbps (N = 2 coding)
  - The bits can be expanded 1:4 (a ‘0’ expands to ‘0011’ and a ‘1’ is expanded to ‘1100’)
  - Gives a data rate of 125 kpbs (N = 8 coding)
  - More over-the-air modulated symbols are used for each actual data bit. This makes it easier for the receiver to distinguish the signal over noise and sensitivity improves
  - RX current consumption is unchanged compared to un-coded PHY
Bluetooth® link budget improvement

• RF link budget is the ratio between the transmit RF power and the receiver sensitivity level

• Link budget can be increased by:
  – Increasing output power
    • Which will increase current consumption
      – Current consumption typically increases significantly above 0 dBm for available BLE wireless MCUs
    • Data rate is unchanged
  – Improving receiver sensitivity through coding techniques
    • Current consumption is unchanged
    • Data rate is reduced
    • Leveraged in BT5 Coded PHYs (500 kbps and 125 kbps)
Bluetooth® 5: advertisement extension

• Legacy Bluetooth Low Energy advertisement
  – Primary channels: 37, 38, 39
  – PDU size 6-37 bytes at 100ms non-connectable or 20ms connectable max rate
  – PHY: 1Mbps only

• New advertising channel extension PDU: ADV_EXT_IND
  – Allows up to 248 byte ADV payload by offloading payload to data channels
  – Supports any PHY
  – Reduces traffic on ADV channels
  – Mandatory for coded PHYs

\[
t_{\text{min}} = 300\,\mu\text{s} \quad t_{\text{max}} = 2.4\,\text{s}
\]
Advertisement extensions (AE)

• Simple peripheral
  – Connection event on coded PHY
  – Connectable advertising on 1M and coded.
ADV_EXT_IND  coded PHY pointer to coded

- No advertiser address but has data ID and det ID to prevent unneeded scans
AUX_ADV_IND – coded PHY data / pointee

- Like a normal advertisement
- Extra headers
  - Can point to even more data
  - Does not have to include adv addr
Featured Technologies

TI’s dynamic multi-protocol manager (DMM)
What is Zigbee?
Architecture and technical details

- Zigbee Coordinator
  - Starts the network
  - Routes the packets
  - Manages security
  - Associates routers and end devices
  - Example: smart hub, heating central

- Zigbee Router
  - Routes packets
  - Associates routers and end devices
  - Example: light

- Zigbee End Device
  - Battery powered
  - Typically asleep
  - Does not route packets
  - Example: light switch

*Zigbee Green Power Proxy Basic is required for all routing devices
What is Zigbee?

Device types

- **Coordinator**
  - Monitoring & control
  - HVAC
  - Smart home controller
  - Gateway

- **Routers**
  - Lights
  - Shades/blinds
  - Fans
  - Smart appliances
  - Thermostat
  - Garage door
  - Displays
  - Smoke/Gas detectors

- **End devices**
  - Portable switches
  - Door/window/motion sensor
  - Ambient sensors
  - Smoke/gas detectors (battery powered)

[Texas Instruments logo]
Zigbee + Bluetooth® Low Energy: 1 chip, multi-protocol solution
Introducing the dynamic multi-protocol manager

• Previously, this system could require 3 separate products:

• Now with the DMM, TI has a multi-protocol solution with only one chip:
Future-proof: Add concurrent mode Bluetooth® Low Energy to your network

- Powered by innovative software IP - dynamic multi-protocol manager
- Allows multiple stacks to run on the same device running concurrently
- Uses a policy manager and scheduler to dynamically arbitrate the RF resource
- Makes scheduling decisions based on the current policy decision which the developer can change to suit their needs
DMM architecture overview

- The DMM will intercept calls to the RF driver & can potentially modify the order in which commands are scheduled based on requirements of the stack & application.

- The scheduler will inspect the command sent to the RF driver & based on policy will:
  - Schedule command as is
  - Cancel command
  - Change priority of command based on current policy & stack state

- PHY Switchover Time 400 usec (600 usec application level)
Using TI’s multi-protocol solution, the DMM can allow Zigbee and BLE to run concurrently on a single chip.

For example, adding a light switch into a Zigbee home network becomes highly simplified by using a BLE interface.

With a Zigbee end device, you can add BLE connectivity to your phone. This end device will be in RX most of the time, and BLE will have periodic connection events.
Hands-on: Bluetooth® Low Energy + Zigbee
Bluetooth® Low Energy + second network concurrent mode available today

- Web landing page
- Technical note
- SW examples (BLE + Sub-1GHz, BLE + Zigbee)
Step 0: set Up

Start with 2 CC2652R devices:

- One is a Zigbee coordinator light (we will denote as ZCL)
- The other is the DMM switch and Zigbee end device (we will denote as ZED)
Step 1: flash the devices

- Flash with the binary files provided using **Uniflash**
- Flash one device with the DMM Switch Application and the other with the ZigBee coordinator light application provided in the `images/` directory
Step 1: flash the devices (cont.)

• After the devices have been flashed open up a putty session to view the serial output for BOTH device.
  – Use the windows Device Manager to identify which COM port your device is on.

• Verify BOTH devices have a cleared non-volatile storage section by ‘Resting to factory new’

  [Image of PTTY Configuration window showing COM Port settings and serial option]

  [Image of command line interface showing 'Press 'a'' and 'Press 'e'' to reset to factory new]
Step 1: flash the devices (cont.)

• You have now flashed a Zigbee coordinator light application and a Zigbee end device switch application!

• Please press ‘e’ while on in this menu to learn how to navigate the Zigbee menus.
Step 2: open Zigbee network for connections

- Navigate to the “COMMISSION” menu on the coordinator device:

- After selecting the “COMMISSION” menu item, the network will be open for new devices to join for 180 seconds:

- The coordinator board light will blink green here to indicate that it is open for connections
Step 3: connect to BLE on your phone

• Open the LightBlue app (available on both iOS and Android), and select the DMM ZED Switch
Step 4: provision the switch

- After connecting to the DMM switch, scroll down and select the provisioning characteristic
- Write a value of “aa” to the switch
Step 4: provision the switch

When the switch has joined the network, the green LED on the ZED board will turn on, and this will display on the terminal to indicate that the switch is connected to the light.

**Note:** If your switch has joined a network but is not controlling your light correctly – it might be on the wrong network.

To resolve, check PAN ID to make sure that the network matches, and that you are connected to your own coordinator light.
Step 5: turn light on and off

- Go back to the DMM switch page in the LightBlue app, and select the “on/off” characteristic
- Write a value of “1” to the “on/off” characteristic
- The ZED switch UI will move over to the 'TOGGLE LIGHT' menu, and the ZCL red LED should turn on:
Step 5: turn light on and off

- Similarly, try writing a value of “0” to the “on/off” characteristic
- The ZCL red LED should turn off:
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<th>SimpleLink™</th>
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<td>Sub-1GHz</td>
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**SimpleLink sensor-to-cloud**

- Web
- Video
- Blog
- TI-RTOS-based design
- Linux-based design

**End equipment information**

- Building Automation, HVAC, and Smart Meters

**Support and training**

- Training
- TI E2E Support Forum
Back up