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UART to Bluetooth® low energy (BLE) Bridge Design Guide

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Design Resources
- TIDC-SPPBLE-SW-RD CC2640
- TIDC-SPPBLE-SW-RD CC2650
- TIDC-SPPBLE-SW-RD BLE Stack

Tool Folder Containing Design Files
Product Folder
Product Folder

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Design Features
- Enables Easy Integration Through Modular Code
- Runs On the SimpleLink™ Bluetooth low energy CC2640 wireless MCU
- Uses the TI Royalty Free BLE-Stack™
- Ports Easily to Other Boards Including the SimpleLink SensorTag 2.0
- Offers a Generic Design to Fit Various Applications

Featured Applications
- Cable Replacement
- Home Automation
- PC
- Wireless Sensors

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1 Overview

In Bluetooth classic (BR/EDR) systems, a Serial Port Profile (SPP) is an adopted profile defined by the Bluetooth Special Interest Group (SIG) used to emulate a serial port connection over a Bluetooth wireless connection. For Bluetooth low energy systems, an adopted profile for implementing SPP over BLE is undefined, thus emulation of a serial port must be implemented as a vendor-specific custom profile. The purpose of this document is to provide an overview of a custom BLE Serial Port Profile on the UART to BLE bridge reference design found on TI.com™ as part of TI Reference Designs™. This SPP over BLE implementation is a complete reference design software built on the existing BLE SDK V2.1. TI recommends reading the SimpleLink Bluetooth low energy CC2640 wireless MCU Software Developer’s Guide (SWRU393) to learn about the BLE protocol stack and software before using these sample applications.

1.1 Introduction

BLE-Stack V2.1 contains reference project implementations that use both adopted and custom profiles. The APIs provided by the SDK, combined with the TI-RTOS real-time operating system, CC26XXWARE DriverLib, and peripheral drivers, let the application developer quickly implement a BLE custom application on a CC2640 wireless MCU. For a complete understanding of the capabilities of the TI BLE-Stack SDK, including an overview of the BLE protocol stack, TI recommends reading the SimpleLink Bluetooth low energy CC2640 wireless MCU Software Developer’s Guide (SWRU393) before implementing a custom profile.

1.2 Terminology

The following table lists common abbreviations and terms and their meanings used in this guide.

<table>
<thead>
<tr>
<th>Terms</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDK</td>
<td>Software Development Kit</td>
</tr>
<tr>
<td>BLE</td>
<td>Bluetooth low energy</td>
</tr>
<tr>
<td>SPP</td>
<td>Serial Port Profile</td>
</tr>
<tr>
<td>Client</td>
<td>Serial communication endpoint, connects to service</td>
</tr>
<tr>
<td>Server</td>
<td>Serial communication endpoint, provides service (such as the serial port service)</td>
</tr>
<tr>
<td>GATT</td>
<td>Generic Attribute, defines how data is transmitting as BLE packets over the air</td>
</tr>
<tr>
<td>IDE</td>
<td>Integrated Development Environment, integrated compiler, linker, and debugger such as IAR and CCS</td>
</tr>
</tbody>
</table>
2 Demonstration

This reference design consists of two IDE projects, the SPPBLEServer and the SPPBLEClient that run on their respective endpoints. These projects connect and exchange data wirelessly with each other. This capability creates a virtual serial link over the air. Each byte input can be sent and received by both the server and client. The SPPBLEServer is based on the SimpleBLEPeripheral project while the SPPBLEClient is based on the SimpleBLECentral project. The main difference between these projects is the addition of the Serial Data Interface (SDI) module, which is based on the NPI component in the HostTest project. TI designed the SPP BLE applications to use the UART transport layer but you could adapt this design to work with other serial protocols, such as SPI.

2.1 Project Overview

The structure of the project is similar to the SimpleBLEPeripheral project in terms of the layout of the project directory. The application directory contains the application source code and header files. The project contains two tested configurations listed below. TI has tested and used both IAR and CCS IDEs in this guide. Refer to Section 5 for the versions in this guide. The demonstration uses the CC2650DK, which contains two SmartRF06 boards and two CC2650 evaluation modules (EM). You can replace the EM boards with other development boards such as the SensorTag 2.0. For convenience, the SPPBLEServer project contains a separate configuration set up to run on the SensorTag 2.0. The reference design includes layout and schematic files for an RS232 DevPack, which can connect to the UART interface on the SensorTag 2.0.

**FlashROM**— Application and stack image using the SmartRF06+CC2650EM hardware platform

**FlashROM_SensorTag**— Application and stack image using the TI SensorTag hardware platform

2.1.1 Using the Interface

The following button inputs exist for the application on the client side (SPPBLEClient project):

- **Button Up**: If not connected, start or stop device discovery. If connected to a device, alternate sample read and write requests.
- **Button Left**: Scroll through the device discovery results.
- **Button Select**: Connect to or disconnect from the device.
- **Button Right**: If connected, send a parameter update request.
- **Button Down**: Does nothing, left for user application

Use the up, left, and select buttons for the client side to discover, select, and connect, respectively, to the server device (SPPBLEServer project).

2.1.2 Hardware and Software Requirements

- **1 x CC2650 Development Kit** (includes 2 x SmartRF06 boards and 2 x CC2650EM-7ID)
- **2 x USB micro cables**
- **A terminal application (such as TeraTerm or RealTerm)**
- **The TI BLE Stack V2.1**
- **A software patch from TI Designs (.zip)**
2.1.3 Operating

1. Unzip this file and replace the files in the respective directories in the SDK.
2. Verify SPPBLESerServer and SPPBLEClient sample application have been added with existing applications here: C:\Texas_Instruments\simplelink\ble_cc26xx_2_01_00_44423\Projects\ble
3. Build and download one CC2650EM board with the SPPBLEClient project. (Alternatively, flash the CC2650EM with the precompiled hex (CC2640_SmartRF-7ID_SPPBLEClient_no.hex) using Flash Programmer 2.
4. Build and download the other CC2650EM board with the SPPBLESerServer project.
5. Connect both boards to a terminal application through USB cables to a PC.
6. Power cycle the boards.
7. Verify the debug output in the terminal application.

The following table shows the default UART settings used by the applications.

<table>
<thead>
<tr>
<th>UART Parameters</th>
<th>Default Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud Rate</td>
<td>115200</td>
</tr>
<tr>
<td>Data Length</td>
<td>8</td>
</tr>
<tr>
<td>Parity</td>
<td>None</td>
</tr>
<tr>
<td>Stop Bits</td>
<td>1</td>
</tr>
<tr>
<td>Flow Control</td>
<td>None</td>
</tr>
</tbody>
</table>

The server side should start advertising.
1. Press up to initiate a device discovery on the client side.
2. Press left until the correct server device is found.
3. Press select to connect to the server device.
4. Verify that the terminal output is connected.

After the client device scans and connects, the client device discovers the serial port service and configures it to enable notifications of the serial port service data characteristic. The client device may also discover the device information service for the manufacturing and serial numbers.

On the client side, debug output in terminal indicates notifications have been enabled. Entering data in one terminal will transfer to the other terminal wirelessly.

When the link terminates, the server will advertise.

The client device may ask the server for read-only device information. Section 2.2.7 presents details on the supported items for this project. These details include the model number, the serial number, the UART configuration, and UART status (including the number of bytes sent and received).

2.2 Software Description

The application is implemented in spp_ble_server.c. The application is simple and the main processing is implemented within the application task function. The application gets the UART data from the SDI layer and sends it over the air in notification packets. The application does not directly receive wireless data; the data goes to the profile layer and gets sent to the UART by the SDI layer. You can implement queues to transfer the data to the application layer for further processing.

2.2.1 Initializing

The initialization of the application is similar to other projects in terms of API function calls. The SPPBLESerServer task function calls the SPPBLESerServer_init function before running the main task. This function configures parameters in the peripheral profile, the GAP, and the GAP bond manager. The function sets up the serial port service with standard GATT and GAP services in the attribute server and lets you change the parameters of UART. You can set up the registration for receiving UART messages from the SDI layer. Also during this phase, the SPPBLESerServer_init function calls the GAPRole_StartDevice function to set up the GAP functions then calls the GAPBondMgr_Register to register with the bond manager.
2.2.2 Event Processing

The application has a main event processing function in SPPBLEServer_taskFxn. This function handles events as follows:

Queues:
- appUARTMsgQueue: Services UART data messages received from the SDI.
- appMsgQueue: Processes application messages from the lower-level BLE stack.

Events:
- SBP_PERIODIC_EVT: Acts as a placeholder for periodic processing for application.
- SBP_UART_CONFIG_EVT: Changes UART parameters such as baud rate.

SPPBLEServer_processAppMsg handles application messages as follows:
- SBP_STATE_CHANGE_EVT: Processes a pending GAP Role state change event.
- SBP_CHAR_CHANGE_EVT: Processes a pending SPP characteristic value change event. When the client device writes to the config characteristic, it sets an event to initiate the change of UART hardware parameters.

2.2.3 Callbacks

The application callback functions are as follows:
- SPPBLEServer_stateChangeCB: Callback from GAP Role that indicates a role state change.
- SPPBLEServer_charValueChangeCB: Callback from SPP that indicates a characteristic value change.

2.2.3.1 Queues

Other tasks can add to the application queues to initiate further message processing as follows:
- SPPBLEServer_enqueueMsg: Creates a message and puts the message in RTOS appMsgQueue queue.
- SPPBLEServer_enqueueUARTMsg: Creates a message and puts the message in RTOS appUARTMsgQueue queue.
2.2.4 Sending Data Wirelessly

The client will send WriteNoRsp packets to the server. The server side sends data through notifications. When the SDI receives UART data, the SDI places it in the appUARTMsgQueue queue. The queue is processed in the SPPBLEServer task as part of the application thread.

For example, in spp_ble_server.c:

```c
static void SPPBLEServer_taskFnx(UArg a0, UArg a1)
{
...
if (!Queue_empty(appUARTMsgQueue))
{
...
// Send the notification
    retVal = SerialPortService_SetParameter(SERIALPORTSERVICE_CHAR_DATA, pMsg->length, pMsg->data);
...
}
```

**NOTE:** To send notifications, you must enable them. The application sends serial data in notification packets wirelessly when the queue is not empty.

2.2.5 Receiving Data Wirelessly

The server will receive this data in the SerialPortService_WriteAttrCB function. The server notifies the application side.

For example, in SerialPortService.c:

```c
// Write the value
if ( status == SUCCESS )
{
    uint8 *pCurValue = (uint8 *)pAttr->pValue;

    // Copy/Store data to the GATT table entry
    memset(pCurValue, 0, SERIALPORTSERVICE_DATA_LEN);
    memcpy(pCurValue, pValue, len);

    // Send Data to UART
    SDITask_sendToUART(pCurValue, len);
    if (len > 0)
    {
        SerialPortService_AddStatusRXBytes( len );
    }
}

    notifyApp = SERIALPORTSERVICE_CHAR_DATA;
}
break;
```

When the server receives data, it also sends data to the UART terminal.
2.2.6 Optimizing Data Throughput

Effective throughput depends on several factors, such as the connection interval and capability of the peer device. By decreasing the connection interval parameter in the application or limiting application processing, you can maximize 1-way throughput. Throughput depends on the limitations of the peer device that might have stricter guidelines on connection intervals and number of packets per connection event than TI’s CC2640 wireless MCU.

To support higher throughput, increase the number of buffers allocated for TX buffers in the controller by adding the following into the preprocessor symbols. This value increases the maximum number of packets that you can queue. Refer to SimpleLink Bluetooth low energy CC2640 wireless MCU Software Developer’s Guide (SWRU393) for more details:

```
MAX_NUM_PDU = 15
```

Increase the heap size in the application to accommodate the increased heap memory usage.

```
HEAPMGR_SIZE = 4096
```

2.2.7 GATT Table

Figure 1 is the GATT table with the handles and UUIDs of characteristics in the SPPBLEServer project. The table was generated using BTOOL.

![Table](image)

**Figure 1. GATT Table**
3 Serial Port Service Specification

TI designed the serial port service to be versatile and easy to use. This protocol can be adapted to most UART communication protocols (including RS-232).

The serial port service has the following UUID: F000C0E0-0451-4000-B000-00000000-0000.

The service has three characteristics:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>UUID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>F000C0E1-0451-4000-B000-00000000-0000</td>
</tr>
<tr>
<td>Status</td>
<td>F000C0E2-0451-4000-B000-00000000-0000</td>
</tr>
<tr>
<td>Config</td>
<td>F000C0E3-0451-4000-B000-00000000-0000</td>
</tr>
</tbody>
</table>

Because the service has dedicated UUIDs, it can operate with different client devices that implement the same service with same UUIDs. For example, a smart phone application can communicate with any other devices that implement this serial port service.

See the TI Serial Port Service specification document for more information on the serial port service.

4 Porting To Other Projects

This section describes how to port the SPPBLEServer to other projects.

4.1 Porting SPPBLEServer to Other Projects

1. Copy the SDI folder to C:\Texas_Instruments\simplelink\ble_cc26xx_2_01_00_44423\Components.
2. Copy the SerialPortService folder to C:\Texas_Instruments\simplelink\ble_cc26xx_2_01_00_44423\Projects\ble\Profiles.
3. Define SDI_USE_UART in preprocessor symbols.
4. In preprocessor settings, add the following include directories:
   - $PROJ_DIR$/../../../../../../../Components/sdi.
   - $PROJ_DIR$/../../../../../../../Projects/ble/Profiles/SerialPortService/CC26xx.
   - $PROJ_DIR$/../../../../../../../Projects/ble/Profiles/SerialPortService.
5. Create the SDI task in main.c.
6. Include header file to avoid compile errors.
7. Initialize semaphore.
8. Add other changes in SPPBLEServer.c (check the difference between the two files [SPPBLEServer.c and SimpleBLEPeripheral.c]), including adding the service and the queues for UART message processing.

4.2 Running SPPBLEServer on SensorTag

The SPPBLEServer application has a project configuration for the SensorTag. You can select the configuration in the workspace pane by selecting FlashROM_SensorTag configuration.

To emulate this configuration, do the following:
1. Remove or exclude the existing board file.
2. Add Board.c from C:\Texas_Instruments\simplelink\ble_cc26xx_2_01_00_44423\Projects\ble\SensorTag\CC26xx\Source\Application\Board_patch.
4. In preprocessor symbols, remove the LCD driver: xTI_DRIVERS_LCD_INCLUDED.
5. Connect to the port enumerated as XDS110 Class Application/User UART when connected to the Debugger DevPack mounted on the SensorTag.
5 Test Results

The demonstration of the application indicates that TI has tested the SPP BLE projects successfully. The following table shows functional tests performed using various configurations.

<table>
<thead>
<tr>
<th>Test Case</th>
<th>Device Under Test</th>
<th>Compiler</th>
<th>Peer Device</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Successfully send/receive</td>
<td>SPP BLE Server</td>
<td>IAR 7.40.2</td>
<td>SPP BLE Client</td>
<td>Passed</td>
</tr>
<tr>
<td>file</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Successfully send/receive</td>
<td>SPP BLE Server</td>
<td>CCS 6.1.0</td>
<td>SPP BLE Client</td>
<td>Passed</td>
</tr>
<tr>
<td>file</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Successfully send/receive</td>
<td>SPP BLE Server</td>
<td>IAR 7.40.2</td>
<td>BLE Scanner on Android 5.0.1</td>
<td>Passed</td>
</tr>
<tr>
<td>bytes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Send/Receive bytes</td>
<td>SPP BLE Server</td>
<td>CCS 6.1.0</td>
<td>LightBlue on iOS 7.0.4</td>
<td>Passed</td>
</tr>
</tbody>
</table>

Troubleshooting

Several problems might be encountered while porting or using the SPP BLE application. The following table lists a few common problems and their solutions.

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project does not download/debug.</td>
<td>Debugger information may be lost during the porting process. Go to</td>
</tr>
<tr>
<td></td>
<td>project settings and configure the Debugger section to match other</td>
</tr>
<tr>
<td></td>
<td>BLE projects like the SimpleBLEPeripheral project.</td>
</tr>
<tr>
<td>Unable to open Application UART</td>
<td>Restart the computer.</td>
</tr>
<tr>
<td>Error connecting to target</td>
<td>Ensure correct debugger is selected in project settings.</td>
</tr>
<tr>
<td>No output on UART terminal</td>
<td>Verify the correct board file is used in the project</td>
</tr>
</tbody>
</table>

For further information and addendums to this guide, see the wiki.

6 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDC-SPPBLE-SW-RD.

7 References

Included with the TI Bluetooth Low Energy V2.1 SDK Release (path and file references in this document assume that the BLE development kit software has been installed to the default path C:\Texas_Instruments\simplelink\ble_cc26xx_2_01_00_44423\Projects\ble\Profiles).  

1. SimpleLink Bluetooth low energy CC2640 wireless MCU Software Developer's Guide (SWRU393)  
2. TI BLE Stack V2.1 www.ti.com/ble-stack  
3. CC2540 and CC2541 Mini Development Kit User's Guide (SWRU270)
About the Author

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## Revision History

### Changes from May 18, 2015 to September 1, 2015

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<tr>
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<th>Page</th>
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<tr>
<td>From V2.0 to V2.1 throughout document</td>
<td>2</td>
</tr>
<tr>
<td>Changed from &quot;If connected, start or cancel RSSI polling.&quot;</td>
<td>3</td>
</tr>
<tr>
<td>Changed from &quot;C:\TI\simplelink\ble_cc26xx_2_00_00_42893\Projects\ble&quot;</td>
<td>4</td>
</tr>
<tr>
<td>Changed from &quot;CC2640_SmartRF_SPPBLEClient.hex.&quot;</td>
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<tr>
<td>Changed from &quot;SPB_CHAR_CHANGE_EVT.&quot;</td>
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<tr>
<td>Changed from &quot;C:\TI\simplelink\ble_cc26xx_2_00_00_42893\Components.&quot;</td>
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</tr>
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<td>8</td>
</tr>
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<td>Changed from &quot;C:\TI\simplelink\ble_cc26xx_2_00_00_42893.&quot;</td>
<td>9</td>
</tr>
</tbody>
</table>

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.
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