Texas Instruments CC2540/41 *Bluetooth*® low energy Sample Applications Guide v1.4.1

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Table Of Contents

Copyright © 2011-2015 Texas Instruments, Inc

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References

Included with Texas Instruments *Bluetooth* low energy v1.4.1 Stack Release (All path and file references in this document assume that the BLE development kit software has been installed to the default path C:\Texas Instruments\BLE-CC254x-1.4.1\):

[1] Texas Instruments *Bluetooth*® low energy Software Developer's Guide (SWRU271G)

C:\Texas Instruments\BLE-CC254x-1.4.1\Documents\TI_BLE_Software_Developer's_Guide.pdf

Adopted *Bluetooth* specifications (which can be downloaded from https://www.bluetooth.org/Technical/Specifications/adopted.htm):

[2] Blood Pressure Profile (BLP) Specification v1.0

[3] Blood Pressure Service (BLS) Specification v1.0

[4] Health Thermometer Profile (HTP) Specification v1.0

[5] Health Thermometer Service (HTS) Specification v1.0

[6] Heart Rate Profile (HRP) Specification v1.0

[7] Heart Rate Service (HRS) Specification v1.0

[8] HID over GATT Profile (HOGP) Specification v1.0

[9] HID Service (HIDS) Specification v1.0

[10] Scan Parameters Profile (ScPP) v1.0

[11] Scan Parameters Service (ScPS) v1.0

[12] Device Information Service (DIS) Specification v1.1

[13] Battery Service (BAS) specification v1.0

[14] Proximity Profile (PXP) Specification v1.0

[15] Find Me Profile (FMP) Specification v1.0

[16] Link Loss Service (LLS) Specification v1.0

[17] Immediate Alert Service (IAS) Specification v1.0

[18] Tx Power Service (TPS) Specification v1.0

[19] Time Profile (TIP) Specification v1.0

[20] Alert Notification Profile (ANP) Specification v1.0

[21] Phone Alert Status (PASP) Specification v1.0

[22] Running Speed and Cadence Profile

[23] Running Speed and Cadence Service

[24] Cycling Speed and Cadence Profile

[25] Cycling Speed and Cadence Service

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1 Overview

The purpose of this document is to give an overview of the sample applications that are included in the Texas Instruments CC2540/41 *Bluetooth*® low energy (BLE) software development kit. It is recommended that you read [1] before attempting to use these sample applications, as some knowledge of the CC2540/41 BLE protocol stack and software is required.

1.1 Introduction

Version 1.4.1 of the Texas Instruments CC2540/41 BLE software development kit includes several sample applications implementing a variety of GATT-based profiles. Some of these implementations are based on specifications that have been adopted by the *Bluetooth* Special Interest Group (BT SIG), while others are based on specifications that are a work-in-progress and have not been finalized. In addition, some applications are not based on any standardized profile being developed by the BT SIG, but rather are custom implementations developed by Texas Instruments. In order to interoperate with other *Bluetooth* low energy devices (such as a mobile phone), an application would need to be written on the other device which implements the proper GATT client and/or server functionality that matches the CC2540/41 sample application. The status of the implementation of each profile/application is included in this document.

The information in this guide specifically mentions only CC2540 projects; however all of the applications and configurations (with the exception of those that use the USB interface) also can run on the CC2541. Be sure to open the correct project file depending on the chipset that is being used.

2 Blood Pressure Sensor

This sample project implements the Blood Pressure profiles in a BLE peripheral device to provide an example blood pressure monitor using simulated measurement data. The application implements the "Sensor" role of the blood pressure profile. The project is based on the adopted profile and service specifications for Blood Pressure ([2] and [3]). The project also includes the Device Information Service ([12]).

The project can be opened with the following IAR workspace file:

C:\Texas Instruments\BLE-CC254x-1.4.1

Projects\ble\BloodPressure\CC2540DB\bloodpressure.eww

2.1 Project Overview

The project structure is very similar to that of the SimpleBLEPeripheral project. The APP directory contains the application source code and header files. The project contains two configurations.

- **CC2540DK-MINI Keyfob Slave**: using the keyfob hardware platform.
- **CC2540 Slave:** using the SmartRF platform**.**

2.1.1 User Interface

There are two button inputs for this application.

KeyFob Right or SmartRF Joystick Right

When not connected, this button is used to toggle advertising on and off. When in a connection, this increases the value of various measurements.

KeyFob Left or SmartRF Joystick Up

This button cycle through different optional measurement formats.

2.1.2 Basic Operation

Power up the device and press the right button to enable advertising. From a blood pressure collector peer device, initiate a device discovery and connection procedure to discover and connect to the blood pressure sensor. The peer device should discover the blood pressure service and configure it to enable indication or notifications of the blood pressure measurement.

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The peer device may also discover the device information service for more information such as mfg and serial number.

Once blood pressure measurements have been enabled the application will begin sending data to the peer containing simulated measurement values. Pressing the left button cycles through different data formats as follows:

- **MMHG | TIMESTAMP | PULSE | USER | STATUS**
- **MMHG | TIMESTAMP**
- **MMHG**
- **KPA**
- **KPA | TIMESTAMP**
- **KPA |TIMESTAMP | PULSE**

If the peer device initiates pairing, it will be done following Just Works model since MITM is not set and DisplayOnly capability is available on the blood pressure sensor.

Upon termination, the BPM will not begin to advertising again until the button is pressed.

The peer device may also query the blood pressure for read only device information. Further details on the supported items are listed in the GATT_DB excel sheet for this project. Examples are model number, serial number, etc.

2.2 Software Description

The application is implemented in the file **bloodpressure.c**.

2.2.1 Initialization

The initialization of the application occurs in two phases: first, the **Bloodpressure_Init** function is called by the OSAL. This function configures parameters in the peripheral profile, GAP, and GAP bond manager. It also sets up the blood pressure service along with standard GATT and GAP services in the attribute server. Then it sets an OSAL **START_DEVICE_EVT** event. This triggers the second phase of the initialization, which can be found within the **Bloodpressure_ProcessEvent** function. During this phase, the **GAPRole_StartDevice** function is called to set up the GAP functions of the application. Then **GAPBondMgr_Register** is called to register with the bond manager.

2.2.2 Event Processing

The application has two main event processing functions, **Bloodpressure_ProcessEvent** and **Bloodpressure_ProcessOSALMsg**.

Function **Bloodpressure_ProcessEvent** handles events as follows:

- **SYS_EVENT_MSG**: Service the OSAL queue and process OSAL messages.
- **BP_START_DEVICE_EVT**: Start the device, as described in the previous section.
- **BP_START_DISCOVERY_EVT**: Start discovery, search for time service on collector.
- **TIMER_BPMEAS_EVT**: Perform final measurement
- **BP_TIMER_CUFF_EVT**: Perform a cutoff measurement
- **BP_DISCONNECT_EVT**: Disconnect after sending measurement

Function **Bloodpressure_ProcessOSALMsg** handles OSAL messages as follows:

- **KEY_CHANGE**: Handle key presses.
- **GATT_MSG_EVENT**: This will handle reception of time information from collector.

2.2.3 Callbacks

The application callback functions are as follows:

- **PeripheralStateNotificationCB**: This is the GAP event callback. It processes GAP events for startup and link connect/disconnect.

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- **bpServiceCB**: This is the blood pressure service callback. It handles enabling or disabling measurements.
- **TimeAppPairStateCB**: This is a GAPBOND callback to handle pairing states.
- **TimeAppPasscodeCB**: Returns the passcode of 0.

2.2.4 Sending Blood Pressure Measurement Indications

The application sends indication of the blood pressure measurement when configured to do so by the peer device.

When the peer device configures the blood pressure measurement for indication the application will receive a blood pressure service callback. The application starts a timer to begin periodic simulated blood pressure measurements. When the timer expires the application calls **bpSendStoredMeas** to build and send a measurement using the blood pressure service API. The application expects the peer device to send back an indication confirmation.

2.2.5 Sending Intermediate Measurement Notifications

The application sends notification of the blood pressure measurement when configured to do so by the peer device.

When the peer device configures the blood pressure measurement for notification the application will receive a blood pressure service callback. The application starts a timer to begin periodic simulated blood pressure measurements. When the timer expires the application calls **bloodPressureIMeasNotify** to build and send a measurement using the blood pressure service API.

2.2.6 Blood Pressure Measurement

	Flags	Blood Pressure Measurement Value			Time Stamp	Pulse Rate	User ID
		Systolic	Diastolic	MAP			
Size	1 octet	2 octets	2 octets	2 octets	7 octets	2 octets	1 octet

3 Health Thermometer

This sample project implements a Health Thermometer and Device Information profile in a BLE peripheral device to provide an example health thermometer application using simulated measurement data. The application implements the "Sensor" role of the Health Thermometer profile. The project is based on the adopted profile and service specifications for Health Thermometer (see [4] and [5]). The project also includes the Device Information Service ([12]).

The project can be opened with the following IAR workspace file:

C:\TexasInstruments\BLE-CC254x-1.4.1\Projects\ble\Thermometer\CC2540DB\thermometer.eww

3.1 Project Overview

The project structure is very similar to that of the SimpleBLEPeripheral project. The APP directory contains the application source code and header files. The project contains two configurations.

- ***CC2540DK-MINI Keyfob Slave***: using the keyfob hardware platform.
- ***CC2540 Slave***: using the SmartRF platform.

3.1.1 User Interface

There are two button inputs for this application.

KeyFob Right | SmartRF Joystick Right

When not connected and not configured to take measurements, this button is used to toggle advertising on and off.

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When in a connection or configured to take measurements, this increases the temperature by 1 degree Celsius. After 3 degrees in temperature rise, the interval will be set to 30 seconds and if configured, this will indicate to the peer an interval change initiated at the thermometer.

KeyFob Left | SmartRF Joystick Up

This button cycle through different measurement formats.

3.1.2 Basic Operation

Power up the device and press the right button to enable advertising. From a thermometer collector peer device, initiate a device discovery and connection procedure to discover and connect to the thermometer sensor. The peer device should discover the thermometer service and configure it to enable indication or notifications of the thermometer measurement. The peer device may also discover the device information service for more information such as mfg and serial number.

Once thermometer measurements have been enabled the application will begin sending data to the peer containing simulated measurement values. Pressing the left button cycles through different data formats as follows:

- **CELCIUS | TIMESTAMP | TYPE**
- **CELCIUS | TIMESTAMP**
- **CELCIUS**
- **FARENHEIT**
- **FARENHEIT | TIMESTAMP**
- **FARENHEIT | TIMESTAMP | TYPE**

If the peer device initiates pairing, the HT will request a passcode. The passcode is “000000”.

The HT operates in the following states:

- **Idle –** In this state, the thermometer will wait for the right button to be pressed to start advertising.
- **Idle Configured** – The thermometer waits the interval before taking a measurement and proceeding to Idle Measurement Ready state**.**
- **Idle Measurement Ready** – The thermometer has a measurement ready and will advertise to allow connection. The thermometer will periodically advertise in this state.
- **Connected Not Configured** - The thermometer may be configured to enable measurement reports. The thermometer will not send stored measurements until the CCC is enabled. Once connection is established, the thermometer sets a timer to disconnect in 20 seconds.
- **Connected Configured** - The thermometer will send any stored measurements if CCC is set to send measurement indications.
- **Connected Bonded** - The thermometer will send any stored measurements if CCC was previously set to send measurement indications.

The peer device may also query the thermometers read only device information. Examples are model number, serial number, etc.

3.2 Software Description

The application is implemented in the file **thermometer.c**.

3.2.1 Initialization

The initialization of the application occurs in two phases: first, the **Thermometer_Init** function is called by the OSAL. This function configures parameters in the peripheral profile, GAP, and GAP bond manager. It also sets up the thermometer service along with standard GATT and GAP services in the attribute server. Then it sets an OSAL **START_DEVICE_EVT** event. This triggers the second phase of the initialization, which can be found within the **Thermometer_ProcessEvent** function. During this phase, the **GAPRole_StartDevice** function is

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called to set up the GAP functions of the application. Then **GAPBondMgr_Register** is called to register with the bond manager.

3.2.2 Event Processing

The application has two main event processing functions, **Thermometer_ProcessEvent** and **Thermometer_ProcessOSALMsg**.

Function **Thermometer_ProcessEvent** handles events as follows:

- **SYS_EVENT_MSG**: Service the OSAL queue and process OSAL messages.
- **START_DEVICE_EVT**: Start the device, as described in the previous section.
- **TH_START_DISCOVERY_EVT**: Start discovery, search for time service on collector.
- **TH_PERIODIC_MEAS_EVT**: Start a measurement.
- **TH_PERIODIC_IMEAS_EVT**: Send immediate measurement.
- **TH_DISCONNECT_EVT**: Terminate connection.

Function **Thermometer_ProcessOSALMsg** handles OSAL messages as follows:

- **KEY_CHANGE**: Handle key presses.
- **GATT_MSG_EVENT**: This will handle reception of time information from collector.

3.2.3 Callbacks

The application callback functions are as follows:

- **PeripheralStateNotificationCB**: This is the GAP event callback. It processes GAP events for startup and link connect/disconnect.
- **ThermometerCB**: This is the thermometer service callback. It handles enabling or disabling measurements.
- **TimeAppPairStateCB**: This is a GAPBOND callback to handle pairing states.
- **TimeAppPasscodeCB**: Returns the passcode of 0.

3.2.4 Sending Temperature Indications

The application enables indication of the thermometer measurement when configured to do so by the peer device.

When the peer device configures the thermometer measurement for indication the application will receive a thermometer service callback. The application starts a timer to begin periodic simulated thermometer measurements. When the timer expires the application calls **thermometerMeasIndicate** to build and store a measurement. Once a measurement is ready, the thermometer will enter connectable state and send advertisements. If the peer device connects and the CCC is enabled, the thermometer will send the stored measurements. The thermometer expects the peer device to send back an indication confirmation for each indication sent.

3.2.5 Sending Intermediate Measurement Notifications

The application sends notification of the thermometer measurement when configured to do so by the peer device.

When the peer device configures the thermometer measurement for notification the application will receive a thermometer service callback. The application starts a timer to begin periodic simulated thermometer measurements. When the timer expires the application calls **thermometerIMeasIndicate** to build and send a measurement using the thermometer service API.

3.2.6 Sending Interval Change Indications

If the CCC for interval change is enabled, the thermometer will send an indication to the peer if the interval is changed by the thermometer. This can be triggered by pressing the right button three times which will increase the simulated temperature by 3 degrees and also reset the interval to 30 seconds.

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3.2.7 Thermometer Measurement Format

	Flags	Temperature Measurement Value	Time Stamp (if present)	Temperature Type (if present)
Size	1 octet	4 octets	0 or 7 octets	0 or 1 octet
Units	None	Based on bit 0 of Flags field	Smallest unit in seconds	None

4 Heart Rate Sensor

This sample project implements the Heart Rate and Battery profiles in a BLE peripheral device to provide an example heart rate sensor using simulated measurement data. The application implements the "Sensor" role of the Heart Rate profile and the "Battery Reporter" role of the Battery profile. The project is based on adopted profile and service specifications for Health Rate ([6] and [7]). The project also includes the Device Information Service ([12]).

The project can be opened with the following IAR workspace file:

C:\Texas Instruments\BLE-CC254x-1.4.1\Projects\ble\HeartRate\CC2540DB\heartrate.eww

4.1 Project Overview

The project structure is very similar to that of the SimpleBLEPeripheral project. The APP directory contains the application source code and header files. The project contains one configuration, **CC2540DK-MINI Keyfob Slave**, using the keyfob hardware platform.

4.1.1 User Interface

When not connected, the keyfob's right button is used to toggle advertising on and off. When in a connection, the keyfob's left button cycles through different heart rate sensor data formats and the right button sends a battery level-state notification.

4.1.2 Basic Operation

Power up the device and press the right button to enable advertising. From a heart rate collector peer device, initiate a device discovery and connection procedure to discover and connect to the heart rate sensor. The peer device should discover the heart rate service and configure it to enable notifications of the heart rate measurement. The peer device may also discover and configure the battery service for battery level-state notifications.

Once heart rate measurement notifications have been enabled the application will begin sending data to the peer containing simulated measurement values. Pressing the left button cycles through different data formats as follows:

- Sensor contact not supported.
- Sensor contact not detected.
- Sensor contact and energy expended set.
- Sensor contact and R-R Interval set.
- Sensor contact, energy expended, and R-R Interval set.
- Sensor contact, energy expended, R-R Interval, and UINT16 heart rate set.
- Nothing set.

If the peer device initiates pairing then the devices will pair. Only "just works" pairing is supported by the application (pairing without a passcode).

The application advertises using either a fast interval or a slow interval. When advertising is initiated by a button press or when a connection is terminated due to link loss, the application will start advertising at the fast interval for 30 seconds followed by the slow interval. When a connection is terminated for any other reason the application will start advertising at the slow interval. The advertising intervals and durations are configurable in file **heartrate.c**.

4.2 Software Description

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The application is implemented in the file **heartrate.c**.

4.2.1 Initialization

The initialization of the application occurs in two phases: first, the **HeartRate_Init** function is called by the OSAL. This function configures parameters in the peripheral profile, GAP, and GAP bond manager. It also sets up the heart rate service and the battery service along with standard GATT and GAP services in the attribute server. Then it sets an OSAL **START_DEVICE_EVT** event. This triggers the second phase of the initialization, which can be found within the **HeartRate_ProcessEvent** function. During this phase, the **GAPRole_StartDevice** function is called to set up the GAP functions of the application. Then **GAPBondMgr_Register** is called to register with the bond manager.

4.2.2 Event Processing

The application has two main event processing functions, **HeartRate_ProcessEvent** and **HeartRate_ProcessOSALMsg**.

Function **HeartRate_ProcessEvent** handles events as follows:

- **SYS_EVENT_MSG**: Service the OSAL queue and process OSAL messages.
- **START_DEVICE_EVT**: Start the device, as described in the previous section.
- **HEART_PERIODIC_EVT**: Send periodic heart rate measurements.
- **BATT_PERIODIC_EVT**: Check the battery level and send notification if it changed.

Function **HeartRate_ProcessOSALMsg** handles OSAL messages as follows:

- **KEY_CHANGE** messages: Call function **HeartRate_HandleKeys** to handle key presses.

4.2.3 Callbacks

The application callback functions are as follows:

- **HeartRateGapStateCB**: This is the GAP event callback. It processes GAP events for startup and link connect/disconnect.
- **HeartRateCB**: This is the heart rate service callback. It handles enabling or disabling periodic heart rate measurements when notifications of the heart rate measurement are enabled or disabled.
- **HeartRateBattCB**: This is the battery service callback. It handles enabling or disabling periodic battery measurements when notifications of the battery level-state are enabled or disabled.

4.2.4 Sending Notifications

The application sends notifications of the heart rate measurement and the battery level-state when configured to do so by the peer device.

When the peer device configures the heart rate measurement for notification the application will receive a heart rate service callback. The application starts a timer to begin periodic simulated heart rate measurements. When the timer expires the application calls **heartRateMeasNotify** to build and send a measurement using the heat rate service API.

When the peer device configures the battery level-state for notification the application will receive a battery service callback. The application starts a timer to periodically measure the battery level. When the timer expires the application calls battery service API function **Batt_MeasLevel** to measure the battery level using the CC2450 ADC. Notification of the battery level-state is handled inside the battery service; if the battery level has dropped since the previous measurement a notification is sent.

5 Cycling Speed and Cadence (CSC) Sensor

This sample project implements the Cycling Speed and Cadence (CSC) profile in a BLE peripheral device to provide a sample application of sensor that would be placed on a bicycle, using simulated measurement data. The application implements the “Sensor” role of the Cycling

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Speed and Cadence Profile. This profile also makes use of the optional Device Info Service, which has default values that may be altered at compile or runtime to aid in identifying a specific BLE device. This information is available in:

C:\Texas Instruments\BLE-CC254x-1.4.1\Projects\ble\Profiles\DevInfo\devinfoservice.c

The project can be opened with the following IAR workspace file:

C:\Texas Instruments\BLE-CC254x-1.4.1\Projects\ble\CyclingSensor\CC2541DB\CyclingSensor.eww

5.1 Project Overview

The project is very similar to the heart rate sensor project. The APP directory contains the application source code and header files. The project contains two configurations:

- ***CC2541DK-MINI Keyfob Slave***: using the keyfob hardware platform.
- ***CC2541***: using the SmartRF platform.

5.1.1 User Interface

When not connected, the keyfob's right button is used to toggle advertising on and off. When in a connection, the keyfob's left button cycles through different cycling speed and cadence sensor data formats.

Holding both keys down for 5 seconds initiates a "soft reset." This includes:

- Terminate all current connections
- Clearing all bond data
- Clearing white list of all peer addresses

5.1.2 Basic Operation

Power up the device and press the right button to enable advertising. From a CSC collector peer device, initiate a device discovery and connection procedure to discover and connect to the cycling sensor. The peer device should receive a slave security request and initiate a bond. Once bonded, the collector should discover the CSC service and configure it to enable cycling speed and cadence measurements.

Once CSC measurement notifications have been enabled the application will begin sending data to the peer containing simulated measurement values. Pressing the left button cycles through different data formats as follows:

- Sensor at rest (no speed or cadence detected).
- Sensor detecting speed but no cadence.
- Sensor detecting cadence but no speed.
- Sensor detecting speed and cadence.

The application advertises using either a fast interval or a slow interval. When advertising is initiated by a button press or when a connection is terminated due to link loss, the application will start advertising at the fast interval for 30 seconds. If the sensor has successfully bonded to a peer device and stored the devices address in its white list, then for the for the first 10 seconds of advertising the sensor will only attempt to connect to any device addresses stored in its white list. After 10 seconds, the sensor will attempt to connect to any peer device that wishes to connect. Independent of white list use, after 30 seconds of fast interval connection, a 30 second period of slow interval advertising passes. After this, the device sleeps and waits for the right button to be pressed before resuming advertising again.

If the device terminates connection for any other reason, the sensor will advertise for 60 seconds at a slow interval and then sleep if no connection is made. It will begin advertising again only if the right button is pressed.

5.2 Software Description

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The application is implemented in the file **cyclingSensor.c**.

5.2.1 Initialization

Initialization of the application occurs in two phases: first, the **CyclingSensor_Init** function is called by the OSAL. This function configures parameters in the peripheral profile, GAP, and GAP bond manager. It also sets up the CSC service along with standard GATT and GAP services in the attribute server. Then it sets an OSAL **START_DEVICE_EVT** event. This triggers the second phase of the initialization, which can be found within the **CyclingSensor_ProcessEvent** function. During this phase, the **GAPRole_StartDevice** function is called to set up the GAP functions of the application. Then **GAPBOND_Mgr_Register** is called to register with the bond manager.

5.2.2 Event Processing

The application has two main event processing functions, **CyclingSensor_ProcessEvent** and **sensor_ProcessOSALMsg**.

Function **CyclingSensor_ProcessEvent** handles events as follows:

- **SYS_EVENT_MSG:** Service the OSAL queue and process OSAL messages.
- **START_DEVICE_EVT:** Start the device, as described in the previous section.
- **CSC_PERIODIC_EVT:** Send periodic CSC measurements.
- **CSC_CONN_PARAM_UPDATE_EVT:** send parameter update until successful
- **CSC_NEGLET_TIMEOUT_EVT:** see section 5.2.8
- **CSC_RESET_EVT:** reset device as described above

Function **cycling_ProcessOSALMsg** handles OSAL messages as follows:

- **KEY_CHANGE** message: Call function **sensor_HandleKeys** to handle key presses.

5.2.3 Callbacks

The application callback functions are as follows:

- **SensorGAPStateCB**: This is the GAP event callback. It processes GAP events for startup and link connect/disconnect.
- **SensorCB**: This is the CSC service callback. It handles enabling or disabling periodic CSC measurements when notifications of the CSC measurements are enabled or disabled. Additionally, it informs the application when the peer device has updated a sensor location or changed the cumulative distance traveled.

5.2.4 Sending Notifications

The application sends notifications of the CSC measurements when configured to do so by the peer device. When the peer device configures the CSC measurements for notification the application will receive a CSC service callback. The application starts a timer to begin periodic simulated CSC measurements for a bicycle. When the timer expires the application calls **sensorMeasNotify** to build and send a measurement using the CSC service API.

5.2.5 Confirming Indications

When the peer device writes to the sensors control point characteristic the peer device will receive an indication in response. When the indication is received by the peer device, the device must send an **ATT_HandleValueConfirmation** back to the server.

5.2.6 Reading from the Sensor

The CSC service has 2 readable characteristics: Features and Sensor Location. Sending a read request to the Features characteristic triggers a response packet containing a byte array of the feature capabilities of the sensor which are as follows:

- Wheel revolutions
- Crank revolutions

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- Total distance
- Multiple sensor locations

Sending a read request to the Sensor Location characteristic triggers a response packet containing the set position of the sensor on the bicycle. This value may be set by writing to the control point (see below), requesting a sensor location update.

5.2.7 Writing to the Sensor

The CSC service has one writeable characteristic: the Control Point. A write request can be set with the following requests:

- **CSC_SET_CUMM_VAL:** Set the total distance traveled field.
- **CSC_START_SENS_CALIB:** Calibrate the sensor. Not supported under current profile spec, but it is required.
- **CSC_UPDATE_SENS_LOC:** Update the location of the sensor.
- **CSC_REQ_SUPP_SENS_LOC**: Request the list of supported sensor locations.

A response will be sent as an indication to the peer device after a write response it received. The indication includes the **CSC_COMMAND_RSP** code, the requested operation code, and a code indicating success or failure. If the command was a request for a list of valid sensor locations, then the indication will also include a byte array containing the valid sensor locations.

5.2.8 Neglect Timer

This device has a compile time option that allows the sensor to terminate a connection if it sees no user input for 15 seconds. In the context of this application, this means that after the device has connected and notifications are disabled, the application starts a timer. This timer is restarted whenever a read or write request comes from the peer device, and is disabled while notifications are enabled. If the value **USING_NEGLECT_TIMEOUT** is set to **FALSE** at compile, then this timer is permanently disabled at runtime.

6 Running Speed and Cadence (RSC) Sensor

This sample project implements the Running Speed and Cadence (RSC) profile in a BLE peripheral device to provide a sample application of sensor that would be placed on a bicycle, using simulated measurement data. The application implements the “Sensor” role of the Running Speed and Cadence Profile. This profile also makes use of the optional Device Info Service in the same manner as the Cycling Sensor.

The project can be opened with the following IAR workspace file:

C:\Texas Instruments\BLE-CC254x-1.4.1\Projects\ble\RunningSensor\CC2541DB\RunningSensor.eww

6.1 Project Overview

The project is very similar to the Cycling Sensor project. The APP directory contains the application source code and header files. The project contains two configurations:

- ***CC2541DK-MINI Keyfob Slave***: using the keyfob hardware platform.
- ***CC2541***: using the SmartRF platform.

6.1.1 User Interface

When not connected, the keyfob’s right button is used to toggle advertising on and off. When in a connection, the keyfob’s left button cycles through different running speed and cadence sensor data formats.

Holding both keys down for 5 seconds initiates a “soft reset.” This includes:

- Terminate all current connections
- Clearing all bond data
- Clearing white list of all peer addresses

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6.1.2 Basic Operation

Power up the device and press the right button to enable advertising. From a RSC collector peer device, initiate a device discovery and connection procedure to discover and connect to the cycling sensor. The peer device should receive a slave security request and initiate a bond. Once bonded, the collector should discover the RSC service and configure it to enable running speed and cadence measurements.

Once RSC measurement notifications have been enabled the application will begin sending data to the peer containing simulated measurement values. Pressing the left button cycles through different data formats as follows:

- At rest: neither instantaneous stride length nor total distance is included in measurement.
- Stride: instantaneous stride length is included in measurement.
- Distance: total distance is included in measurement.
- All: both stride length and total distance are included in measurement.

The application advertises using either a fast interval or a slow interval. When advertising is initiated by a button press or when a connection is terminated due to link loss, the application will start advertising at the fast interval for 30 seconds. If the sensor has successfully bonded to a peer device and stored the devices address in its white list, then for the for the first 10 seconds of advertising the sensor will only attempt to connect to any device addresses stored in its white list. After 10 seconds, the sensor will attempt to connect to any peer device that wishes to connect. Independent of white list use, after 30 seconds of fast interval connection, a 30 second period of slow interval advertising passes. After this, the device sleeps and waits for the right button to be pressed before resuming advertising again.

If the device terminates connection for any other reason, the sensor will advertise for 60 seconds at a slow interval and then sleep if no connection is made. It will begin advertising again only if the right button is pressed.

6.2 Software Description

The application is implemented in the file **runningSensor.c**.

6.2.1 Initialization

Initialization of the application occurs in two phases: first, the **RunningSensor_Init** function is called by the OSAL. This function configures parameters in the peripheral profile, GAP, and GAP bond manager. It also sets up the RSC service along with standard GATT and GAP services in the attribute server. Then it sets an OSAL **START_DEVICE_EVT** event. This triggers the second phase of the initialization, which can be found within the **RunningSensor_ProcessEvent** function. During this phase, the **GAPRole_StartDevice** function is called to set up the GAP functions of the application. Then **GAPBOND_Mgr_Register** is called to register with the bond manager.

6.2.2 Event Processing

The application has two main event processing functions, **RunningSensor_ProcessEvent** and **sensor_ProcessOSALMsg**.

Function **RunningSensor_ProcessEvent** handles events as follows:

- **SYS_EVENT_MSG:** Service the OSAL queue and process OSAL messages.
- **START_DEVICE_EVT:** Start the device, as described in the previous section.
- **RSC_PERIODIC_EVT:** Send periodic CSC measurements.
- **RSC_CONN_PARAM_UPDATE_EVT:** send parameter update until successful
- **RSC_NEGLECT_TIMEOUT_EVT:** see section 6.2.8
- **RSC_RESET_EVT:** reset device as described above

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Function **cycling_ProcessOSALMsg** handles OSAL messages as follows:

- **KEY_CHANGE** message: Call function **sensor_HandleKeys** to handle key presses.

6.2.3 Callbacks

The application callback functions are as follows:

- **SensorGAPStateCB**: This is the GAP event callback. It processes GAP events for startup and link connect/disconnect.
- **SensorCB**: This is the RSC service callback. It handles enabling or disabling periodic RSC measurements when notifications of the RSC measurements are enabled or disabled. Additionally, it informs the application when the peer device has updated a sensor location or changed the cumulative distance traveled.

6.2.4 Sending Notifications

The application sends notifications of the RSC measurements when configured to do so by the peer device. When the peer device configures the RSC measurements for notification the application will receive a RSC service callback. The application starts a timer to begin periodic simulated RSC measurements for a bicycle. When the timer expires the application calls **sensorMeasNotify** to build and send a measurement using the RSC service API.

6.2.5 Confirming Indications

When the peer device writes to the sensors control point characteristic the peer device will receive an indication in response. When the indication is received by the peer device, the device must send an **ATT_HandleValueConfirmation** back to the server.

6.2.6 Reading from the Sensor

The RSC service has 2 readable characteristics: Features and Sensor Location. Sending a read request to the Features characteristic triggers a response packet containing a byte array of the feature capabilities of the sensor which are as follows:

- Instantaneous Stride Length
- Walking or Running Status
- Total distance
- Multiple sensor locations
- Sensor Calibration Procedure Supported

Sending a read request to the Sensor Location characteristic triggers a response packet containing the set position of the sensor on the body. This value may be set by writing to the control point (see below), requesting a sensor location update.

6.2.7 Writing to the Sensor

The CSC service has one writeable characteristic: the Control Point. A write request can be set with the following requests:

- **RSC_SET_CUMM_VAL:** Set the total distance traveled field.
- **RSC_START_SENS_CALIB:** Calibrate the sensor. Not supported under current profile spec, but it is required.
- **RSC_UPDATE_SENS_LOC:** Update the location of the sensor.
- **RSC_REQ_SUPP_SENS_LOC**: Request the list of supported sensor locations.

A response will be sent as an indication to the peer device after a write response it received. The indication includes the R**SC_COMMAND_RSP** code, the requested operation code, and a code indicating success or failure. If the command was a request for a list of valid sensor locations, then the indication will also include a byte array containing the valid sensor locations.

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6.2.8 Neglect Timer

This device has a compile time option that allows the sensor to terminate a connection if it sees no user input for 15 seconds. In the context of this application, this means that after the device has connected and notifications are disabled, the application starts a timer. This timer is restarted whenever a read or write request comes from the peer device, and is disabled while notifications are enabled. If the value **USING_NEGLECT_TIMEOUT** is set to **FALSE** at compile, then this timer is permanently disabled at runtime.

7 Glucose Collector

This sample project implements a Glucose Collector. The application is designed to connect to the glucose sensor sample application to demonstrate the operation of the Glucose Profile.

7.1 Project Overview

The Glucose Collector project structure is very similar to that of the SimpleBLECentral project. The APP directory contains the application source code and header files. The project contains one configuration, **CC2540EM Master**, using the SmartRF05EB + CC2540EM hardware platform.

7.1.1 User Interface

The SmartRF05EB joystick and display provide a user interface for the application. The joystick and buttons are used as follows:

- Joystick Up: If not connected, start or stop device discovery. If connected to a glucose sensor, request the number of records that meet configured filter criteria.
- Joystick Left: Scroll through device discovery results. If connected to a glucose sensor, send a record access abort message.
- Joystick Center: Connect or disconnect to/from the currently selected device.
- Joystick Right: If connected, request records that meet configured filter criteria.
- Joystick Down: If connected, clear records that meet configured filter criteria. If not connected, erase all bonds.

The LCD display is used to display the following information:

- Device BD address.
- Device discovery results.
- Connection state.
- Pairing and bonding status.
- Number of records requested.
- Sequence number, glucose concentration, and Hba1c value of received glucose measurement and context notifications.

7.1.2 Basic Operation

When the application powers up it displays "Gluc. Collector" and the BD address of the device. Press Joystick Up to start device discovery. When discovery completes the number of devices found will be displayed. Press Joystick Left to scroll through the devices.

To connect to the selected device press Joystick Center. The connection status will be displayed. Once connected, the application will attempt to discover the Glucose service and Device Information service on the peer device. Since the Glucose profile required security the application will also initiate bonding. When the bonding is complete, other operations such as reading or erasing records can be performed described in the previous section. It is important to note that, due to the input / output capabilities of the keyfob, we have to use a fixed password in order to achieve authenticated pairing. We have set the I/O capabilities of the keyfob to display only. The idea is that the keyfob will display the passcode and it will be entered on the SmartRF. However, because the keyfob and SmartRF don't actually have these I/O capabilities, we hard code the passcode in the sensor and collector projects to be 19655.

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To disconnect press Joystick Center again. To reconnect to the same device again press Joystick Center again.

7.1.3 Record Filter Configuration

Glucose record requests use filters to select the records that will be operated on by the request. These filters are configured in the collector using compile time configuration.

In file glucoseCollector.c, macro GLUCOSE_FILTER_ENABLED controls whether filters are used. When set to FALSE, operations that read, erase, or get the number of records will operate on all records. When set to TRUE, these operations will use either a time filter or sequence number filter, as configured in macro DEFAULT_FILTER_TYPE. When set to CTL_PNT_FILTER_SEQNUM the collector will filter on sequence number. When set to CTL_PNT_FILTER_TIME the collector will filter on time.

File glucoseCollector.c has hardcoded time and sequence number filter values. These are set in variables filterTime1, filterTime2, filterSeqNum1, and filterSeqNum2.

7.2 Software Description

The application is implemented in the following files:

- **glucoseCollector.c**: Main initialization, event handling and callback functions.
- **glucose_config.c**: Characteristic configuration functions.
- **glucose_discovery.c**: Service discovery functions.
- **glucose_ind.c**: Indication and notification handling functions.
- **glucose_ctlpnt.c**: Record access control point functions.

7.2.1 Initialization

The initialization of the application occurs in two phases: first, the **GlucColl_Init** function is called by the OSAL. This function configures parameters in the central profile, GAP, and GAP bond manager and also initializes GATT for client operation. It also sets up standard GATT and GAP services in the attribute server. Then it sets an OSAL **START_DEVICE_EVT** event. This triggers the second phase of the initialization, which can be found within the **GlucColl_ProcessEvent** function. During this phase, the **GAPCentralRole_StartDevice** function is called to set up the GAP functions of the application. Then **GAPBondMgr_Register** is called to register with the bond manager.

7.2.2 Event Processing

The application has two main event processing functions, **GlucColl_ProcessEvent** and **GlucColl_ProcessOSALMsg**.

Function **GlucColl_ProcessEvent** handles events as follows:

- **SYS_EVENT_MSG**: Service the OSAL queue and process OSAL messages.
- **START_DEVICE_EVT**: Start the device, as described in the previous section.
- **START_DISCOVERY_EVT**: Start service discovery.
- **PROCEDURE_TIMEOUT_EVT**: A glucose record access procedure has timed out.

Function **GlucColl_ProcessOSALMsg** handles OSAL messages as follows:

- **KEY_CHANGE** messages: Call function GlucColl_HandleKeys to handle keypresses.
- **GATT_MSG_EVENT** messages: Call function GlucCollProcessGATTMsg to handle messages from GATT.

7.2.3 Callbacks

The application callback functions are as follows:

- **GlucCollCentralEventCB**: This is the GAP event callback. It processes GAP events for initialization, device discovery, and link connect/disconnect.

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- **GlucCollPairStateCB**: This is the GAP bond manager state callback. It displays the status of pairing and bonding operations.
- **GlucCollPasscodeCB**: This is the GAP bond manager passcode callback. It generates and displays a passcode.

7.2.4 Service Discovery

The GlucColl application performs service discovery for the Glucose service and Device Information service. Discovery is initiated when a connection is established by setting OSAL event **START_DISCOVERY_EVT**. This will result in execution of function **GlucCollCentralStartDiscovery**, which performs primary service discovery for the Glucose service and Device ID service. When GATT events are received during service discovery function **glucCollProcessGATTMsg** is called. This function processes the results of the previous GATT procedure and initiates the next step in the discovery process.

7.2.5 Service Configuration

When service discovery completes the service configuration procedure is initiated. This procedure reads and writes characteristics of interest in the discovered services.

The main service configuration function is **glucoseConfigNext**. This function searches the cached handle array for the next characteristic of interest and performs a read or write on that characteristic.

When a GATT read or write response is received, function **glucoseConfigGattMsg** is called. This function processes the received response and performs an action, such as updating the clock display, and then calls **glucoseConfigNext** to initiate the next read or write.

The application writes all discovered client characteristic configuration descriptors to enable notification or indication. The application also reads some characteristics and then performs no action with the received response. This is done simply for testing and demonstration.

7.2.6 Record Access Control Point

The Glucose profile uses a characteristic called the record access control point to perform operations on glucose measurement records stored by the glucose sensor. File glucose_ctlpnt.c contains functions for sending control point messages. The following different operations can be performed:

- Retrieve stored records.
- Delete stored records.
- Abort an operation in progress.
- Report number of stored records.

The collector sends control point messages to a sensor by using write requests, while the sensor sends control point messages to the collector by using indications. When records are retrieved, the glucose measurement and glucose context are sent via notifications on their respective characteristics.

If an expected response is not received, the operation will time out after 30 seconds and the collector will close the connection.

8 Glucose Sensor

This sample project implements the Glucose profile in a BLE peripheral device to provide an example glucose sensor using simulated measurement data. The application implements the "Sensor" role of the Glucose Profile.

8.1 Project Overview

The project structure is very similar to that of the SimpleBLEPeripheral project. The APP directory contains the application source code and header files. The project contains one configuration, **CC2540DK-MINI Keyfob Slave**, using the keyfob hardware platform.

8.1.1 User Interface

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When not connected, the keyfob's right button is used to toggle advertising on and off. When in a connection, the keyfob's left button sends a glucose measurement and glucose context.

8.1.2 Basic Operation

Power up the device and press the right button to enable advertising. From a glucose collector peer device, initiate a device discovery and connection procedure to discover and connect to the glucose sensor. The peer device should discover the glucose service and configure it to enable notifications of the glucose measurement. It may also enable notifications of the glucose measurement context.

Once glucose measurement notifications have been enabled a simulated measurement can be sent by pressing the left button. If the peer device has also enabled notifications of the glucose measurement context then this will be sent following the glucose measurement.

The peer device may also write commands to the record access control point to retrieve or erase stored glucose measurement records. The sensor has four hardcoded simulated records.

If the peer device initiates pairing then the devices will pair. Only "just works" pairing is supported by the application (pairing without a passcode).

8.2 Software Description

The application is implemented in the file **glucose.c**.

8.2.1 Initialization

The initialization of the application occurs in two phases: first, the **Glucose_Init** function is called by the OSAL. This function configures parameters in the peripheral profile, GAP, and GAP bond manager. It also sets up the glucose service along with standard GATT and GAP services in the attribute server. Then it sets an OSAL **START_DEVICE_EVT** event. This triggers the second phase of the initialization, which can be found within the **Glucose_ProcessEvent** function. During this phase, the **GAPRole_StartDevice** function is called to set up the GAP functions of the application. Then **GAPBondMgr_Register** is called to register with the bond manager.

8.2.2 Event Processing

The application has two main event processing functions, **Glucose_ProcessEvent** and **Glucose_ProcessOSALMsg**.

Function **Glucose_ProcessEvent** handles events as follows:

- **SYS_EVENT_MSG**: Service the OSAL queue and process OSAL messages.
- **START_DEVICE_EVT**: Start the device, as described in the previous section.

Function **Glucose_ProcessOSALMsg** handles OSAL messages as follows:

- **KEY_CHANGE** messages: Call function **Glucose_HandleKeys** to handle keypresses.
- **CTL_PNT_MSG**: Call function **glucoseProcessCtlPntMsg** to process record access control point messages.

8.2.3 Callbacks

The application callback functions are as follows:

- **glucoseGapStateCB**: This is the GAP event callback. It processes GAP events for startup and link connect/disconnect.
- **glucosePairStateCB**: This is the GAP pairing state callback. It is used to store the bonding state of pairing.

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- **GlucoseCB**: This is the glucose service callback. It handles enabling or disabling of indications of the glucose measurement, context, glucose measurement context, and record access control point.

8.2.4 Sending Notifications and Indications

The application sends notifications of the glucose measurement and glucose measurement context when configured to do so by the peer device. The application sends indications of the record access control point when configured to do so by the peer device.

Transmissions of notifications are paced by using a timer to trigger the next transmission. The period of the timer is set in macro DEFAULT_NOTI_PERIOD.

8.2.5 Record Access Control Point Processing

The record access control point is used to perform retrieval and management of measurements stored in the glucose sensor. The record access control point has its own protocol to perform these functions. The application implements this protocol in function **glucoseProcessCtlPntMsg**. This function is executed when the peer device writes a message to the control point.

Function **glucoseProcessCtlPntMsg** processes received messages by decoding the message operation and operands. It then executes function **glucoseCtlPntHandleOpcode** to perform the detailed processing required by the operation.

A set of example utility functions is implemented that processes the simulated glucose measurement data. These utility functions perform operations such as:

- Find records earlier than or later than a given time and date.
- Find records within a range of two given times and dates.
- Find first, last, or all records.

9 HID Advanced Remote Control

The HID Advanced Remote Control is a sample application which implements a HID mouse, keyboard, and consumer controls. A gyro and accelerometer act as inputs allow the user to move a mouse by simply pointing the remote. The example is HID compliant and has been tested with Windows8 for example. For more information, refer to the *TI_CC2541_ARC_User_Guide* included with this release.

The example applications for both peripheral and HID Dongle are located at

C:\TexasInstruments\BLE-CC254x-1.4.1\Projects\ble\HIDAdvRemote\ HIDAdvRemote.eww

C:\TexasInstruments\BLE-CC254x-1.4.1\Projects\ble\HIDAdvRemoteDongle\ HIDAdvRemoteDongle.eww

10 HID Emulated Keyboard

This sample project implements the HID Over GATT profile in a BLE peripheral device to provide an example of how a HID keyboard can be emulated with a simple two button remote control device. The project is based on adopted profile and service specifications for HID over GATT ([8] and [9]) and Scan Parameters ([10] and [11]). The project also includes the Device Information Service ([12]) and Battery Service ([13]).

The project can be opened with the following IAR workspace file:

C:\TexasInstruments\BLE-CC254x-1.4.1\Projects\ble\HIDEmuKbd\CC2540DB\ HidEmuKbd.eww

10.1 Project Overview

The project structure is very similar to that of the SimpleBLEPeripheral project. The APP directory contains the application source code and header files.

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The project contains one configuration, **CC2540DK-MINI Keyfob Slave**, using the keyfob hardware platform.

10.1.1 User Interface

When not connected and not already advertising, pressing either button will initiate advertising. When in a connection, the keyfob's left button sends a “left arrow” key and the right button sends a “right arrow” key.

Note that a secure connection must be established before key presses will be sent to the peer device.

10.1.2 Basic Operation

Power up the device and press either button to enable advertising. From a HID Host peer device, initiate a device discovery and connection procedure to discover and connect to the HID device. The peer device should discover the HID service and recognize the device as a keyboard. The peer device may also discover and configure the battery service for battery level-state notifications.

By default the HID device requires security and uses “just works” pairing. After a secure connection is established and the HID host configures the HID service to enable notifications, the HID device can send HID key presses to the HID host. A notification is sent when a button is pressed and when a button is released.

The HID host can send keyboard LED information to the device to illuminate the keyfob LEDs. The “caps lock” setting controls the green LED and the “num lock” setting controls the red LED.

If there is no HID activity for a period of time (20 seconds by default) the HID device will disconnect. When the connection is closed the HID device will not advertise. Press either button to enable advertising and connect again.

10.2 Software Description

The project uses the following services and profiles:

- Battery service (battservice.c and battservice.h).
- Device Information service (devinfoservice.c and devinfoservice.h).
- Scan Parameters service (scanparamservice.c and scanparamservice.h).
- HID service for keyboard (hidkbdservice.c hidkbdservice.h).
- HID device profile (hiddev.c and hiddev.h). This is a common profile for HID devices that performs the following procedures:
    - Advertising, connection procedures, and security procedures.
    - Sending HID notifications.
    - Handling read and write of HID service characteristics.

10.3 HidEmuKbd Application

The application is implemented in the file **hidemukbd.c**.

10.3.1 Initialization

The **HidEmuKbd_Init** function is called by the OSAL to perform task initialization procedures. This function sets parameters for the peripheral profile, GAP bond manager, and Battery service. The function also registers the HID keyboard service and HID device profile.

10.3.2 Event Processing

The application has two main event processing functions, **HidEmuKbd_ProcessEvent** and **HidEmuKbd_ProcessOSALMsg**.

Function **HidEmuKbd_ProcessEvent** handles the **SYS_EVENT_MSG** event, which services the OSAL queue and processes OSAL messages.

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Function **HidEmuKbd_ProcessOSALMsg** handles OSAL messages as follows:

- **KEY_CHANGE** messages: Call function **HidEmuKbd_HandleKeys** to handle keypresses.

10.3.3 Callbacks

The application callback functions are as follows:

- **hidEmuKbdRptCB**: This is the HID device report callback. It processes HID reports received from the HID host.
- **hidEmuKbdEvtCB**: This is the HID device event callback. It handles HID events, such as enter/exit suspend or enter/exit boot mode.

10.3.4 Sending Notifications

The application sends notifications containing HID keypress data when a button is pressed. This is done in function **HidEmuKbd_HandleKeys** by calling HID device profile function **HidDev_Report**. The details of sending notifications are handled in the HID device profile.

10.4 HID Device Profile

The HID device profile is implemented in the file **hiddev.c**.

10.4.1 Initialization

The initialization of occurs in two phases: first, the **HidDev_Init** function is called by OSAL. This function sets up the battery, device information, and scan parameters services along with standard GATT and GAP services in the attribute server. Then it sets an OSAL **START_DEVICE_EVT** event. This triggers the second phase of the initialization, which can be found within the **HidDev_ProcessEvent** function. During this phase, the **GAPRole_StartDevice** function is called to set up the GAP functions of the application. Then **GAPBondMgr_Register** is called to register with the bond manager.

10.4.2 Event Processing

The application has two main event processing functions, **HidDev_ProcessEvent** and **HidDev_ProcessOSALMsg**.

Function **HidDev_ProcessEvent** handles events as follows:

- **SYS_EVENT_MSG**: Service the OSAL queue and process OSAL messages.
- **START_DEVICE_EVT**: Start the device, as described in the previous section.
- **HID_IDLE_EVT**: Terminate the connection if idle.
- **BATT_PERIODIC_EVT**: Check the battery level and send notification if it changed.

Function **HidDev_ProcessOSALMsg** handles OSAL messages as follows:

- **GATT_MSG_EVENT** messages: Call function **hidDevProcessGattMsg** to process GATT messages.

10.4.3 Callbacks

The HID device profile callback functions are as follows:

- **HidDevGapStateCB**: This is the GAP event callback. It processes GAP events for startup and link connect/disconnect.
- **hidDevPairStateCB**: This is the pairing state callback. Handle pairing events.
- **hidDevPasscodeCB**: This is the passcode callback. Send a passcode response.
- **HidDevBattCB**: This is the battery service callback. It handles enabling or disabling periodic battery measurements when notifications of the battery level-state are enabled or disabled.

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- **hidDevScanParamCB**: This is the scan parameters service callback. Handle a scan parameters service event.

10.4.4 GATT Read and Write Callbacks

The HID device profile GATT read and write callbacks, **HidDev_WriteAttrCB** and **HidDev_ReadAttrCB** handle reading and writing of all HID characteristics. These functions are used by a HID service when registering the service with GATT.

10.4.5 Mapping HID Reports to HID Characteristics

A HID service defines one or more HID reports in its service that are used to send and receive HID data. The HID device profile has a table that maps HID reports to HID characteristics. The table is constructed by the HID service using the HID device profile and must be registered with the HID device profile by calling function **HidDev_RegisterReports**.

10.4.6 Sending and Receiving HID Reports

The application calls function **HidDev_Report** to send a HID report. The HID device sends HID report notifications to the HID host when configured to do so. When notifications are enabled or disabled for a HID report characteristic the HID report callback is executed with event HID_DEV_OPER_ENABLE or HID_DEV_OPER_DISABLE.

A HID report is received from the HID host is either a read event or write event. The HID report callback is executed with event HID_DEV_OPER_READ or HID_DEV_OPER_WRITE.

10.4.7 Advertising and Connection Procedures

The HID device profile manages advertising and connection procedures. The device will start advertising if the **HidDev_Report** function is called when not connected and not already advertising.

Advertising is performed at an “initial” rate when not bonded, and at a “low” or “high” rate if bonded. The advertising intervals and durations for the different rates are configurable.

If the device is bonded the device will advertise at the high rate when reconnecting to send a HID report. If the connection is terminated and the device is bonded and the flags are set to HID_FLAGS_NORMALLY_CONNECTABLE the device will advertise at the low rate. Otherwise the device will not advertise when disconnected until it has data to send.

If no HID data is sent or received within an idle timeout period the HID device profile will terminate the connection, unless pairing is in progress. The idle timeout is configured by the application and can be disabled by setting it to zero.

11 HostTestRelease- BLE Network Processor

The HostTestRelease project implements a BLE network processor, for use with an external microcontroller or a PC software application such as BTool. More information on the HostTestRelease project can be found in [1].

12 KeyFobDemo

The KeyFobDemo application will demonstrate the following.

- Report battery level
- Report 3 axis accelerometer readings.
- Report proximity changes
- Report key press changes

The following GATT services are used:

- Device Information (see [12])

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- Link Loss (for Proximity Profile, Reporter role; see [14] and [16])
- Immediate Alert (for Proximity Profile, Reporter role and Find Me Profile, Target role; see [14], [15], and [17])
- Tx Power (for Proximity Profile, Reporter role; see [18])
- Battery (see [13])
- Accelerometer
- SimpleKeys

The accelerometer and simple keys profiles are not aligned to official SIG profiles, but rather serve as an example of profile service implementation. The device information service and proximity-related services are based on adopted specifications.

12.1 Project Overview

The project structure is very similar to that of the SimpleBLEPeripheral project. The APP directory contains the application source code and header files. The project supports the following configurations.

- **CC2540DK-MINI Keyfob Slave**: using the keyfob hardware platform.

12.1.1 User Interface

There are two button inputs for this application, an LED, and buzzer.

Right Button

When not connected, this button is used to toggle advertising on and off. When in a connection, this will register a key press which may be enabled to notify a peer device or may be read by a peer device.

Left Button

When in a connection, this will register a key press which may be enabled to notify a peer device or may be read by a peer device.

LED

Flash when Link Loss Alert is triggered.

Buzzer

The buzzer turns on if a Link Loss Alert is triggered.

12.1.2 Battery Operation

They KeyFob used an ADC to read remaining battery level. The battery profile allows for the USB Dongle to read the percentage of battery remaining on the keyfob by reading the value of < BATTERY_LEVEL_UUID>

12.1.3 Accelerometer Operation

The keyfob uses SPI to interface to a 3 axis accelerometer on the KeyFobDemo. The accelerometer must be enabled < ACCEL_ENABLER_UUID> by writing a value of “01”. Once the accelerometer is enabled, each axis can be configured to send notifications by writing “01 00” to the characteristic configuration for each axis < GATT_CLIENT_CHAR_CFG_UUID>. In addition, the values can be read by reading <ACCEL_X_UUID>, <ACCEL_Y_UUID>,<ACCEL_Z_UUID>.

12.1.4 Keys

The simple keys service on the keyfob allows the device to send notifications of key presses and releases to a central device. The application registers with HAL to receive a callback in case HAL detects a key change.

The peer device may read the value of the keys by reading <SK_KEYPRESSED_UUID>.

The peer device may enable key press notifications by writing a “01” to <GATT_CLIENT_CHAR_CFG_UUID>.

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A value of “00” indicates that neither key is pressed. A value of “01” indicates that the left key is pressed. A value of “02” indicates that the right key is pressed. A value of “03” indicates that both keys are pressed.

12.1.5 Proximity

One of the services of the proximity profile is the link loss service, which allows the proximity reporter to begin an alert in the event the connection drops.

The link loss alert can be set by writing a value to <PROXIMITY_ALERT_LEVEL_UUID>.

The default alert value setting is “00”, which indicates “no alert.” To turn on the alert, write a 1-byte value of “01” (low alert) or “02” (high alert). By default, the link does not timeout until 20 seconds have gone by without receiving a packet. This “Supervision Timeout” value can be changed in the “Connection Services” tab; however the timeout value must be set before the connection is established. After completing the write, move the keyfob device far enough away from the USB Dongle until the link drops. Alternatively, you can disconnect the USB Dongle from the PC, effectively dropping the connection. Once the timeout on the keyfob expires, the alarm will be triggered. If a low alet was set, the keyfob will make a low pitched beep. If a high alert was set, the keyfob will make a high pitched beep and the LED will blink. In either case, the keyfob will beep ten times and then stop. Alternatively to stop the beeping, either a new connection can be formed with the keyfob, or the button can be pressed.

12.2 Software Description

The application is implemented in the file **keyFobDemo.c**.

12.2.1 Initialization

The initialization of the application occurs in two phases: first, the **KeyFobApp_Init** function is called by the OSAL. This function configures parameters in the peripheral profile, GAP, and GAP bond manager. It also sets up the KeyFobDemo example services along with standard GATT and GAP services in the attribute server. Then it sets an OSAL **START_DEVICE_EVT** event. This triggers the second phase of the initialization, which can be found within the **KeyFobApp_ProcessEvent** function. During this phase, the **GAPRole_StartDevice** function is called to set up the GAP functions of the application. Then **GAPBondMgr_Register** is called to register with the bond manager.

12.2.2 Event Processing

The application has two main event processing functions, **KeyFobApp_ProcessEvent** and **KeyFobApp_ProcessOSALMsg**.

Function **KeyFobApp_ProcessEvent** handles events as follows:

- **SYS_EVENT_MSG**: Service the OSAL queue and process OSAL messages.
- **KFD_START_DEVICE_EVT**: Start the device, as described in the previous section.
- **KFD_ACCEL_READ_EVT**: Read accelerometer and set timer for periodic reads.
- **KFD_BATTERY_CHECK_EVT**: Read battery level and set timer for periodic reads.
- **KFD_TOGGLE_BUZZER_EVT**: Toggle buzzer on proximity state.

Function **KeyFobApp_ProcessOSALMsg** handles OSAL messages as follows:

- **KEY_CHANGE**: Handle key presses.

12.2.3 Callbacks

The application callback functions are as follows:

- **PeripheralStateNotificationCB**: This is the GAP event callback. It processes GAP events for startup and link connect/disconnect.
- **ProximityAttrCB**: Receive info on link loss and setup from proximity service.
- **AccelEnablerChangeCB**: Handle enabling of accelerometer.

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13 SensorTag

The SensorTag is a BLE peripheral slave device which runs on the CC2541 SensorTag hardware platform. The Sensor Tag includes five peripheral sensors with a complete software solution for sensor drivers interfaced to a GATT server running on TI BLE stack. The GATT server contains a primary service for each sensor for configuration and data collection.

13.1 Operation

On startup, the SensorTag is advertising with a 100ms interval. The connection is established by a Central Device and the sensors can then be configured to provide measurement data. The Central Device could be any BLE compliant device and the main focus is on BLE compliant mobile phones, running either Andriod or iOS. The central device should be able to

- Scan and discover the Sensor Tag. (Scan response contain name “SensorTag”)
- Establish connection based on user defined Connection Parameters
- Perform Service Discovery – Discover Characteristic by UUID
- Operate as a GATT Client - Write to and read from Characteristic Value

The Central Device shall initiate the connection and thereby become the Master.

To obtain the data, the corresponding sensor must first be activated, which is done via a Characteristic Value write to appropriate service.

The most power efficient way to obtain measurements for a sensor is to

- Enable notification
- Enable Sensor
- When notification with data is obtained at the Master side, disable the sensor (notification still on though)

Alternative do not use notifications at all, then simply

- Enable sensor
- Read data and verify
- Disable sensor

For the latter alternative please keep in mind that sensor take different amount of time to perform measurement. Depending on the connection interval (~10 – 4000 ms) set by the Central Device, the time for achieving measurement data can vary. The individual sensors require varying delays to complete measurements. Recommended setting is 100ms but for fast accelerometer and Magnetometer data updates, a lower is necessary. Notifications can be stopped and the sensors turned on/off

13.2 Sensors

The SensorTag has support for the following sensors:

- IR Temperature, both object and ambient temperature
- Accelerometer, 3 axis
- Humidity, both relative humidity and temperature
- Magnetometer, 3 axis
- Barometer, both pressure and temperature
- Gyroscope, 3 axis

13.3 Buttons

- **Side Button:** When not connected, this button is used to toggle advertising on and off. When in a connection, this terminates the current connection. Pressing this button for more than 3 seconds resets the system.

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- **Left and Right Buttons:** The Simple Keys service on the SensorTag allows the device to send notifications of key presses and releases to a central device.

14 SimpleBLECentral

The SimpleBLECentral project implements a very simple BLE central device with GATT client functionality. It makes use of the SmartRF05 + CC2540EM hardware platform. This project can be used as a framework for developing many different central-role applications. More information on the SimpleBLECentral project can be found in [1].

15 SimpleBLEPeripheral

The SimpleBLEPeripheral project implements a very simple BLE peripheral device with GATT services, including configurations for the CC2540DK-MINI keyfob as well as the SmartRF05 + CC2540EM hardware platforms. This project can be used as a framework for developing many different peripheral-role applications. More information on the SimpleBLEPeripheral project can be found in [1].

16 TimeApp- BLE Watch

This sample project implements time and alert-related profiles in a BLE peripheral device to provide an example of how Bluetooth LE profiles are used in a product like a watch. The project is based on adopted profile specifications for Time ([19]), Alert Notification ([20]), and Phone Alert Status ([21]). All profiles are implemented in the Client role. In addition, the following Network Availability Profile, Network Monitor role has been implemented, based on Network Availability Draft Specification d05r04 (UCRDD).

The project can be opened with the following IAR workspace file:

C:\Texas Instruments\BLE-CC254x-1.4.1\Projects\ble\TimeApp\CC2540\TimeApp.eww

16.1 Project Overview

The TimeApp project structure is very similar to that of the SimpleBLEPeripheral project. The APP directory contains the application source code and header files. The project contains one configuration, **CC2540EM Slave**, using the SmartRF05EB + CC2540EM hardware platform.

16.1.1 User Interface

The SmartRF05EB joystick and display provide a user interface for the application. The joystick and buttons are used as follows:

- Joystick Up: Start or stop advertising.
- Joystick Left: If connected, send a command to the Alert Notification control point.
- Joystick Center: If connected, disconnect. If held down on power-up, erase all bonds.
- Joystick Right: If connected, initiates a Reference Time update.
- Joystick Down: If connected, initiates a Ringer Control Point update

The LCD display is used to display the following information:

- Device BD address.
- Connection state.
- Pairing and bonding status.
- Passcode display.
- Time and date.
- Network availability.
- Battery state of peer device.
- Alert notification messages.
- Unread message alerts.
- Ringer status.

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16.1.2 Basic Operation

When the application powers up it displays "Time App", the BD address of the device, and a default time and date of "00:00 Jan01 2000". To connect, press Joystick Up to start advertising then initiate a connection from a peer device. The connection status will be displayed. Once connected, the application will attempt to discover the following services on the peer device:

- Current Time Service
- DST Change Service
- Reference Time Service
- Alert Notification Service
- Phone Alert Status Service
- Network Availability Service
- Battery Service

The discovery procedure will cache handles of interest. When bonded to a peer device, the handles are saved so that the discovery procedure is not performed on subsequent connections.

If a service is discovered certain service characteristics are read and displayed. The network availability status and battery level will be displayed and the current time will be updated.

The application also enables notification or indication for characteristics that support these operations. This allows the peer device to send notifications or indications updating the time, network availability, or battery status. The peer device can also send alert notification messages and unread message alerts. These updates and messages will be displayed on the LCD.

The peer device may initiate pairing. If a passcode is required the application will generate and display a random passcode. Enter this passcode on the peer device to proceed with pairing.

The application advertises using either a fast interval or a slow interval. When advertising is initiated by a button press or when a connection is terminated due to link loss, the application will start advertising at the fast interval for 30 seconds followed by the slow interval. When a connection is terminated for any other reason the application will start advertising at the slow interval. The advertising intervals and durations are configurable in file **timeapp.c**.

16.2 Software Description

The TimeApp application is implemented in the following files:

- **timeapp.c**: Main initialization, event handling and callback functions.
- **timeapp_clock.c**: Clock timekeeping and display functions.
- **timeapp_config.c**: Characteristic configuration functions.
- **timeapp_discovery.c**: Service discovery functions.
- **timeapp_ind.c**: Indication and notification handling functions.

16.2.1 Initialization

The initialization of the application occurs in two phases: first, the **TimeApp_Init** function is called by the OSAL. This function configures parameters in the peripheral profile, GAP, and GAP bond manager and also initializes GATT for client operation. It also sets up standard GATT and GAP services in the attribute server. Then it sets an OSAL **START_DEVICE_EVT** event. This triggers the second phase of the initialization, which can be found within the **TimeApp_ProcessEvent** function. During this phase, the **GAPRole_StartDevice** function is called to set up the GAP functions of the application. Then **GAPBondMgr_Register** is called to register with the bond manager.

16.2.2 Event Processing

The application has two main event processing functions, **TimeApp_ProcessEvent** and **timeApp_ProcessOSALMsg**.

Function **TimeApp_ProcessEvent** handles events as follows:

- **SYS_EVENT_MSG**: Service the OSAL queue and process OSAL messages.

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- **START_DEVICE_EVT**: Start the device, as described in the previous section.
- **START_DISCOVERY_EVT**: Start service discovery.
- **CLOCK_UPDATE_EVT**: Update the clock display.

Function **timeApp_ProcessOSALMsg** handles OSAL messages as follows:

- **KEY_CHANGE** messages: Call function timeApp_HandleKeys to handle keypresses.
- **GATT_MSG_EVENT** messages: Call function timeAppProcessGATTMsg to handle messages from GATT.

16.2.3 Callbacks

The application callback functions are as follows:

- **timeAppGapStateCB**: This is the GAP event callback. It processes GAP events for startup and link connect/disconnect.
- **timeAppPairStateCB**: This is the GAP bond manager state callback. It displays the status of pairing and bonding operations.
- **timeAppPasscodeCB**: This is the GAP bond manager passcode callback. It generates and displays a passcode.

16.2.4 Service Discovery

The application performs service discovery for several Bluetooth LE services. Discovery is initiated when a connection is established to a peer device with which there is no existing bond. Discovery starts when the discovery delay timer expires, which sets event **START_DISCOVERY_EVT**. This will result in execution of function **timeAppDiscStart**. However if a pairing procedure is in progress when the timer expires discovery will be postponed until pairing completes. This is done in case the peer device requires security before its characteristics are read or written.

A service discovery procedure is performed for each service until discovery has been attempted on all services of interest. The service discovery procedure is generalized as follows:

1. Discovery the service by UUID.
2. If found, discover all characteristics of the service. Cache the handles of characteristics of interest.
3. If a discovered characteristic uses a client characteristic configuration descriptor (abbreviated as CCCD in the code), discover all descriptors of the characteristic.

If the mandatory characteristics and descriptors of the service are discovered then discovery of the service is deemed successful.

The handles of discovered characteristics of interest are stored in array **timeAppHdlCache**.

The main service discovery function is **timeAppDiscGattMsg**. This function is executed when a discovery-related GATT message response is received. This function then executes a separate discovery function for each service. The service discovery state is maintained in variable **timeAppDiscState**.

16.2.5 Service Configuration

When service discovery completes the service configuration procedure is initiated. This procedure reads and writes characteristics of interest in the discovered services.

The main service configuration function is **timeAppConfigNext**. This function searches the cached handle array for the next characteristic of interest, and once found it performs a read or write on that characteristic.

When a GATT read response or write response is received, function **timeAppConfigGattMsg** is called. This function processes the received response and performs an action, such as updating the clock display, and then calls **timeAppConfigNext** to initiate the next read or write.

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The application writes all discovered client characteristic configuration descriptors to enable notification or indication. The application also reads some characteristics and then performs no action with the received response. This is done simply for testing and demonstration.

16.2.6 Handling Indications and Notifications

Handling of received indications and notifications is performed by function **timeAppIndGattMsg**. This function is called when a GATT indication or notification message is received. The function will process the data in the received message and display it on the LCD.

16.2.7 Clock Time

The application uses the OSAL Clock service to update and maintain the clock time. When new date and time data is received from the peer device, function **timeAppClockSet** is called to update the time in OSAL and display the updated time on the LCD. The LCD is periodically updated by an OSAL timer that sets event **CLOCK_UPDATE_EVT**.

17 Serial Bootloader

17.1 Basic Operation

The SBL is a utility application allowing the user download an image over the serial port. This might be useful for field updates or allowing an external MCU to change firmware without using the CC Debugger. There are project options for both UART and SPI.

17.1.1 SBL Developer's Guide

A detailed guide on the serial bootloader can be found on the Texas Instruments wiki page.

http://processors.wiki.ti.com/index.php/SerialBootLoader

17.2 Target Requirements

The target must be setup with the SBL (Serial Bootloader). For encrypted OAD, the EBL (Encrypted bootloader) is used instead.

This SBL is located at:

C:\Texas Instruments\BLE-CC254x-1.4.1\Projects\ble\SBL\iar\cc254x\sbl.eww.

The EBL is located at:

C:\Texas Instruments\BLE-CC254x-1.4.1\Projects\ble\SBL\iar\cc254x\ebl.eww.

An example of a project with SBL and EBL support is:

C:\Texas Instruments\BLE-CC254x-1.4.1\Projects\ble\HostTestApp\CC254xDB\HostTestRelease.eww

17.3 Server Requirements

There is a PC tool which acts as a server to download the .bin image over the serial link. This SBLTool can be downloaded from:

http://processors.wiki.ti.com/index.php/Category:SBLTool

18 USB Bootloader

This sample application allows the user load an image over the USB port.

18.1 Basic Operation

The UBL is a utility application allowing the user to download an image to the USB dongle by drag and drop in Microsoft Windows. This would be useful for updating the firmware on a USB dongle when no programming pins are available. The example provided in this release is specific to USB dongle and Nano dongle.

18.1.1 Flash UBL

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The UBL is provided as a hex file. Some source is provided, but this is only for reference. Flash the image using the TI Flash Programmer.

For USB Dongle provided with CC2540DK-mini kit use

C:\Texas Instruments\BLE-CC254x-1.4.1\Projects\ble\UBL\soc_8051\usb_msd\bin\ ubl_cc2540-dk.hex

For the Nano dongle use

C:\Texas Instruments\BLE-CC254x-1.4.1\Projects\ble\UBL\soc_8051\usb_msd\bin\ ubl_cc2540-nano.hex

18.1.2 Build the Project to be Bootloaded

This release contains an example project which creates a bootload compatible image. The example project is located at

C:\Texas Instruments\BLE-CC254x-1.4.1\Projects\ble\HostTestApp\CC2540\HostTestRelease.ewp

Select the CC2540USB-UBL project configuration, and build the project. The .bin is located at

C:\TexasInstruments\BLE-CC254x-1.4.1\Projects\ble\HostTestApp\CC2540\CC2540USB-UBL\Exe\ HostTestReleaseCC2540USB-UBL.bin

18.1.3 Download the User Project Image (.bin)

Once the bootloader has been flashed, the USB dongle will show up as a mass storage device. Use Microsoft Windows explorer to drag and drop the HostTestReleaseCC2540USB-UBL.bin to the mass storage. Once it is copies over, the dongle will change and register with Windows as a virtual com port. Press and hold the USB dongle button furthest from port while inserting the dongle to run the bootloader again. The nano dongle will enter mass storage on insertion, but will stay in that mode for a short amount of time only.

19 Over Air Download

OAD is an extended stack feature provided as a value-enhancing solution for updating code in deployed devices without the cost of physical access via a programming header. OAD is a client-server mechanism in which one device acts as the OAD image server (OAD manager) and the other device is the OAD image client (OAD target). There is also a method for performing encrypted OAD using the hardware AES engine.

19.1 OAD Developer's Guide

A detailed guide on the entire OAD process can be found on the Texas Instruments wiki page.

http://processors.wiki.ti.com/images/8/82/OAD_for_CC254x.pdf

19.2 Target Requirements

The target must be setup with a BIM (Boot Image Manager) and at least one image with OAD profile support. For encrypted OAD, the BEM (Boot Encrypted Manager) is used instead.

The BIM project can be found at:

C:\Texas Instruments\BLE-CC254x-1.4.1\Projects\ble\util\BIM\cc254x\BIM.eww

The BEM project can be found at:

C:\Texas Instruments\BLE-CC254x-1.4.1\Projects\ble\util\BIM\cc254x\BEM.eww

An Example of an Image with standard OAD and encrypted OAD support is:

C:\Texas Instruments\BLE-CC254x-1.4.1\Projects\ble\SimpleBlePeripheral\CC254xDB\SimpleBlePeripheral.eww

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19.3 Server Requirements

The installer includes a server application compatible with the SBL Tool which runs on the SmartRF board. The project allows the user to connect load an image over the serial port, and then transfer it over the air to the target.

This example server application is located at:

C:\Texas Instruments\BLE-CC254x-1.4.1\Projects\ble\OADManager\CC2541DB\OADManager.eww

In addition, other servers can be used such as a phone with BLE support or a PC. For PC support, there is dev monitor application which can be found on TI CC2541 product page.

http://www.ti.com/product/cc2541

For iOS, there is a sensorTag application which performs OAD. For more information visit the SensorTag wiki

http://processors.wiki.ti.com/index.php/SensorTag_User_Guide

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20 General Information

20.1 Document History

Table 1: Document History

Revision	Date	Description/Changes
1.0	2011-07-13	Initial release, documenting sample applications included in BLEv1.1 release
1.2	2012-02-07	Updated to align with BLEv1.2 release sample applications.
1.2.2	2012-04-12	Updated with Glucose Collector/Sensor sample applications
1.3.2	2013-06-13	Updated with Sensor Tag, OAD, Advanced Remote
1.4	2013-09-13	Updated for 1.4 release
1.4.1	2015-05-13	Updated for 1.4.1 release

21 TI Worldwide Technical Support

Internet

TI Semiconductor Product Information Center Home Page: support.ti.com
TI Semiconductor KnowledgeBase Home Page: support.ti.com/sc/knowledgebase
TI LPRF forum E2E community: http://www.ti.com/lprf-forum

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Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

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