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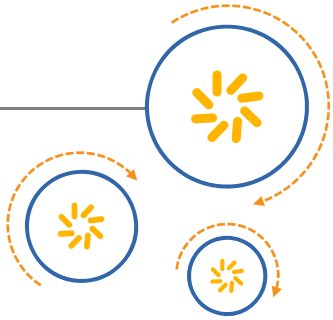

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Push every boundary.™

CSR µEnergy®

Heart Rate Sensor

Application Note

Issue 10

Document History

Revision	Date	History
1	15 OCT 13	Original publication of this document
2	16 JUN 12	Table 8.1 corrected
3	13 SEP 12	Figure 4.1 and Figure 4.2 updated
4	11 FEB 13	Updated to reference CSR101x devices and for SDK 2.1
5	22 FEB 13	Updated current consumption values
6	10 MAY 13	Updated for SDK 2.2; static random address, dormant mode and connection parameter update
7	04 FEB 14	Updated to new CSR branding and changes to connection parameters
8	02 JUL 14	Updated for SDK 2.4; added support for OTA Update Application Service
9	07 NOV 14	Updated USB dongle information and OTA Update to v6
10	04 AUG 15	Updated current consumption values for SDK 2.5, added low battery handling and SPI Flash device support in OTA Update

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Contents

Tables, Figures and Equations

1. Introduction

This document describes the Heart Rate Sensor application supplied with the CSR µEnergy® Software Development kit (SDK) and provides guidance on how to customise the on-chip application.

This application demonstrates the Heart Rate profile which is specified by the Bluetooth SIG.

The Heart Rate Sensor application now supports Over-the-Air (OTA) Update of its application software.

1.1. Application Overview

1.1.1. Profile Supported

The Heart Rate Sensor application supports the Heart Rate profile.

1.1.1.1. Heart Rate Profile

The Heart Rate profile is used to enable a data collection device to obtain Heart Rate measurements from a Heart Rate Sensor that exposes the Heart Rate Service.

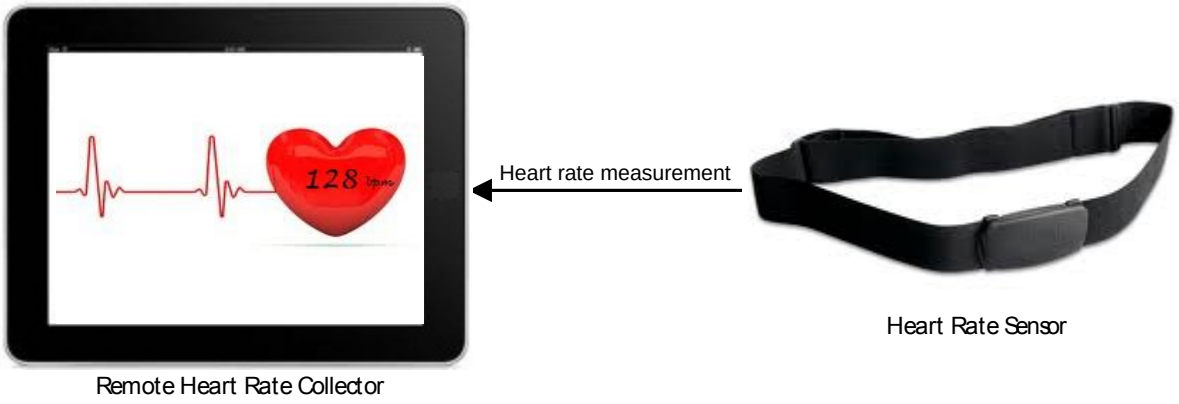

Figure 1.1: Heart Rate Profile Use Case

The Heart Rate profile defines two roles, see Table 1.1:

Role	Description
Heart Rate Sensor	Heart Rate Sensor is the device that measures heart rate and related information.
Heart Rate Collector	Heart Rate Collector is the device that receives heart rate measurement and related data from the sensor.

Table 1.1: Heart Rate Profile Roles

For more information about the Heart Rate profile, see *Heart Rate Profile Specification Version 1.0.*

1.1.2. Application Topology

The Heart Rate Sensor application implements the Heart Rate profile in Heart Rate Sensor role, see Table 1.2:

Role	Heart Rate Profile	GAP Service	GATT Service	Device Information Service	Battery Service	OTA Update Application Service
GATT Role	GATT Server	GATT Server	GATT Server	GATT Server	GATT Server	GATT Server
GAP Role	Peripheral	Peripheral	Peripheral	Peripheral	Peripheral	Peripheral

Table 1.2: Application Topology

Role	Description
GATT Server	Accepts incoming commands and requests from the client and sends responses, indications and notifications to the client.
GAP Peripheral	Accepts connection request from the remote device and acts as a slave in the connection.

Table 1.3: Responsibilities

For more information about GATT server and GAP peripheral, see *Bluetooth Core Specification Version 4.1*.

1.1.3. Services

This application exposes the following services:

- Heart Rate v1.0
- Device Information v1.1
- Battery v1.0
- GAP
- GATT
- CSR OTA Update Application Service v6

The Heart Rate profile mandates only two services:

- Heart Rate
- Device Information

GAP and GATT services are mandated by *Bluetooth Core Specification Version 4.1*. The Battery and CSR OTA Update Application services are optional as shown in Figure 1.2.

For more information on Heart Rate, Device information and Battery services, see the *Heart Rate Service Specification Version 1.0*, *Device Information Specification Version 1.1* and *Battery Service Specification Version 1.0* respectively. For more information on GATT and GAP services, *see Bluetooth Core Specification Version 4.1*. For more information on CSR OTA Update Application Service, see section 6.

See Appendix B for information on characteristics supported by each service.

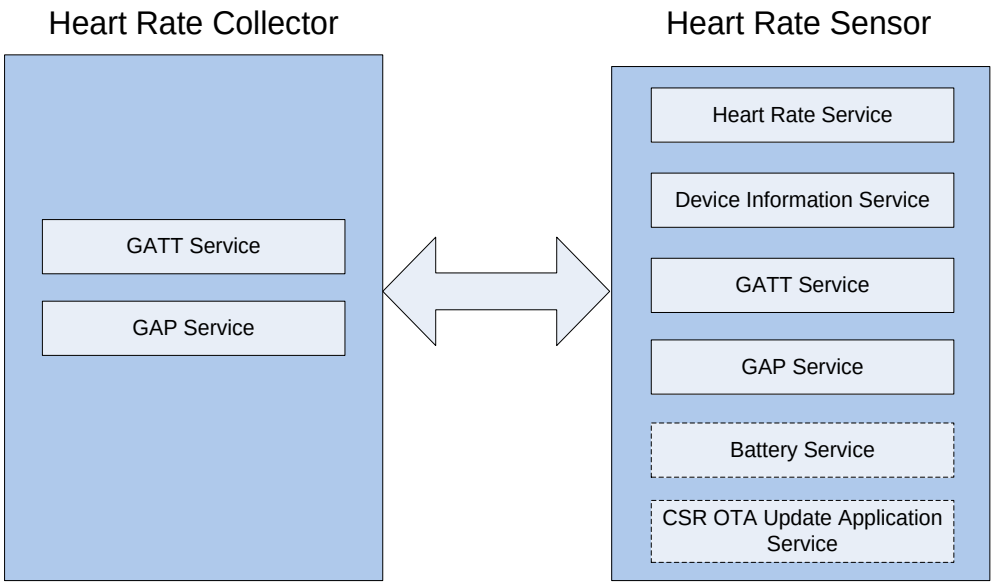

Figure 1.2: Primary Services

1.1.4. Measurement Modes

The Heart Rate Sensor application operates in two measurement modes, see Table 1.4:

Measurement Mode	Description
Sample Measurement Mode (Default Mode)	The Heart Rate Sensor application generates sample heart rate measurements at one second intervals in this mode.
Actual Measurement Mode	The Heart Rate Sensor application takes actual heart rate measurement as input via a PIO from an external Heart Rate device.

Table 1.4: Measurement Modes

For more information on switching between these two modes, see section 7.1.

2. Using the Application

This section describes how the Heart Rate Sensor application is used with the CSR µEnergy Profile Demonstrator application available from CSR.

2.1. Demonstration Kit

Table 2.1 lists the components of the Heart Rate Sensor.

Component	Hardware	Application
Heart Rate Sensor	CSR10x0 Development Board	Heart Rate Sensor Application
Heart Rate Collector	CSR µEnergy Bluetooth USB dongle	CSR µEnergy Profile Demonstrator Application

Table 2.1: Demonstration Components

Note:

Although the Heart Rate Sensor application primarily targets the CSR1010 development board, the CSR1011 development board may also be used as an alternative hardware platform.

The SDK includes the CSR µEnergy Profile Demonstrator application, CSR device driver and installation guide.

2.1.1. Heart Rate Sensor

The SDK is used to build and download the Heart Rate Sensor application to the development board. See the *CSR µEnergy xIDE User Guide* for further information.

Ensure the development board is switched on using the Power On/Off switch. Figure 2.1 shows the switch in the *Off* position.

Note:

When disconnected from the USB to SPI Adapter, wait at least 1 minute before switching the board on. This allows any residual charge received from the SPI connector to be dissipated.

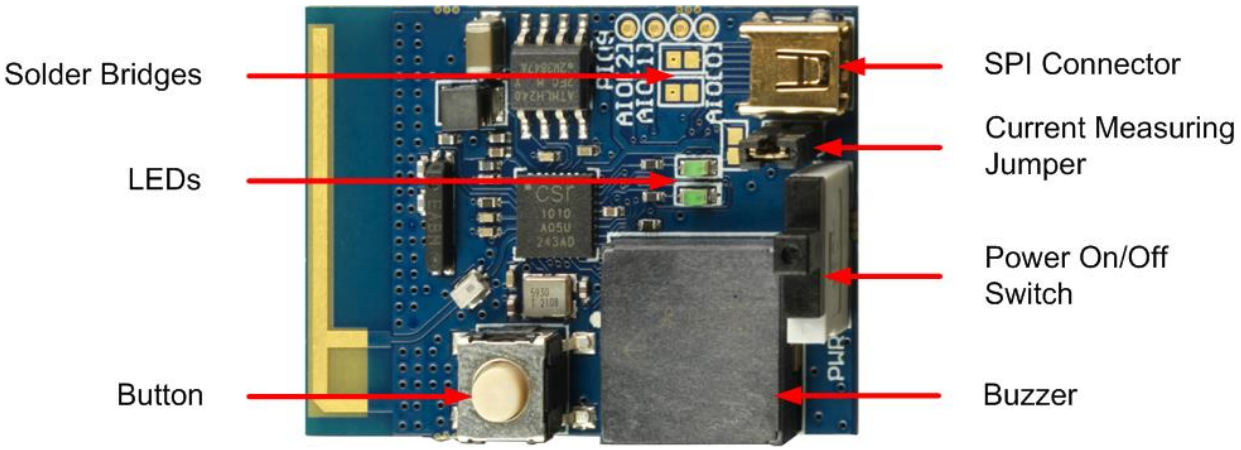

Figure 2.1: CSR1010 Development Board

2.1.1.1. User Interface

This application makes use of the button and buzzer available on the development board.

Button Press Behaviour

- In Sample Measurement mode, a *short* button press disconnects the link if connected, otherwise the application starts advertising.
- In Actual Measurement mode, a *short* button press is ignored by the application.
- An *extra-long* button press disconnects the link if present, removes bonding and starts advertising.

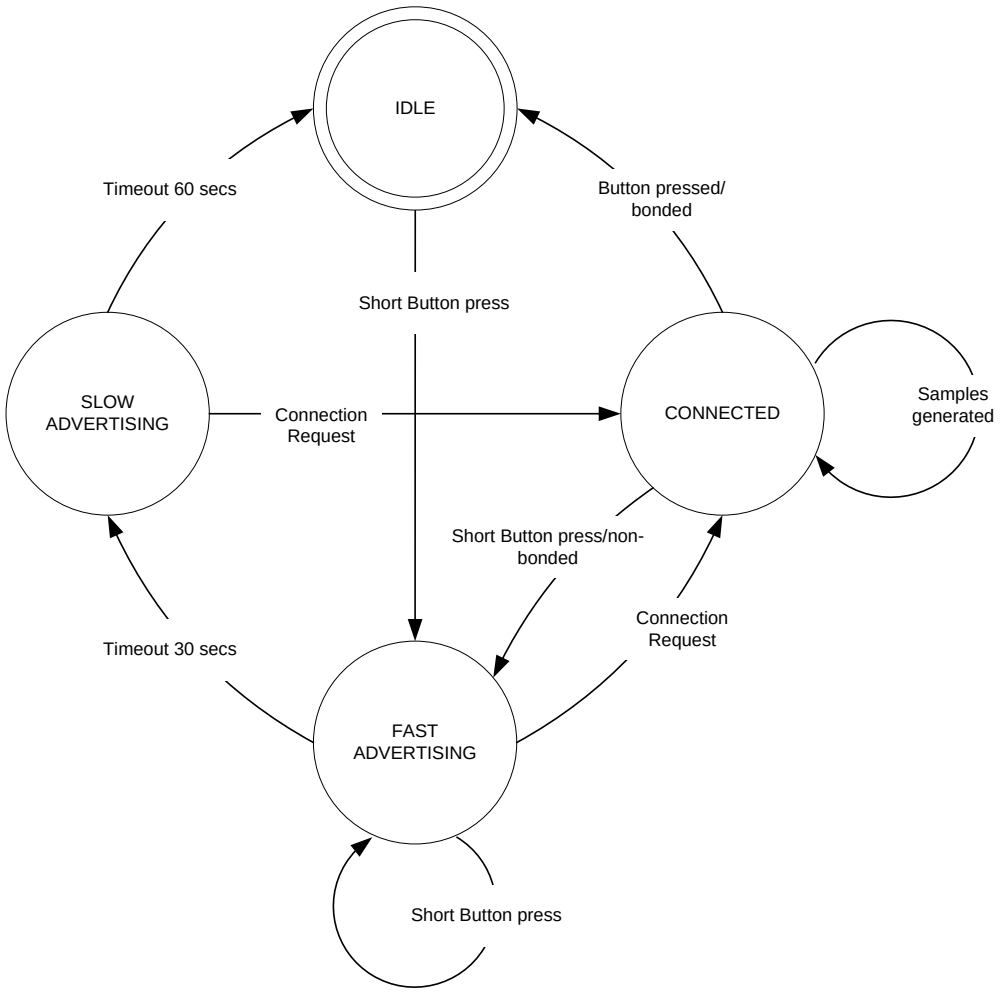

Figure 2.2: Device Behaviour (Sample Measurement Mode)

Note:

As the Heart Rate Sensor application does not perform any specific operation on a *long* button press, it is handled in a similar way to a *short* button press.

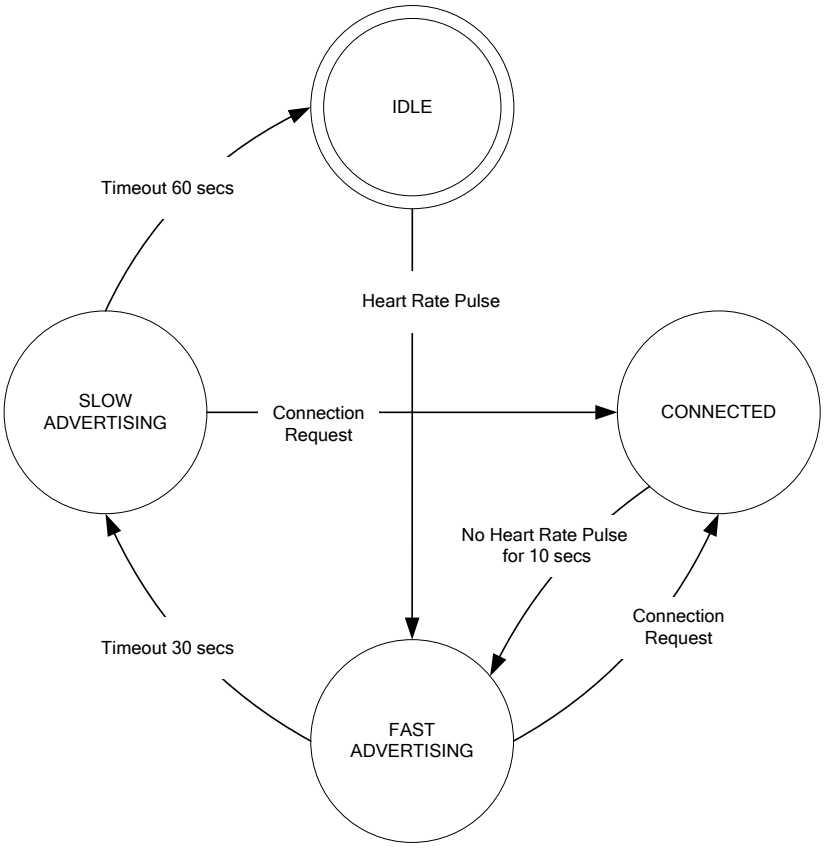

Figure 2.3: Device Behaviour (Actual Measurement Mode)

Buzzer Behaviour

- A single *short* beep on a *short* button press indicates the execution of the *short* button press operation as described earlier. This is applicable to the Sample Measurement mode only.
- Two *short* beeps indicate the start of advertisements.
- Three *short* beeps indicate the removal of bonding.
- A *long* beep without the button being pressed indicates that the application has entered idle mode.

2.1.2. Heart Rate Collector

2.1.2.1. CSR µEnergy Bluetooth USB Dongle

The CSR µEnergy Bluetooth USB dongle must be used with the CSR µEnergy Profile Demonstrator application to complete the Bluetooth Smart link between two devices. To use the USB dongle, the default USB Bluetooth Windows device driver must be replaced with the CSR BlueCore device driver as described in the *CSR µEnergy Bluetooth USB Dongle Driver Installation User Guide*.

Figure 2.4: CSR µEnergy Bluetooth USB Dongle

2.1.2.2. CSR µEnergy Profile Demonstrator Application

The CSR µEnergy Profile Demonstrator application is compatible with a PC running Windows 7 (32-bit and 64-bit) or Windows 8 (32-bit and 64-bit). Launch the application once the CSR µEnergy Bluetooth USB dongle is attached to the PC and the driver has been loaded.

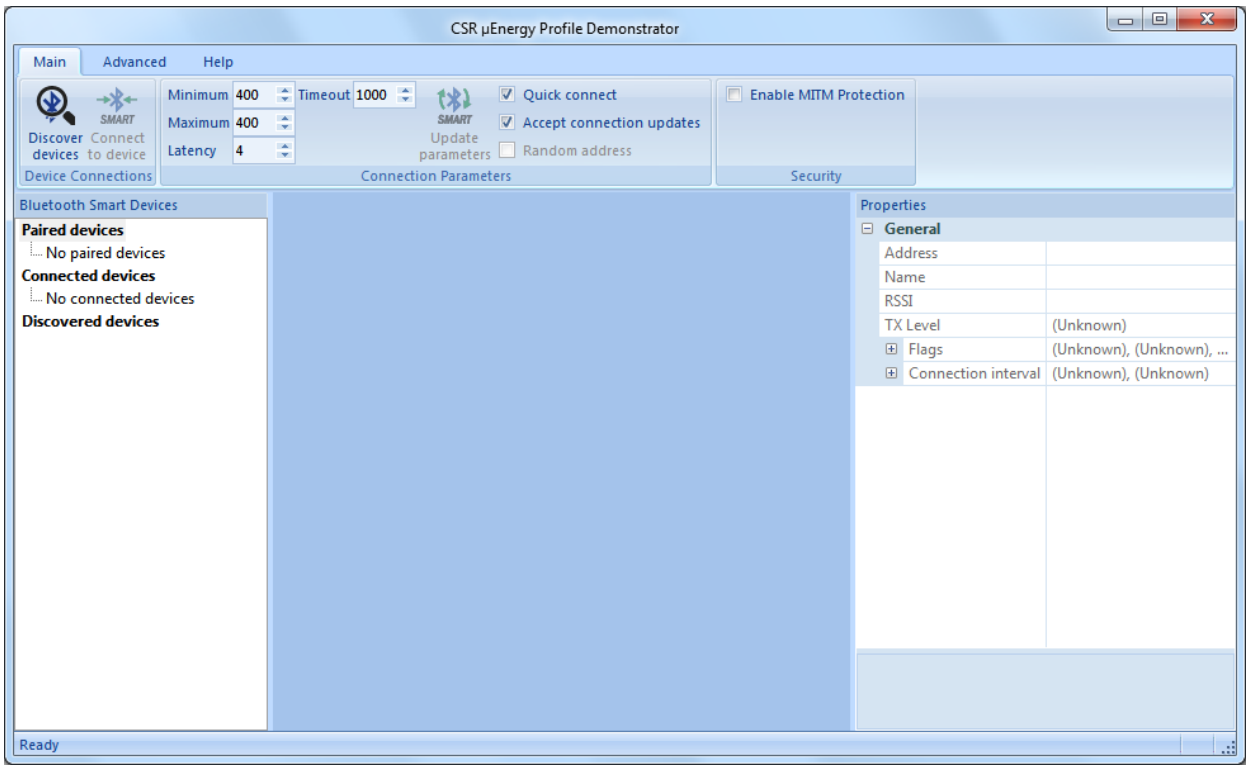

Figure 2.5: CSR µEnergy Profile Demonstrator

2.2. Demonstration Procedure

To demonstrate the Heart Rate Sensor application:

1. Switch on the development board to trigger advertisements.
2. Click on the **Discover devices** button in the **CSR µEnergy Profile Demonstrator** application window. The application searches for Bluetooth Smart devices and lists all the discovered devices on the left hand side of the application window, see Figure 2.6.

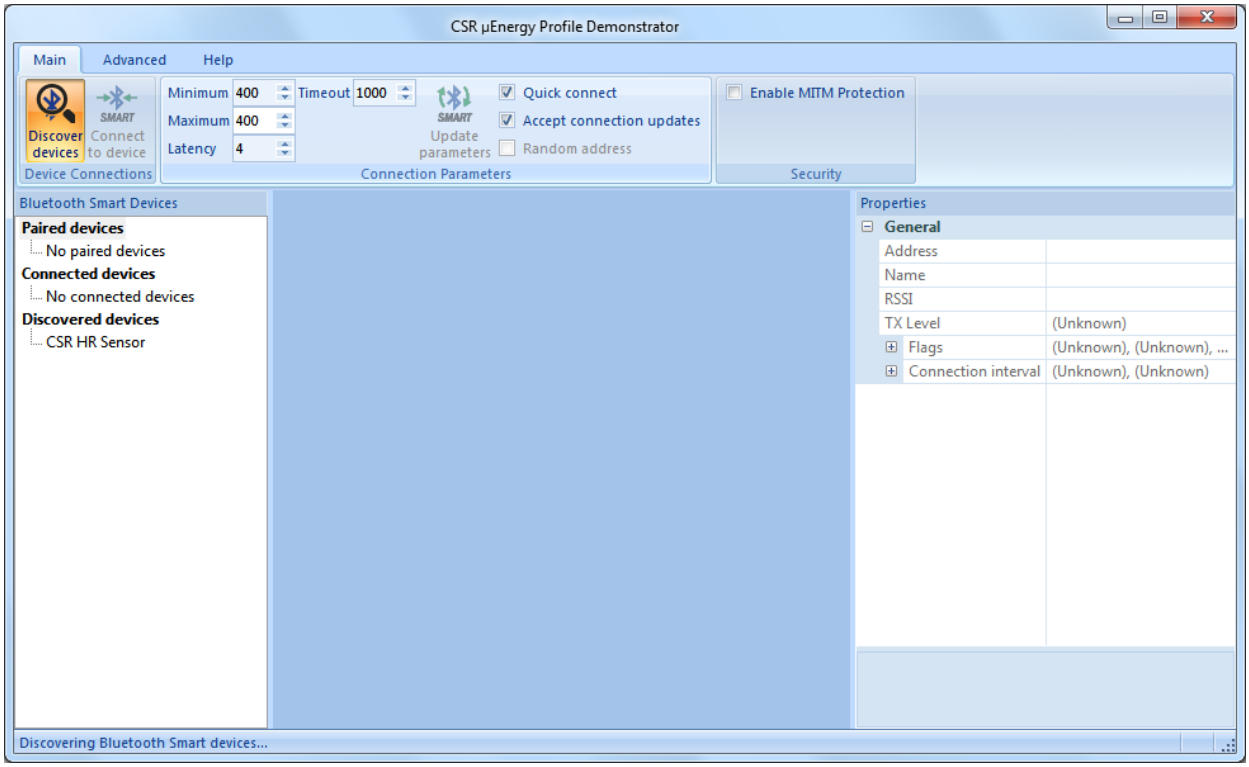

Figure 2.6: Heart Rate Sensor Device Discovered

3. When the device labelled **CSR HR Sensor** appears, select it to display the device address on the right hand side of the screen. Enter the preferred connection parameters from Table 7.4 in the **Connection Parameters** tab. Click on the **Connect to device** button to connect to this device. The CSR µEnergy Profile Demonstrator application displays a tabbed pane corresponding to different services supported by the device, see Figure 2.7.

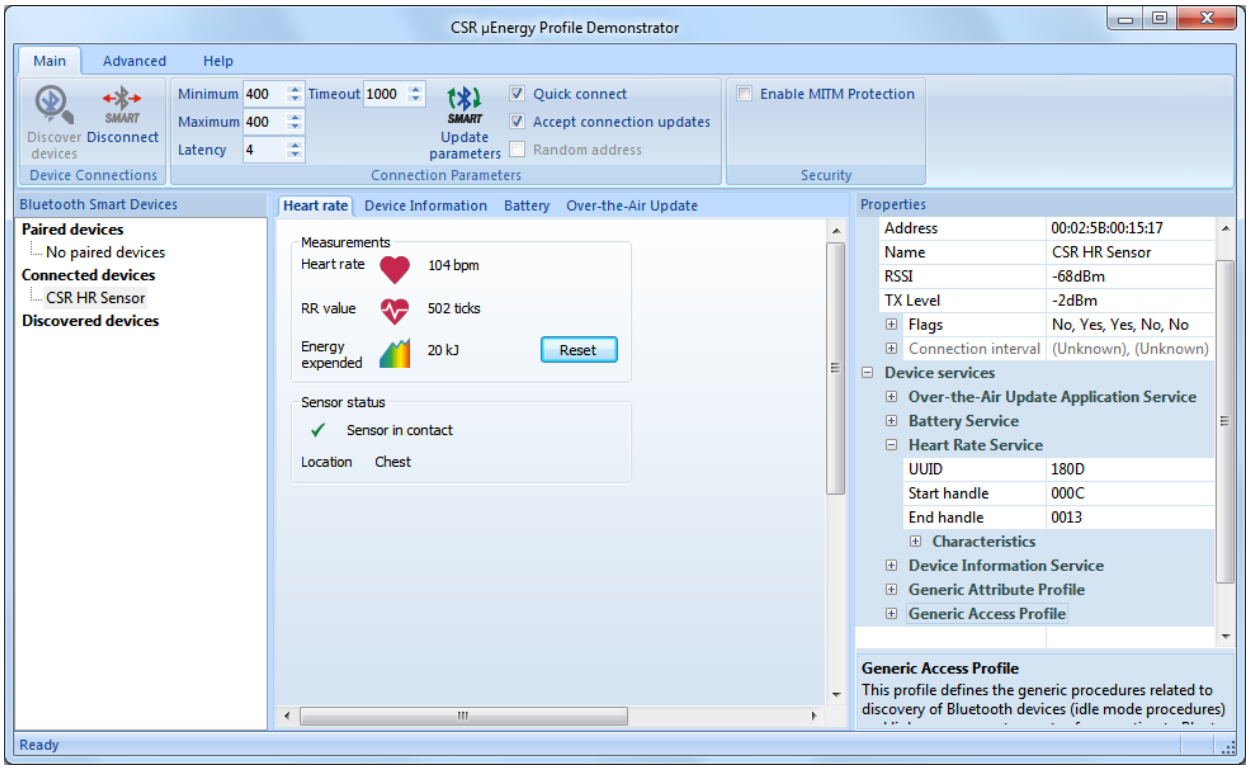

Figure 2.7: Device Connected

4. The **Heart Rate** tab in the **CSR µEnergy Profile Demonstrator** application window, see Figure 2.7 shows the latest received Heart Rate measurement and the status of the sensor.

- Measurements
  Displays the received Heart Rate measurement value in BPM, RR-interval value in ticks and energy expended in kilo Joules. The Heart Rate Sensor application sends accumulated expended energy values once every 10 seconds.
- Sensor Status
  Displays the location of the Heart Rate Sensor.
- **Reset** Button
  Clicking this button resets the expended energy value on the Heart Rate Sensor to zero.

5. The **Battery** tab, see Figure 2.8, displays the current state of battery.

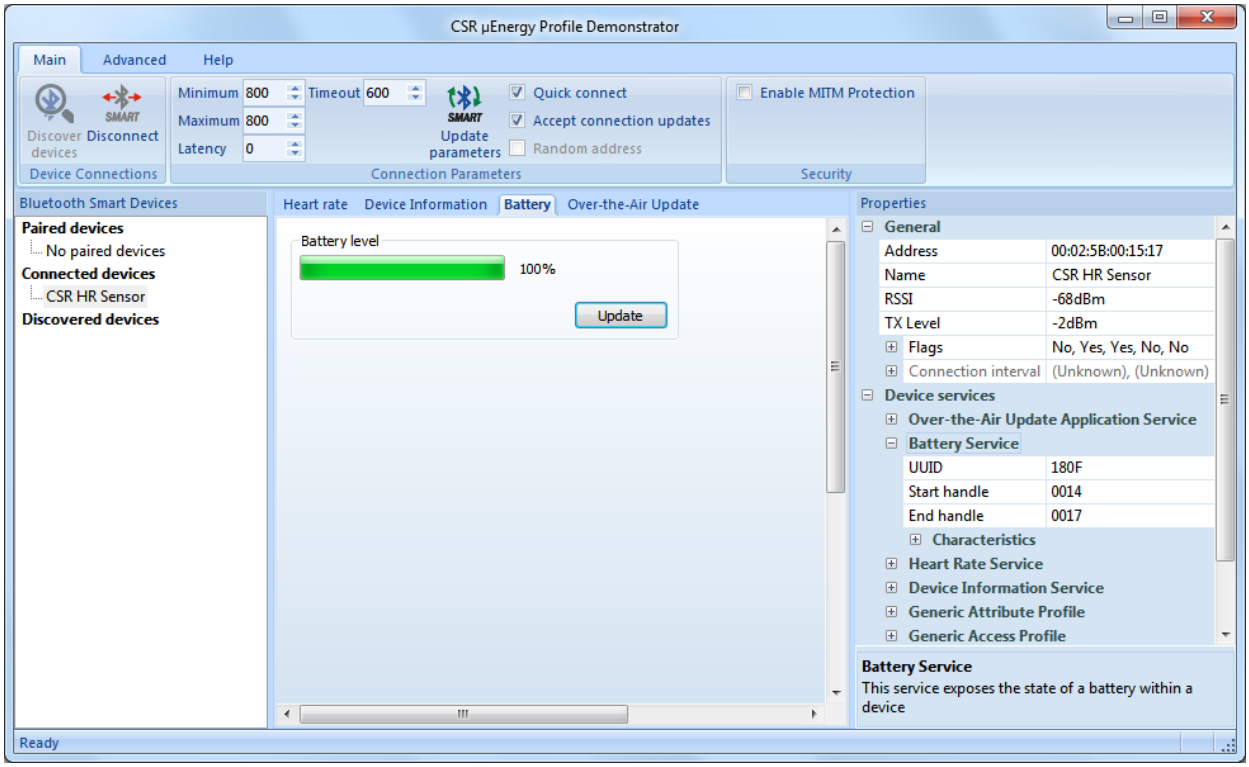

Figure 2.8: Battery Level Tab

Note:

The battery level may fluctuate depending on the connection state.

6. The **Device Information** tab, see Figure 2.9, displays the Device Information characteristics of the application.

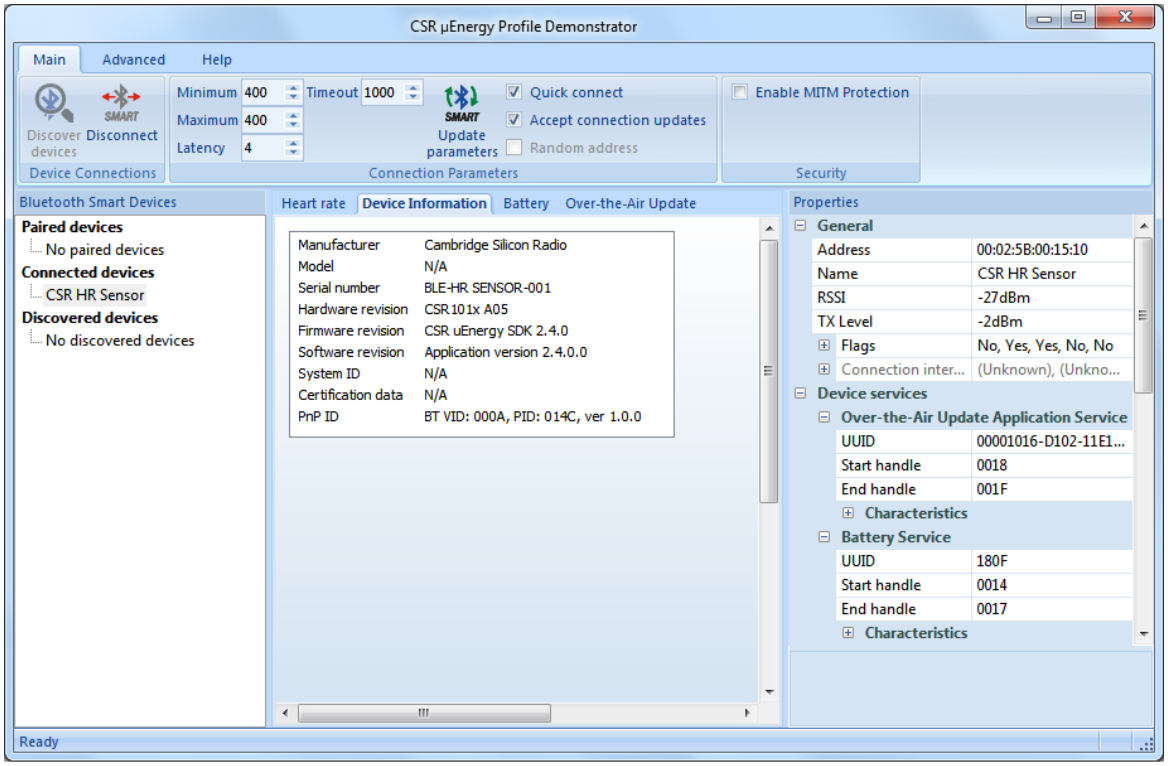

Figure 2.9: Device Information Service Tab

7. If CSR OTA Update Application Service is supported by the application, the **Over-the-Air Update** service tab displays the current application index, see Figure 2.10.

Note:

OTA Update mode cannot be triggered from the **Over-the-Air Update** service tab. A separate application is needed to perform the update procedure, see section 6 for more information.

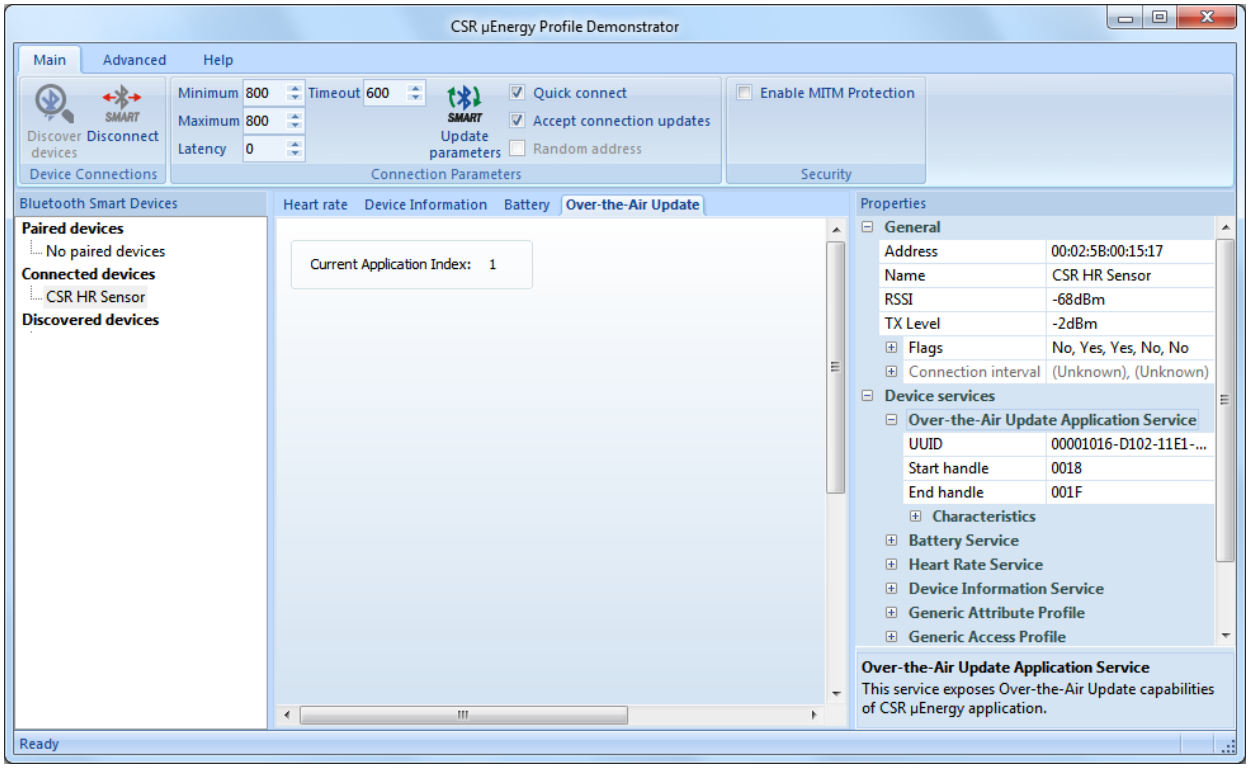

Figure 2.10: Over-the-Air Update Service Tab

8. Click **Disconnect** to disconnect the Bluetooth Smart link to the application.

3. Application Structure

3.1. Source Files

The table below lists the source files and their purpose.

File Name	Purpose
battery_service.c	Implements routines required for the Battery Service e.g. reading Battery Level and notifying it to the remote device, and handling access indications on the Battery Service specific ATT attributes.
csr_ota_service.c	Implements a basic framework for adding the CSR OTA Update Application Service.
gap_service.c	Implements routines for GAP Service e.g. handling read/write access indications on the GAP Service characteristics, reading/writing device name on NVM etc.
gatt_service.c	Implements routines for GATT characteristics.
heart_rate_service.c	Implements routines for handling read/write access on Heart Rate Service characteristics and for sending notifications of Heart Rate measurements.
hr_sensor.c	Implements all the entry functions e.g. `AppInit()`, `AppProcessSystemEvent()` and `AppProcessLmEvent()`. Events received from the hardware and firmware are first handled here. This file contains handling functions for all the LM and system events.
hr_sensor_gatt.c	Implements routines for triggering advertisement procedures.
hr_sensor_hw.c	Implements routines for hardware initialization, button press handling and sounding the buzzer.
nvm_access.c	Implements the NVM read/write routines.

Table 3.1: Source Files

3.2. Header Files

The table below lists the header files and their purpose.

File Name	Purpose
app_gatt.h	Contains macro definitions, user defined data type definitions and function prototypes which are being used across the application.
appearance.h	Contains the appearance value macro of the Heart Rate Sensor application.
battery_service.h	Contains prototypes of externally referred functions defined in the battery_service.c file.
battery_uuids.h	Contains macro definitions for UUIDs of Battery Service and related characteristics.
csr_ota_service.h	Contains prototypes of externally referred routines in the csr_ota_service.c file.
csr_ota_uuids.h	Contains macros for UUID values of the CSR OTA Update Application Service and related characteristics.

File Name	Purpose
gap_conn_params.h	Contains macro definitions for fast/slow advertising, preferred connection parameters, idle connection timeout values etc.
gap_service.h	Contains prototypes of the externally referred functions defined in the gap_service.c file.
gap_uuids.h	Contains macros for UUID values of the GAP Service and related characteristics.
gatt_service.h	Contains prototypes of externally referred routines in the gatt_service.c file.
gatt_service_uuids.h	Contains macros for UUID values for GATT Service.
heart_rate_service.h	Contains prototypes of externally referred functions defined in the heart_rate_service.c file.
heart_rate_service_uuids.h	Contains macro definitions for UUID values of the Heart Rate Service and related characteristics.
hr_sensor.h	Contains timeout values for fast/slow advertising and prototypes of externally referred functions defined in the hr_sensor.c file.
hr_sensor_gatt.h	Contains macro definitions for advertising timer values and prototypes of externally referred routines in the hr_sensor_gatt.c file.
hr_sensor_hw.h	Contains prototypes of externally referred routines in the hr_sensor_hw.c file.
nvm_access.h	Contains prototypes of externally referred NVM read/write functions defined in the nvm_access.c file.
ota_customisation.h	Contains macros for customising the application for CSR OTA Update Application Service.
user_config.h	Contains macros for customising the application.

Table 3.2: Header Files

3.3. Database Files

The SDK uses database files to generate attribute database for the application. For more information on how to write database files, see *GATT Database Generator User Guide*.

Table 3.3 lists the database files and their purpose.

File Name	Purpose
app_gatt_db.db	Master database file which includes all service specific database files. This file is imported by the GATT Database Generator.
battery_service_db.db	Contains information related to Battery Service characteristics, their descriptors and values. See Table B.1 for more information on Battery Service characteristics.
csr_ota_db.db	Contains information related to CSR OTA Update Application Service characteristics, their descriptors and values. See Table B.2 for CSR OTA Update Application Service characteristics.

File Name	Purpose
dev_info_service_db.db	Contains information related to Device Information Service characteristics, their descriptors and values. See Table B.3 for Device Information service characteristics.
gap_service_db.db	Contains information related to GAP Service characteristics, their descriptors and values. See Table B.4 for GAP characteristics.
gatt_service_db.db	Contains information related to GATT Service characteristics, their descriptors and values. See Table B.5 for GATT Service characteristics.
heart_rate_service_db.db	Contains information related to Heart Rate Service characteristics, their descriptors and values. See Table B.6 for Heart Rate Service characteristics.

Table 3.3: Database Files

4. Code Overview

This section describes significant functions of this application.

4.1. Application Entry points

4.1.1. AppInit()

This function is invoked when the application is powered on or the chip resets and performs the following initialisation functions:

- Initialises the application timers, hardware and application data structures.
- Configures GATT entity for server role.
- Configures the NVM manager to use I^2C EEPROM.
- Initialises all the services.
- Reads the persistent store.
- Registers the attribute database with the firmware.

4.1.2. AppProcessLmEvent()

This function is invoked whenever a LM-specific event is received by the system. The following events are being handled in this function:

4.1.2.1. Database Access

- `GATT_ADD_DB_CFM`: This confirmation event marks the completion of database registration with the firmware. On receiving this event, the Heart Rate Sensor application starts advertising.
- `GATT_ACCESS_IND`: This indication event is received when the remote Heart Rate Collector tries to access an ATT characteristic managed by the application.

4.1.2.2. LS Events

- `LS_CONNECTION_PARAM_UPDATE_CFM`: This confirmation event is received in response to the connection parameter update request by the application. The connection parameter update request from the application triggers the L2CAP connection parameter update signalling procedure. See Volume 3, Part A, Section 4.20 of *Bluetooth Core Specification Version 4.1*.
- `LS_CONNECTION_PARAM_UPDATE_IND`: This indication event is received when the remote central device updates the connection parameters. On receiving this event, the application validates the new connection parameters against the preferred connection parameters and triggers a connection parameter update request if the new connection parameters do not comply with the preferred connection parameters.
- `LS_RADIO_EVENT_IND`: This radio event indication is received when the chip firmware receives an acknowledgement for the Tx data sent by the application. On receiving this event, the application aligns the timer wakeup, which sends data periodically to the collector, with the latent connection interval.

4.1.2.3. SMP Events

- `SM_KEYS_IND`: This indication event is received on completion of the bonding procedure. It contains keys and security information used on a connection that has completed the short term key generation. The application stores the received diversifier (DIV) and Identity Resolving Key (IRK), if the collector device uses resolvable random address, to NVM. See Volume 3, Part H, Section 2.4 and Section 3.6 of the *Bluetooth Core Specification Version 4.1*.
- `SM_SIMPLE_PAIRING_COMPLETE_IND`: This indication event indicates that the pairing has completed successfully or otherwise. See Volume 3, Part H, Section 2.4 and Section 3.6 of *Bluetooth Core Specification Version 4.1.* In the case of a successful completion of the pairing procedure, the Heart

Rate sensor application is bonded with the collector and bonding information is stored in the NVM. The bonded device address will be added to the white list, if it is not a resolvable random address.

- SM_DIV_APPROVE_IND: This indication event is received when the remote connected device re-encrypts the link or triggers encryption at the time of reconnection. The firmware sends the diversifier in this event and waits for the application to approve or reject the encryption. The application shall reject the encryption if the bond has been removed by the user or diversifier does not match the diversifier that is stored during the bonding procedure. The application compares the diversifier with the one received in the SM_KEYS_IND event at the time of the first encryption. If similar, the application approves the encryption, otherwise it rejects it.

4.1.2.4. Connection Events

- GATT_CONNECT_CFM: This confirmation event indicates that the connection procedure has completed. If it has not successfully completed, the application goes to idle state and waits for user action. See section 4.2 for more information on application states. If the application is bonded to a device with resolvable random address and connection is established, the application tries to resolve the connected device address using the IRK stored in NVM. If the application fails to resolve the address, it disconnects the link and restarts advertising.
- GATT_CANCEL_CONNECT_CFM: This confirmation event confirms the cancellation of connection procedure. When the application stops advertisements to change advertising parameters or to save power, this signal confirms the successful stopping of advertisements by the Heart Rate Sensor application.
- LM_EV_CONNECTION_COMPLETE: This event is received when the connection with the master is considered to be complete and includes the new connection parameters.
- LM_EV_DISCONNECT_COMPLETE: This event is received on link disconnection. Disconnection could be due to link loss, locally triggered or triggered by the remote connected device.
- LM_EV_ENCRYPTION_CHANGE: This event indicates a change in the link encryption.
- LM_EV_CONNECTION_UPDATE: This event indicates that the connection parameters have been updated to a new set of values and is generated when the connection parameter update procedure is either initiated by the master or the slave. These new values are stored by the application for comparison against the preferred connection parameter, see section 7.7.

4.1.3. AppProcessSystemEvent()

This function handles the system events such as a low battery notification or a PIO change. It currently handles the following two system events:

- sys_event_battery_low: This event is received whenever the battery voltage crosses the low battery voltage threshold. If connected and notifications are configured, the Heart Rate Sensor application notifies the battery level to the collector device.
- sys_event_pio_changed: This event indicates a change in PIO value. Whenever the user presses or releases the button, the corresponding PIO value changes and the application receives a PIO changed event and takes the appropriate action.

4.2. Internal State Machine

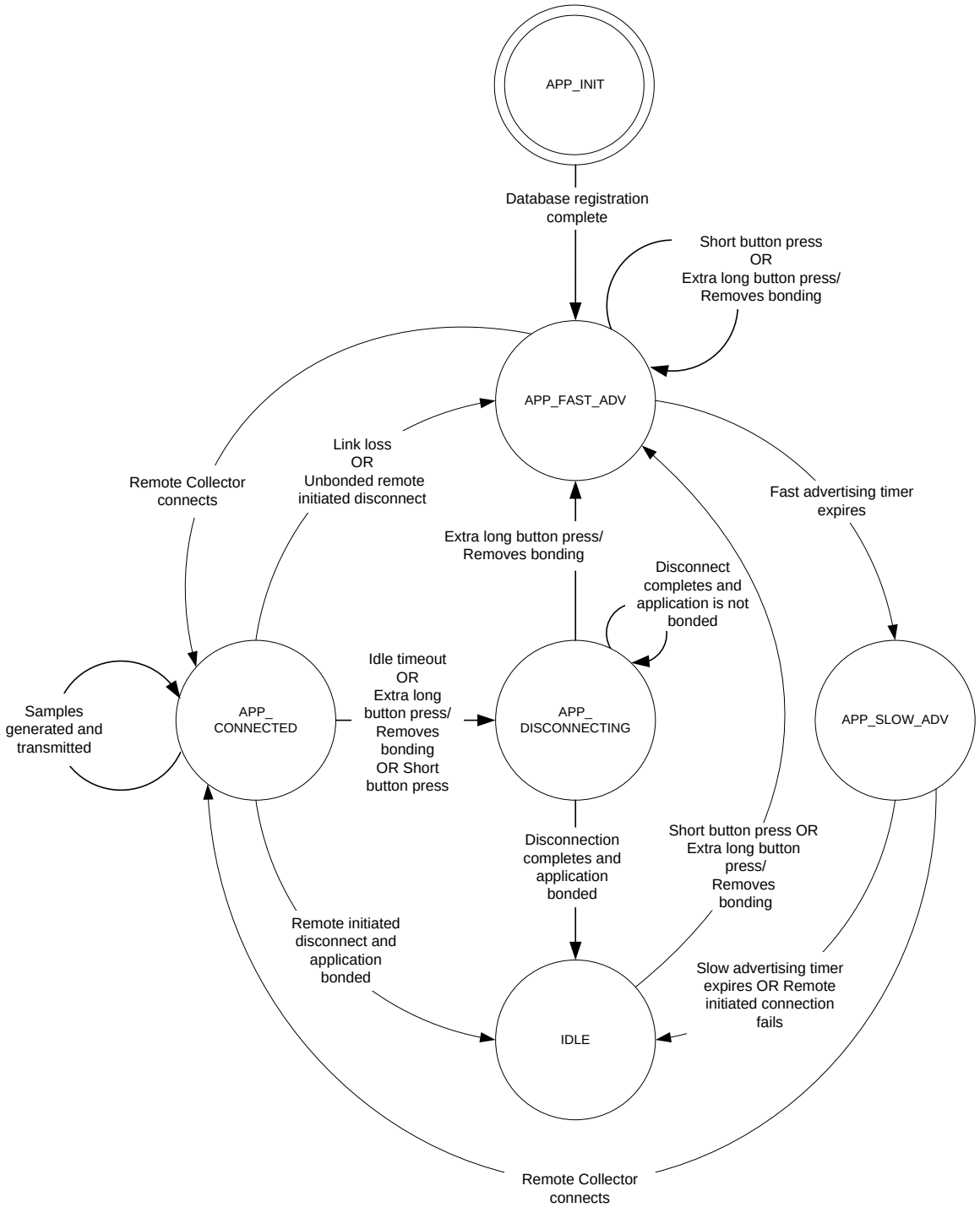

Figure 4.1: Internal State Diagram (Sample Measurement Mode)

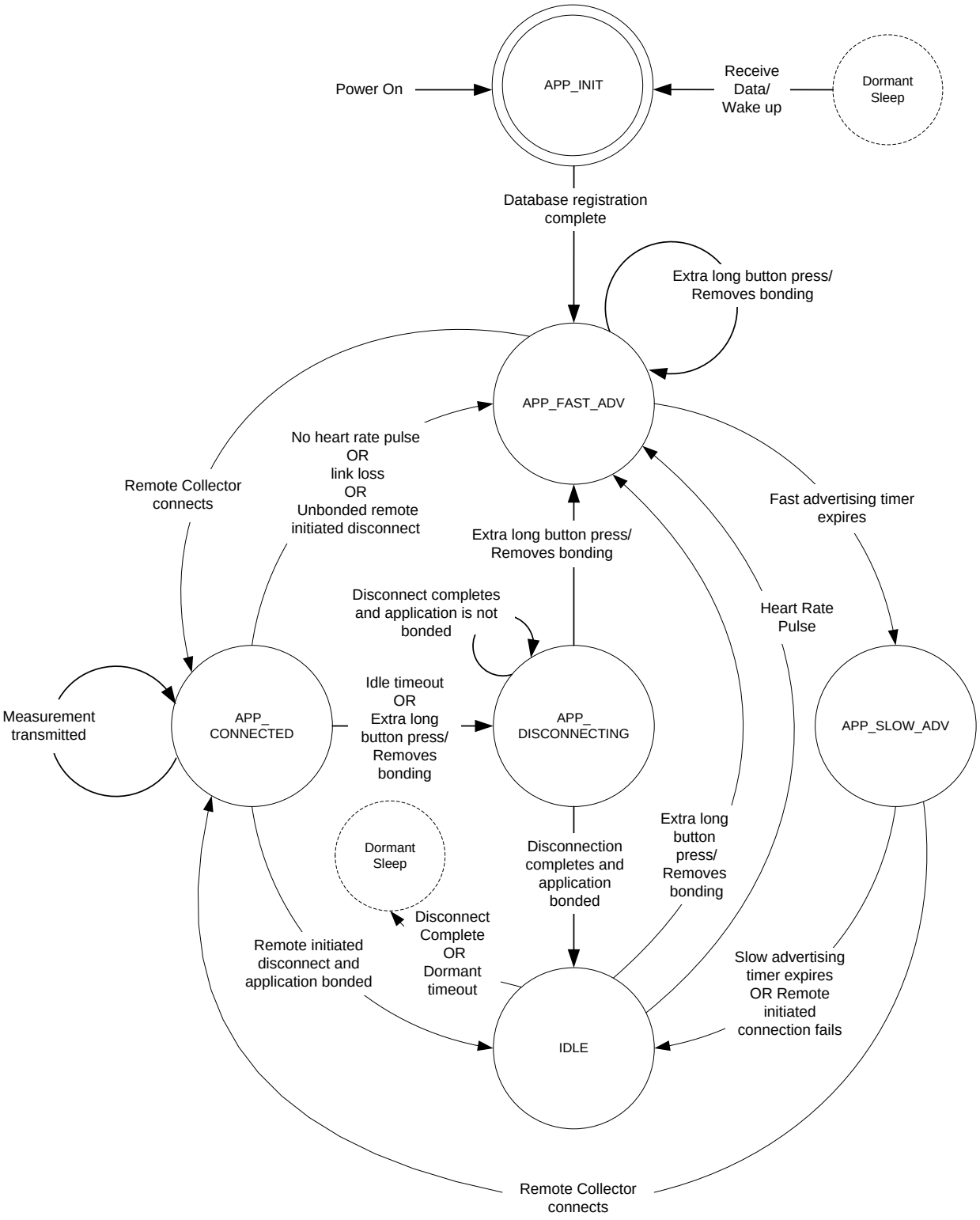

Figure 4.2: Internal State Diagram (Actual Measurement Mode)

The Heart Rate Sensor application has five internal states, see Figure 4.1 and Figure 4.2.

Note:

A *Short* button press does not alter the behaviour of the device in Actual Measurement mode.

4.2.1. APP_INIT

When the application is powered on or the chip resets it enters this state. The Heart Rate Sensor application registers the service database with the firmware and waits for a confirmation. On a successful database registration it starts advertising.

4.2.2. APP_IDLE

In this state, the Heart Rate Sensor application is not connected to any Heart Rate Collector.

- On an *extra-long* button press, the application removes the bonding information and enters the `APP_ADVERTISING` state.
- On a *short* button press in Sample Measurement mode, the application triggers advertisements and enters the `APP_ADVERTISING` state.
- When a Heart Rate Pulse is available in Actual Measurement mode, the application triggers advertisements and enters the `APP_ADVERTISING` state.
- When no signal is received on the `HR_INPUT_PIO` PIO in Actual Measurement mode, the Heart Rate Sensor application automatically moves to dormant sleep state after a timeout period. See 7.6 for more information on the dormant idle timer.

4.2.3. APP_ADVERTISING

In this state, the Heart Rate Sensor application advertises itself and beeps twice to indicate the start of advertisements.

- Sub state `APP_FAST_ADVERTISING`: The application starts in this sub state and uses fast advertising parameters in this state. If a remote collector connects to it, it stops advertisements and enters the `APP_CONNECTED` state. If the fast advertising timer expires before connection is made, the `APP_SLOW_ADVERTISING` sub state is entered. See section 7.3 for more information on advertisement timers.
- Sub state `APP_SLOW_ADVERTISING`: The application uses slow advertising parameters in this sub state. If a remote device connects to it, it stops advertisements and enters the `APP_CONNECTED` state. If the slow advertising timer expires before a connection is made, the `APP_IDLE` state is entered.

While in any of the above two states:

- If the application is bonded to some remote Heart Rate Collector, it will add the bonded device's address to its white list. This means that it will accept connections only from this bonded device. While triggering advertisements, it starts a Bonded Device Advertisement Timer. If the bonded remote device connects to it within this interval, it stops advertising and enters the `APP_CONNECTED` state.
- If the Bonded Device Advertisement Timer expires before the remote bonded Heart Rate connects to it, it stops advertising, disables the white list and again starts fast advertising for a certain interval period. If the remote collector connects to it, it stops advertisements and enters the `APP_CONNECTED` state.
- On an *extra-long* button press, the application stops advertisements, removes bonding and enters the sub state `APP_FAST_ADVERTISING` without any white list.

See the *Bluetooth Core specification Version 4.1* for more information on white lists.

4.2.4. APP_CONNECTED

In this state, the Heart Rate sensor application is connected to a remote Heart Rate Collector and sends Heart Rate measurements at intervals specified in Table 1.4. See Figure B.1 for the measurement data format.

- On a *short* button press in Sample Measurement mode, the application disconnects the link and moves to the `APP_DISCONNECTING` state.

- When the Heart Rate Pulse is not available for the idle timeout period in Actual Measurement mode, the application disconnects the link and moves to the `APP_DISCONNECTING` state. See section 7.5 for information on the idle timer.
- On an *extra-long* button press, application disconnects the link, removes the bonding and enters the `APP_DISCONNECTING` state.
- If link loss occurs, the application switches to the `APP_ADVERTISING` state.
- In the case of a Remote triggered disconnection, if the application is not bonded to any remote device, it again starts advertising and enters the `APP_ADVERTISING` state else it enters the `APP_IDLE` state.

4.2.5. APP_DISCONNECTING

In this state, the Heart Rate Sensor application waits for a disconnect confirmation after initiating the disconnection. After receiving the disconnect confirmation, it checks if it is bonded to any Heart Rate Collector.

- If the disconnection was triggered by an idle timeout, then the application will enter a dormant sleep state in Actual Measurement mode. The application will wake up from this sleep state whenever the wake pin matches the configured state of the macro `WAKE_SIGNAL_LEVEL` in `user_config.h`.
- If the application is bonded, it enters the `APP_IDLE` state and waits for user activity.
- If the application is not bonded, it starts advertising and enters the `APP_ADVERTISING` state.
- On an *extra-long* button press, the application removes the bonding information.

5. NVM Memory Map

The applications can store data in NVM to prevent data loss in the event of a power off or chip panic.

Entity Name	Type	Size of Entity (Words)	NVM Offset (Words)
Sanity Word	uint16	1	0
Bonded Flag	Boolean	1	1
Bonded Device Address	structure	5	2
Diversifier	uint16	1	7
IRK	uint16 array	8	8

Table 5.1: NVM Memory Map for Application

Entity Name	Type	Size of Entity (Words)	NVM Offset (Words)
GAP Device Name Length	uint16	1	16
GAP Device Name	uint8 array	20	17

Table 5.2: NVM Memory Map for GAP Service

Entity Name	Type	Size of Entity (Words)	NVM Offset (Words)
Heart Rate Measurement Characteristic Client Configuration Descriptor	uint16	1	37
Heart Rate Energy Expended	uint16	1	38

Table 5.3: NVM Memory Map for Heart Rate Service

Entity Name	Type	Size of Entity (Words)	NVM Offset (Words)
Battery Level Characteristic Client Configuration Descriptor	uint16	1	39

Table 5.4: NVM Memory Map for Battery Service

Entity Name	Type	Size of Entity (Words)	NVM Offset (Words)
Service Changed Characteristic Client Configuration Descriptor	uint16	1	40
Service Changed Indication Flag	uint16	1	41

Table 5.5: NVM Memory Map for GATT Service

Note:

The application does not pack the data before writing it to the NVM. This means that writing a `uint8` takes one word of NVM memory.

6. CSR OTA Update Application

The CSR OTA Update Application service enables wireless update of the application software. A PC or mobile phone application provided by the device manufacturer enables the end-user to keep their device up-to-date with the latest features and bug fixes.

To enable a device for future OTA updates, the application needs to:

- Add OTA Update functionality to the on-chip application
- Add support for the CSR OTA Update Application Service and GATT Services to an application
- Configure the on-chip bootloader

The CSR OTA Update bootloader image must be present on the device and configured to contain the correct device name and optional shared authentication key.The user can select from different bootloader versions in the application as required. See section 6.1 for more information on bootloader versions.

When the device is enabled for OTA Update, the CSR µEnergy Over-the-Air Updater host application included in the SDK can update the device.

For more information on CSR OTA Update, see *CSR µEnergy Over-the-Air (OTA) Update System Application Note*, *CSR µEnergy Modifying an Application to Support OTA Update Application Note*, *CSR µEnergy Over-the-Air (OTA) Update Application and Bootloader Services Specification* and *Interfacing Large Serial Flash and EEPROM Application Note.*

For information on CSR OTA Update applications for iOS and Android, see www.csrsupport.com.

6.1. Bootloader Version

The application can switch between different bootloader versions using the **Version (OTA Update Bootloader)** project property in xIDE. Bootloader version 6 only supports devices with 512 kbits EEPROM NVM storage. Bootloader version 7 supports devices with EEPROM or SPI Flash NVM storage, 512 kbits or greater. If bootloader version 7 is used, application slot addresses need to be configured depending on EEPROM/Flash size being used. By default, the bootloader version is 7 and application slot addresses have been configured for 512 kbits EEPROM. For more information on configurable slot addresses, see *CSR µEnergy Over-the-Air (OTA) Update System Application Note*. See section 6.2 for information on customising the application for large SPI flash.

Note:

The NVM Store configuration for bootloader version 6 is shown in Figure 6.1.The NVM Store configuration will change if bootloader version 7 is selected. For larger NVM devices (> 512 kbits) NVM Store should be moved to just after the OTAU bootloader and before the first application, see Figure 6.2.The NVM Store must reside within the first 512 kbits of NVM. Follow the comments provided in the `keyr` file to switch between NVM store configurations for different bootloader versions. For detailed information, see *Interfacing Large Serial Flash and EEPROM Application Note* and *CSR µEnergy Over-the-Air (OTA) Update System Application Note*.

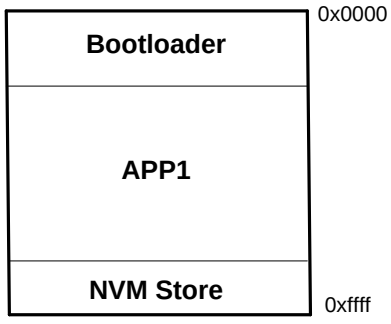

Figure 6.1: Memory Layout for 512kbit EEPROM devices

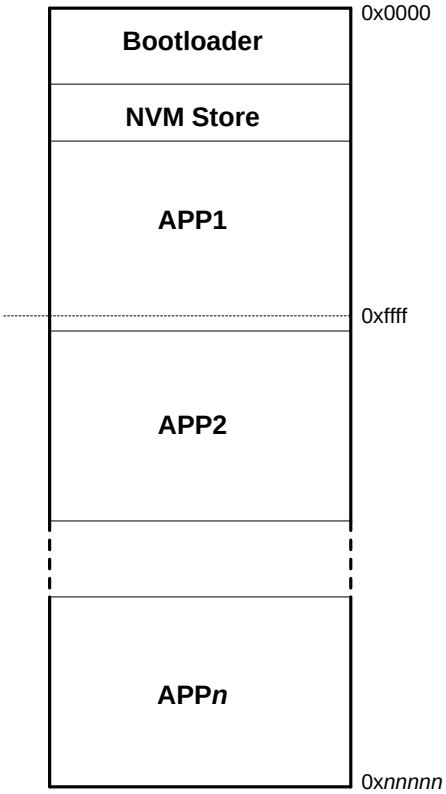

Figure 6.2: Memory layout for >= 512kbit EEPROM/Flash devices

6.2. Large SPI Flash

If **NVM Type** is set to `NVM_TYPE_FLASH` and if the SPI flash device capacity is greater than 512 kbits, then the application needs to set both **SPI Flash Clock PIO** and **SPI Flash MISO PIO** properties in the xIDE Project Properties. These PIOs must not conflict with the PIOs already in use by the application. For more information on large SPI flash, see *Interfacing Large Serial Flash and EEPROM Application Note.*

7. Customising the Application

The developer can customise the application by modifying the following parameter values.

7.1. Actual Measurement Mode

The Heart Rate Sensor application, by default, operates in Sample Measurement mode, see Table 1.4. The macro `NO_ACTUAL_MEASUREMENT`, defined in the `user_config.h` file, is used to select the measurement mode. To switch to Actual Measurement mode, see Table 1.4, the `user_config.h` file must be modified by commenting out the definition of the `NO_ACTUAL_MEASUREMENT` macro.

In Actual Measurement mode, the heart rate measurements are fed from an external Heart Rate device to the application via the `HR_INPUT_PIO` PIO defined in the `hr_sensor_hw.h` file. The application calculates heart rate measurements from the signal received on the `HR_INPUT_PIO` PIO and sends these measurements to the connected Heart Rate Collector.

PIO Name	PIO Number
HR_INPUT_PIO	[9]

Table 7.1: PIO for External Heart Rate Input

7.2. Advertising Parameters

The Heart Rate Sensor application uses the parameters in Table 7.2 for fast and slow advertisements. The macros for these values are defined in file `gap_conn_params.h`. These values have been chosen by considering the overall current consumption of the device. See *Bluetooth Core Specification Version 4.1* for the advertising parameters range.

Parameter Name	Slow Advertisements	Fast Advertisements
Minimum Advertising Interval	1280 ms	60 ms
Maximum Advertising Interval	1280 ms	60 ms

Table 7.2: Advertising Parameters

7.3. Advertisement Timers

The Heart Rate Sensor application enters the appropriate state on expiry of the advertisement timers. See section 4.2 for more information. The macros for these timer values are defined in the file `hr_sensor_gatt.h`.

Timer Name	Timer Values
Bonded Device Advertisement Timer Value	10 s
Fast Advertisement Timer Value	30 s
Slow Advertisement Timer Value	1 min

Table 7.3: Advertisement Timers

7.4. Connection Parameters

The Heart Rate Sensor application uses the connection parameters listed in Table 7.4 by default, and should be used to configure the Profile Demonstrator before a connection is attempted. The macros for these values are defined in the file `gap_conn_params.h`. These values have been chosen by considering the overall current consumption of the device. See *Bluetooth Core Specification Version 4.1* for the connection parameter range. See section 7.7 for the connection update procedure.

Parameter Name	Parameter Value	Profile Demonstrator Configuration
Minimum Connection Interval	1000 ms	800
Maximum Connection Interval	1000 ms	800
Slave Latency	0 intervals	0
Supervision Timeout	6000 ms	600

Table 7.4: Connection Parameters (Default)

When connecting to Apple products, the connection parameters listed in Table 7.5 should be used.

Parameter Name	Parameter Value	Profile Demonstrator Configuration
Minimum Connection Interval	980 ms	800
Maximum Connection Interval	1000 ms	800
Slave Latency	0 intervals	0
Supervision Timeout	6000 ms	600

Table 7.5: Preferred Connection Parameters for Apple Products

7.5. Idle Connected Timeout

While in Actual Measurement mode, the Heart Rate Sensor application runs an idle timer in the connected state. If the application does not receive any heart rate measurements during this period, it disconnects the link. The macro for this timer value is defined in file `hr_sensor.c`.

Parameter Name	Parameter Value
Idle Connected Timeout	10 s

Table 7.6: Idle Connected Timeout

7.6. Idle Timeout

The Heart Rate Sensor application runs a dormant timer after moving to the idle state. If the application does not receive any heart rate measurements during this period, it moves to dormant sleep after the time out. The macro for this timer value is defined in file `user_config.h`. To disable the transition to dormant sleep, `user_config.h` must be modified by commenting out the definition of the `ENABLE_DORMANT_MODE_FUNCTIONALITY` macro.

Parameter Name	Parameter Value
Idle Timeout	1800 s

Table 7.7: Idle Timeout

7.7. Connection Parameter Update

The Heart Rate Sensor application can request the remote connected Collector to update the connection parameters according to its power requirements. The application requests a connection parameter update as per the recommendations in *Bluetooth Core Specification Version 4.1* [Vol. 3], Part C Section 9.3.9, or 30 seconds after the remote Collector changes the connection parameters. Upon connection establishment with the Collector, the following procedure is used to send a connection parameter update request:

1. Upon connection, the 5s $T_{GAP(conn\_pause\_peripheral)}$ timer is started.
2. Upon the expiry of $T_{GAP(conn\_pause\_peripheral)}$, the 1s $T_{GAP(conn\_pause\_central)}$ timer is started.
3. During this 1s $T_{GAP(conn\_pause\_central)}$ period, if the application receives a `GATT_ACCESS_IND LM` event, the timer will be deleted and re-created. The receipt of this event means that the service discovery procedure is in progress and the Heart Rate Sensor application should not request a connection parameter update.
4. Upon the expiry of $T_{GAP(conn\_pause\_peripheral)}$, a connection parameter update request will be sent from the Heart Rate Sensor application.

The remote Collector may or may not accept the requested connection parameters. If the remote Collector rejects the new requested connection parameters, the application again requests an update after 30 seconds. The macro for this time value is defined in file `hr_sensor.c` and can be modified as required .After two failed attempts, the Heart Rate Sensor application tries to update with the Apple preferred connection parameters another two times. Ensure the **Accept connected parameters** option on the CSR µEnergy Profile Demonstrator application is checked to accept the requested connection parameters, see Figure 7.1.

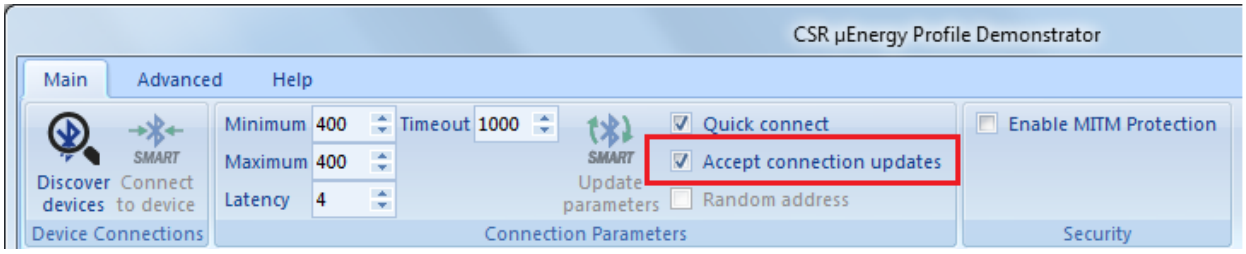

Figure 7.1: Accept Connection Parameters

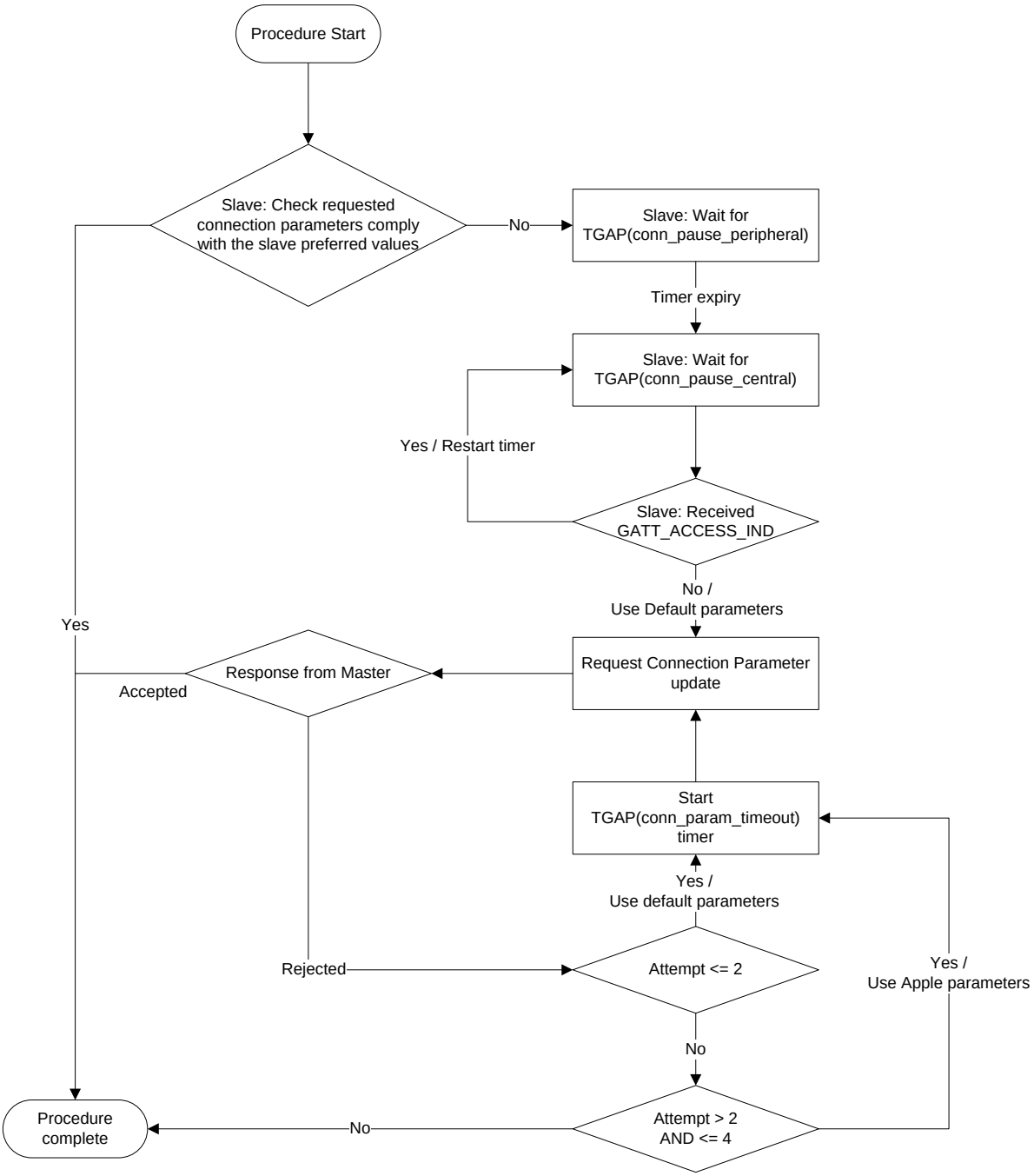

Figure 7.2: Connection Parameter Update Procedure

7.8. Device Name

The user can change the device name for the application. By default, it is set to `CSR HR Sensor` in the file `gap_service.c`. The maximum length of the device name is 20 octets.

7.9. Buzzer

The Heart Rate Sensor application uses the buzzer to indicate different states and events to the user. The user can enable or disable the buzzer as required by the application. The buzzer should be disabled while taking current consumption readings, see section 8. The macro for enabling the buzzer is defined in the file `user_config.h`. To disable the buzzer, comment out the macro `ENABLE_BUZZER` in file `user_config.h`.

7.10. Device Address

The Heart Rate Sensor application uses a public address by default. The `USE_STATIC_RANDOM_ADDRESS` macro in `user_config.h` file can be used to enable the support for static random addresses.

7.11. Configuring the Wake Pin

The application is expecting the wake pin to be connected to the `HR_INPUT_PIO` PIO input. Since the application pulls this PIO up, the wake pin default state will also be `HIGH`. Wake should therefore be configured to trigger on the `LOW` value. The default value for wake is defined by the macro `WAKE_SIGNAL_LEVEL` in `user_config.h`.

7.12. Body Location

The default location can be changed by setting the `CURRENT_BODY_SENSOR_LOCATION_VALUE` to one of the values defined in `heart_rate_service_uuids.h`. The default location is set to *chest*.

7.13. Non-Volatile Memory

The Heart Rate Sensor application uses one of the following macros to store and retrieve persistent data in either the EEPROM or Flash-based memory.

- `NVM_TYPE_EEPROM` for I^2C EEPROM.
- `NVM_TYPE_FLASH` for SPI Flash.

Note:

The macros are enabled by selecting the **NVM Type** using the Project Properties in xIDE. This macro is defined during compilation to let the application know which NVM type it is being built for. If EEPROM is selected `NVM_TYPE_EEPROM` will be defined and for SPI Flash the macro `NVM_TYPE_FLASH` will be defined. Follow the comments provided in the `keyr` file to switch between EEPROM and SPI Flash NVM settings.

7.14. Battery Low Threshold Voltage

In order to prevent NVM corruption at low battery levels and to ensure stable operation, the application checks the battery voltage before every NVM read/write operation. If the battery voltage is below the threshold voltage, NVM operations are not performed and a battery low notification with a battery level of 0 is returned to the remote host. The threshold is configured using the `BATTERY_THRESHOLD` CS Key in the `keyr` file, and by default is set to 2100 mV.

8. Current Consumption

The current consumed by the application can be measured by removing the Current Measuring Jumper, see Figure 2.1 and installing an ammeter in its place. The ammeter should be set to DC, measuring current from µA to mA. Any code that sounds the buzzer should be disabled before measuring the actual current consumed.

The setup used while measuring current consumption is described in section 2.1. The CSR µEnergy Profile Demonstrator application must be configured to accept connection parameter update requests, see Figure 2.5.

Table 8.1 shows the typical current consumption values measured during testing under noisy RF conditions with Channel Map Updates disabled, and with typical connection parameter values using the CSR1010 development board. See the Release Notes for the actual current consumption values measured for the application.

Test Scenario	Description	Average Current Consumption	Remarks
Fast Advertisements	1. Switch on the Heart Rate Sensor device 2. Wait for 5 s 3. Take the measurement	468 µA	▪ Advertising Interval: 60 ms ▪ Advertisement Data length: 29 ▪ Measurement Time Duration: 20 s
Slow Advertisements	1. Switch on the Heart Rate Sensor device 2. Wait for 40 s 3. Take the measurement	29 µA	▪ Advertising Interval: 1.28 s ▪ Advertisement Data length: 29 ▪ Measurement Time Duration: 40 s
Connected Active	1. Connect to the Collector 2. Wait for 60 s 3. In sample measurement mode, Heart Rate Sensor device will start sending heart rate measurements at 1 second intervals. See section 1.1.4 for details. 4. Take the measurement	21 µA	▪ Connection parameters: Minimum Connection Interval: 1000 ms Maximum Connection Interval: 1000 ms Slave Latency: 0 ▪ Measurement Time Duration: 60 s
Notes: ▪ Average current consumption is measured at 3.0 V ▪ Ammeter Used: Agilent 34411A ▪ Channel map update has been disabled on the USB dongle by setting the AFH options PS Key to `0x0037` (Default value: `0x0017`) using the PSTool application included in CSR BlueSuite available on www.CSRSupport.com			

Table 8.1: Current Consumption Values

Appendix A Definitions

A.1 User interface definitions

Term	Meaning
Short button press	Button press for less than 2 seconds
Long button press	Button press for greater than or equal to 2 seconds but less than 4 seconds
Extra-long button press	Button press for greater than or equal to 4 seconds
Short beep	Beep for 100 ms
Long beep	Beep for 500 ms

Table A.1: Definitions

Appendix B GATT Database

B.1 Battery Service Characteristics

Characteristic Name	Database Handle	Access Permissions	Managed By	Security Permissions	Value
Battery Level	0x0016	Read, Notify	Application	Security Mode 1 and Security Level 1	Current battery level
Battery Level-Client Configuration Descriptor	0x0017	Read, Write	Application	Security Mode 1 and Security level 2	Current client configuration for Battery Level characteristic

Table B.1: Battery Service Characteristics

For more information on Battery service, see *Battery Service Specification Version 1.0*. For information related to security permissions, see *Bluetooth Core Specification Version 4.1*.

B.2 CSR OTA Update Application Service Characteristics

Characteristic Name	Database Handle	Access Permissions	Managed By	Security Permissions	Value
Current Application	0x001a	Read, Write	Application	Security Mode 1 and Security Level 2	Current live application 0x0 - OTA Update Bootloader 0x1 - Identifies application 1 0x2 - Identifies application 2
Read CS Block	0x001c	Write	Application	Security Mode 1 and Security Level 2	Format - uint16[2] Index 0 - An offset in 16-bit words into the CS defined in the SDK documentation. Index 1 - The size of the CS block expected, in octets.
Data Transfer	0x001e	Read, Notify	Application	Security Mode 1 and Security Level 2	This characteristic is ATT_MTU-3 (20)-bytes long. The format of the 20-bytes is defined by the message context.
Data Transfer Client Characteristic Configuration	0x001f	Read, Write	Application	Security Mode 1 and Security Level 2	Current client configuration for Data Transfer characteristic
Version	0x0021	Read	Application	Security Mode 1 and Security Level 2	Service version Format - uint8

Table B.2: CSR OTA Update Application Service Characteristics

For more information on CSR OTA Update Application Service characteristics, *see OTA Update Bootloader and Application Services Specification*.

B.3 Device Information Service Characteristics

Characteristic Name	Database Handle	Access Permissions	Managed By	Security Permissions	Value
Serial Number String	0x0024	Read	Firmware	Security Mode 1 and Security Level 1	BLE-HR SENSOR-001
Hardware Revision String	0x0026	Read	Firmware	Security Mode 1 and Security Level 1	<Chip Identifier>
Firmware Revision String	0x0028	Read	Firmware	Security Mode 1 and Security Level 1	<SDK Version>
Software Revision String	0x002a	Read	Firmware	Security Mode 1 and Security Level 1	<Application Version>
Manufacturer Name String	0x002c	Read	Firmware	Security Mode 1 and Security Level 1	Cambridge Silicon Radio
PnP ID	0x002e	Read	Firmware	Security Mode 1 and Security Level 1	Vendor ID source is BT Vendor ID is 0x000a Product ID is 0x014c Product Version is 1.0.0

Table B.3: Device Information Service Characteristics

See *Bluetooth Core Specification Version 4.1* for more information on security permissions. For information on Device Information Service see *Device Information Service specification version 1.1*.

B.4 GAP Service Characteristics

Characteristic Name	Database Handle	Access Permissions	Managed By	Security Permissions	Value
Device Name	0x0007	Read, Write	Application	Security Mode 1 and Security Level 1	Device name Default value : CSR HR Sensor
Appearance	0x0009	Read	Firmware	Security Mode 1 and Security Level 1	Generic Heart Rate Sensor 0x0340
Peripheral Preferred Connection Parameters	0x000b	Read	Firmware	Security Mode 1 and Security Level 1	Min connection interval - 1000 ms Max connection interval – 1000 ms Slave latency – 0 Connection timeout - 6 s

Table B.4: GAP Service Characteristics

For more information on GAP service and security permissions, see *Bluetooth Core Specification Version 4.1*.

B.5 GATT Service Characteristics

Characteristic Name	Database Handle	Access Permissions	Managed By	Security Permissions	Value
Service Changed	0x0003	Indicate	Application	Security Mode 1 and Security Level 1	Service Changed Handle value
Service Changed Client Characteristic Configuration Descriptor	0x0004	Read, Write	Application	Security Mode 1 and Security Level 1	Current client configuration for Service Changed characteristic

Table B.5: GATT Service Characteristics

For more information on GATT service and security permissions, see *Bluetooth Core Specification Version 4.1*.

B.6 Heart Rate Service Characteristics

Characteristic Name	Database Handle	Access Permissions	Managed By	Security Permissions	Value
Heart Rate Measurement	0x000e	Notify	Application	Security Mode 1 and Security Level 1	Heart Rate measurement value

Characteristic Name	Database Handle	Access Permissions	Managed By	Security Permissions	Value
Heart Rate Measurement - Client Characteristic Configuration Descriptor	0x000f	Read, Write	Application	Security Mode 1 and Security Level 1	Current client configuration for Heart Rate Measurement characteristic
Body Sensor Location	0x0011	Read	Firmware	Security Mode 1 and Security Level 1	0x01 - Default sensor location is *chest*
Heart Rate Control Point	0x0013	Write	Application	Security Mode 1 and Security Level 1	Supported control points for Heart Rate Sensor

Table B.6: Heart Rate Service Characteristics

See *Bluetooth Core Specification Version 4.1* for more information on security permissions. For information on Heart rate service see *Heart Rate Service Specification version 1.0*.

Figure B.1 defines the data format for the Heart Rate Measurement characteristic as used in the application. For more information on Heart Rate Measurement characteristic see the *Bluetooth SIG Developer Portal*.

The Energy Expended field is sent once for every 10 measurements to the collector and the type of the HR Measurement field is a `uint8`.

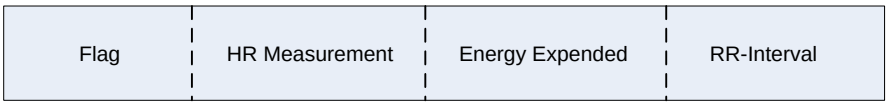

Figure B.1: Heart Rate Measurement Data Format

Note:

This application is usable in public environments, for example a gymnasium, where fitness equipment such as treadmills or steppers do not have the ability to bond. Hence the security permissions for all the characteristics of this application have been set to Security Mode 1 and Security Level 1 i.e. No Security. See *Heart Rate Profile Specification Version 1.0* for more information on public environment requirements and security aspects.

Characteristics are managed by either the firmware or the application. The characteristics managed by the application have flags set to `FLAG_IRQ` in the corresponding database file. When the remote connected device accesses that characteristic, the application receives an `GATT_ACCESS_IND` LM event that is handled in the `AppProcessLmEvent()` function defined in the `hr_sensor.c` file. See section 4.1.2.1 for more information on the handling of the `GATT_ACCESS_IND` LM event. For more information on flags, see the *GATT Database Generator User Guide*.

Appendix C Advertising/Scan Response Data

The Heart Rate Sensor application adds the following fields to the Advertising Data:

Advertising Data Field	Contents
Flags	The Heart Rate Sensor application sets the General Discoverable Mode bit. See section 11, Part C of Volume 3 in *Bluetooth core Specification Version 4.1* for more information.
Service UUIDs	The Heart Rate Sensor application adds 16-bit UUIDs of the following service ▪ Heart Rate Service
Device Appearance	Generic Heart Rate Sensor: `0x0340`
Tx Power	Current Tx power level
Device Name(1)	Device name, Default value: `CSR HR Sensor.`
Note: (1) If the Device Name length is greater than the space left in the Advertising Data field then the application adds it to Scan Response data.	

Table C.1: Advertising Data Fields

Appendix D Known Issues or Limitations

See the Heart Rate Sensor application and SDK Release Notes.

Document References

Document	Reference
Bluetooth Core Specification Version 4.1	https://www.bluetooth.org/Technical/Specifications/adopted.htm
Heart Rate Profile Specification Version 1.0	https://www.bluetooth.org/Technical/Specifications/adopted.htm
Heart Rate Service Specification Version 1.0	https://www.bluetooth.org/Technical/Specifications/adopted.htm
Battery Service Specification Version 1.0	https://www.bluetooth.org/Technical/Specifications/adopted.htm
Device Information Service Specification Version 1.1	https://www.bluetooth.org/Technical/Specifications/adopted.htm
Service Characteristics And Descriptions	http://developer.bluetooth.org/gatt/characteristics/Pages/default.aspx
SDK Documentation	Supplied with the CSR µEnergy SDK as the Firmware Library Documentation
GATT Database Generator	CS-219225-UG
CSR µEnergy xIDE User Guide	CS-212742-UG
CSR µEnergy Bluetooth USB Dongle Driver Installation User Guide	CS-315781-UG
CSR µEnergy Modifying an Application to Support OTA Update Application Note	CS-304564-AN
CSR µEnergy Over-the-Air (OTA) Update System Application Note	CS-316019-AN
Over-the-Air Update Application and Bootloader Services Specification	CS-316220–SP
Interfacing Large Serial Flash and EEPROM Application Note	CS-324434-AN

Terms and Definitions

ATT	Attribute
BLE	Bluetooth Low Energy (now known as Bluetooth Smart)
Bluetooth Smart	Formerly known as Bluetooth Low Energy
Bluetooth®	Set of wireless technologies providing audio and data transfer over short-range radio connections
BPM	Beats Per Minute
CS	Configuration Store
CSR	Cambridge Silicon Radio
DIV	Diversifier
e.g.	*exempli gratia*, for example
EEPROM	Electrically Erasable Programmable Read Only Memory
etc.	*et cetera*, and the rest, and so forth
GAP	Generic Access Profile
GATT	Generic Attribute Profile
i.e.	*Id est*, that is
I^2C	Inter-Integrated Circuit
IC	Integrated Circuit
IDE	Integrated Development Environment
IRK	Identity Resolving Key
kJ	Kilo Joules
LM	Link Manager
MISO	Master-In Slave-Out: a SPI data line
NVM	Non Volatile Memory
OTA	Over The Air
PC	Personal Computer
PIO	Programmable Input Output
PnP	Plug and Play
PWM	Pulse Width Modulation
RR-interval	R wave to R wave interval (inverse of heart rate)
SPI	Serial Peripheral Interface
UUID	Universally Unique Identifier