SimpleLink™ *Bluetooth*® low energy CC2640 wireless MCU

Over-the-Air Download User's Guide

For BLE-Stack™ Version: 2.2.1

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1.1 Document Updates

This document is constantly being improved. For the best user experience, please ensure that you are using the latest version. Newer revisions will be posted online on the OAD User's Guide wiki page.

1.2 Legacy OAD Versions

Prior to the BLE-Stack v2.2.0 release, there were three versions of OAD supported by the SDK:

1. Off chip OAD with preserved page 0 using BIM
2. Off chip OAD without preserved page 0 using Baseloader
3. On chip OAD using BIM

In BLE-Stack SDK versions prior to 2.2.0, the SensorTag embedded project supported the baseloader (Method 2) from above. In conjunction with the embedded project, the SensorTag mobile applications (iOS, Android) only supported the baseloader method (Method 2). This method has been discontinued* as of BLE-Stack v2.2.0, all projects (including the SensorTag) have now standardized on Methods 1 and 3.

This guide (and its previous versions) will describe the BIM based on On-chip and Off-chip methods (Method 1 and Method 3 above).

The baseloader method has been discontinued because there is a risk where a device may become bricked (require wired JTAG access to recover) if a power loss is experienced while updating page 0

1.3 Supported OAD Downloaders

As mentioned above, the SensorTag mobile applications supported the baseloader method prior to BLE-Stack v2.2.0. These applications are in the process of being updated to support BIM based methods. For the best out of box experience, TI recommends that customers use BLE Device Monitor v2.1.5 or later as their OAD downloader, as it supports all OAD methods mentioned above.

1.4 Additional Resources

For hands on training using OAD as well as guidance on the out of the box demos, please refer to the OAD Simple Link Academy module (coming soon):

http://software-dl.ti.com/lprf/simplelink_academy/overview.html

2 Revision History

Date	**Author's Name**	**Doc Revision**	**Section(s)**	**Summary**
12/17/14	SP	1.0	5, 6, 7, 8, 9, 13, 14	Edited for correctness
2/16/2015	SP	2.0		Finalization
7/14/2015	CK	2.1	All	Reorganized chapters / Added Off-chip OAD / Removed OAD Manager / Added downloading methods / Added compiler dependencies / Added sequence diagrams

1/14/2016	ZH	2.1.1	All	Re-organized for user-friendliness / Separate Off-chip and On-Chip OAD chapters / Added Appendix chapter
5/17/16	ZH, SML	2.2	All	Update to BLE Stack 2.2
10/21/16	AR	2.2.1	10,11	Update to BLE Stack 2.2.1

3 References

1. Texas Instruments CC2640 Bluetooth® low energy Software Developer's Guide
   http://www.ti.com/lit/pdf/swru393
2. OAD User's Guide Wiki Page
   http://processors.wiki.ti.com/index.php/CC2640_OAD_User%27s_Guide
3. BLE Device Monitor User's Guide
   http://processors.wiki.ti.com/index.php/BLE_Device_Monitor_User_Guide
4. BLE Device Monitor Download Link
   http://www.ti.com/lit/zip/swrc258
5. SimpleLink Academy
   http://software-dl.ti.com/lprf/simplelink_academy/overview.html

4 Definitions, Abbreviations, Acronyms

Term	**Definition**
BIM	Boot Image Manager, the software bootloader
BLE	Bluetooth low energy wireless protocol
CCCD	Client Characteristic Configuration Descriptor
CCFG	Customer Configuration Area, contains lock-bits on flash page 31
CCS	Code Composer Studio
MCU	Microcontroller Unit
OAD	Over the Air Download
RCFG	RTOS in ROM Configuration Table
ROM	Read Only Memory
RTOS	Real Time Operating System
SNV	Simple Non-Volatile storage
TI	Texas Instruments
TI-RTOS	Texas Instruments Real Time Operating System

5 Purpose

This document describes the process by which a developer can enable a SimpleLink™ Bluetooth® low energy CC2640 wireless MCU project and application to successfully implement the TI OAD Profile to remotely upgrade the image on a CC2640 BLE device, a process further referred to as an Over-the-Air Download (OAD). This process provides tremendous value to a BLE product solution, as a target device does not need to be physically accessed to provide a software upgrade. Our purpose here is to make OAD simple by providing detailed instructions from enabling OAD in an application project to receiving the new image over the air, verifying its correctness, and running it from the bootloader.

6 Scope

This document provides instruction on how to setup a BLE-Stack™ project to be OAD enabled, such as our example simple_peripheral project for OAD. An overview of the OAD architecture and how to build, download, and debug the components shall be discussed here as well. Details about the BLE runtime system on CC26xx devices and the interrupt vector tables will be discussed as is necessary to elucidate how an OAD build differs from a project which does not provide OAD capability.

There are two different types of OAD. One is On-chip OAD which doesn't require any additional hardware and the other is Off-chip OAD which supports a system where an external flash memory is equipped. In the sample application projects, it is assumed that the hardware is the CC2650 LaunchPad where 1MB external flash memory is connected to the CC2650 via SPI.

Topics omitted from this document are reducing the size of an application which does not meet the size limitation (see 9.1), or an On-chip OAD on the BLE stack image or the bootloader. It is important to note that an On-chip OAD of the application image does not include an upgrade of the BLE Stack image as well. Also OAD for the sensortag project is not specifically mentioned in this guide since it uses the same Off-chip OAD method as the simple_peripheral project, see the SensorTag User's Guide wiki for more information on the SensorTag:
http://processors.wiki.ti.com/index.php/CC2650_SensorTag_User's_Guide.

Note: On-chip OAD is currently only supported by IAR with CC2640 devices, while Off-chip OAD works with both IAR and CCS.

NOTE: This kit supports development of Bluetooth low energy applications on the following SimpleLink wireless MCUs: CC2640 and CC2650. The multi-standard CC2650 wireless MCU supports Bluetooth low energy as well as other wireless protocols, such as ZigBee® and 6LoWPAN. The CC2640 supports Bluetooth low energy only. All code generated from the BLE-Stack v2.x SDK is binary compatible and exchangeable with both the CC2650 and CC2640 wireless MCUs. Throughout this document, CC2640 and CC2650 may be used interchangeably.

Also, it is assumed that the developer is familiar with the CC2640 Software Developer's Guide [1], including the dual-image architecture used by the SDK.

For additional support, please visit the following online resources:

- TI Bluetooth LE Wiki-page: www.ti.com/ble-wiki
- TI E2E support forum: www.ti.com/ble-forum

7 OAD Concept Overview

This section aims to explain the major concepts involved in the OAD process from a high level. The concepts here will be expanded on further in the following sections. Some concepts, such as the Boot Image Manager (BIM) may vary in their implementation details. Wherever possible, the concepts will be covered in this chapter with their implementation details covered in the following chapters.

7.1 OAD Types

There are two methods of performing an over the air download: On-chip and Off-chip. The key difference between the two methods is where the downloaded image is to be stored during the OAD. In On-chip OAD, the downloaded image is written to internal flash, allowing for a single chip OAD solution. Off-chip OAD stores the downloaded image in an external flash part, requiring a two chip OAD solution. A graphic showing the different OAD methods is shown below (Figure 1). Each type of OAD has associated tradeoffs and benefits which will be discussed in their respective sections.

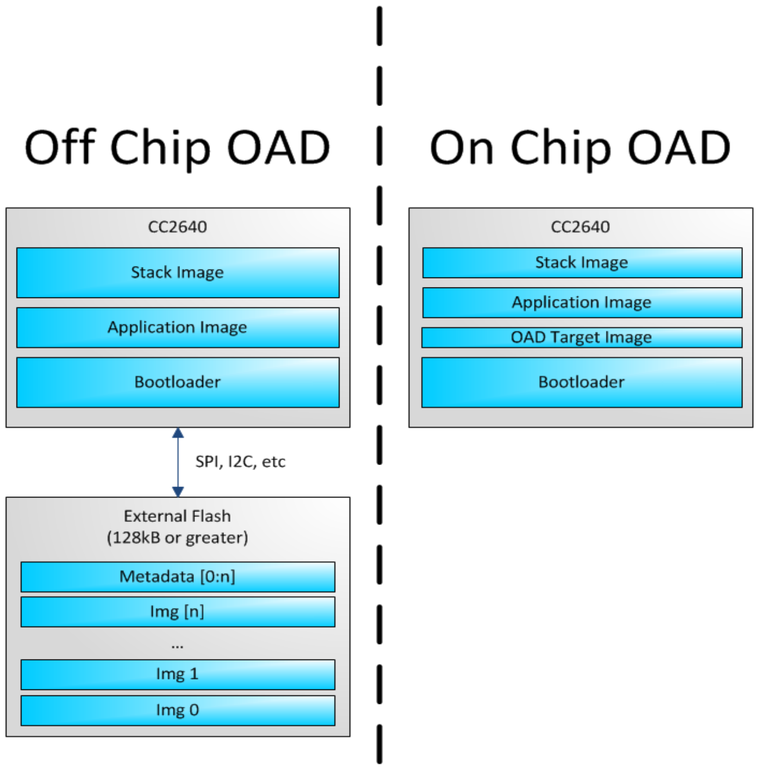

Figure 1. Two Types of OAD

7.2 OAD Topology Overview

Two BLE capable devices are required for performing an OAD. The terms for the devices involved in an OAD exchange are listed below:

- **OAD Target:** The device whose firmware is being upgraded over the air. This is assumed to be a CC26xx device running the TI OAD service.

- **OAD Downloader:** The device responsible for accepting an OAD enabled image from the compiler and transferring it over the air to the OAD target.

OAD roles are independent of the GAP role; they are dependent on which device exposes the OAD service. The OAD target is always the device that runs the OAD service (GATT server), and the OAD downloader is always the device that consumes the OAD service (GATT client).

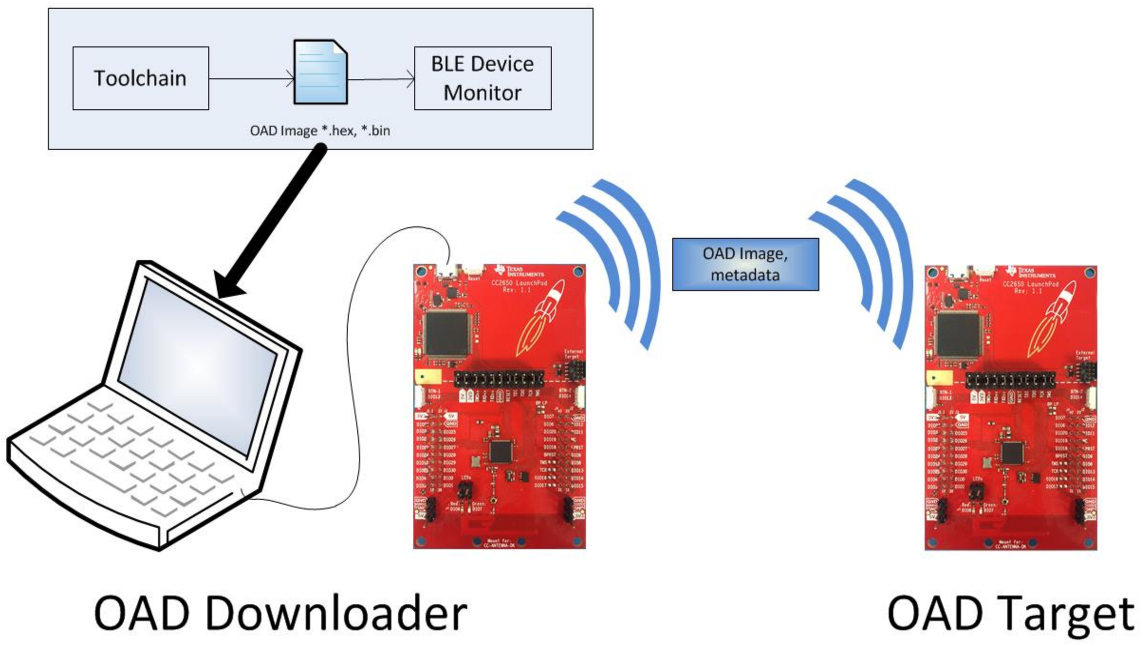

Figure 2. OAD Downloader and Target

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All provided TI example applications (BLE Device Monitor, mobile applications, etc.) are implemented such that the OAD Target is a peripheral device, and the OAD Downloader is a central device. For this reason, other configurations are outside of the scope of this document.

7.3 OAD Image Metadata

There are many points in the OAD process where information must be gathered about images. This information can be used by the OAD service to determine whether or not an image is acceptable for download or by the bootloader to determine which image should be run. In order to prevent this information from being calculated multiple times and to assist in the linking process, all TI OAD images use a standard 16-byte metadata vector. This metadata vector is embedded at the beginning of the image, occupying the first 16 bytes before the application code. This section aims to explain the various fields within the metadata vector and what they mean. The following sections will describe how the fields are used specifically for On-chip and Off-chip OAD.

Figure 3 below shows a description of the metadata vector.

Field	Size (in bytes)	Description
CRC	2	Cyclic Redundancy Check
CRC Shadow	2	Place holder for CRC
Version	2	Version
Length	2	Length of the image in words*
UID	4	User Identification
Start Address	2	The destination address of the image in words*
Image Type	1	The type of image to be downloaded
State	1	The status of this image

Figure 3. Metadata description

Note that the above fields that are marked with an asterisk * are measured in 32-bit words. For example, an image length of 0x100 describes an image that is 1024 bytes in size. This OAD word size is defined by EFL_OAD_ADDR_RESOLUTION for off chip OAD and by HAL_FLASH_WORD_SIZE for on chip OAD.

7.3.1 CRC and CRC Shadow

The cyclic redundancy check (CRC) is a means to check an image to ensure that it has not become corrupted. This must be done in two steps. First the CRC must be calculated when the image is generated from the toolchain, this will be stored in the CRC field in the metadata vector. This initial CRC will be sent over the air via the OAD service (see section 7.4). Later, the target will need to ensure that the image has not been corrupted during transfer. The target will then re-calculate the CRC of the downloaded image; this will be stored in the CRC shadow field of the metadata vector.

If the CRC and CRC shadow are equivalent, the target can assume that the image was not corrupted while sending over the air.

The algorithm selected for CRC calculations is the CRC-16-CCITT, it is a 16 bit CRC calculation that boasts a 99.9984% error detection rate in the worst case.

7.3.2 Version

The image version field is used to track revisions of images and ensure upgrade compatibility. Customers may implement their own versioning scheme. See Section 8.5.2 and Section 9.5.2 how these version checks are done in Off-chip and On-chip OAD, respectively.

7.3.3 Length

The length field is the length of the image in words, where the word size is defined by EFL_OAD_ADDR_RESOLUTION and HAL_FLASH_WORD_SIZE for On-chip and Off-chip OAD respectively. Off-chip OAD customers who are using different external flash parts may need to modify EFL_OAD_ADDR_RESOLUTION to match the word size of their part. For On-chip OAD, the word size of the CC2640 is fixed.

7.3.4 User Identification (UID)

This field is un-used by the TI OAD profile, but the hooks are in place for a customer to add their own implementation of verifying images based on UID.

For on chip OAD, the convention is that Image A will embed ‘A’, ‘A’, ‘A’, ‘A’ and Image B will embed ‘B’, ‘B’, ‘B’, ‘B’. Off chip images use ‘E’, ‘E’, ‘E’, ‘E’ by default.

7.3.5 Start Address

The start address is the first address where the proposed image is to be stored in internal flash. Similar to the length field, this is calculated in words. Off-chip OAD solutions put restrictions on the start address based on image type (more on this in the next section).

Note that for On-chip OAD solutions, this field is reserved in the metadata as they use a fixed start address that is based on the internal flash memory map (OAD_IMG_D_PAGE).

7.3.6 Image Type

In Off-chip OAD systems with external flash, there are multiple types of images that can be uploaded. These image types include: App + Stack, App only, Network Processor, or Stack only.

Note: While BLE Stack only upgrades are possible, the user must be sure that the App/Stack boundary has not changed between the resident OAD image and the proposed OAD image. Since there are no runtime checks on the App/Stack boundary, a Stack only OAD will overwrite the resident application if the boundary has grown. Users should exercise care when using this option.

If a boundary change is required (i.e. BLE stack is growing or shrinking), it is recommended that a user perform a merged update (App+Stack) to ensure that the OAD image is ready to run.

Note that for on chip OAD solutions this field is reserved in the metadata as they determine image type based on the least significant bit of the image version field as discussed above.

The supported image types are listed below:

Image Type	Value	Description
EFL_OAD_IMG_TYPE_APP	1	An application or application + stack merged update
EFL_OAD_IMG_TYPE_STACK	2	A stack only update
EFL_OAD_IMG_TYPE_NP	3	A network processor update. This only applies to the SimpleAP + SimpleNP demo
EFL_OAD_IMG_TYPE_FACTORY	4	Describes the permanently resident production image that runs on the device before any OTA updates.

Figure 4. Off-chip OAD Image Types

7.3.7 Image State

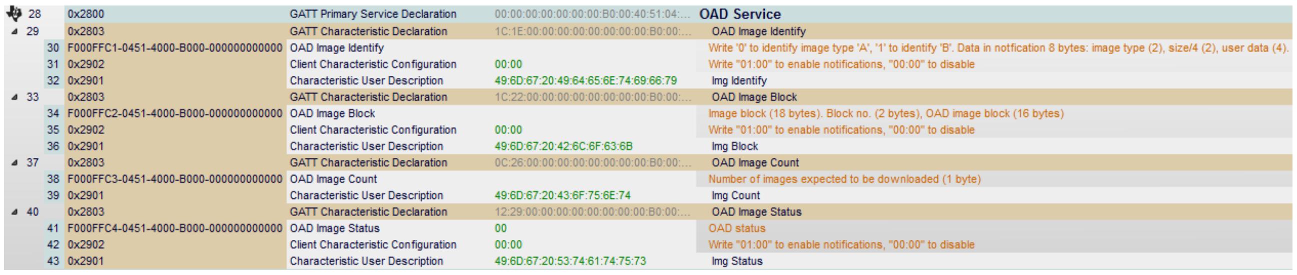
The image state is a one byte metadata field that is used only by Off-chip OAD solutions. The state informs the bootloader whether or not the image is ready to run or currently running. This prevents the bootloader from copying the same image from external to internal flash on every boot.

Note that for On-chip OAD solutions this field is reserved in the metadata as the OAD reset service handles switching between images in the bootloader.

7.4 OAD Service Description

The OAD service has been designed to provide a simple and customizable implementation for the customer. In its most rudimentary form, this service is responsible for accepting/rejecting an OAD interaction based on image header criteria, storing the image in its appropriate location, and causing a device reset if the download is successful so that the downloaded application image is run by the BIM.

A screenshot of BLE Device Monitor displaying the OAD service is shown below.



28	0x2800	GATT Primary Service Declaration	00:00:00:00:00:00:00:B0:00:40:51:04:...	OAD Service
29	0x2803	GATT Characteristic Declaration	1C:1E:00:00:00:00:00:00:00:00:B0:00:...	OAD Image Identify
30	F000FFC1-0451-4000-B000-000000000000	OAD Image Identify		Write '0' to identify image type 'A', '1' to identify 'B'. Data in notfication 8 bytes: image type (2), size/4 (2), user data (4).
31	0x2902	Client Characteristic Configuration	00:00	Write "01:00" to enable notifications, "00:00" to disable
32	0x2901	Characteristic User Description	49:6D:67:20:49:64:65:6E:74:69:66:79	Img Identify
33	0x2803	GATT Characteristic Declaration	1C:22:00:00:00:00:00:00:00:00:B0:00:...	OAD Image Block
34	F000FFC2-0451-4000-B000-000000000000	OAD Image Block		Image block (18 bytes). Block no. (2 bytes), OAD image block (16 bytes)
35	0x2902	Client Characteristic Configuration	00:00	Write "01:00" to enable notifications, "00:00" to disable
36	0x2901	Characteristic User Description	49:6D:67:20:42:6C:6F:63:6B	Img Block
37	0x2803	GATT Characteristic Declaration	0C:26:00:00:00:00:00:00:00:00:B0:00:...	OAD Image Count
38	F000FFC3-0451-4000-B000-000000000000	OAD Image Count		Number of images expected to be downloaded (1 byte)
39	0x2901	Characteristic User Description	49:6D:67:20:43:6F:75:6E:74	Img Count
40	0x2803	GATT Characteristic Declaration	12:29:00:00:00:00:00:00:00:00:B0:00:...	OAD Image Status
41	F000FFC4-0451-4000-B000-000000000000	OAD Image Status	00	OAD status
42	0x2902	Client Characteristic Configuration	00:00	Write "01:00" to enable notifications, "00:00" to disable
43	0x2901	Characteristic User Description	49:6D:67:20:53:74:61:74:75:73	Img Status

Figure 5. OAD Service Overview

The OAD service is a primary service with four characteristics. The characteristics of the OAD service, their UUIDs, and descriptions are listed in Figure 6.

Note that the characteristics use the 128-bit TI base UUID of the format F000XXXX-0451-4000-B000-000000000000 where XXXX is their shortened 16bit UUID. For brevity, this document will refer to the characteristics by their 16-bit short UUID.

UUID	Name	Description
0xFFC0	OAD Service	OAD service declaration
0xFFC1	Image Identify	Used to send image properties (metadata) over the air so that the OAD target device can determine if it should accept or reject the proposed image
0xFFC2	Image Block	Actual block of image data along with offset into the image.
0xFFC3	Image Count	Number of complete images to be downloaded in the OAD session

0xFFC4	Image Status	Status of current OAD download

Figure 6. OAD Service Description

The primary method for sending data from the OAD downloader to the OAD target is the GATT writes with no response message. GATT notifications are the primary method used to send data from the target to the downloader. This communication scheme was selected to prevent the target device from having to include the GATT client code required in order to receive notifications from the downloader. The downloader shall register for notifications from any characteristic with a CCCD (by writing 01:00 to the CCCD).

Note that both GATT notifications and GATT write with no response are non-acknowledged message types. This means that in poor RF conditions, the OAD process may not be successful. There is an inherent tradeoff between the speed of the OAD process and its reliability. Implementing a reliable OAD communication protocol (with retries, acknowledgments, etc.) is outside the scope of this document.

For a message sequence chart describing the OAD process in terms OAD service messages exchanged between the target and downloader please see **Figure 11**.

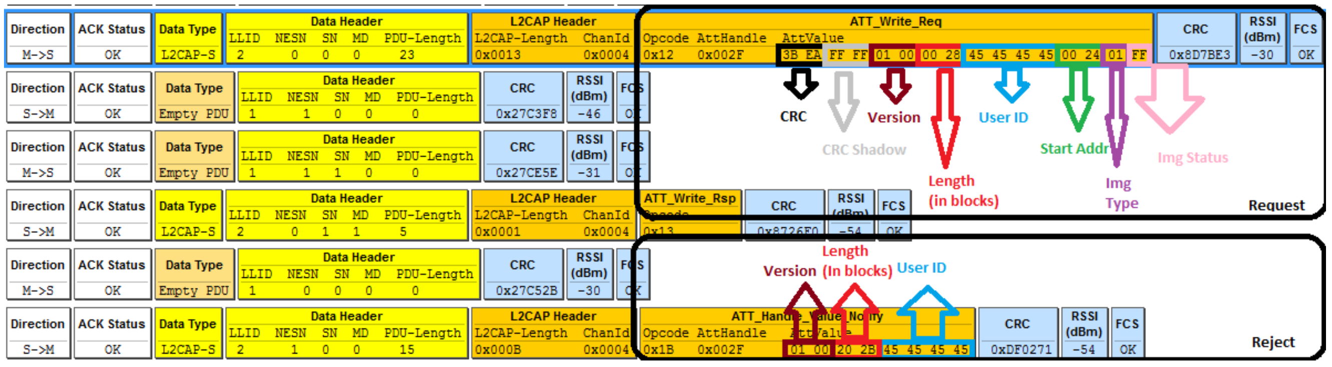
7.4.1 OAD Image Identify (0xFFC1)

The Image Identify characteristic is used to exchange image metadata between downloader and target. The OAD process begins when the downloader sends the 16 byte metadata of the proposed OAD image to the target. Upon receiving the candidate metadata, the target will do some calculations to determine whether or not the proposed image should be downloaded. “01:00” shall be written to the CCCD of this characteristic so that notification for metadata rejection is enabled.

Note that the conditions under which an OAD is accepted vary slightly between the on and off chip methods. Please see the respective sections for more information about image reject conditions.

If the target accepts the image it will continue the OAD process by sending a notification on the Image Block characteristic requesting the first block. Otherwise the target will reject the image by sending back a portion the currently resident image’s metadata. The reject metadata contains the Image Version, Image version, and User ID fields. For more information about these fields, please refer to the metadata section.

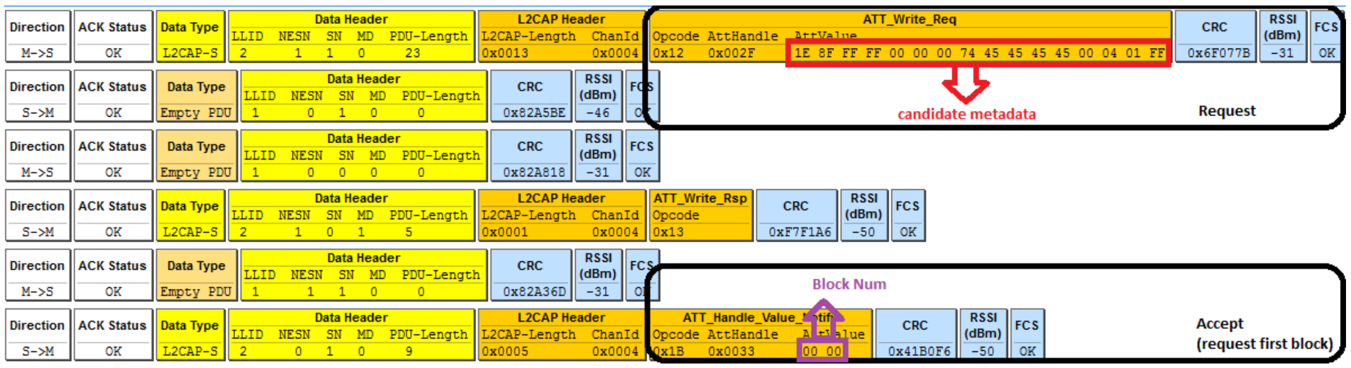
A sniffer capture of the image identify characteristic being used to reject a candidate OAD image is shown below. Note that only image version, length, and user ID are contained in the reject notification.



```
Direction ACK Status Data Type  | Data Header: LLID NESN SN MD PDU-Length | L2CAP Header: L2CAP-Length ChanId | ATT_Write_Req: Opcode AttHandle AttValue                         | CRC      | RSSI (dBm) | FCS
M->S      OK         L2CAP-S    | 2    0    0  0  23                       | 0x0013       0x0004               | 0x12   0x002F    3B EA FF FF 01 00 00 28 45 45 45 45 00 24 01 FF | 0x8D7BE3 | -30        | OK
S->M      OK         Empty PDU  | 1    1    0  0  0                        |                                   |                                                                 | 0x27C3F8 | -46        | OK
M->S      OK         Empty PDU  | 1    1    1  0  0                        |                                   |                                                                 | 0x27CE5E | -31        | OK
S->M      OK         L2CAP-S    | 2    0    1  1  5                        | 0x0001       0x0004               | ATT_Write_Rsp: Opcode 0x13                                      | 0x8726F0 | -54        | OK
M->S      OK         Empty PDU  | 1    0    0  0  0                        |                                   |                                                                 | 0x27C52B | -30        | OK
S->M      OK         L2CAP-S    | 2    1    0  0  15                       | 0x000B       0x0004               | ATT_Handle_Value_Notify: Opcode AttHandle AttValue 0x1B 0x002F 01 00 20 2B 45 45 45 45 | 0xDF0271 | -54 | OK
```

Figure 7. Reject Notification in Sniffer Capture

Alternatively, a successful OAD initiation is shown in Figure 8.

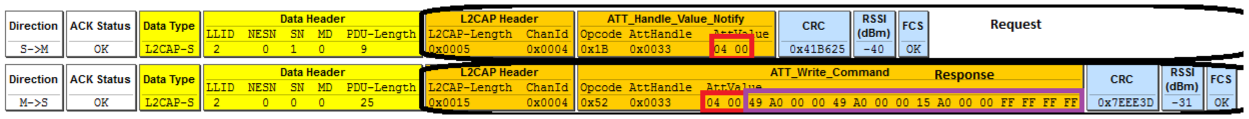


```
Direction ACK Status Data Type  | Data Header: LLID NESN SN MD PDU-Length | L2CAP Header: L2CAP-Length ChanId | ATT_Write_Req: Opcode AttHandle AttValue                         | CRC      | RSSI (dBm) | FCS
M->S      OK         L2CAP-S    | 2    1    1  0  23                       | 0x0013       0x0004               | 0x12   0x002F    1E 8F FF FF 00 00 00 74 45 45 45 45 00 04 01 FF | 0x6F077B | -31        | OK
S->M      OK         Empty PDU  | 1    0    1  0  0                        |                                   |                                                                 | 0x82A5BE | -46        | OK
M->S      OK         Empty PDU  | 1    0    0  0  0                        |                                   |                                                                 | 0x82A818 | -31        | OK
S->M      OK         L2CAP-S    | 2    1    0  1  5                        | 0x0001       0x0004               | ATT_Write_Rsp: Opcode 0x13                                      | 0xF7F1A6 | -50        | OK
M->S      OK         Empty PDU  | 1    1    1  0  0                        |                                   |                                                                 | 0x82A36D | -31        | OK
S->M      OK         L2CAP-S    | 2    0    1  0  9                        | 0x0005       0x0004               | ATT_Handle_Value_Notify: Opcode AttHandle AttValue 0x1B 0x0033 00 00 | 0x41B0F6 | -50   | OK
```

Figure 8. Successful OAD Initiation Sniffer Capture

7.4.2 OAD Image Block Characteristic (0xFFC2)

The OAD Image Block characteristic is used to request and transfer a block of the OAD image. "01:00" shall be written to the CCCD of this characteristic so that notification for block request is enabled. The target requests the next block of the image by sending a GATT notification to the downloader with the requested block number. The downloader will respond (GATT write no response) with the block number and a 16 byte OAD image block. The image block contains the actual binary data from OAD image offset by the block number. Figure 9 shows a block request/response sniffer capture.



```
Direction ACK Status Data Type | Data Header: LLID NESN SN MD PDU-Length | L2CAP Header: L2CAP-Length ChanId | Opcode AttHandle AttValue                                                   | CRC      | RSSI (dBm) | FCS
S->M      OK         L2CAP-S   | 2    0    1  0  9                       | 0x0005       0x0004               | ATT_Handle_Value_Notify: 0x1B 0x0033 04 00                                  | 0x41B625 | -40        | OK
M->S      OK         L2CAP-S   | 2    0    0  0  25                      | 0x0015       0x0004               | ATT_Write_Command: 0x52 0x0033 04 00 49 A0 00 00 49 A0 00 00 15 A0 00 00 FF FF FF FF | 0x7EEE3D | -31 | OK
```

Figure 9. Block Request/Response Sniffer Capture

In Figure 9 above, the block number field is 2 bytes (little endian) and highlighted in red. The OAD image block is 16 bytes and highlighted in purple.

7.4.3 OAD Image Count Characteristic (0xFFC3)

The OAD Image Count characteristic is used to set the number of OAD images to be downloaded. This is used for only Off-chip OAD and the default value of the characteristic is 1. Note On-chip OAD only supports one image download per session. See On-chip OAD 9.1 for details.

7.4.4 OAD Image Status (0xFFC4)

The OAD image status characteristic is used to report various failures that may occur during the OAD process. The downloader may use this information to determine why an OAD failed, so that it may correct for the errors and try again. “01:00” shall be written to the CCCD of this characteristic so that notification for status update is enabled. There are four OAD status messages that are defined by default. The OAD status codes are listed in the table below:

OAD Status Code	Value	Description
OAD_SUCCESS	0	OAD succeeded
OAD_CRC_ERR	1	The downloaded image’s CRC doesn’t match the one expected from the metadata
OAD_FLASH_ERR	2	The external flash cannot be opened
OAD_BUFFER_OFL	3	The block number of the received packet doesn’t match the one requested. An overflow has occurred.

Figure 10. OAD Status Codes

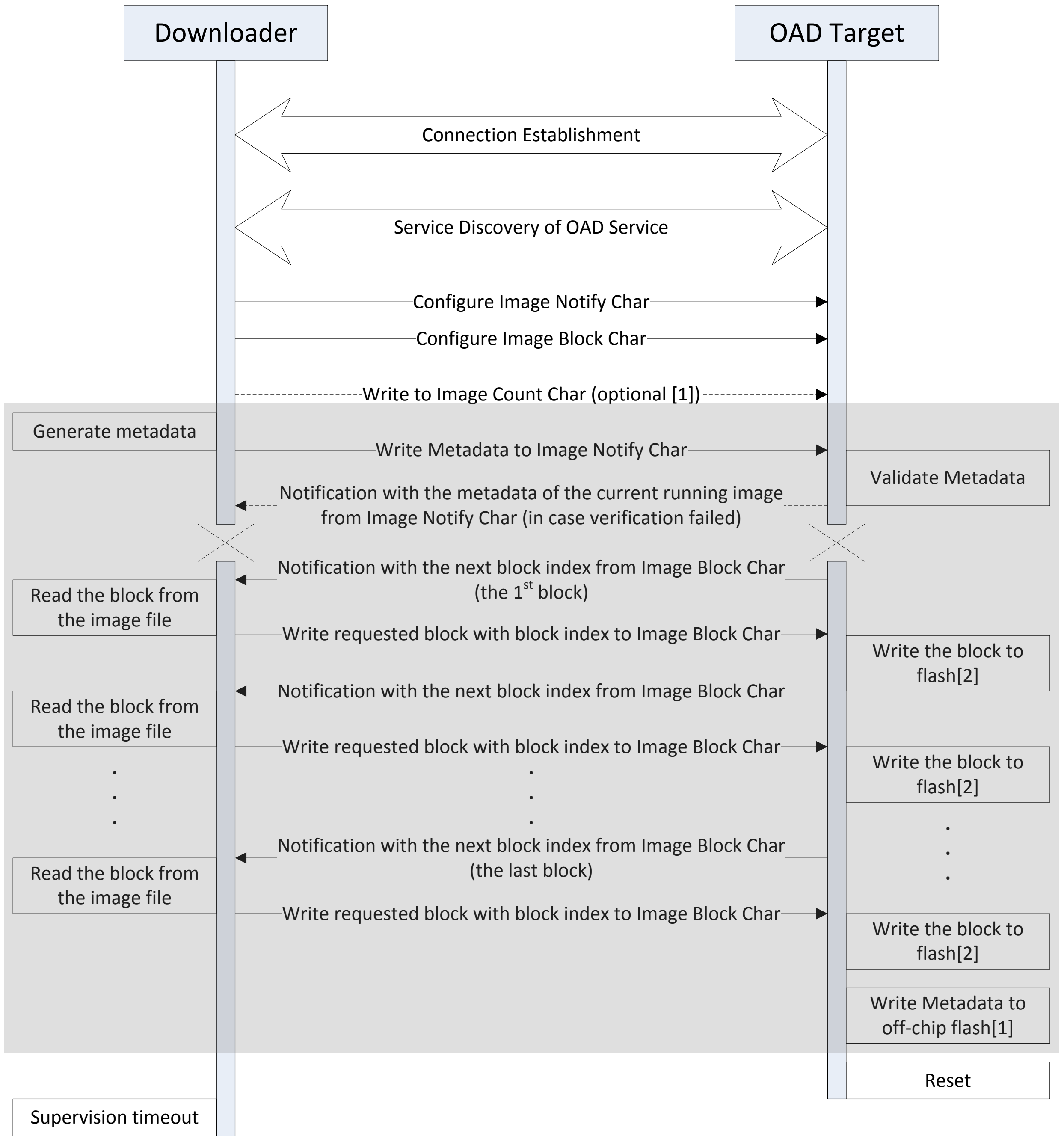
The customer may extend these values as needed, and use the OAD_sendStatus() function to send updates to the downloader.

7.5 OAD Process

This Profile has been designed to provide a simple and customizable OAD Profile for the customer. In its most rudimentary form, for both On-chip and Off-chip OAD, this profile is responsible for accepting an OAD interaction based on image header criteria, storing the image onto the flash and causing a device reset if the download is successful so that the downloaded application image is run by the BIM. Downloader and OAD Target perform Client role and Server role respectively.

7.5.1 Initiation of the On-chip OAD Process

After establishing a new connection, updating the connection interval for a faster OAD and enabling notifications of OAD Image Identify and OAD Image Block characteristics on the OAD Target, the Downloader shall write to the Image Identify characteristic of the OAD Target. The message data will be the header retrieved from the OAD Image available for OAD.


Downloader
OAD Target
Connection Establishment
Service Discovery of OAD Service
Configure Image Notify Char
Configure Image Block Char
Write to Image Count Char (optional [1])
Generate metadata
Write Metadata to Image Notify Char
Validate Metadata
Notification with the metadata of the current running image from Image Notify Char (in case verification failed)
Notification with the next block index from Image Block Char (the 1st block)
Read the block from the image file
Write requested block with block index to Image Block Char
Write the block to flash[2]
Notification with the next block index from Image Block Char
Read the block from the image file
Write requested block with block index to Image Block Char
Write the block to flash[2]
Notification with the next block index from Image Block Char (the last block)
Read the block from the image file
Write requested block with block index to Image Block Char
Write the block to flash[2]
Write Metadata to off-chip flash[1]
Reset
Supervision timeout

[1] Applies only to Off-chip OAD
[2] Writes to on-chip flash if using On-chip OAD and off-chip flash if using Off-chip OAD

Figure 11. OAD Sequence Diagram

Upon receiving the write request to the Image Identify characteristic, the OAD Target will compare the image available for OAD to its own running image. By default, only the image size and version number, which implies whether the image is of type A or B, are checked to determine if the new image is acceptable to download.

If the OAD Target determines that the image available for OAD is acceptable, the OAD Target will initiate the OAD process by notifying the Image Block Transfer characteristic to the Downloader requesting the first block of the new image. Otherwise, if the OAD Target finds that the new image does not meet its criteria to begin the OAD process, it shall respond by notifying the Image Identify characteristic with its own Image Header data as sign of rejection. In that case, the OAD procedure will end at the moment where dotted 'X's are placed as depicted in **Figure 11**.

7.5.2 Image Block Transfers

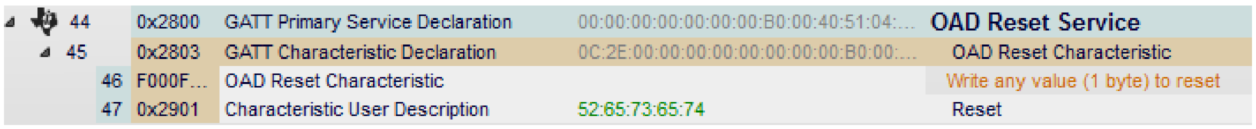
The Image Block Transfer characteristic allows the two devices to request and respond with the OAD image, one block at a time. The image block size is defined to be 16 bytes – see OAD_BLOCK_SIZE in oad.h. The OAD Target will request an image block from the Downloader by notifying the OAD Image Block characteristic with the correct block index. The Downloader shall then respond by writing to the OAD Image Block characteristic. The message's data will be the requested block's index followed by the corresponding 16-byte block of the image. Whenever the OAD Target is ready to digest another block of the OAD image, it will notify the Image Block Transfer characteristic with the index of the desired image block. The Downloader will then respond.

7.5.3 Completion of the On-chip OAD Process

After the OAD Target has received the final image block, it will verify that the image is correctly received and stored by calculating the CRC over the stored OAD image. The OAD Target will then invalidate its own image and reset so that the BIM can run the new image in-place. The burden is then on the Downloader, which will suffer a lost BLE connection to the OAD Target during this verification and instantiation process, to restart scanning and the to reestablish a connection and verify that the new image is indeed running.

7.6 OAD Reset Service

The OAD reset service is only used by on chip OAD solutions. It implements a method for invalidating the currently running image and resetting the device. This must occur because in on chip solutions the currently running image cannot update itself. More information about the on chip OAD process will be covered in the on chip OAD chapter. Figure 12 shows an overview of the OAD reset service and it's characteristic. Like the OAD service, the reset service uses the 128 bit TI base UUID with a 16 bit short UUID of 0xFFD0.



44	0x2800	GATT Primary Service Declaration	00:00:00:00:00:00:00:B0:00:40:51:04:...	OAD Reset Service
45	0x2803	GATT Characteristic Declaration	0C:2E:00:00:00:00:00:00:00:00:B0:00:...	OAD Reset Characteristic
46	F000F...	OAD Reset Characteristic		Write any value (1 byte) to reset
47	0x2901	Characteristic User Description	52:65:73:65:74	Reset

Figure 12. OAD Reset Service

7.6.1 OAD Reset (0xFFD1)

The OAD reset is accomplished by invalidating Image B, which forces the bootloader to revert to Image A until another successful OAD of Image B has occurred. Image B is invalidated by corrupting its CRC. After the corruption, the reset service immediately invokes a HAL reset to jump to the bootloader. Note that a GATT write of any value to the reset service will trigger a reset of the device/invalidation of Image B.

7.7 Bootloader

Since a running image cannot update itself, both On-chip and Off-chip OAD methods must employ a bootloader. A bootloader is a lightweight section of code that is designed to run every time the device resets, check the validity of newly downloaded images, and if necessary, load the new image into internal flash. TI's bootloader implementation is called the Boot Image Manager (BIM). BIM's implementation varies slightly for On-chip and Off-chip OAD solutions, thus there is a separate BIM project for each.

- /util/bim – This project implements an On-chip OAD bootloader
- /util/bim_extflash – This project implements an Off-chip OAD bootloader

Note: Some BIM projects contain project configurations for a baseloader. This a legacy implementation of BIM that is no longer used. Please see section 1.2 for more details.

BIM is always linked to page 0 and page 31 of internal flash, and will always link the CCFG section with it.

8 Off- Chip OAD

8.1 Constraints and Requirements for Off-chip OAD

Using the internal flash of CC2640F128, the first page and the last page, or 8kB in total, of flash are reserved for the flash interrupt vectors and the BIM. The flash page 31 or the last page starting at address 0x1F000 where BIM is located is shared with the CCFG. Neither the first page nor the BIM is designed to be upgraded by Off-chip OAD.

An off-chip flash component of at least 120kB plus space for a 16 byte image metadata block is required for a full flash update. A SPI connection is used to communicate with the off-chip flash component.

The OAD image to be downloaded to the off-chip flash memory can be an application image, a stack image, a hex merge of application plus stack, an image intended for the upgrade of a network processor, or any type of image as far as it is supposed to eventually replace any part of the on-chip 120kB area between the first and the last pages. More than one image can be downloaded before the system reset followed by BIM's copying the downloaded images from the off-chip flash memory to the on-chip flash memory.

Since page 0 cannot be updated in Off-chip OAD, an application must include its own TI-RTOS instance in flash without dependency on the TI-RTOS ROM implementation (see section 10.3 for more info). Also, it must include OAD profile so that further OAD upgrades are available when it runs on the on-chip flash memory since Off-chip OAD doesn't require any OAD-dedicated application like Image A for On-chip OAD.

The first and last flash pages must never be attempted to update because a power cycle during an update of either page could render the device unresponsive until physically reprogrammed.

While On-chip OAD Target receives only one application OAD image, Off-chip OAD Target can receive up to 3 OAD images. Usually the Downloader generates metadata of OAD images for the Off-chip OAD, but the Python script can also embed the metadata in the image (see section 10.2 for details). The metadata is inserted into the beginning of the Off-chip OAD Image when transferred and is also stored separately in the off-chip flash.

8.2 Out of box demo (Off-chip OAD)

This section will go over the basic steps in building and running the Off-chip OAD simple_peripheral project that comes with the SDK with IAR IDE.

Software requirements

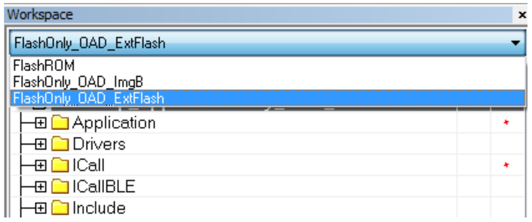
- BLE-Stack SDK v2.2+
- Python 2.7.x (v2.7.10 or higher)
- Flash Programmer 2
- Device Monitor (v2.1.5 or higher)

Hardware requirements

- CC2650 LaunchPad (Target)
- CC2650 LaunchPad or CC2540 USB Dongle (Downloader)

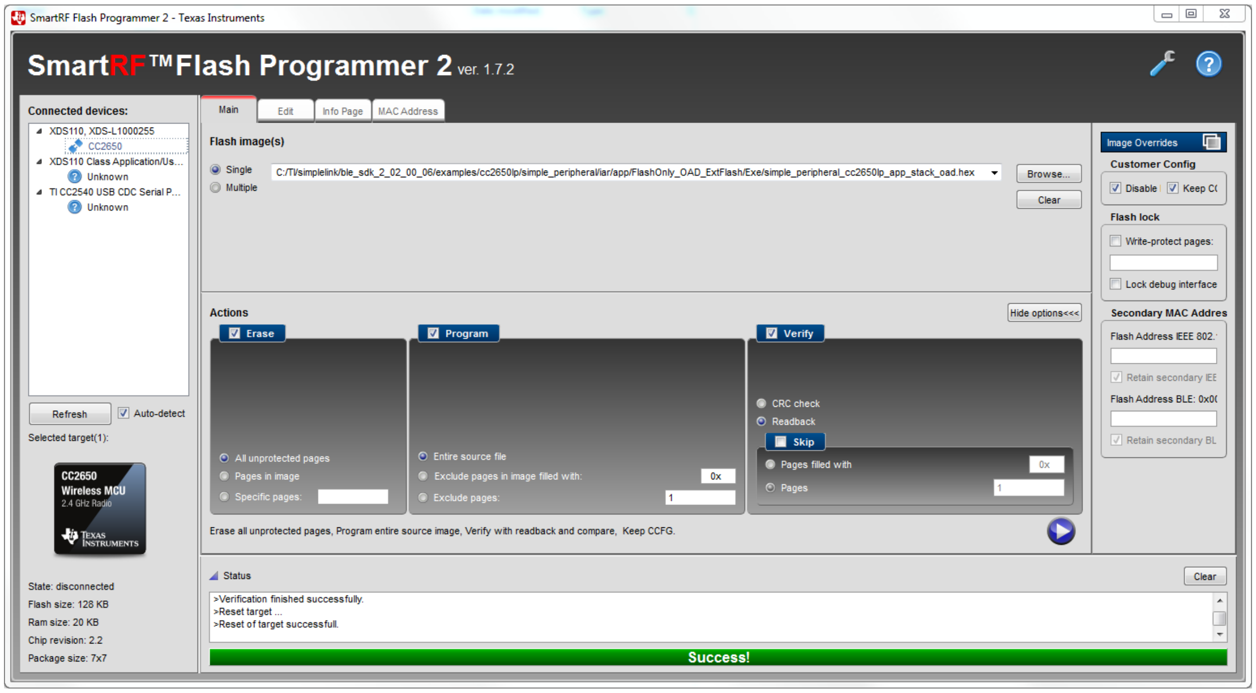
The basic steps are as follows:

1. Build and download BIM project ($BLE_INSTALL$\examples\util\bim_extflash\cc2640\iar) after choosing FlashOnly_LP configuration.
2. Open simple_peripheral project in IAR ($BLE_INSTALL$\examples\cc2650lp\simple_peripheral\iar)
    a. Build and download the cc2650lp_stack – FlashROM project
    b. Build and download cc2650lp_app – FlashOnly_OAD_ExtFlash project



3. Alternatively, the App project should run merge.bat file found in \examples\cc2650lp\simple_peripheral\iar\app to create a hex merged App+BIM+Stack image (simple_peripheral_cc2650lp_all.hex). (Note the hex file ending in “all” is used to flash the device for the first time. Use the other generated hex files for downloading over-the-air, i.e. App or App+Stack in Step 5 below). Then use Flash Programmer 2 to download the image to the

device.



Selected target(1):

State: disconnected
Flash size: 128 KB
Ram size: 20 KB
Chip revision: 2.2
Package size: 7x7

[✓ Single] Multiple: C:/TI/simplelink/ble_sdk_2_02_00_06/examples/cc2650lp/simple_peripheral/iar/app/FlashOnly_OAD_ExtFlash/Exe/simple_peripheral_cc2650lp_app_stack_oad.hex

✓ Erase: [✓ All unprotected pages] Pages in image, Specific pages:

✓ Program: [✓ Entire source file] Exclude pages in image filled with: 0x, Exclude pages: 1

✓ Verify: CRC check [✓ Readback]

Skip: Pages filled with 0x, Pages 1

Customer Config: ✓ Disable ✓ Keep C(

Flash lock: Write-protect pages: Lock debug interface

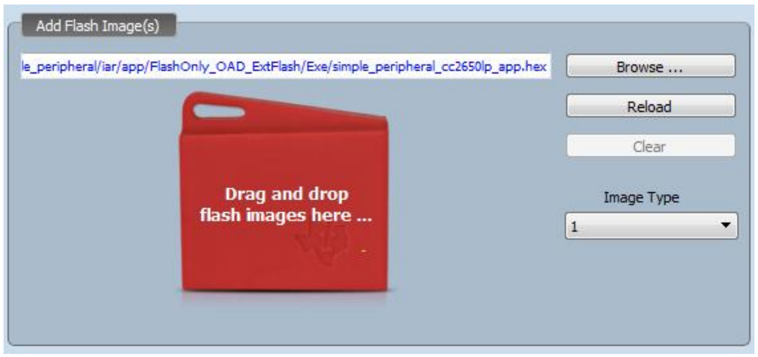
Secondary MAC Addres: Flash Address IEEE 802.: ✓ Retain secondary IEE; Flash Address BLE: 0x0(✓ Retain secondary BL

Erase all unprotected pages, Program entire source image, Verify with readback and compare, Keep CCFG.

```
>Verification finished successfully.
>Reset target ...
>Reset of target successfull.
```

Success!

4. Press Reset button on the CC2650 LaunchPad and verify device is advertising, default device name should be “SimpleBLEPeripheral”
5. OAD new version of simple_peripheral App image
    a. Modify cc2650lp_app – FlashOnly_OAD_ExtFlash (for example, change fields in scan response data (scanRspData[])) and build app and generate output hex file from IAR IDE
    b. (Optional) Alternatively, the Python script can be used to generate metadata in the hex file. See section 10.2 for details. BLE Device Monitor will generate the metadata otherwise.
    c. Connect using a device with HostTest project with BLE Device Monitor and load the hex((($BLE_INSTALL$\examples\cc2650lp\simple_peripheral\iar\app\FlashOnly_OAD_ExtFlash\Exe\simple_peripheral_cc2650lp_app.hex)

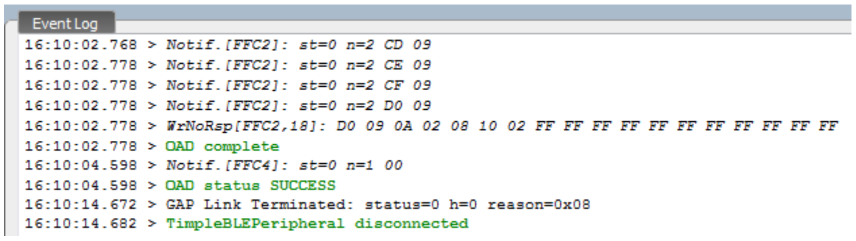


le_peripheral/iar/app/FlashOnly_OAD_ExtFlash/Exe/simple_peripheral_cc2650lp_app.hex

Image Type: 1

    d. Press the Start button to begin downloading the image over the air

e. Device should reset and run the new image, verify link is terminated in event log as shown in the Event Log pane below:



```
16:10:02.768 > Notif.[FFC2]: st=0 n=2 CD 09
16:10:02.778 > Notif.[FFC2]: st=0 n=2 CE 09
16:10:02.778 > Notif.[FFC2]: st=0 n=2 CF 09
16:10:02.778 > Notif.[FFC2]: st=0 n=2 D0 09
16:10:02.778 > WrNoRsp[FFC2,18]: D0 09 0A 02 08 10 02 FF FF FF FF FF FF FF FF FF FF FF
16:10:02.778 > OAD complete
16:10:04.598 > Notif.[FFC4]: st=0 n=1 00
16:10:04.598 > OAD status SUCCESS
16:10:14.672 > GAP Link Terminated: status=0 h=0 reason=0x08
16:10:14.682 > TimpleBLEPeripheral disconnected
```

8.3 OAD Target

8.3.1 Overview of OAD Target for Off-chip OAD

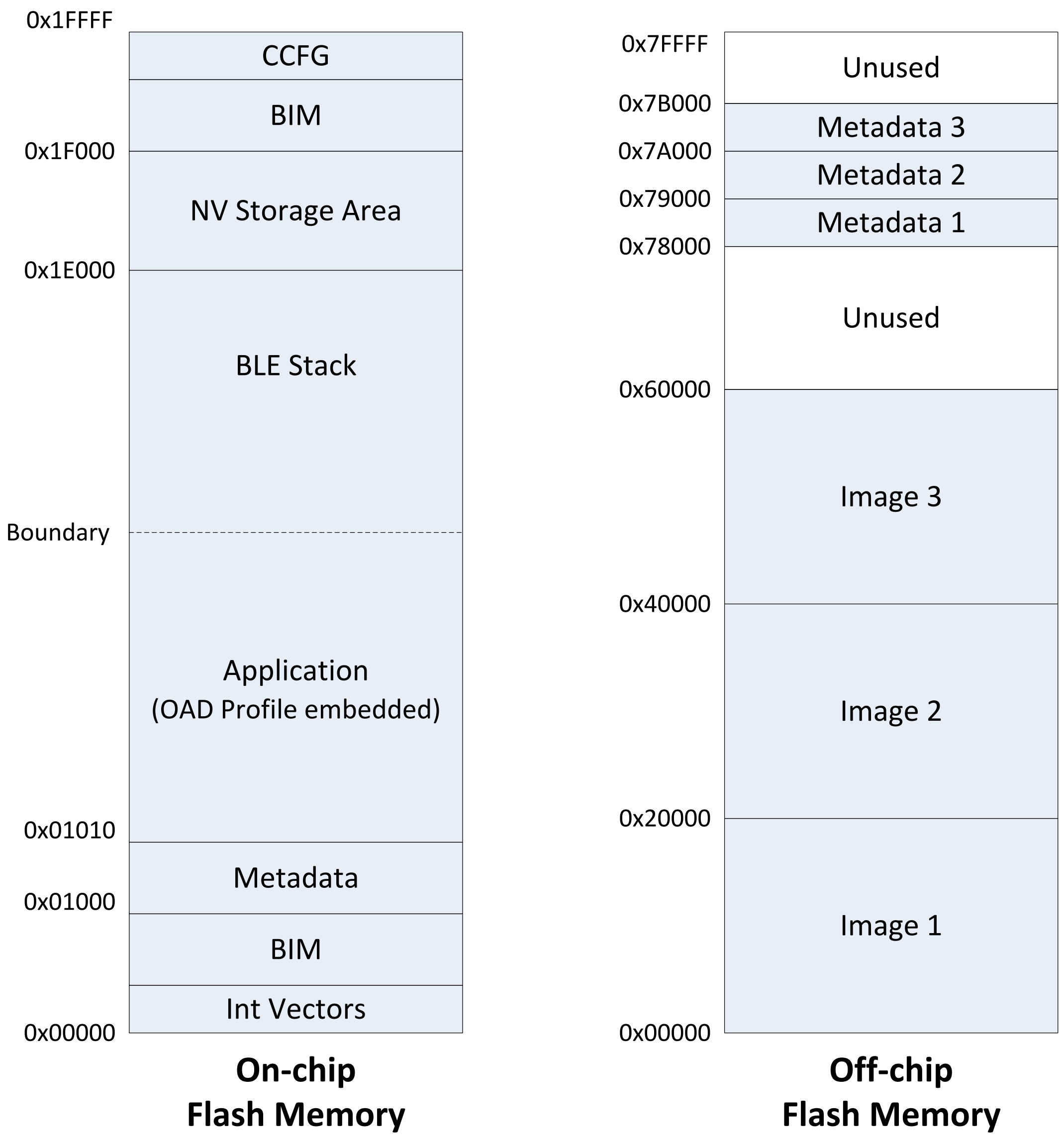


Figure 13. Off-chip OAD Target Memory Partition

The Off-chip OAD Target has both on-chip flash memory and off-chip flash memory device. The on-chip flash memory contains the Interrupt Vectors, the BLE Stack, the Application where OAD Profile is embedded, the BLE stack image, the NV Storage Area, the BIM and the CCFG.

The off-chip flash memory contains up to 3 OAD Images and up to 3 Metadatas corresponding to the OAD Images. The size of each OAD Image placeholder is 128kB. The memory partition of the OAD Target for Off-chip OAD is depicted in **Figure 13**. Each OAD image, if it's of either App only or App+Stack, must support OAD Profile so that further OAD is enabled after it is downloaded to the off-chip memory, copied to the on-chip memory and executed.

8.3.2 BIM for Off-chip OAD

The OAD solution requires that permanently resident boot code, the BIM, exists in order to provide a fail-safe mechanism for determining whether to run the existing application image or to copy a new image or images from off-chip flash to on-chip flash. It is assumed that a valid image exists either in off-chip flash ready to be copied or already placed in on-chip flash at any given time. Given this assumption, the initial image placed in internal flash which does not exist in external flash will have invalid external image metadata, and so the bootloader will choose to jump to the existing image's entry point.

At startup, BIM checks if the application image metadata in off-chip flash has a status indicating that the image is to be copied to the on-chip flash. If the status is 0xFF, copies the image if a valid CRC and CRC Shadow are found. If the status is anything other than 0xFF, assumes the application in the on-chip flash is valid to run. If a 2 byte value is found that is neither 0x0000 nor 0xFFFF, but a 0xFFFF shadow checksum is found, the BIM computes the CRC over the image. Image length is determined by the metadata that is also stored contiguous with the CRC in on-chip flash that was copied over during the original write of the image from the off-chip flash.

If off-chip flash contains a "bad" image to be downloaded, but this image is undesirable, BIM can be programmed with symbol NO_COPY to skip image checking and jump directly into the image already placed in on-chip flash; at which point the on-chip flash image could invalidate the bad image's metadata or OAD a new image in its place. BIM will not be able to load any new images while NO_COPY is defined in the build.

BIM is only responsible for making an application image failsafe upon entry. This could mean an app and stack image, or just the application. BIM has exactly one entrance to the application image.

The BIM occupies the last flash page with CCFG and uses the interrupt vectors at the start of flash where the Reset Interrupt Vector calls the BIM startup routine to ensure its control of the system upon a device reset.

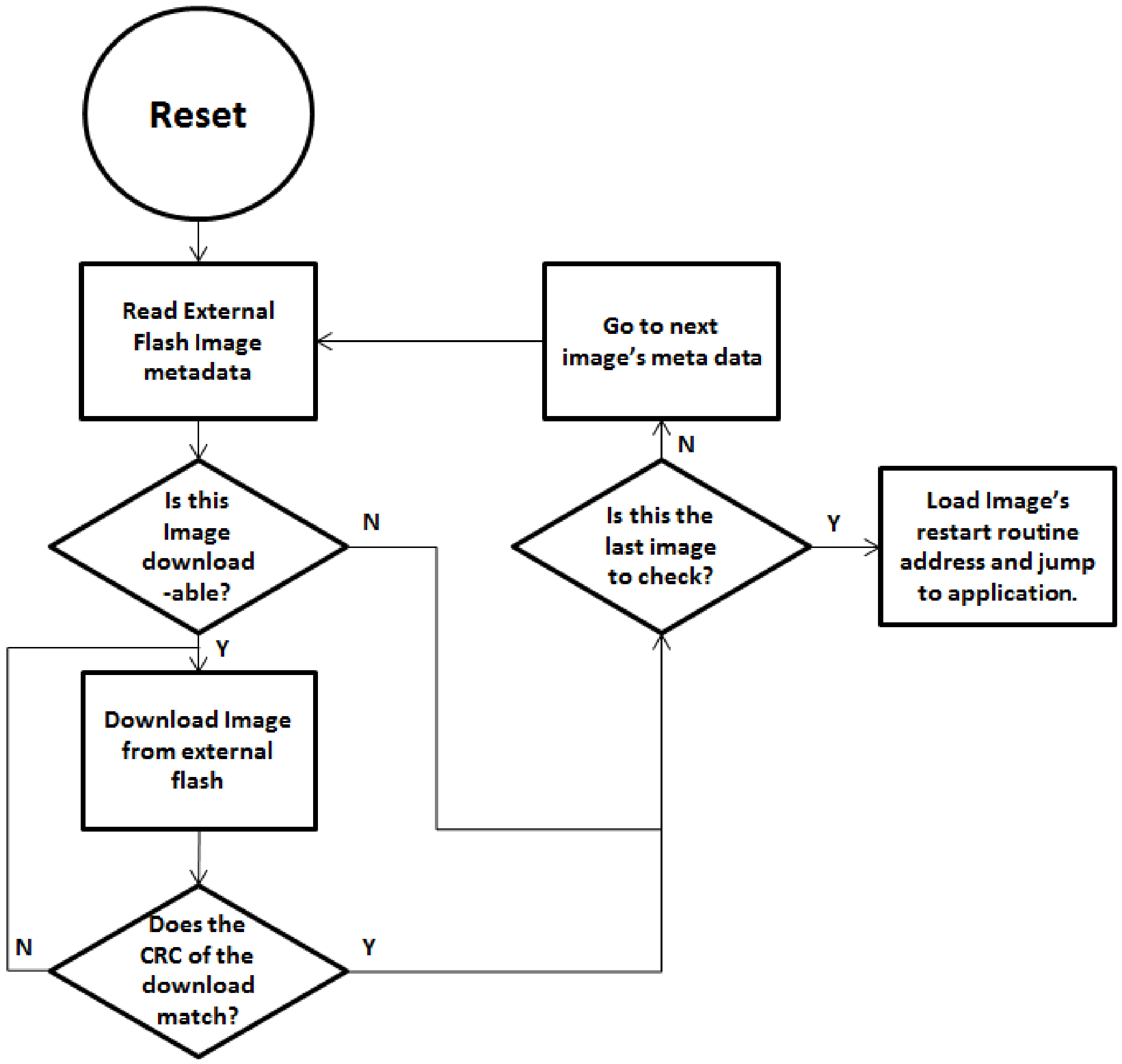

Reset
Read External Flash Image metadata
Go to next image's meta data
Is this Image download -able?
N
Y
Is this the last image to check?
N
Y
Load Image's restart routine address and jump to application.
Download Image from external flash
Does the CRC of the download match?
N
Y

Figure 14. Functional Overview of Off-chip BIM

8.4 Building Off-chip OAD

8.4.1 Building BIM

The boot code is separately built, debugged, and programmed via the IAR or CCS IDE. The projects are located at:

$BLE_INSTALL$\examples\util\bim_extflash\cc2640\

Choose "FlashOnly_LP" configuration and build. "FlashOnly_ST" configuration is out of scope in this document.

By default, the symbol NO_COPY described in 8.3.2 is undefined as it is very unlikely there is a valid image, to be copied onto the on-chip flash, in the off-chip flash for the first-time use.

8.4.2 Building the BLE Stack

There is nothing special to be done for an existing BLE Stack project to make it capable of running with OAD-enabled application.

For IAR, the example BLE Stack project is included in the simple_peripheral workspace. For CCS, the simple_peripheral_cc2650lp_stack project exists separately. The only change that should be made for the stack to be flashed on the CC2650 LaunchPad platform is the Debugger setting. With IAR, select "TI XDS110 Emulator" in *Project→Options→Runtime Checking→Debugger→TI XDS→Setup→Emulator*. With CCS, select "Texas Instruments XDS110 USB Debug Probe" in *Properties→General→Main→Device→Connection*.

8.4.3 Building the Application Image

The simple_peripheral project contains a configuration of 'FlashOnly_OAD_ExtFlash' designed for the application to run on CC2650 LaunchPad hardware platform and utilize the external flash component. The Stack built as described in 8.4.2 works with this application.

The simple_peripheral with FlashOnly_OAD_ExtFlash configuration is made through the following procedures. The procedures can be applied to convert any existing application to the downloadable On-chip OAD Image. In addition to the procedures described in 8.4.3.1 and 8.4.3.2, registration and callbacks for the OAD service should be added to the application. Changes to be made for those are found under FEATURE_OAD in simple_peripheral.c.

The application image contains a Python script that creates a combined image of Application and Stack. To create an image that includes Application and Stack and BIM to load the first time, see Appendix section 10.2.

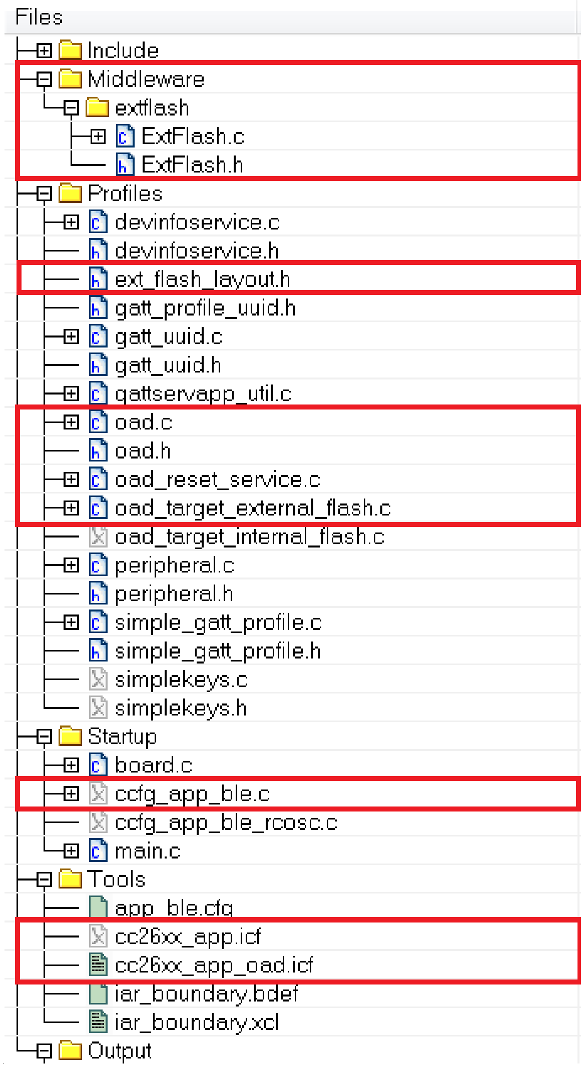
8.4.3.1 Building the Application Image using IAR

Using IAR, the Application Image can be built through the following procedure.

I. Select *Project→Options→C/C++ Compiler→Preprocessor* and add the following new definitions to *Defined symbols*:
```
FEATURE_OAD
HAL_IMAGE_E
```
Add the following lines to *Additional include directories*:
```
$SRC_EX$/profiles/oad/cc26xx
$TI_RTOS_DRIVERS_BASE$/ti/mw/extflash
```

II. Select *Project→Options→Linker→Config→Linker configuration file* and paste the following line:
```
$SRC_EX$/common/cc26xx/iar/cc26xx_app_oad.icf
```
And add the following symbols to *Configurable file symbol definitions*:
```
APP_IMAGE_START=0x1000
```
Append the following in Build Actions under *Pre-build command line*:
```
--cfgArgs NO_ROM=1,OAD_IMG_E=1
```

III. Under Tools, include cc26xx_app_oad.icf and exclude cc26xx_app.icf. Also exclude ccfg_app_ble.c. Add the OAD profile modules to the PROFILES folder of the workspace. These files are located here: `$BLE_INSTALL$/src/profiles/oad/cc26xx`.



```
Files
├⊞ Include
├⊟ Middleware
│ └⊟ extflash
│   ├⊞ ExtFlash.c
│   └── ExtFlash.h
├⊟ Profiles
│ ├⊞ devinfoservice.c
│ ├── devinfoservice.h
│ ├── ext_flash_layout.h
│ ├── gatt_profile_uuid.h
│ ├⊞ gatt_uuid.c
│ ├── gatt_uuid.h
│ ├⊞ gattservapp_util.c
│ ├⊞ oad.c
│ ├── oad.h
│ ├⊞ oad_reset_service.c
│ ├⊞ oad_target_external_flash.c
│ ├── oad_target_internal_flash.c
│ ├⊞ peripheral.c
│ ├── peripheral.h
│ ├⊞ simple_gatt_profile.c
│ ├── simple_gatt_profile.h
│ ├── simplekeys.c
│ └── simplekeys.h
├⊟ Startup
│ ├⊞ board.c
│ ├⊞ ccfg_app_ble.c
│ ├── ccfg_app_ble_rcosc.c
│ └⊞ main.c
├⊟ Tools
│ ├── app_ble.cfg
│ ├── cc26xx_app.icf
│ ├── cc26xx_app_oad.icf
│ ├── iar_boundary.bdef
│ └── iar_boundary.xcl
└⊟ Output
```

8.4.3.2 Building the Application Image using CCS

Using CCS, the Application Image can be built through the following procedure.

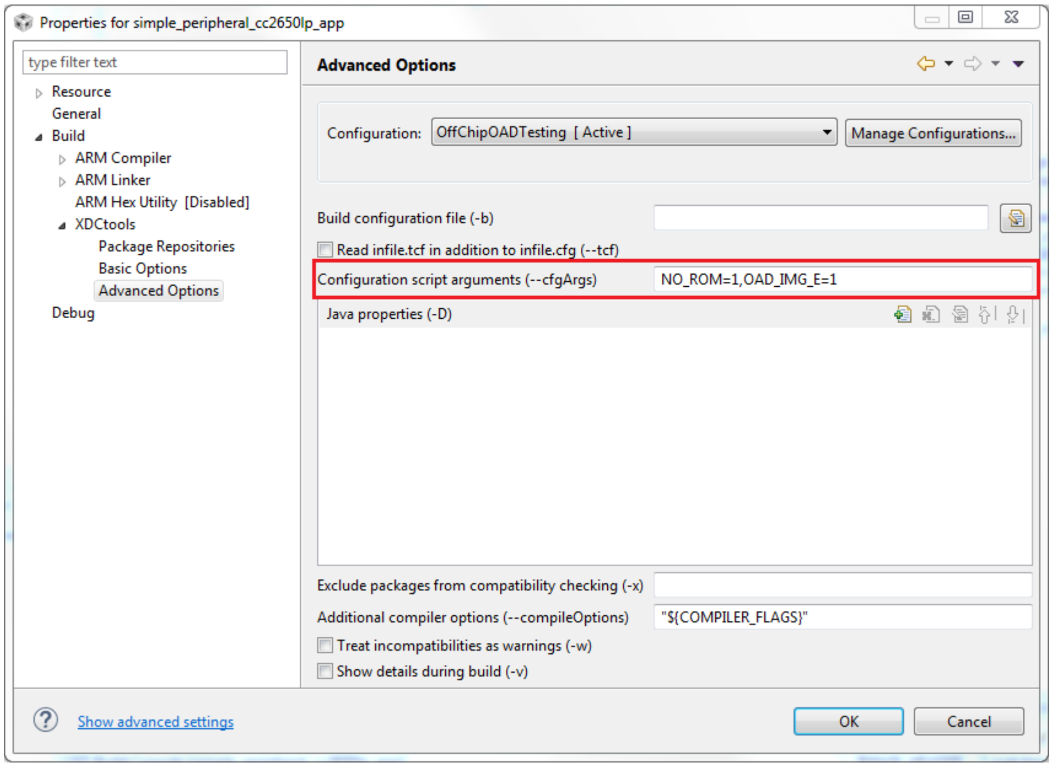
I. Select *Project→Properties→Build→ARM Compiler→Advanced Options→Predefined Symbols* and add the following to *Pre-define NAME*:
`FEATURE_OAD`

II. Select *Project→Properties→Build→ARM Compiler→Include Options* and add the following lines to *Add dir to #include search path*:
`"${SRC_EX}/profiles/oad/cc26xx"`

Select *Project→Properties→Build* and verify the lines below in *Steps→Post-build steps*:

```
${CG_TOOL_HEX} -order MS --memwidth=8 --romwidth=8 --intel -o
${ProjName}.hex ${ProjName}.out
```

Define “NO_ROM=1,OAD_IMG_E=1" in *Project→Properties→Build→XDCtools→Advanced Options* as shown below:


Properties for simple_peripheral_cc2650lp_app

Advanced Options

Configuration: OffChipOADTesting [Active]

Build configuration file (-b)

Read infile.tcf in addition to infile.cfg (--tcf)

Configuration script arguments (--cfgArgs) NO_ROM=1,OAD_IMG_E=1

Java properties (-D)

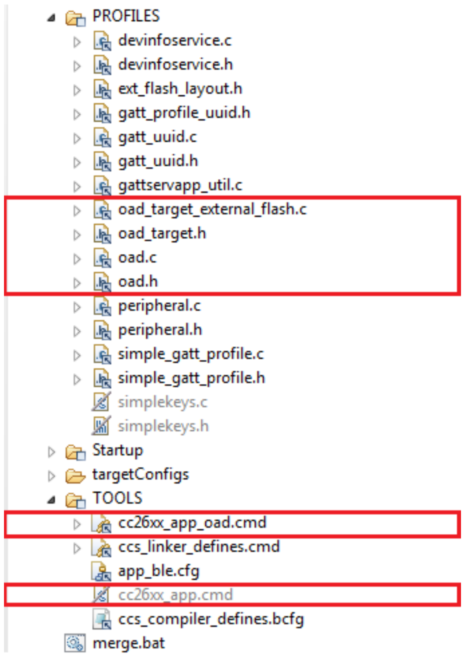
Exclude packages from compatibility checking (-x)

Additional compiler options (--compileOptions) "${COMPILER_FLAGS}"

Treat incompatibilities as warnings (-w)

Show details during build (-v)

III. Add the OAD profile modules to the PROFILES folder of the workspace. Use cc26xx_ble_app_oad.cmd as a linker command file instead of cc26xx_ble_app.cmd (Right-click on the file →Exclude from Build). These files are located here: `$BLE_INSTALL$/src/profiles/oad/cc26xx`.


```
PROFILES
  devinfoservice.c
  devinfoservice.h
  ext_flash_layout.h
  gatt_profile_uuid.h
  gatt_uuid.c
  gatt_uuid.h
  gattservapp_util.c
  oad_target_external_flash.c
  oad_target.h
  oad.c
  oad.h
  peripheral.c
  peripheral.h
  simple_gatt_profile.c
  simple_gatt_profile.h
  simplekeys.c
  simplekeys.h
Startup
targetConfigs
TOOLS
  cc26xx_app_oad.cmd
  ccs_linker_defines.cmd
  app_ble.cfg
  cc26xx_app.cmd
  ccs_compiler_defines.bcfg
merge.bat
```

8.5 Considerations for Off-chip OAD

8.5.1 Adjusting Off-chip Flash Memory Layout

The Off-chip OAD described in this document is based on the assumption that it is running on CC2650 LaunchPad hardware where 1MB off-chip flash memory is equipped. If the size of the off-chip flash is different, there may be a need of changing the layout of the off-chip flash. The layout is defined in ext_flash_layout.h and referred by both BIM and Application.

As an example, assuming the external flash size is 128kB, the OAD image and the Metadata should fit in the 128kB space. Since the size of the OAD Image cannot exceed 120kB in Off-chip OAD design, there is at least 8kB available space for the Metadata. We can place the Metadata in the last page of the off-chip flash memory. This can be done by modifying EFL_ADD_META from 0x78000 to 0x1F000.

8.5.2 Conditions for Rejecting Metadata

Off-chip OAD Target checks that the new image's version is greater than the current image's version. However, as a bypass mechanism, any image of version 0 will be accepted. See OADTarget_validateNewImage() in oad_target_external_flash.c for more details.

9 On-Chip OAD

9.1 Constraints and Requirements for On-chip OAD

Using the internal flash of CC2640F128, the first 9 pages, or 36KB, of flash are, by default, reserved for the flash interrupt vectors, the BIM and the permanently resident OAD Target App using an instance of TI-RTOS partially implemented in ROM. BIM and the OAD Target App also use the remaining space on flash page 31, starting at address 0x1F000, shared with the CCFG. Neither BIM nor the OAD Target App is designed to be upgraded by On-chip OAD.

The OAD Image to be downloaded is, by default, allocated 10 flash pages, or 40KB, from address 0x9000 to 0x12FFF. Because page 0 cannot be updated, an application must include its own TI-RTOS instance in flash without dependence on the TI-RTOS ROM implementation. This image also shares the CCFG referenced in the above paragraph. It is not possible to update the CCFG parameters via an OAD.

The OAD Target App and the OAD image should share the same RAM range as only one is used per device reset. The OAD Image must be a complete application image, capable of running independently of the permanently resident OAD Target App.

The BLE protocol stack defaults to a range of 12 flash pages, or 48kB, ranging from address 0x13000 to 0x1EFFF and no SNV pages are used by default. If the OAD Image is too large to fit in its allocated space, consider removing some features of the BLE stack to reduce its size. This will be discussed further in 9.5.

The OAD Target App, or the Image A, and the Image B shall share the same BLE stack. It is not possible to perform an On-chip OAD of the BLE Stack image.

The first and last flash pages must never be erased as doing so puts the device in an unsafe state and a reset at this time will "brick" the chip and prevent it from restarting without the help of a JTAG or serial boot loader.

9.2 Out of box demo

This section will go over the basic steps in building and running the On-chip OAD simple_peripheral project that comes with the SDK.

Software requirements

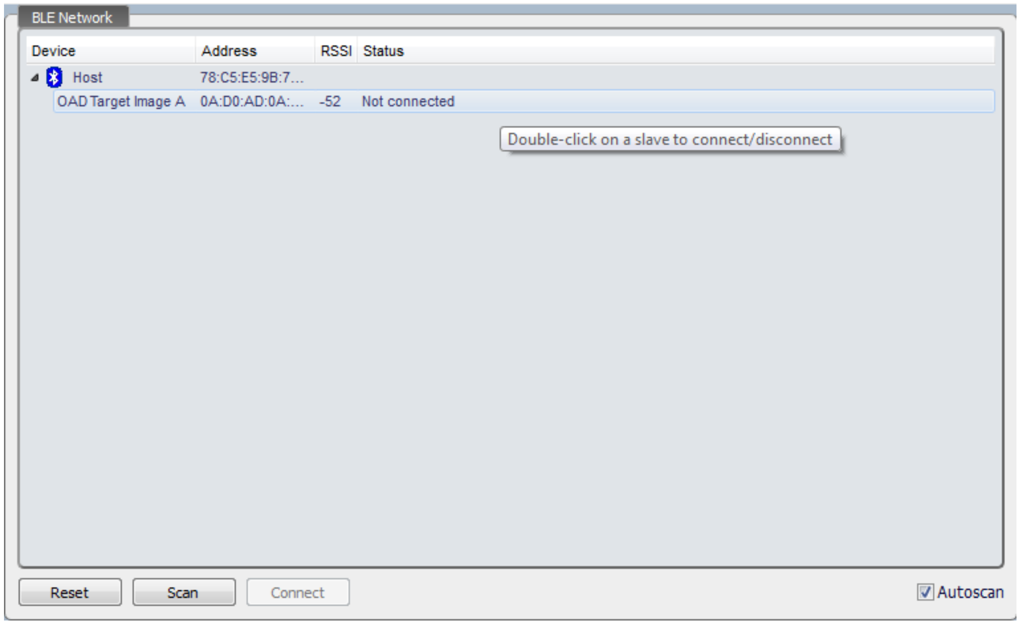
- BLE-Stack SDK v2.2+
- Python 2.7.x (v2.7.10 or higher)
- Flash Programmer 2
- Device Monitor (v2.1.5 or higher)

Hardware requirements

- CC2650 LaunchPad (Target)
- CC2650 LaunchPad or CC2540 USB Dongle (Downloader)

The basic steps are as follows:

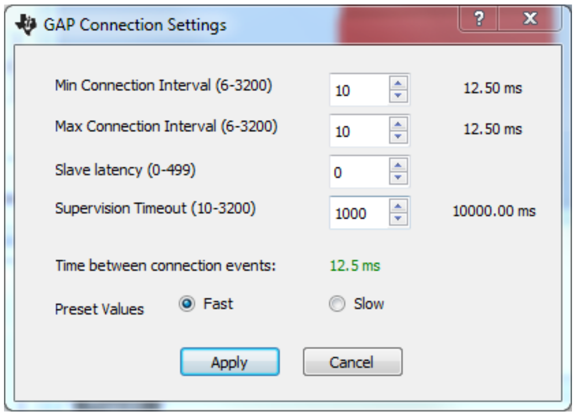
1. Build the OAD Target app found in $BLE_INSTALL$\examples\cc2650lp\oad_target\iar
    a. Build bim, cc2650lp_stack, and cc2650lp_app projects
2. Create the unified hex file
    a. Run the merge.bat found in $BLE_INSTALL$\examples\cc2650lp\oad_target\iar\app
    b. Download to the CC2650 LaunchPad with Flash Programmer 2
3. Connect with Device Monitor
    a. Open BLE Device Monitor, connect to COM port with device running HostTest (i.e. on devices such as CC2650 LaunchPad or CC2540 USB Dongle)
    b. After scanning, click on OAD Target Image to connect to it in the BLE Network pane in Device Monitor:



Device	Address	RSSI	Status
Host	78:C5:E5:9B:7...		
OAD Target Image A	0A:D0:AD:0A:...	-52	Not connected

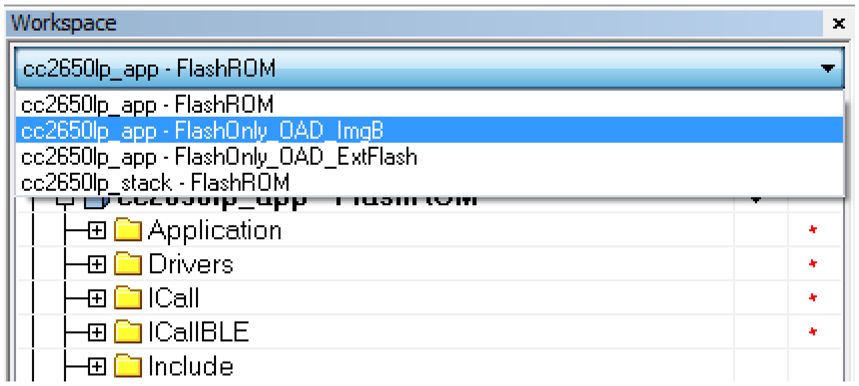
Double-click on a slave to connect/disconnect

c. Go to Options -> GAP settings and click on Apply to enable fast connection interval

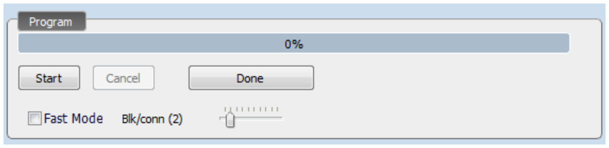


Min Connection Interval (6-3200) 10 12.50 ms
Max Connection Interval (6-3200) 10 12.50 ms
Slave latency (0-499) 0
Supervision Timeout (10-3200) 1000 10000.00 ms
Time between connection events: 12.5 ms
Preset Values [✓ Fast] Slow

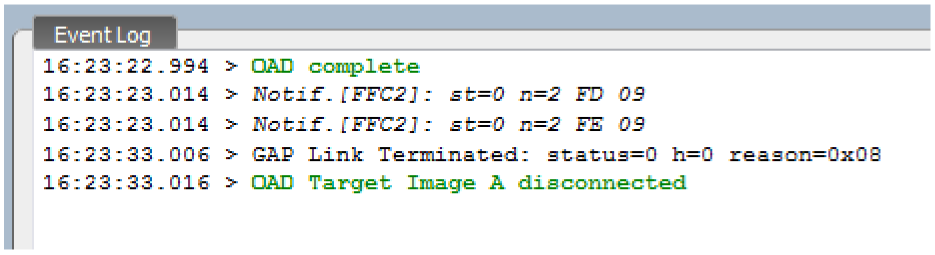
4. Build Image B
   a. Open up simple_peripheral project in IAR found in $BLE_INSTALL$\examples\cc2650lp\simple_peripheral\iar and choose the FlashOnly_OAD_ImgB configuration and build the project


Workspace
cc2650lp_app - FlashROM
cc2650lp_app - FlashROM
cc2650lp_app - FlashOnly_OAD_ImgB
cc2650lp_app - FlashOnly_OAD_ExtFlash
cc2650lp_stack - FlashROM
Application
Drivers
ICall
ICallBLE
Include

   b. In BLE Device Monitor, open up OAD Programming tab (File -> Program (OAD)). Add the hex image from previous step
   c. Press the Start button to begin programming (leave "Fast Mode" unchecked)



   d. Device should reset and start running new Image B, verify in the Event Log pane below:



```
16:23:22.994 > OAD complete
16:23:23.014 > Notif.[FFC2]: st=0 n=2 FD 09
16:23:23.014 > Notif.[FFC2]: st=0 n=2 FE 09
16:23:33.006 > GAP Link Terminated: status=0 h=0 reason=0x08
16:23:33.016 > OAD Target Image A disconnected
```

9.3 OAD Target

9.3.1 Overview of OAD Target for On-chip OAD

The flash memory of OAD Target for On-chip OAD contains the Interrupt Vectors, RCFG, the permanently resident OAD Target App which is also called Image A, the Image B which is initially empty and the place holder for the downloaded OAD Image, the BLE stack, the NV Storage Area, the BIM and the CCFG as shown in **Figure 15**.

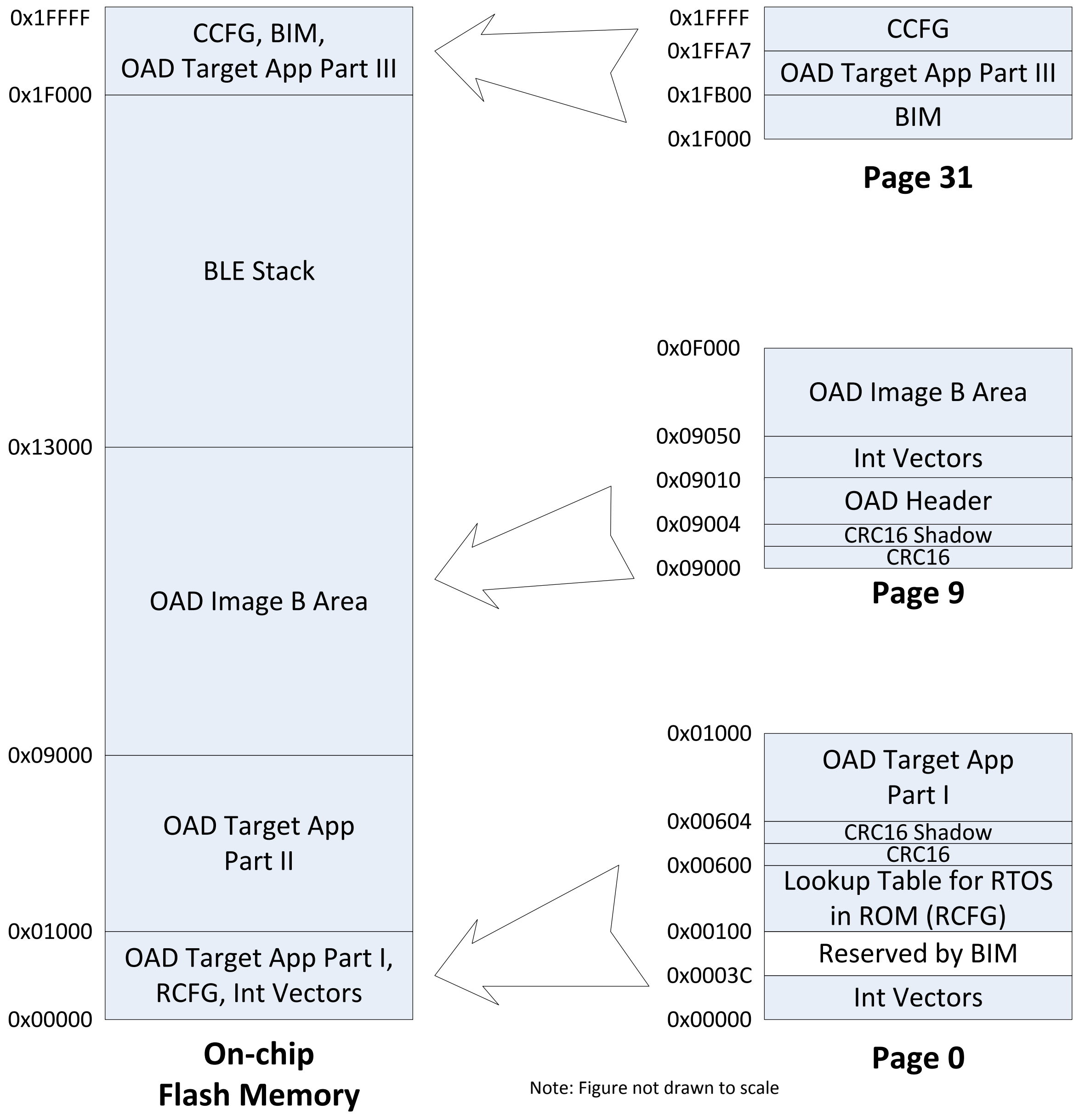


Figure 15. On-chip OAD Target Memory Partition

BIM's design offers the flexibility of having two valid images ready to run; the choice as to which image will run is decided in the BIM. Only the OAD Image B can be downloaded. The OAD Target application, Image A, is a permanent resident which relies on code in the first and last flash page – which if erased during a power down would break the device. The advantage of a permanently resident Image A whose sole purpose is to implement the BLE Stack and OAD Profile is that it increases the amount of available flash for Image B. The developer of a custom Image B does not have to include the OAD Profile implementation. The only reference to OAD feature that Image B needs is a valid image header described in Figure 3. The reference to the valid image header is necessary to use OAD Reset Service described in 7.6. Both Image A and Image B must be developed using exactly the same BLE Stack build, linked at the same location in memory.

9.3.2 BIM for On-chip OAD

The OAD solution requires that permanently resident boot code, the BIM, exists in order to provide a fail-safe mechanism for determining (in preferential order) the image which is ready to run. When a valid image is found, the BIM jumps to that image at which point the image takes over execution. Either Image A or Image B must implement the proprietary TI OAD Profile. By default, this is Image A's role. When an image with the OAD Profile downloads a new image, a system reset can be executed to return to BIM to verify the correctness of the download and begin execution.

The BIM co-occupies the last flash page with CCFG and additional OAD Target application code. The OAD Target application code is linked into a specific section of the last flash page as defined in the linker file. BIM uses the interrupt vectors at the start of flash where the Reset Interrupt Vector calls the BIM startup routine to ensure its control of the system upon a device reset.

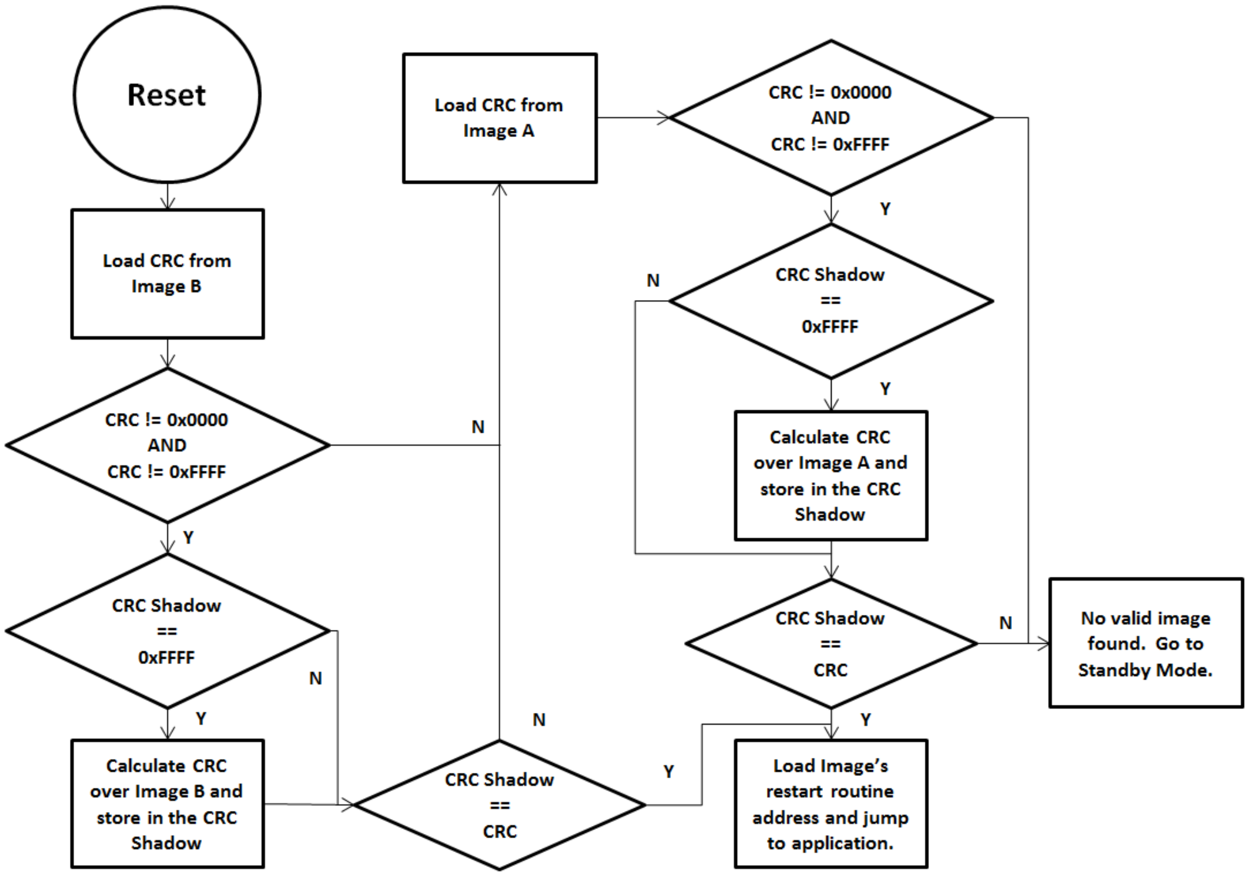

Reset
Load CRC from Image B
CRC != 0x0000 AND CRC != 0xFFFF
Y
N
CRC Shadow == 0xFFFF
Y
N
Calculate CRC over Image B and store in the CRC Shadow
CRC Shadow == CRC
N
Y
Load CRC from Image A
CRC != 0x0000 AND CRC != 0xFFFF
Y
CRC Shadow == 0xFFFF
N
Y
Calculate CRC over Image A and store in the CRC Shadow
CRC Shadow == CRC
N
Y
No valid image found. Go to Standby Mode.
Load Image's restart routine address and jump to application.

Figure 16. Functional Overview of On-chip BIM

As the permanent owner of the flash interrupt vectors, BIM provides a fail-safe mechanism for intercepting the reset vector, putting the hardware into a safe state, and taking the most appropriate action by reading the headers of Image A and Image B.

By default, BIM gives precedence to Image B, as Image A is only expected to be run when a newer instance of Image B is ready to OAD or no valid Image B exists. If the preferred image is not ready to run, then the other image is checked. If neither image is ready to run – an unlikely scenario because Image A, the OAD Target App, need not ever be erased – then BIM puts the device into a low power Standby mode. Also by default, a CRC check is not performed on Image A because it is expected that the OAD Target App will be used as a fixed image. The check on Image A will only read the checksum placed by IAR to see if an image exists, it will not calculate the CRC shadow.

In order to verify that an image is valid, a fixed 4-byte area known as the CRC and CRC-shadow will be queried. If the 2-byte CRC16 output calculated at build time matches the 2-byte CRC16 shadow calculated by BIM, then the image is commissioned to run immediately. If the CRC is not zero and not the erased-flash value of 0xFFFF and the CRC-shadow is the erased-flash value of 0xFFFF, then the CRC can be calculated over the entire image (not including this 4-byte area) and the result can be compared to the valid CRC to determine whether the image should be commissioned as ready to run.

9.4 Building On-chip OAD

9.4.1 Building BIM

The boot code is separately built, debugged and programmed via the IAR IDE. There is a project connection within the OAD Target workspace; however, the standalone project is located at:

$BLE_INSTALL$\examples\util\bim\cc2640\

On CC26xx, flash pages are erased before written when downloading code. This complicates the download of BIM as it shares the last flash page with code generated by the OAD Target Application. This is resolved by generating a hex file from the build and merging this hex file with the OAD Target App's hex file, as is described in 9.4.3."

By default, BIM defines symbol FEATURE_FIXED_IMAGE as a way to bypass the CRC check on Image A, as it is expected that a fixed image will be used. It is not suggested that this symbol be removed unless architectural changes to OAD made by a user require a CRC check to prove the validity of Image A. Image B will always be checked, for security and integrity reasons.

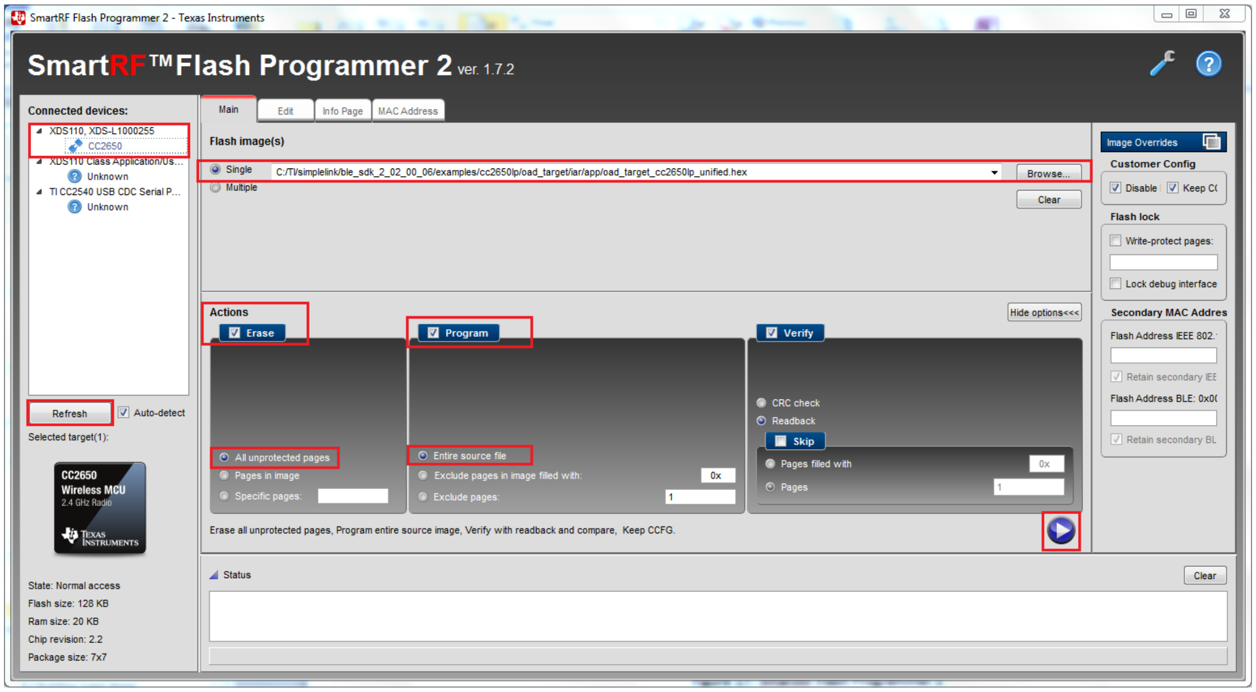
9.4.2 Building the BLE Stack

The OAD Target App and the OAD image share the BLE Stack image. This image can never be upgraded or modified via OAD. This emphasizes the importance of developing and testing an OAD image with the same stack that is downloaded onto the device. Like BIM, this project outputs a hex image to be merged with the OAD Target App so all three can be downloaded simultaneously. To reduce the size of the BLE Stack image, the NV memory storage space has been removed and does not utilize any flash pages. The NV module is too large to fit without reducing the space reserved for the OAD image. Further restrictions on the BLE Stack require that it uses the library with minimal features. By default, the OAD Target's CC2650lp_stack project is configured for these requirements and it is generally encouraged that it be used as the shared BLE Stack image.

9.4.3 Building the OAD Target Application

The OAD Target is the permanently resident application image designed to perform OAD of an image into the Image B area. The project is located at $BLE_INSTALL$\examples\cc2650lp\oad_target\iar". For simplicity, the OAD Target starts in the first flash page following its RCFG. In the BIM functional design (**Figure 16**), the OAD Target app is Image A so that by default the downloaded Image B always runs, if a valid instance exists. A separate Python script in the project directory can be executed to merge the OAD Target image, the BLE Stack Image and BIM into one .hex file. Make sure the BLE Stack Image, BIM, and OAD Target app is built before running the hex merge script. If any of these projects are modified, they must be rebuilt along with the OAD Target app to update the "super" hex file. See Appendix section 10.2 on how to use Python script to merge hex files.

Use the Flash Programmer 2 to program the hex file onto a CC2640 device. If this tool is not already installed, download it from here: http://www.ti.com/tool/flash-programmer. Under the main tab, click browse, navigate to the location of the merged hex file and select it. Click "Refresh" under "Connected devices" and if your device is connected, it should show up under "Connected devices". Select your device by clicking on CC2650 and it will become highlighted. Check the "Erase" box and select "All unprotected Pages". Check the "Program" box and select "Entire source file". Click the play button on the bottom right to program the device. See **Figure 17** for how this should look.



Single: C:/TI/simplelink/ble_sdk_2_02_00_06/examples/cc2650lp/oad_target/iar/app/oad_target_cc2650lp_unified.hex

Erase all unprotected pages, Program entire source image, Verify with readback and compare, Keep CCFG.

State: Normal access
Flash size: 128 KB
Ram size: 20 KB
Chip revision: 2.2
Package size: 7x7

Figure 17. SmartRF Flash Programmer 2

9.4.4 Building OAD Image B

Although the OAD-enabled application image is built and linked separately from the supporting BIM, it must forever adhere to the constraints of the image boundaries and relative locations of external interfaces (e.g. CRC and Image Header) that are expected by BIM. The OAD Target App image is also dependent on BIM existing on the device when it is downloaded as only BIM places its interrupt vectors at the start of flash. Without interrupt vectors at this location, the device will break and become unusable. The example project for building an Image B included in simple_peripheral workspace as 'FlashOnly_OAD_ImgB' configuration can be reproduced through following procedures. The procedures can be applied to convert any existing application to downloadable On-chip OAD Image in IAR.

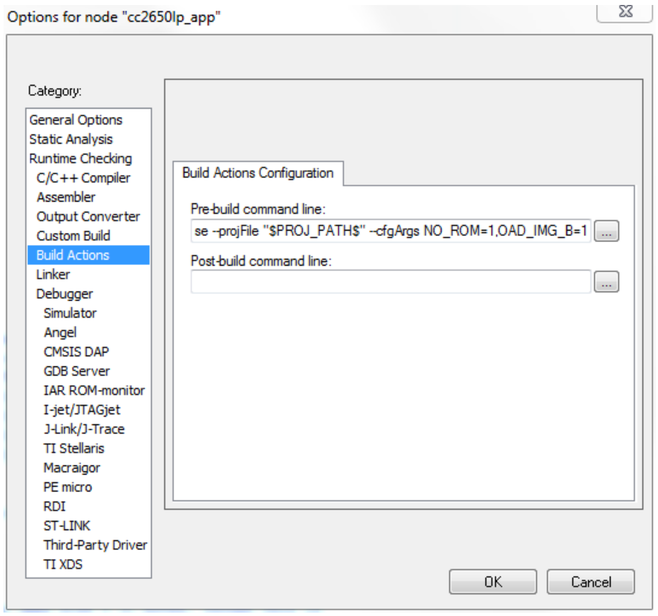
I. Select *Project→Options→C/C++ Compiler→Preprocessor→Defined symbols* and add the following new definitions:

```
FEATURE_OAD
FEATURE_OAD_ONCHIP
IMAGE_INVALIDATE
HAL_IMAGE_B
```

Add the following line to the "Additional include directories":

```
$SRC_EX$/profiles/oad/cc26xx
```

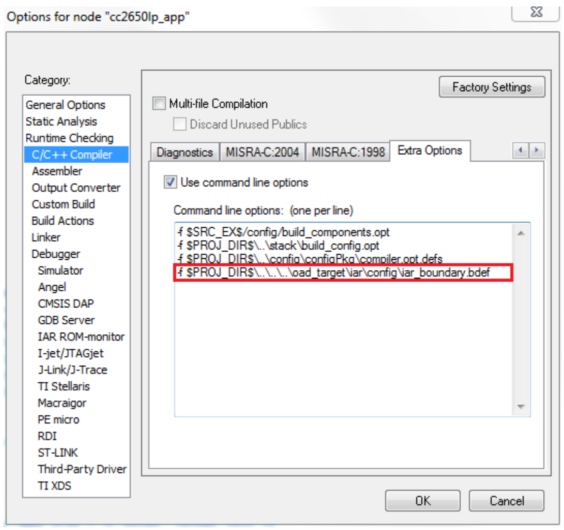
Append the following in Build Actions under *Pre-build command line*:
--cfgArgs NO_ROM=1,OAD_IMG_B=1



Pre-build command line:
se --projFile "$PROJ_PATH$" --cfgArgs NO_ROM=1,OAD_IMG_B=1

Post-build command line:

Verify in *Project→Options→C/C++ Compiler→Extra Options*, the correct iar_boundary.bdef file is included:

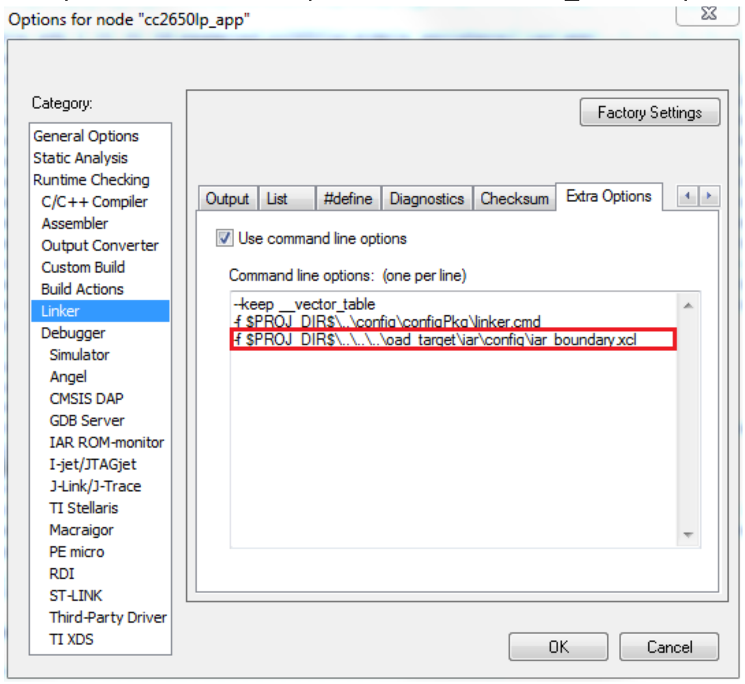


Use command line options [✓]

Command line options: (one per line)

```
-f $SRC_EX$/config/build_components.opt
-f $PROJ_DIR$\..\stack\build_config.opt
-f $PROJ_DIR$\..\config\configPkg\compiler.opt.defs
-f $PROJ_DIR$\..\..\..\oad_target\iar\config\iar_boundary.bdef
```

Verify in Linker -> Extra Options, the correct iar_boundary.xcl file is included:



Use command line options [✓]

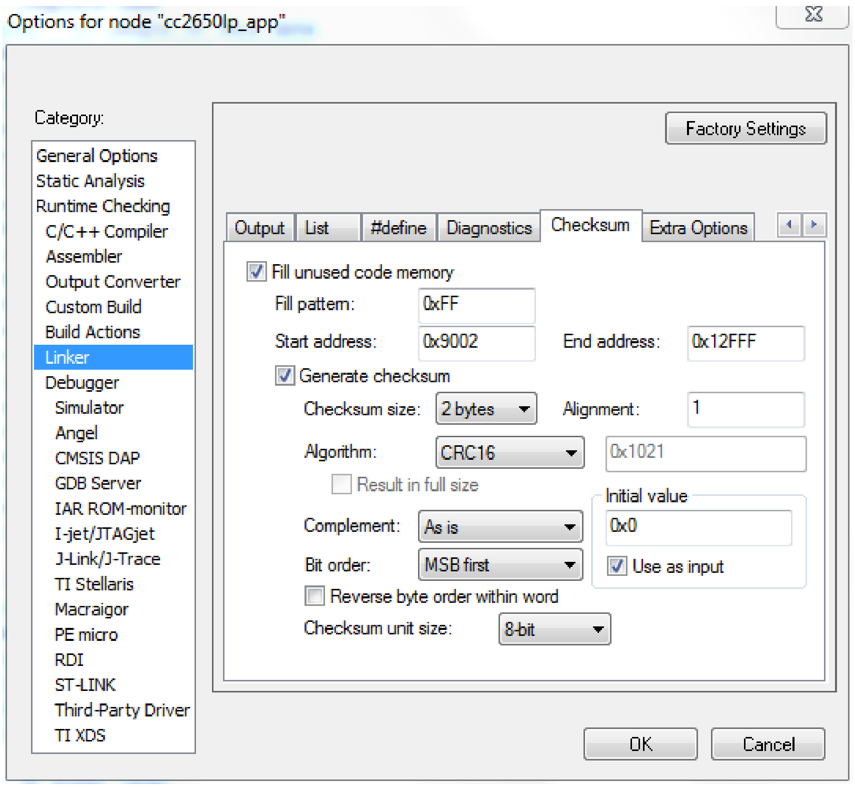
Command line options: (one per line)

```
--keep __vector_table
-f $PROJ_DIR$\..\config\configPkg\linker.cmd
-f $PROJ_DIR$\..\..\..\oad_target\iar\config\iar_boundary.xcl
```

II. Select *Project→Options→Linker→Config*. Paste the following line to 'Linker configuration file':
`$SRC_EX$/common/cc26xx/iar/cc26xx_app_oad.icf`
And add the following symbol to 'Configuration file symbol definitions':
`FLASH_ONLY_BUILD=1`

III. Setup the Linker for an image's flash and RAM usage. By default the linker guarantees 10 flash pages, or 40KB, to the OAD image starting at 0x9000 to Image B. It is generally recommended that the values for Image B starting address are not changed from the default settings unless OAD Target App needs to be modified in its size.

IV. Select *Project→Options→Linker→Checksum* to configure a CRC16 calculation over the application image. Make sure that the start address does not include the CRC and CRC Shadow locations and that the checksum ends at the last address of the specified image region of the OAD Target. By default, then, the CRC covers the range 0x9004 through 0x12FFF. Make sure that the Algorithm uses CRC16 with 0x1021. If this value is set to any other value than 0x1021, it can be modified by setting the algorithm first to CRC polynomial, and then setting the Algorithm back to CRC16.

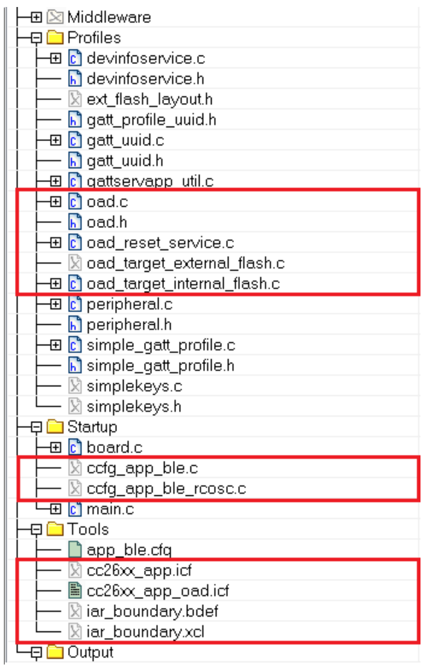

Options for node "cc2650lp_app"

Category: General Options, Static Analysis, Runtime Checking, C/C++ Compiler, Assembler, Output Converter, Custom Build, Build Actions, Linker, Debugger, Simulator, Angel, CMSIS DAP, GDB Server, IAR ROM-monitor, I-jet/JTAGjet, J-Link/J-Trace, TI Stellaris, Macraigor, PE micro, RDI, ST-LINK, Third-Party Driver, TI XDS

Tabs: Output, List, #define, Diagnostics, Checksum, Extra Options

☑ Fill unused code memory
Fill pattern: 0xFF
Start address: 0x9002
End address: 0x12FFF
☑ Generate checksum
Checksum size: 2 bytes
Alignment: 1
Algorithm: CRC16
0x1021
☐ Result in full size
Initial value: 0x0
☑ Use as input
Complement: As is
Bit order: MSB first
☐ Reverse byte order within word
Checksum unit size: 8-bit

V. Under Tools, include cc26xx_app_oad.icf and exclude cc26xx_app.icf. Also exclude ccfg_app_ble.c. Add the OAD profile modules to the PROFILES folder of the workspace. These files are located here: `$BLE_INSTALL$/src/profiles/oad/cc26xx`.



```
Middleware
Profiles
    devinfoservice.c
    devinfoservice.h
    ext_flash_layout.h
    gatt_profile_uuid.h
    gatt_uuid.c
    gatt_uuid.h
    gattservapp_util.c
    oad.c
    oad.h
    oad_reset_service.c
    oad_target_external_flash.c
    oad_target_internal_flash.c
    peripheral.c
    peripheral.h
    simple_gatt_profile.c
    simple_gatt_profile.h
    simplekeys.c
    simplekeys.h
Startup
    board.c
    ccfg_app_ble.c
    ccfg_app_ble_rcosc.c
    main.c
Tools
    app_ble.cfg
    cc26xx_app.icf
    cc26xx_app_oad.icf
    iar_boundary.bdef
    iar_boundary.xcl
Output
```

9.5 Considerations for On-chip OAD

9.5.1 Adjusting Stack and Application Sizes

By default, 40kB is available for Image B because the BIM, the flash interrupt vectors and the OAD Target App occupy 40kB, the BLE protocol stack takes 48kB in the 128kB on-chip flash as shown in **Figure 15**. If Image B needs more flash, the only way to make it possible is to reduce the size of other components. Since modifying BIM or OAD Target App is not an option, we can consider downsizing the BLE Stack and/or reducing the number of SNV pages.

9.5.2 Conditions for Rejecting Metadata

The LSB of the new image's version must not be equal to the LSB of the current image's version. This is to prevent redundant OAD sessions. The LSB is checked using the OAD_IMG_ID() macro. See OADTarget_validateNewImage() in oad_target_internal_flash.c for more details.

10 Appendix

10.1 Installing Python

Python scripts are used to create hex and bin files from project output. Make sure Python 2.7.10+ is installed and added to your system path environment variables. Also required is the Python IntelHex (v2.1+) script hex_merge.py, freely available on the web at https://launchpad.net/intelhex/+download. The expected location of the script is "C:\Python27\Scripts\" as the post build procedure assumes the script is there.

For IAR, Python post build commands can be added in Project Options -> Build Actions -> Post-build command line. For CCS, Python post build commands can be added in Project Options -> CCS Build -> Steps -> Post-build steps. Change the above commands to include the full path of the Python executable if a post-build issue occurs due to file path issues. See 10.2.5 for an example.

NOTE: To build the hex file, make sure Python is installed and added to your system path environment variables.

10.2 TI OAD Image Tool (Python)

In order to accelerate the process of converting the compiler's hex file output to an OAD ready binary file with embedded metadata, TI has created a Python based OAD image tool. The tool supports On-chip and Off-chip OAD implementations as well as creating super hex merges that should be flashed on the device at production time. OAD Image Tool is provided in source and binary format.

10.2.1 Download the tool

The OAD Image Tool is hosted on TI's SimpleLink Github account: https://github.com/ti-simplelink/ble_examples. It can be found under the /tools/oad_image_tool folder. The binary version can be found under the /bin folder.

10.2.2 Dependencies

The tool requires Python 2.7.10+ to run, as well as the following modules:

```
# Needs Python 2.7.10
from __future__ import print_function
import __builtin__
import argparse
import crcmod # pip -[--proxy <addr>] install crcmod
from intelhex import IntelHex # pip [--proxy <addr>] install intelhex, needs
latest version (v2.1+)
import struct
import textwrap
import sys
import math
import ntpath
from collections import namedtuple
```

When running from source, pip or another package manager should be used to import the required modules.

Running from binary does not require any installation.

10.2.3 Using the tool

The purpose of the tool is to create OTA ready OAD images and also production images. An OTA ready image is defined as an image that has already been processed, merged, and is ready to send to the target device using an OAD downloader. OTA ready images have metadata embedded where necessary.

Production images are images that are intended to be flashed on the device at production time. They contain an entire internal flash image including code that is never updated via OAD such as the BIM.

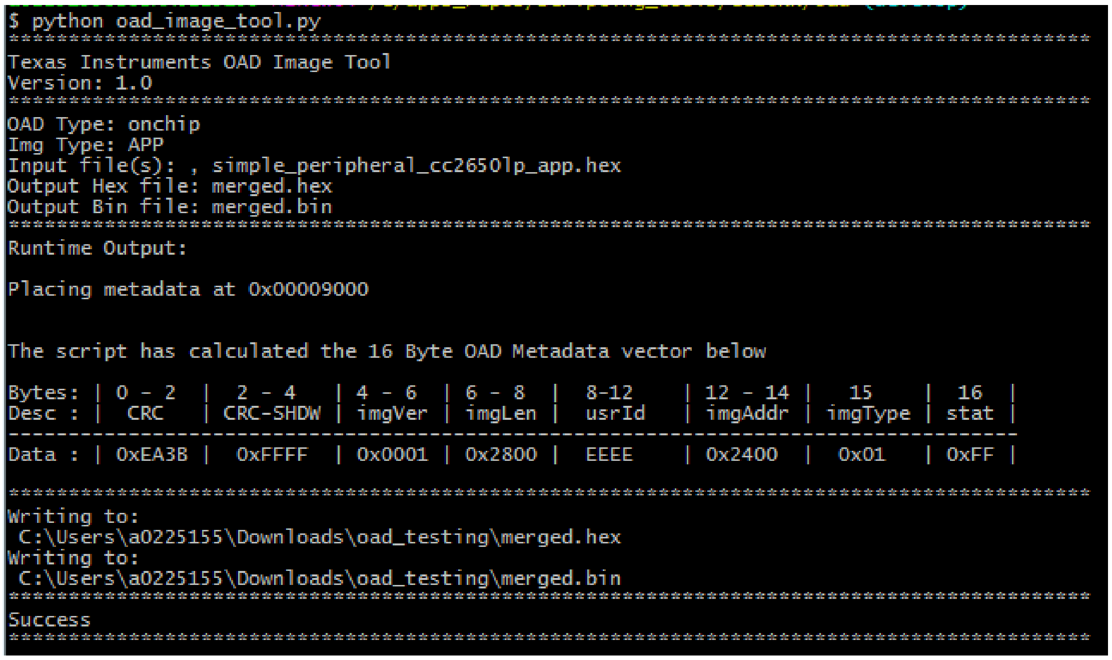
The tool is configured using a range of arguments that will allow the customer to configure the output of the tool dynamically. The tool's arguments are documented below in Figure 18. You may also invoke the help menu of the script by typing:

```
python oad_image_tool.py –help
```

Argument	Acceptable input	Description
-h **--help**	None	Display the help menu
-t **--oadtype**	{onchip, offchip}	Whether the generated image is for on chip or off chip OAD
-i **--imtype**	{app, stack, np, production}	The type of image to be generated. This argument is used to set the metadata and also enforce some imgType based rules
-v **--imgver**	Any	The version of the image. This is used to populate the metadata
-o **--out**	Valid system path	Used to specify where the script should place the output hex file
-ob **--outbin**	Valid system path	Used to specify where the script should place the output binary file
-f **--fill**	One byte hex value	Value to fill empty addresses within the output image with. Default is 0xFF
-m **--metta**	Any valid internal flash address	Address where the metadata header should be placed
-r **--range**	Any valid internal flash address	Ranges of addresses to be included in the output file
-n **--dry-run**	N/A	Do no produce output files, only print information
-q **--quiet**	N/A	Only produce output files, do not print to the console
--round	Valid sector size	Round sectors up to the nearest internal flash sector size.
--version	N/A	Print the version info of this tool

Figure 18. OAD Image Tool Arguments

Once the tool has successfully run, it will print output similar to what is shown in Figure 19.



```
$ python oad_image_tool.py
************************************************************************************************
Texas Instruments OAD Image Tool
Version: 1.0
************************************************************************************************
OAD Type: onchip
Img Type: APP
Input file(s): , simple_peripheral_cc2650lp_app.hex
Output Hex file: merged.hex
Output Bin file: merged.bin
************************************************************************************************
Runtime Output:

Placing metadata at 0x00009000


The script has calculated the 16 Byte OAD Metadata vector below

Bytes: | 0 - 2  |  2 - 4   | 4 - 6  | 6 - 8  |  8-12     | 12 - 14 |   15    |  16  |
Desc : |  CRC   | CRC-SHDW | imgVer | imgLen |  usrId    | imgAddr | imgType | stat |
-------------------------------------------------------------------------------------
Data : | 0xEA3B |  0xFFFF  | 0x0001 | 0x2800 |  EEEE     | 0x2400  |  0x01   | 0xFF |

************************************************************************************************
Writing to:
 C:\Users\a0225155\Downloads\oad_testing\merged.hex
Writing to:
 C:\Users\a0225155\Downloads\oad_testing\merged.bin
************************************************************************************************
Success
************************************************************************************************
```

Figure 19. OAD Image Tool Output

10.2.4 Building a Production Image

The tool supports two types of production images depending on how your application will be supporting OAD; On-Chip or Off-Chip. As previously described, On-Chip will require metadata of the image that will be initially flashed onto the device. Review section On-Chip OAD for more information on On-Chip OAD. Review section on Off- Chip OAD for information on required materials.

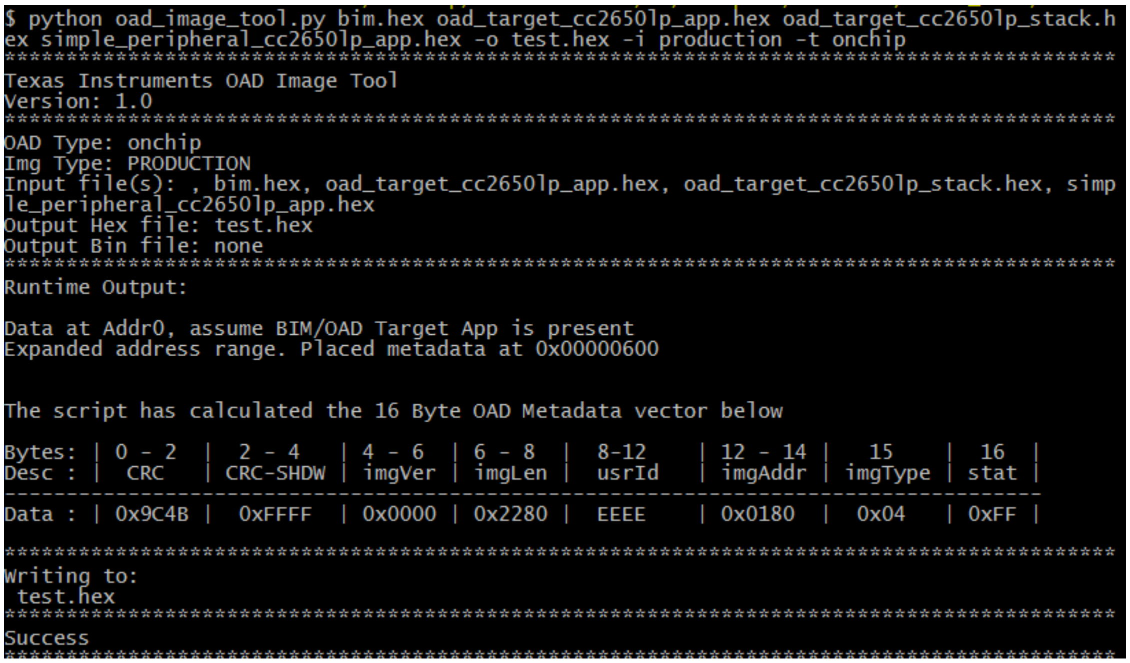
10.2.4.1 On-Chip OAD Production Image Example Usage

On-Chip OAD's Production image is a hex merge of BIM for On-Chip OAD, Image A (the resident Application that implements the TI OAD Profile + Uses the BLE Stack), Image B (the initial Application) and the BLE Stack.

Once all the hex files are correctly generated– invoke the TI OAD Image Tool with:

<python> <oad_image_tool.py> <BIM hexfile> <Image A hexfile> <Stack hexfile> <Image B hexfile> -o <Output hexfile> -i production –t onchip

Where '<*item*>' indicate location of *item* on the system. The flags used in the tool are highlighted. The output should look similar to Figure 20.



```
$ python oad_image_tool.py bim.hex oad_target_cc2650lp_app.hex oad_target_cc2650lp_stack.h
ex simple_peripheral_cc2650lp_app.hex -o test.hex -i production -t onchip
******************************************************************************************
Texas Instruments OAD Image Tool
Version: 1.0
******************************************************************************************
OAD Type: onchip
Img Type: PRODUCTION
Input file(s): , bim.hex, oad_target_cc2650lp_app.hex, oad_target_cc2650lp_stack.hex, simp
le_peripheral_cc2650lp_app.hex
Output Hex file: test.hex
Output Bin file: none
******************************************************************************************
Runtime Output:

Data at Addr0, assume BIM/OAD Target App is present
Expanded address range. Placed metadata at 0x00000600


The script has calculated the 16 Byte OAD Metadata vector below

Bytes: | 0 - 2  |  2 - 4   | 4 - 6  | 6 - 8  |  8-12    | 12 - 14 |   15    |  16  |
Desc : |  CRC   | CRC-SHDW | imgVer | imgLen |  usrId   | imgAddr | imgType | stat |
-------------------------------------------------------------------------------------
Data : | 0x9C4B |  0xFFFF  | 0x0000 | 0x2280 |  EEEE    | 0x0180  |  0x04   | 0xFF |

******************************************************************************************
Writing to:
 test.hex
******************************************************************************************
Success
******************************************************************************************
```

Figure 20. OnChip OAD Production Image Example invocation.

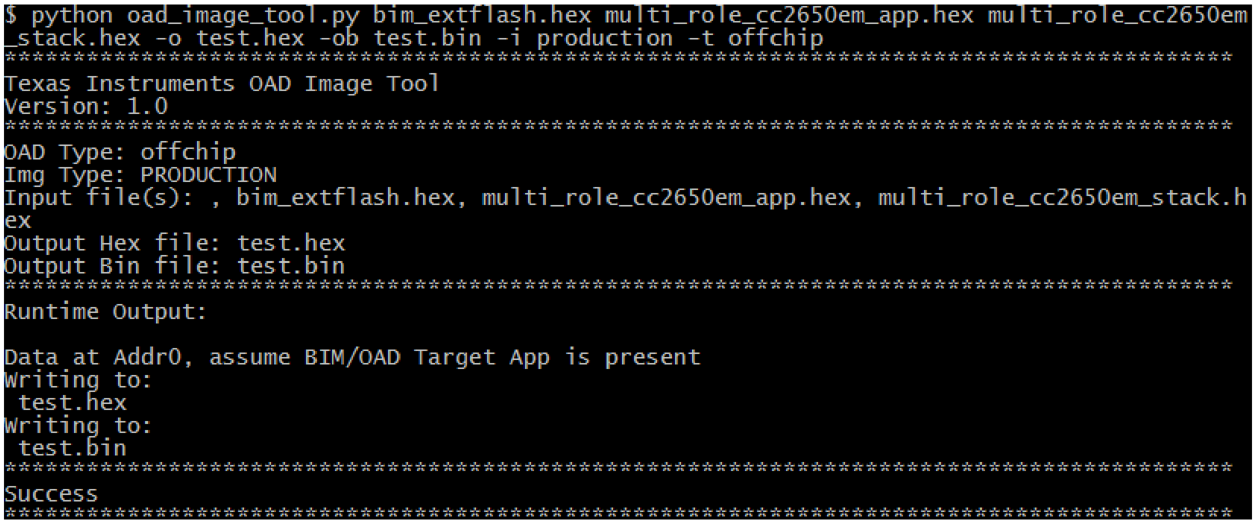
10.2.4.2 Off-Chip OAD Production Image Example Usage

Off-Chip OAD's Production image is simply a hex merge of BIM for External Flash + Initial Application Image + Initial Stack Image.

Once all the hex files are correctly generated – invoke the TI OAD Image Tool with:

<python> <oad_image_tool.py> <BIM hexfile> <App hexfile> <Stack hexfile> -o <Output hexfile> -i production –t offchip

Where '<*item*>' indicate location of *item* on the system. The flags used in the tool are highlighted. The output should look similar to Figure 21.



```
$ python oad_image_tool.py bim_extflash.hex multi_role_cc2650em_app.hex multi_role_cc2650em
_stack.hex -o test.hex -ob test.bin -i production -t offchip
******************************************************************************************
Texas Instruments OAD Image Tool
Version: 1.0
******************************************************************************************
OAD Type: offchip
Img Type: PRODUCTION
Input file(s): , bim_extflash.hex, multi_role_cc2650em_app.hex, multi_role_cc2650em_stack.h
ex
Output Hex file: test.hex
Output Bin file: test.bin
******************************************************************************************
Runtime Output:

Data at Addr0, assume BIM/OAD Target App is present
Writing to:
 test.hex
Writing to:
 test.bin
******************************************************************************************
Success
******************************************************************************************
```

Figure 21. OffChip OAD Production Image Example invocation

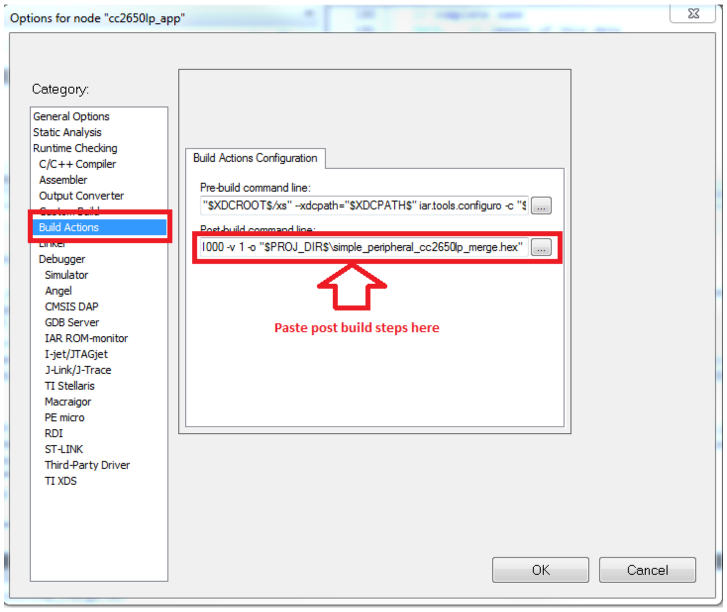
10.2.5 Automating the script

Once the script is installed, it is possible to automate the OAD file generation for rapid testing. This can be accomplished by hooking the script into the post build steps of your tool chain. Instructions for IAR/CCS can be found below.

IAR

Right click on the application project in IAR and select project options->Build Actions. Paste the following code into the Post-build command line section. Be sure to replace sections in <> with actual paths from the PC running IAR. Note that if the full path ("C:\Python27") to the Python executable has been added to the system path environment variables, the “python” command is sufficient for the <PYTHON_INSTALL_DIR>.

"<PYTHON_INSTALL_DIR>" "<OAD_IMAGE_TOOL_DIR>\oad_image_tool.py" "$PROJ_DIR$\FlashOnly_OAD_ExtFlash\Exe\simple_peripheral_cc2650lp_app.hex" "$PROJ_DIR$\..\stack\FlashROM\Exe\simple_peripheral_cc2650lp_stack.hex" -t offchip -i app -m 0x1000 -v 1 -o "$PROJ_DIR$\simple_peripheral_cc2650lp_merge.hex"



Pre-build command line:
"$XDCROOT$/xs" --xdcpath="$XDCPATH$" iar.tools.configuro -c "$

Post-build command line:
l000 -v 1 -o "$PROJ_DIR$\simple_peripheral_cc2650lp_merge.hex"

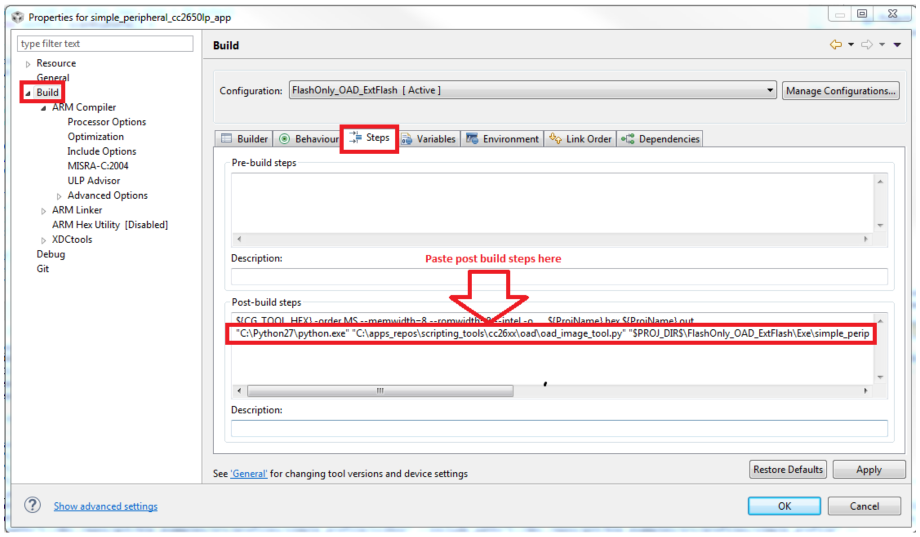
Figure 22. IAR Post-build step

CCS

Right click on the application project in CCS and select properties->Build->Steps. Paste the below code snippet in the Post Build Steps line:

"C:/Python27/python.exe" "C:/apps_repos/scripting_tools/cc26xx/oad/oad_image_tool.py" "${PROJECT_LOC}/FlashOnly_OAD_ExtFlash/simple_peripheral_cc2650lp_app.hex" "${PROJECT_LOC}/../stack/FlashROM/simple_peripheral_cc2650lp_stack.hex" -t offchip -i app -m 0x1000 -v 1 -o "${PROJECT_LOC}/simple_peripheral_cc2650lp_merge.hex"

See the screenshot below for instructions on how to insert the post build steps in CCS.



Configuration: FlashOnly_OAD_ExtFlash [Active]   Manage Configurations...

```
${CG_TOOL_HEX} -order MS --memwidth=8 --romwidth=8 --intel -o ${ProjName}.hex ${ProjName}.out
"C:\Python27\python.exe" "C:\apps_repos\scripting_tools\cc26xx\oad\oad_image_tool.py" "$PROJ_DIR$\FlashOnly_OAD_ExtFlash\Exe\simple_perip
```

See 'General' for changing tool versions and device settings

Figure 23. CCS Post-build step

10.3 RTOS RCFG Section

In order to save space, the CC26xx contains portions of the TI-RTOS kernel in its ROM image. These ROM functions have dependencies on a data structure called the RCFG within flash page 0 of internal flash. The RCFG section is essentially a table of function pointers (and some other kernel data) that allows the kernel ROM functions to access certain data structures in the internal flash memory.

When building a new RTOS in ROM image, the RCFG must be updated. However, since the RCFG lies within page 0 (which contains the vector table and thus is write protected) it cannot be updated via OAD.

This means that all images intended to be sent over the air must use an RTOS in flash configuration that includes their own instance of the RCFG.

10.4 Additional updates

For more up to date information or errata to this document, please check the wiki page: http://processors.wiki.ti.com/index.php/CC2640_OAD_User%27s_Guide

11 Troubleshooting Guide

11.1 General Troubleshooting Guide Prior to BIM

There are various places where OAD can fail; use the following steps to determine where the issue is occurring during the interaction:

- Use a BLE Packet Sniffer and Record the OAD Transaction
  This will verify that the profile is implemented correctly and a valid image was transferred over the air.
  - Look for a OAD Initiation
    Notifications from OAD Image Notify should be requested – and the appropriate response from the OAD Target after a GATT Write of the Candidate metadata.
  - Look for OAD Image Status Characteristic
    This will contain the status of the image prior to BIM launching the image.

Solutions –

- Verify that the OAD Downloader supports the TI OAD Profile as a GATT Client
- Verify that the OAD Downloader is sending the correct image with updated meta data
- Verify that the OAD Target supports the TI OAD Profile as a GATT Server

- Read external/internal flash to ensure CRC Shadow is valid and matches CRC field
  This will verify that the image was received fully without errors by the OAD Target
  - For Internal, various tools can be used. SmartRF Programmer 2 or using a jtag debugger and connecting to running target and utilizing a memory viewer are possible options.
  - For External, interface another MCU or another serial device to dump out the Flash.

Solutions –

- Power cycle and Retry Downloading the Image
- Verify that the Flash Pages, on-chip or off are not corrupt

11.2 Downloaded OAD Image Isn't Starting

If the application doesn't start running the downloaded firmware after a successful download, it's a BIM issue.

Depending on OAD type, on-chip or off-chip, refer to sections 9.3.2 or 8.3.2 respectively. Utilize how BIM operates and a debugger to find where the issue is occurring.

11.3 OAD_CRC_ERR Randomly Occurs

CRC errors occur when the CRC of the downloaded image doesn't match the CRC in the image header sent by the OAD downloader. This means that an image block was corrupted. An option for debugging is to read the external or internal flash storing the image and compare to the original hex file sent over the air. Methods for reading external/internal flash are described in 11.1.

11.4 Should External Flash be Used During OAD?

No, External flash should not be utilized while OAD Profile is active; the Profile is designed to have uninterrupted access to Flash, in both On-Chip and Off-Chip configurations.

11.5 Building Super Hex Files

To build merged hexfiles, there are various methods to do this. One option is to utilize the TI OAD Image Tool (Python). Examples for building a production image, On-Chip OAD Production Image Example Usage and Off-Chip OAD Production Image Example Usage, can be used as reference.

11.6 Mobile Application Can't Perform OAD

Ensure the latest version of the Application is downloaded from your Phone's Application Store and try again.

If problem persists, please post your Phone's Model and OS Version number along with details to reproduce your setup on our Support Forums. Utilize BLE Monitor and verify that the OAD works correctly.

11.7 OAD_TARGET’s Merge.bat Reports Data Overlapped

Utilize the TI OAD Image Tool with the hex files. Verify Linker configurations are correct.

11.8 Individually Flashing Hex Files for On-Chip OAD - App doesn’t work!

This is known issue with the flash tools – the issue is due to the tools being designed to work on pages instead of on words. When two applications utilize the same page this problem manifests. For example, in On-Chip OAD, BIM and Part of the Image A (the resident application image) share Page 0. Depending on which application is flashed second, the information from the first image will not be preserved.

Solution –

Generate a Merged Hex File instead – this can be done with the TI OAD Image Tool. Look at Section 10.2 for more information on this tool. Then use an external flasher to flash the merged hexfile.

Utilize the .out files for debugging information and connect to the running target using IAR to verify functionality if needed.