UG267: Switched Multiprotocol User's Guide

This user's guide provides details about the Silicon Labs switched multiprotocol implementation released in March 2017. Details on the Multiprotocol Stack Interface (MPSI) are provided, including message structure and protocol operation. Data storage issues are reviewed. Finally, a detailed procedure for using the switched multiprotocol feature is provided.

The multiprotocol implementation relies on the Gecko Bootloader, also introduced in March 2017. For more information see *UG266: Silicon Labs Gecko Bootloader User's Guide*.

KEY POINTS

- Switched multiprotocol operational overview
- About the Switched Multiprotocol Stack Interface (MPSI) communications protocol and message structure
- Data storage and the mailbox
- Changing application images
- Implementing switched multiprotocol

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1. Introduction

Multiprotocol devices are capable of running more than one networking protocol. The device can change protocols in different ways, as described in *UG103.16: Multiprotocol Fundamentals*. In March 2017 Silicon Labs introduced support for switched multiprotocol on their Mighty Gecko family of products. In switched multiprotocol, a device running one type of wireless stack/application uses the bootloader to load and run a different type of wireless stack/application. The focus of this document is on devices operating in SoC (System-on-Chip) mode, but the concepts apply to NCP (network co-processor) implementations as well.

One of the most common uses for switched multiprotocol devices is where Bluetooth commissioning is used to add devices onto a mesh network. A device is shipped with a Bluetooth stack and commissioning application active, and also stores a mesh networking application. The focus of this document is on a Zigbee® implementation.

Figure 1.1. Zigbee/Bluetooth Light Example

To install the product:

1. The end user downloads a mobile commissioning application for the product onto a smartphone.
2. The end user then takes the product out of its packaging and powers it up.
3. At startup the product runs a Bluetooth commissioning application.
4. The mobile commissioning application establishes a Bluetooth connection with new product.
5. If new firmware images are available for the target zigbee application, the mobile application can load these onto the device's flash.
6. When all is complete, the mobile application tells the device to switch to the target zigbee application.

2. Switched Multiprotocol Operation Overview

This section provides an overview of the Silicon Labs implementation of a switched multiprotocol device (SMPD), using the Silicon Labs Bluetooth stack and EmberZNet PRO, the Silicon Labs implementation of a zigbee stack. This implementation is supported by three technologies:

- The Silicon Labs Gecko Bootloader
- The Multiprotocol Stack Interface (MPSI) communications protocol
- A mobile application

The Gecko Bootloader is a customizable bootloader application framework that supports image acquisition from multiple storage locations, or slots. For more information on the Gecko Bootloader, see *UG266, Using the Silicon Labs Gecko Bootloader*. For more information about the MPSI see section 5. About the Multiprotocol Stack Interface (MPSI).

An overview of switched multiprotocol operation is an existing network with a trust center shown in the following figure.

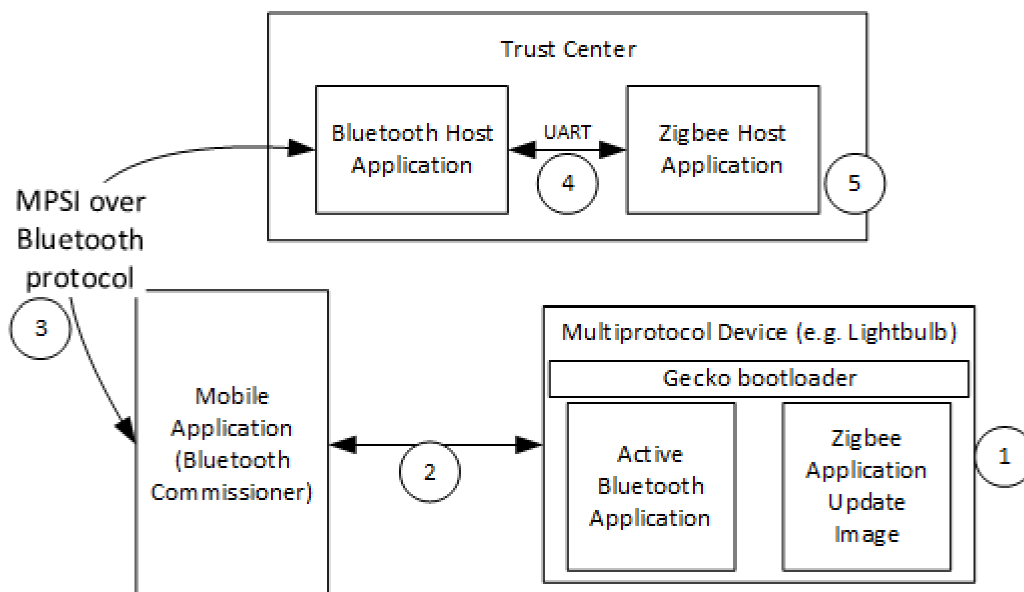


Figure 2.1. Switched Multiprotocol Overview

1. The user powers up the multiprotocol device. The device:
   - Boots up into the Bluetooth application.
   - Starts advertising.
   - Pairs with the Bluetooth commissioner on the mobile device.
2. The Bluetooth commissioner gets an install code and any other information required by the trust center.
3. The Bluetooth commissioner pushes the device's trust center information to the Bluetooth host application along with the instruction that a switch is needed.
4. The Bluetooth host application in turn pushes the information to the zigbee host application.

   Note: The mobile application and the zigbee host application both incorporate MPSI parsers. Therefore, the Bluetooth host application does not need to understand the contents of the MPSI message.

5. The mobile application triggers the multiprotocol device to join to the zigbee network by first sending a message to initiate joining and second sending a command to initiate boot to zigbee.

3. Storing Multiple Images

A switched multiprotocol application uses internal flash or external SPI flash to store upgrade images. The Gecko Bootloader must be configured correctly to access this storage. An API to access image files to be used in the file update must be included. This API is based on the concept of *storage slots*, where each slot has a predefined size and location in memory, and can be used to store a single upgrade image. The following provides an overview of storage with multiple slots enabled. See *UG266: Silicon Labs Gecko Bootloader User Guide* for details.

When multiple storage slots are configured, a bootload list is used to indicate the order in which the bootloader should access slots to find upgrade images. Before rebooting into the bootloader to initiate a firmware update, the application should write the bootload list by calling `bootloader_setBootloadList`. The bootloader attempts to verify the images in these storage slots in sequence, and applies the first image to pass verification.

3.1 Internal Storage Configuration

When configuring the Gecko Bootloader to obtain images from internal storage, modify the following configuration parameters:

Base address: The address where the bootloader places the bootload list.

The location and size of the storage slots: The addresses are absolute addresses (not offsets from the base address). Enough space must be reserved between the base address and the first storage slot to fit two copies of the bootload list. These two copies need to reside on different flash pages, to provide redundancy in case of power loss during writing. Two full flash pages therefore need to be reserved. The following figure illustrates how the storage area can be partitioned.

Internal storage with two storage slots

0	340 kB	342 kB	344 kB	648 kB
Application	Bootload list	Bootload list	Storage slot 0 Size = 340 kB	Storage slot 1 Size = 340 kB

Figure 3.1. Internal Storage Area Two-Slot Configurations

3.2 SPI-Flash Storage Configuration

When configuring the Gecko Bootloader to obtain images from SPI flash storage, modify the following configuration parameters.

Base address: The address where the bootloader places the bootload list, if more than one storage slot is configured. Defaults to 0.

The location and size of the storage slots: The addresses are absolute addresses (not offsets from the base address). Enough space to fit two copies of the bootload list must be reserved between the base address and the first storage slot. These two copies need to reside on different flash pages, to provide redundancy in case of power loss during writing. Two full flash pages therefore need to be reserved. In the default example application, a SPI flash part with 4 kB flash sectors is used. This means that 8 kB must be reserved before the first storage slot, as shown in the following figure.

External storage with two storage slots

0	4 kB	8 kB	260 kB
Bootload list	Bootload list	Storage slot 0 Size = 252 kB	Storage Slot 1 Size = 252 kB

Figure 3.2. SPI Flash Storage Area Two-Slot Configuration

4. About the Mailbox

The mailbox is a location in memory where MPSI messages are stored. This is only applicable for a switched SoC device, where only one application can run at a time. The intent is that a running Bluetooth application can store commissioning MPSI messages destined for another application that is about to be booted.

The mailbox itself lives in PS Store. PS Store is a utility for saving information in persistent storage. Physically, it resides in main flash.

When written into PS Store, an MPSI message is encapsulated into a PS Store entry. The PS Store entry format is shown in the following table.

Table 4.1. PS Store Entry Format

Tag	Field	Length	Data
2 bytes	1 byte	1 byte	Length bytes

An MPSI message is identified as having a tag between 0x3000 and 0x3FFF. As such the mailbox can theoretically fit 4096 (0x1000) messages between boots, but the PS Store limits this to a smaller number.

The 'field' field can be ignored, while the 'length' field is determined by the size of the MPSI message. The 'data' array contains the MPSI message serialized into a byte array. The serialization order of MPSI messages is LSB (Least Significant Byte) first.

Silicon Labs provides the MPSI Storage plugin that handles storing and reading MPSI messages in the mailbox. Messages are written to the mailbox on demand. However, messages are only read and processed from the mailbox once during system initialization. When an application first boots, it checks for any MPSI messages in the mailbox. If all messages are supported by the running application, then the messages are all processed. If any message is not supported (either it is not meant for the running application or the message ID is not understood), then all messages in the mailbox are discarded. This default behavior can be changed to fit a project's needs.

5. About the Multiprotocol Stack Interface (MPSI)

5.1 Summary

The MPSI provides a common protocol to communicate to any Silicon Labs stack. MPSI messages may be commands, configuration items, queries, or customer-designed request/responses. To support switched multiprotocol, MPSI implements a mailbox style design with persistent storage, as the device will be rebooting and bootloading when switching application. See section 4. About the Mailbox for more information about the mailbox design.

5.2 End-to-end Messaging

MPSI can send messages from a remote device to a Silicon Labs multiprotocol device. In the following figure the Mobile Phone is running the MPSI protocol and will transmit messages ultimately bound for the zigbee application. In this case the Bluetooth wireless protocol is just a transport for shipping those messages. The Bluetooth stack can also support the protocol for receiving MPSI messages from a co-located stack or from a remote device.

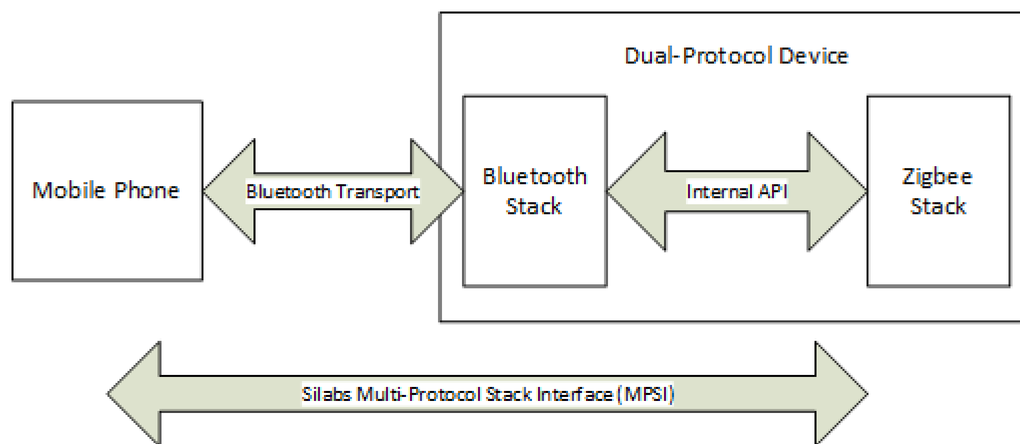


Figure 5.1. MPSI Implementation

5.3 Half-Duplex Single Queue

In the switched multiprotocol implementation, a single, half-duplex queue passes messages between stacks. Since only one application can run at a time, there is no need to store multiple messages for different stacks. When a running application (application A) wants to send messages to a different application (application B), the existing queue must be empty. Application A writes one or more messages into that queue and then triggers a reboot and bootload into Application B. Application B is responsible for draining the queue completely after reboot, which involves erasing the area of persistent storage that was used. The entire set of messages is treated as a single transaction, where Application B will does everything possible to execute the complete set. If one of the steps cannot be executed then Application B aborts running any of them (if possible). For more on failure processing see section 5.5 Message Support. For an example flow, see section 6. Changing Application Images.

5.4 Message Design

The following table illustrates MPSI message design. A more detailed description of each field follows.

Table 5.1. MPSI Message Design

Field	Size	Description	Values
destinationAppId	1 byte [uint8]	Specifies which image the messages are intended for.	0x00: None 0x01: Mobile Application 0x02: Zigbee 0x03: Thread 0x04: Connect 0x05: Bluetooth 0x06: MCU 0xFF: Any application
messageId	2 bytes [uint16]	Message identifier. The most significant bit indicates whether the message is a custom message or not.	See the table in section 5.5.1 Message IDs
payload	Variable [array]	Contains information pertinent to message.	Message-specific; see individual messages in the table in section 5.5.1 Message IDs
payloadLength	1 byte [uint8]	Specifies number of bytes contained in payload field.	0-255

destinationAppId field

This field specifies which image the message is intended for. If the field matches the currently running image, then the message can be processed. If the field indicates it is for an application that is not currently active, then the system may store it in the mailbox and boot into that application at a later point.

messageId field

This field contains a range of values, where 0-32767 are predefined (non-custom) messages and 32768-65535 are custom messages. Some of the predefined message values are provided in section 5.5.1 Message IDs.

payload

This field specifies the additional parameters that go in hand with the message ID. Some messages do not have options and have no payload. All integers are transmitted in LSB order.

payloadLength

This field specifies the length of the payload associated with the message ID.

5.5 Message Support

5.5.1 Message IDs

The following table lists some message IDs along with their origin and description. For up-to-date information refer to the latest SDK installation.

Table 5.2. Message IDs

MessageId	Name	Origin	Destination	Description
0	Get Applications Info	Mobile App	Any App	Requests information for all applications on the remote device.
1	Applications Info	Any App	Mobile App	Returns application information such as the slot ID and application ID for both the the running application and those in storage. The first entry in this payload is the currently running image, identified by a slot ID of 0xFF.
2	Bootload Slot	Mobile App	Any App	Triggers the device to bootload the application in the passed slot ID.
3	Error	Bluetooth JD and Any TC App	Mobile App	Sent to the mobile app to indicate an error at the MPSI layer.
4	Initiate Joining	Any App	Any App except Mobile App	Triggers an attempt to join a network with current parameters. For Bluetooth, this is interpreted as 'send Bluetooth advertisements for up to the amount of minutes specified by the Option parameter and wait for Bluetooth pairing'.
5	Get zigbee Joining Device Info	Mobile App	Bluetooth App	Requests the device EUI and installation code for joining the zigbee device to a network.
6	zigbee Joining Device Info	Bluetooth App	Mobile App	Returns the EUI and installation code for the zigbee joining device.
7	Set zigbee Joining Device Info	Mobile App	zigbee App (Trust Center)	Converts an install code to link key and adds to the Trust Center's local link key table.
8	Get zigbee Trust Center Joining Credentials	Mobile App	zigbee App (Trust Center)	A command sent to request the zigbee network parameters and open the network for joining. The parameters returned can be used by a joining device to join the zigbee network. On the Trust Center, this command generates a random key and sets it into the transient key table paired with a wildcard EUI64. This key, along with the channel mask and extended PAN ID, are passed along in the response to this message. The network is then opened for joining for 5 minutes.
9	zigbee Trust Center Joining Credentials	zigbee App (Trust Center)	Mobile App	The channel mask, extended PAN ID, and link key that are used to join the zigbee network.
10	Set zigbee Trust Center Joining Credentials	Mobile App	zigbee App (Joining Device)	Connect to a zigbee network on the channel mask specified that matches the extended PAN specified using the link key specified.

5.5.2 Custom Messages

Support for adding custom messages is integrated into Simplicity Studio.

5.5.3 Transaction Paradigm

The application attempts to treat all messages in the mailbox as a single transaction to perform.

Before taking action on any messages, an application verifies that all messages are known to the device and that it has necessary resources to take the action. For example, if the message indicates that the device should add a link key and also add a binding then the application checks that there are enough free entries for both of these before executing the action.

5.5.4 Probing Supported Messages

MPSI allows an application to probe what messages another application understands. This is especially important in the switched use case because the cost of switching is high.

Each application records the version number of the MPSI protocol that it understands and this can be retrieved regardless of whether the application is running or not. With this information the sender of the MPSI message can reasonably be assured it will be understood by the target device.

5.5.5 Unknown Messages in the Mailbox

Normally, the running application should not send unsupported messages to another partner application. However if an unknown command is found in the queue and the partner application needs to inform the first application it can do the following.

- Add an error indicator into the mailbox. This indicator specifies the first unknown message.
- Reboot and bootload back into the other application.

6. Changing Application Images

Switched multiprotocol makes it possible to update the application code in the flash while running another application. For example, the zigbee application can be updated while the Bluetooth application is running.

There are two ways to update an application image: either using the Gecko Bootloader or using a custom application implementing application image upload. For example, the Switched Multiprotocol Joining Device Bluetooth application provided with the Silicon Labs Bluetooth SDK implements this feature along with MPSI support. By flashing this application into the device, you will be able to update application images in the external flash memory, and then reboot the device from the updates memory slot.

The application is updated as follows:

1. The zigbee application is running in a Switch Multiprotocol Device (SMPD). Through some stimulus, it decides to switch to the Bluetooth application.
2. The Bluetooth application advertises it is connectable. The mobile application connects to the SMPD.
3. The mobile application queries the SMPD for the application operating in the "other" (non-Bluetooth) slot using MPSI.
4. The application issues a command to update the slot.
5. The mobile application ships blocks of the image to the Bluetooth application to write to flash. This is very similar to the Bluetooth OTA DFU (see *AN1045: Bluetooth Over-the-Air Device Firmware Update for EFR32xG1 and BGM11x Series Products*) with the difference that the application is written to another slot, and it does not overwrite itself.
6. The application verifies that the image is from a trusted source. See *UG266: Silicon Labs Gecko Bootloader User's Guide* for more information on verification procedures.
7. The application issues a command to reboot from the other slot.
8. The updated zigbee application is running.

The following diagram shows the flow of the Bluetooth application:

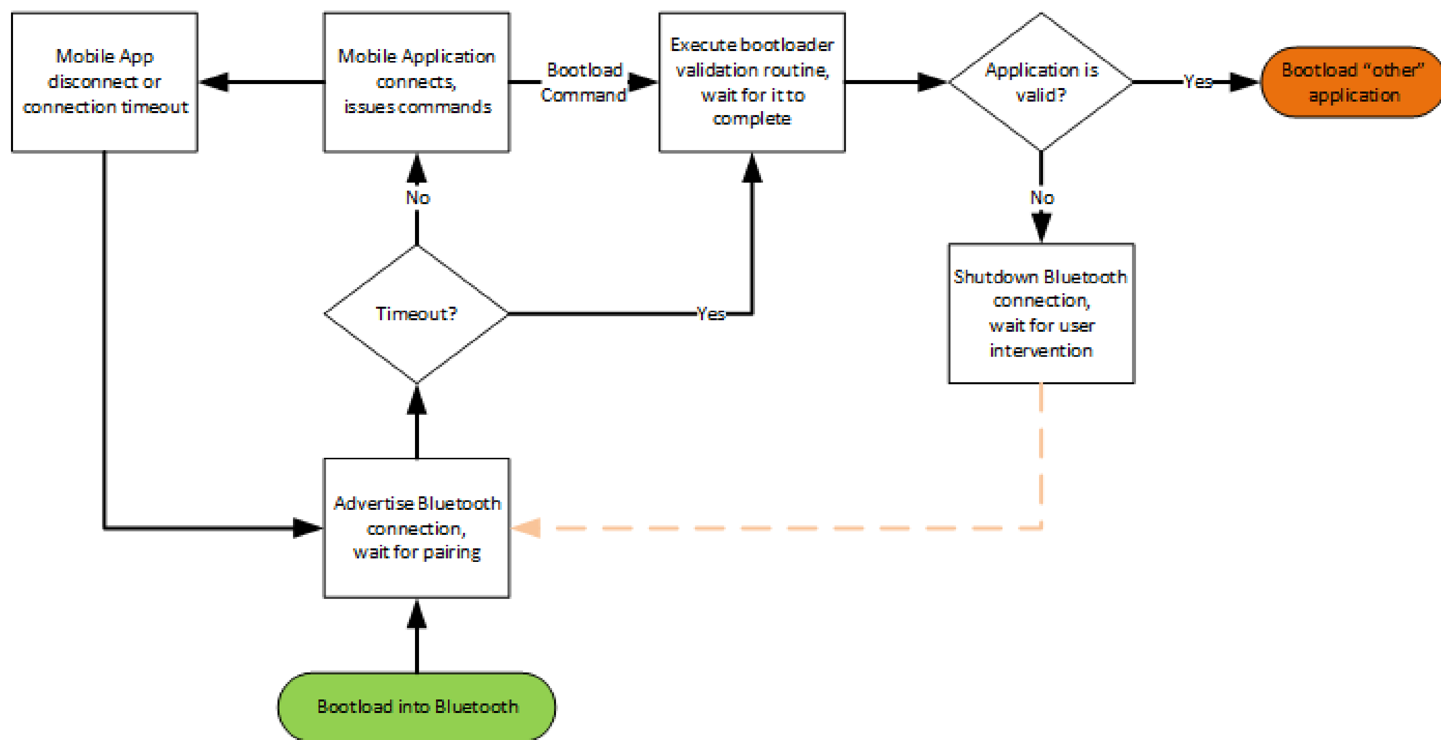


Figure 6.1. Bluetooth Application Flow

A potential security issue is that a malicious mobile application can connect to the device before the trusted one. In this case, the zigbee application can be overwritten by the malicious device. Although the new application will not be accepted as valid due to the false signature, the old application will be lost. In order to prevent such scenario, the provided example does not use the Bluetooth just-works pairing mechanism, but instead uses a passkey compare mechanism.

7. Implementing Switched Multiprotocol

To program a multiprotocol device you need at least three steps:

- Programming the bootloader
- Uploading the image of the first application (for example, the Bluetooth application)
- Uploading the image of the second application (for example, the zigbee application)

The bootloader can be programmed only by flashing the device. The first application can either be flashed to the device or be uploaded by the bootloader. The second application can either be flashed to the device, be uploaded by the bootloader, or be uploaded by the first application as discussed in section 6. Changing Application Images.

Before uploading images, the images can also be signed (except the main bootloader image) in order to protect the device from malicious software. Signing ensures that the image is from a trusted source.

This section provides a step-by-step guide to building and flashing a Gecko Bootloader, generating security keys, packaging, signing the application image, and loading the various required pieces to bootload an image from external flash. Finally, this section describes a scenario to switch between zigbee and Bluetooth applications using the Gecko Bootloader.

The procedures assume that you have a Wireless Start Kit (WSTK) with 4151A board header and you have installed the following:

- Simplicity Studio v4.11 or later
- Silicon Labs EmberZNet PRO stack v5.9 or higher
- Silicon Labs Bluetooth stack v2.3 or higher
- IAR Workbench 7.80.2 (this version is required for Silicon Labs stacks)

7.1 Compiling and Flashing the Gecko Bootloader

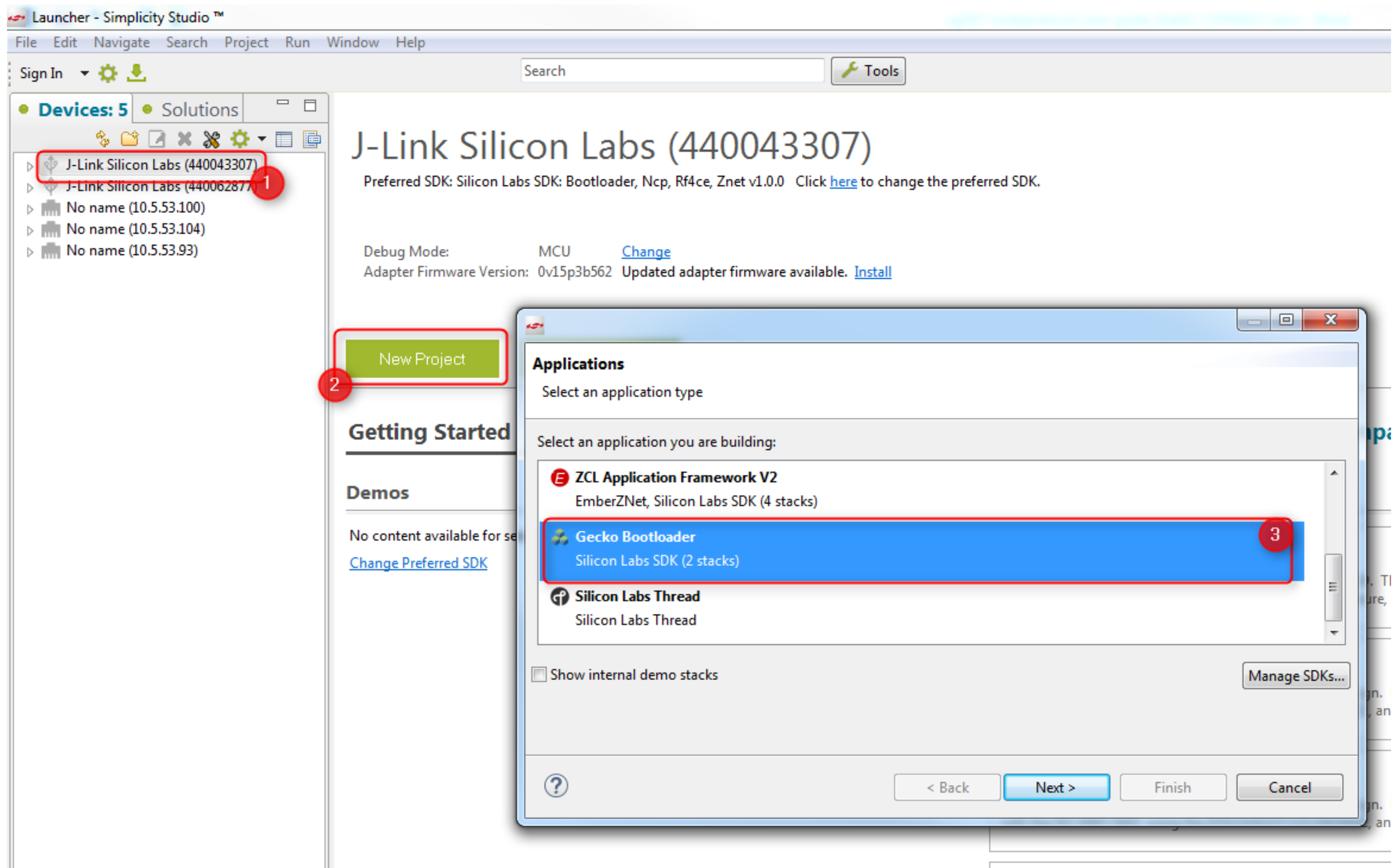
The Gecko Bootloader can be configured in a number of ways in order to enable different functions, such as:

- Legacy or secure booting
- Updating applications by UART or OTA
- Loading applications into external or internal flash
- Using XMODEM or BGAPI protocol

In the following example an SPI Flash Storage Bootloader is used, which makes it possible to upload application images (received OTA) into the external SPI flash. Use a radio board with SPI flash for testing. In this example a BRD4151A board is used. For more details about Gecko Bootloader configurations please refer to *UG266, Silicon Labs Gecko Bootloader User's Guide*. The Gecko Bootloader is provided both in the Bluetooth SDK v2.3 and in the EmberZNet SDK v5.9.

To create a new bootloader project:

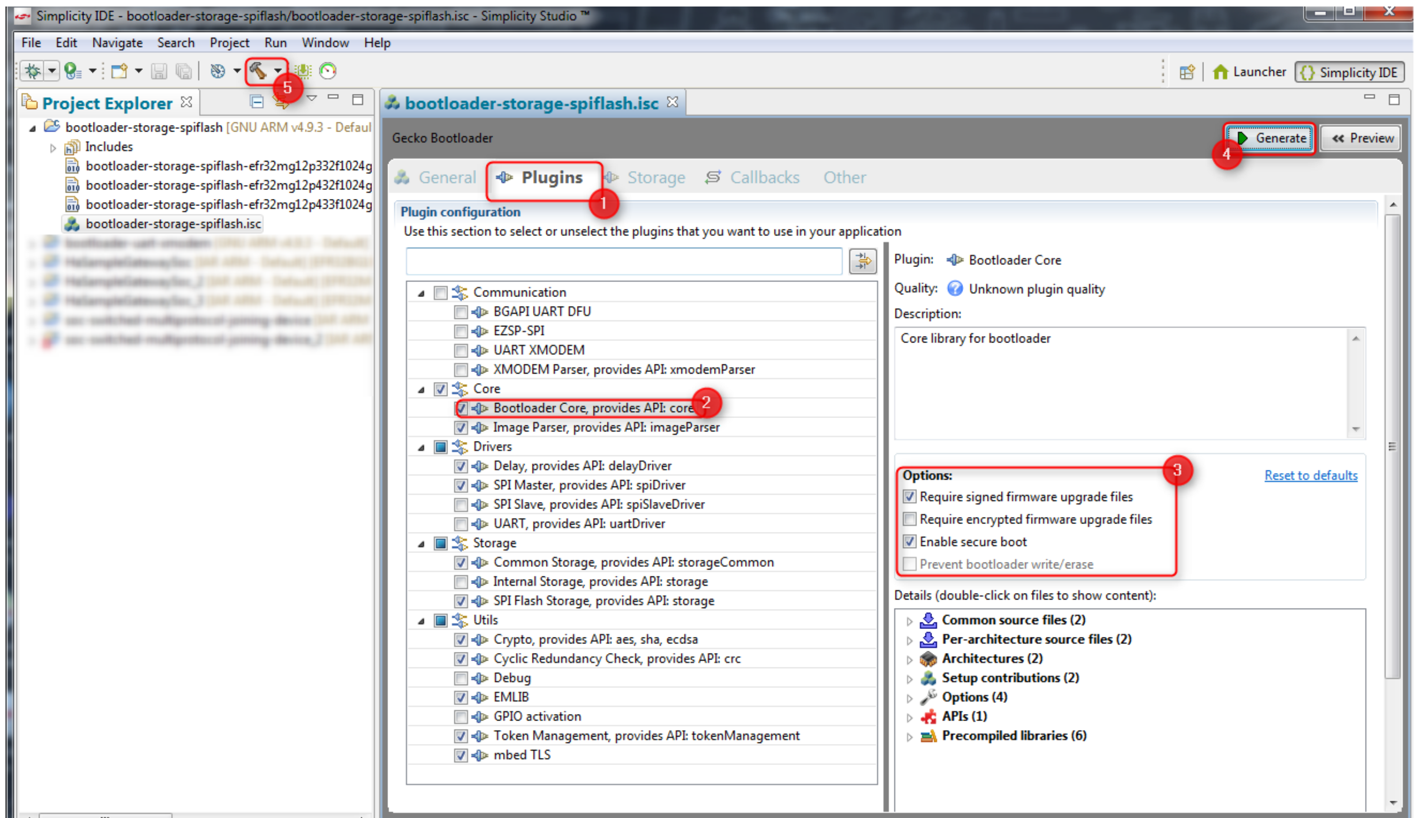
1. Open Simplicity Studio and click your device in the Devices tab to select it.
2. Click [**New Project**].
3. Select the Gecko Bootloader application. Click [**Next**].



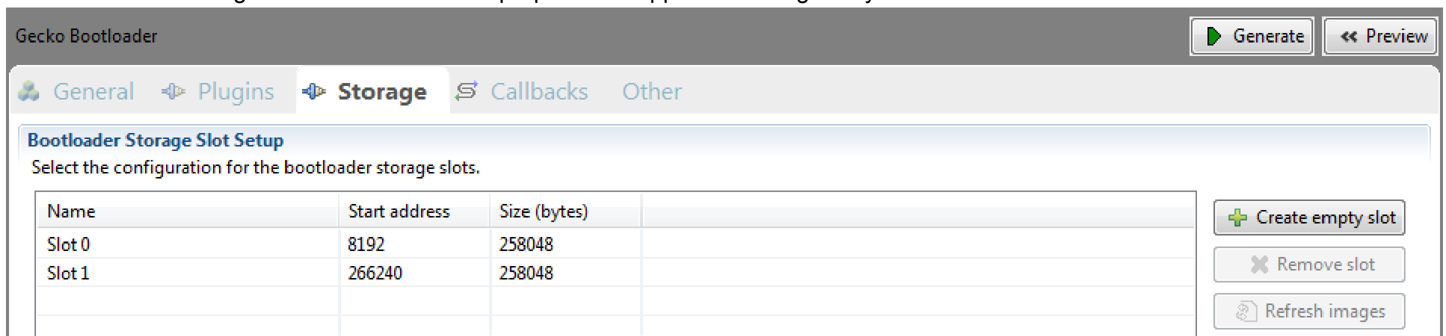
4. In the next dialog select any of the stacks (Bluetooth / ZNet). The selection does not affect a Gecko Bootloader configuration. Click [**Next**].
5. Select the 'SPI Flash Storage Bootloader (multiple images)' example. Click [**Next**], then [**Next**] again, then [**Finish**]. The Simplicity IDE perspective opoens, with the project's General tab selected.

To configure the Gecko Bootloader:

1. Click the Plugins tab.
2. Click **Bootloader Core.**
3. Check basic settings such as Secure Boot.



Click the Storage tab to check the slots prepared for application images. By default two slots of 252 kB each are available.



4. Click [**Generate**] to generate the bootloader project.
5. Click Build to build the project.

The build results in a number of output files. The most important ones are 'bootloader-storage-spiflash.s37' and 'bootloader-storage-spiflash-combined.s37'. The first includes the main bootloader only. The second contains both the first stage bootloader and the main bootloader. The first time you flash new bootloader firmware to a device in a development or manufacturing scenario, you should use the second, combined file. The main-stage-only firmware is provided for upgrade purposes on devices already loaded with a prior build of the Gecko Bootloader.

To flash .s37 files to the device you can use the Flash Programmer tool in Simplicity Studio or you can use Simplicity Commander version 0v21 or later.

To start the Flash Programmer in Simplicity Studio

1. Start Simplicity Studio and select your device in the Devices tab.
2. Click the Compatible Tools tab.
3. Click **Flash Programmer**.

Alternatively you can click the Flash Programmer button in the Simplicity IDE perspective.

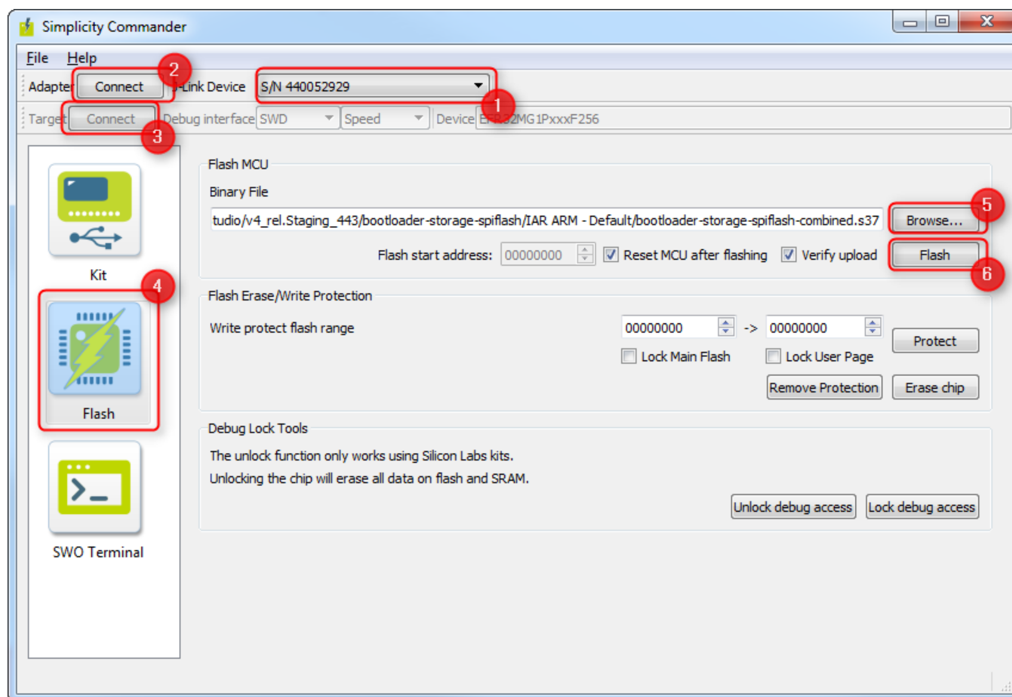
Browse for the .s37 file to be uploaded and click **Program**.

To flash the device with Simplicity Commander start it from

```
$SIMPLICITY_STUDIO/v4/developer/adapter_packs/commander/.
```

On the Simplicity Commander GUI

1. Select the J-Link adapter to be used.
2. Connect to the adapter.
3. Connect to the target device.
4. Select the Flash tab.
5. Browse for the .37 file to be uploaded.
6. Click [**Flash**].



Alternatively use the Simplicity Commander CLI to flash the device in the following form

```
commander flash -s <J-link serial no.> bootloader-storage-spiflash-combined.s37
```

Refer to *UG162: Simplicity Commander Reference Guide* for more information about Simplicity Commander CLI commands.

7.2 Security Features

The Gecko Bootloader has three security feature:

- Authenticated upgrade file
- Encrypted upgrade file
- Secure Boot

Upgrade files are in a custom GBL (Gecko Bootloader) format. An authenticated upgrade file means that an electronic signature is attached to the GBL file. The signature is produced with a public-private key pair. The public key is stored in the device, while the private key is kept secret by the manufacturer. The signature ensures that the upgrade file is from a trusted source.

An encrypted upgrade file means that the content of the GBL file is encrypted to protect against eavesdroppers.

Secure Boot means that a signature is attached to the bootloader image (.s37). Note that this differs from signing the GBL file, as a GBL upgrade file is a packed version of the image files. A signed image file ensures that the image was not modified, and that it is from a trusted source. This is checked at every boot.

In this multiprotocol example we use authenticated upgrade files and Secure Boot, and we show how to sign an .s37 image file and how to sign a GBL upgrade file. Note that the default configurations of the example applications in the SDK do not have security features enabled. For more information on security refer to *UG266: Silicon Labs Gecko Bootloader User's Guide.*

7.2.1 Generating Key Files

For switched multiprotocol with the Gecko Bootloader, it is recommended to sign the images to be uploaded to the device. For this, you need an ECC key pair in PEM format and a public key token file generated as a by-product.

You need Simplicity Commander 0v21 or later to implement this procedure. The `gbl keygen` command with the type option "ecc-p256" can be used to generate an ECC key pair in PEM format. The following command creates the ECC key pair and also generates the text file with which the public key can be written to the appropriate address in the flash.

```
commander gbl keygen --type ecc-p256 --outfile signing-key.pem
```

This creates three files: signing-key.pem, signing-key.pem.pub, and signing-key.pem-token.txt.

7.2.2 Flashing Keys

To validate the signature of signed images the bootloader has to be aware of the public key. The private key has to be kept secret by the company for signing. In order to let the bootloader know the public key, it must be written into the flash memory. We use the token system for this purpose. The public key is flashed into a predefined token known by the bootloader.

To flash the public key, use the following Simplicity Commander command:

```
commander flash --tokenfile signing-key.pem-tokens.txt --tokengroup znet -d EFR32F256
```

The last parameter describes the device family (based on flash size).

7.2.3 Signing an Image File

When a Bluetooth or zigbee project is built, the image file is generated in different formats (.out, .hex, .bin, .s37). In the multiprotocol environment the .s37 format is used. To sign an image file you can use Simplicity Commander's `convert` command:

```
commander convert --secureboot --keyfile signing-key.pem original_project_name.s37 --outfile signed_project_nam
e.s37
```

This image can then be flashed to the device using

```
commander flash -s <J-link serial no.> signed_project_name.s37
```

If the bootloader is configured with the Secure Boot option, then only signed images will be executed! If Secure Boot is disabled in the bootloader, you can use unsigned images.

7.2.4 Signing a GBL Upgrade File

If the application will not be flashed directly to the device, a GBL upgrade file must be generated. This upgrade file is then sent to the bootloader, which either parses the image file from the GBL file and writes the image file into the flash for executing, or stores the GBL file for later use. The upgrade file can be sent to the bootloader in many different ways, depending on the bootloader configuration:

- Via UART
- Over-The-Air
- From external flash

A signed upgrade file can be created and signed using Simplicity Commander's `gbl create` command:

```
commander gbl create signed_GBL_name.gbl --app original_project_name.s37 --sign signing-key.pem
--encrypt encryption-key
```

This single command performs three actions:

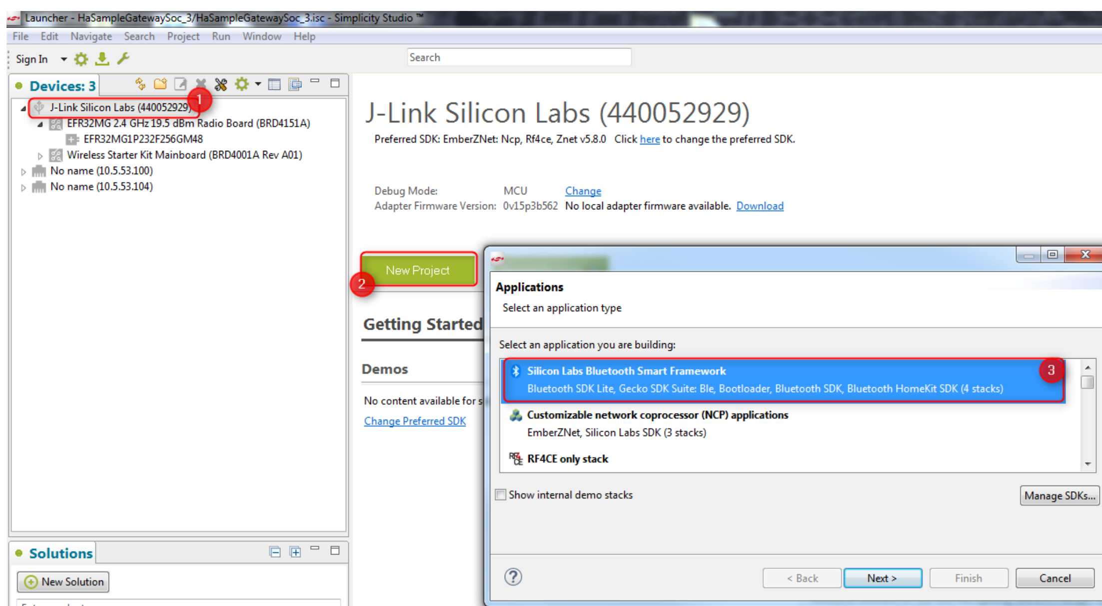
- Creates a GBL file
- Encrypts the GBL file
- Signs the GBL file

If Secure Boot is also desired, the application must be signed using `commander convert --secureboot` prior to creating the GBL.

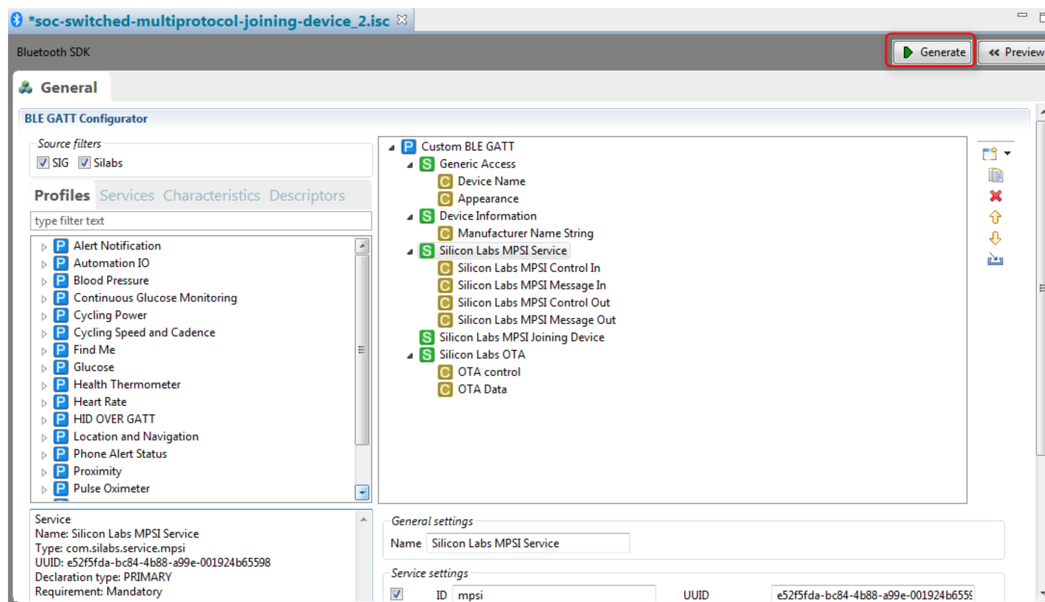
7.3 Build a Multiprotocol Bluetooth Application

These instructions assume you have Simplicity Studio and the Bluetooth stack version 2.3 or higher installed. To build a multiprotocol Bluetooth example:

1. Open Simplicity Studio 4 and click your device in the Devices tab.
2. Click [**New Project**].
3. Select "Silicon Labs Bluetooth Smart Framework". Click [**Next**].
4. Select the latest Bluetooth SDK version. Click [**Next**].
5. Select the "SOC – Switched Multiprotocol Joining Device" application from list of example applications. Click [**Next**], then [**Next**], and then [**Finish**]. The Simplicity IDE perspective opens.



6. Click [**Generate**] to generate the Bluetooth project.

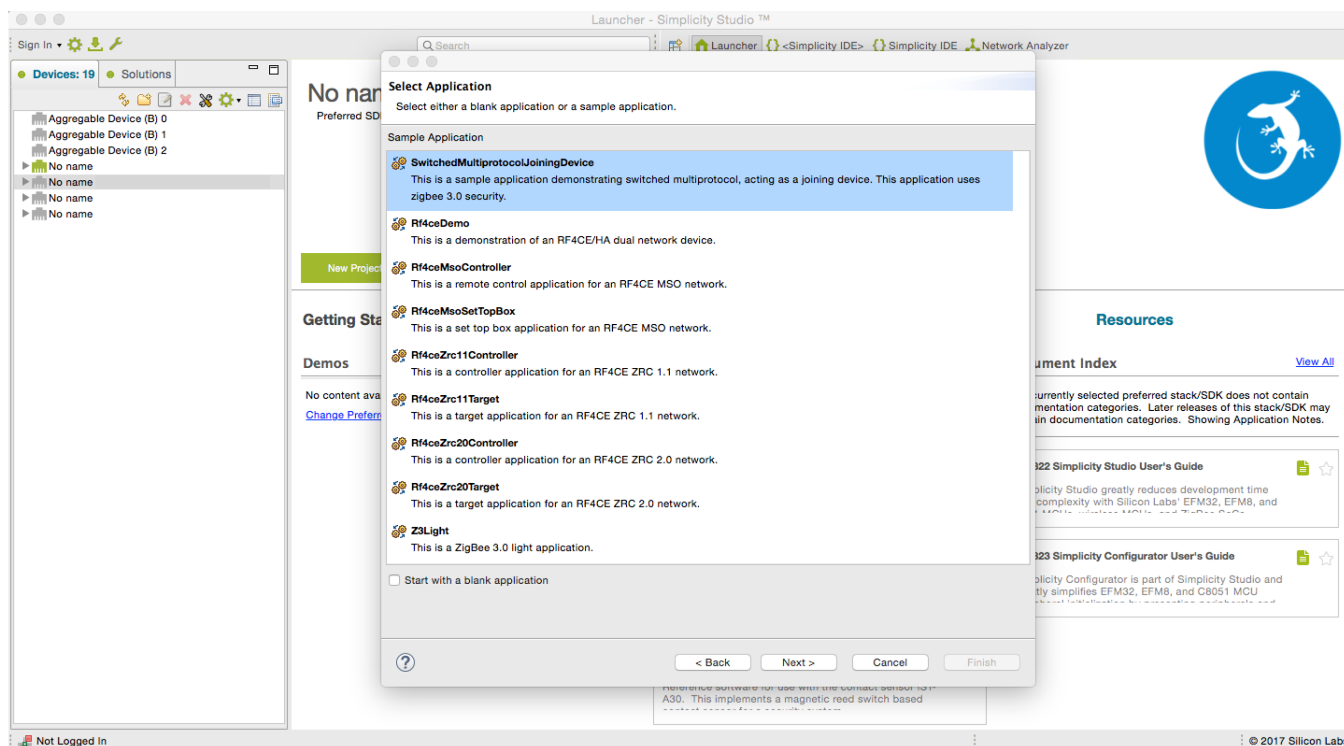


7. Click Build to build the project.

7.4 Build a Multiprotocol zigbee Application

These instructions assume you have Simplicity Studio and the EmberZNet PRO stack version 5.9 or higher installed. To build a multi-protocol zigbee example follow these steps:

1. Open Simplicity Studio 4 and click your device in the Devices tab.
2. Click [**New Project**].
3. Select 'ZCL application Framework V2'. Click [**Next**].
4. Select the appropriate EmberZNet PRO stack for the SoC application and click [**Next**].
5. Select the "SwitchedMultiprotocolJoiningDevice" application from the list of example applications. Click [**Next**], then [**Next**], and then [**Finish**].



6. The Simplicity IDE perspective opens. Click [**Generate**] to generate the zigbee SwitchedMultiprotocolJoiningDevice project.
7. Click Build to build the project.

7.5 Load the Main Application Image into Internal Flash

The application loaded into the internal flash will be the primary one executed by the bootloader, after verifying its signature. This application has to be flashed in .s37 format in order to be immediately executable. If Secure Boot was enabled in the bootloader the .s37 file has to be signed, too. The signing and flashing process is described in section 7.2.3 Signing an Image File.

Assume the zigbee application is the primary one. Sign and upload the .s37 file with the following commands:

```
commander convert --secureboot --keyfile signing-key.pem SwitchedMultiprotocolJoiningDeviceSoc.s37 --outfile si
gned_SwitchedMultiprotocolJoiningDeviceSoc.s37
commander flash -s <J-link serial no.> signed_SwitchedMultiprotocolJoiningDeviceSoc.s37
```

7.6 Load the Upgrade Files into Flash

Switched multiprotocol means that multiple application images can be stored to be loaded later by the bootloader for execution. The application images can be stored in internal or external flash. In the example an external SPI flash is used, but commands are shown below showing how to load upgrade files into slots in internal storage.

The images are stored in GBL upgrade file format in order to be loadable. The GBL file format is used in order to make the bootloading process unified for all communication interfaces: UART, OTA, external flash.

If Secure Boot is enabled in the Gecko Bootloader configuration, the application images have to be signed first. If "Authenticated upgrade files" is enabled, then the GBL upgrade file has to be signed, too. This can be done in one step as described in 7.2.4 Signing a GBL Upgrade File.

7.6.1 Load the Upgrade Files into External Flash

First, create a signed upgrade file both for the Bluetooth and the zigbee application with the following commands:

```
commander gbl create bluetooth_upgrade_signed.gbl --app soc-switched-multiprotocol-joining-device.s37 --sign si
gning-key.pem

commander gbl create zigbee_upgrade_signed.gbl --app SwitchedMultiprotocolJoiningDeviceSoc.s37 --sign signing-k
ey.pem
```

Now the upgrade files must be written onto the external flash to the appropriate addresses. The slot addresses are defined in the bootloader as seen in section 7.1 Compiling and Flashing the Gecko Bootloader. In the example case slot 0 is on the address 0x2000 and slot 1 is on the address 0x41000. To flash the upgrade files to the external flash use the Simplicity Commander command `extflash write`:

```
commander extflash write bluetooth_upgrade_signed.gbl --address 0x2000

commander extflash write zigbee_upgrade_signed.gbl --address 0x41000
```

7.6.2 Load the Upgrade Files into Internal Flash/Storage

Although not shown in this example, a chip may store images in internal flash, provided that it uses the Gecko Bootloader configured for internal storage and that it actually has enough internal flash space. The process for saving upgrade files in the internal storage slots is similar to that of loading into external flash.

First, create a signed upgrade file both for the Bluetooth and the zigbee application with the following commands. Note that instead of producing a file with a .gbl extension, we append a .bin extension onto the filename.

```
commander gbl create bluetooth_upgrade_signed.gbl.bin --app soc-switched-multiprotocol-joining-device.s37 --sig
n signing-key.pem

commander gbl create zigbee_upgrade_signed.gbl.bin --app SwitchedMultiprotocolJoiningDeviceSoc.s37 --sign signi
ng-key.pem
```

Next, the upgrade files are written into internal flash to appropriate addresses. As before with writing to external flash, the upgrade files should be written to align with slot addresses. These addresses are the same ones defined when building a Gecko Bootloader with internal storage. In this example, slot 0 starts at address 0x5A000 and slot 1 starts at address 0xAC800. To flash the upgrade files to internal flash, use the Simplicity Commander command `flash`:

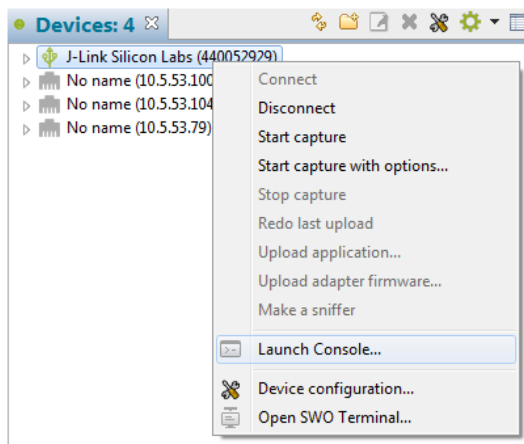
```
commander flash bluetooth_upgrade_signed.gbl.bin --address 0x5A000

commander flash zigbee_upgrade_signed.gbl.bin --address 0xAC800
```

7.7 Switching between Zigbee and Bluetooth Applications

After upgrade files are uploaded onto the external flash, and the main zigbee application is loaded into the internal flash, reset the device. The zigbee application is started. Now you can use the Slot Manager plugin to list the application images and bootload from the Bluetooth slot. This results in loading the Bluetooth application image into the internal flash for execution.

To use the Slot Manager, in Simplicity Studio launch the console for the command line interface for the zigbee application.



On the Serial 1 tab, enter the following commands to get info about upgrade images:

```
plugin slot-manager ext-flash-info
plugin slot-manager slots-info
```

Output is as follows.

```
SwitchedMultiprotocolJoiningDeviceSoc>plugin slot-manager ext-flash-info
Version     : 513
Part        : MX25R8035F
Capabilities: 0x03
Part size   : 1048576 B
Page size   : 4096 B
Word size   : 1 B
Slots       : 2
SwitchedMultiprotocolJoiningDeviceSoc>plugin slot-manager slots-info
Slot 0
  Address     : 0x00002000
  Length      : 0x0003F000 (258048 bytes)
  Type        : Bluetooth application
  Version     : 0x00000000
  Capabilities: 0x00000000
  Product ID  : 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00
Slot 1
  Address     : 0x00041000
  Length      : 0x0003F000 (258048 bytes)
  Type        : ZigBee
  Version     : 0x00000000
  Capabilities: 0x80000000
  Product ID  : 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00 0x00
```

To boot from the Bluetooth slot (slot 0) use the command:

```
plugin slot-manager boot-slot 0
```

Note: To implement rebooting from other slot functionality in your custom application you can use the Gecko Bootloader API, which includes functions for switching slots, rebooting, and so on. For details see the Gecko Bootloader API Reference Manual, shipped with the SDK.

This loads the Bluetooth application into the internal flash, and reboots the device. Now you can see the Bluetooth device advertising.

```
SwitchedMultiprotocolJoiningDeviceSoc>plugin slot-manager boot-slot 0
Slot Manager: beginning image verification.....................................................................
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...............................................................................................................
...............................................................................................................
...............................................................................................................
...............................................................................................................
...............................................................................................................
...........................................passed! Booting slot 0


*** Startup ***
Build Date: Mar  1 2017
Build Time: 15:01:42

Server booted!
Local address:00:0b:57:07:ae:4b
HEADS UP! Removing all bondings!
Server: Security Manger is configured.
Server is bondable.
Starting advertisement for 10 minute(s).
Server is discoverable/connectable.
```

To switch back to the zigbee application, you need to boot from slot 1. Note that now the Bluetooth application is running, which has different commands than the zigbee application. The Switched Multiprotocol Joining Device Bluetooth example has the following command for booting from slot 1. Enter it and it loads the zigbee application into the internal flash again, and reboots the device:

```
set-slot-bootload 1

> set-slot-bootload 1
Slot Manager plugin: beginning image verification..............................................................
...............................................................................................................
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...............................................................................................................
...........................................................passed! Booting slot 1
Reset info: 0x02 (BTL)
Extended Reset info: 0x0201 (GO )

SwitchedMultiprotocolJoiningDeviceSoc>
```
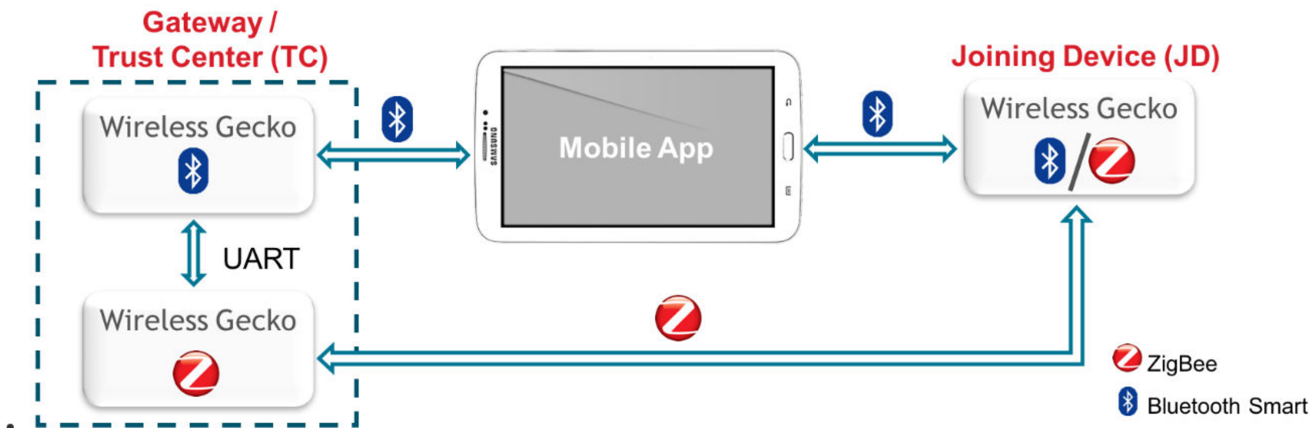

8. Bluetooth Commissioning Test System

8.1 Overview

One of the most common uses for switched multiprotocol devices is where Bluetooth commissioning is used to add devices onto a mesh network. To demonstrate this use case a test system is designed and implemented including both protocol switching and MPSI.

The Bluetooth commissioning test system contains three main components: the zigbee trust center, the mobile phone application, and the Switched Multiprotocol Joining Device. Both the trust center and the joining device connect to the Mobile Phone Application over a Bluetooth protocol connection, and they communicate with MPSI messages.



For testing purposes three different Bluetooth applications are implemented:

- **Trust Center Bluetooth Interface**: This application provides the Bluetooth interface in the trust center. It is implemented as an NCP target running on a radio board and a host application running on a PC / Raspberry Pi. The zigbee interface of the trust center is emulated in the test system with a command line interface. The NCP target image is provided in the Silicon Labs Bluetooth SDK as "NCP target – Switched Multiprotocol Trust Center". The host application can be found in the SDK under:

```
C:\SiliconLabs\SimplicityStudio\v4\developer\sdks\gecko_sdk_suite\v1.0\app\bluetooth_2.3
\examples_ncp_host\switched_multipr_trust_center
```

- **Mobile App**: A mobile app is available for Android devices from the Google Play Store (Opt In URL: https://play.google.com/apps/testing/com.siliconlabs.worcester).
- **Switched Multiprotocol Joining Device**: This is a Bluetooth SoC application that runs the "Switched Multiprotocol Joining Device" application provided in the Silicon Labs Bluetooth SDK. It runs on a standalone radio board, which is capable of booting both in Bluetooth and in zigbee mode.

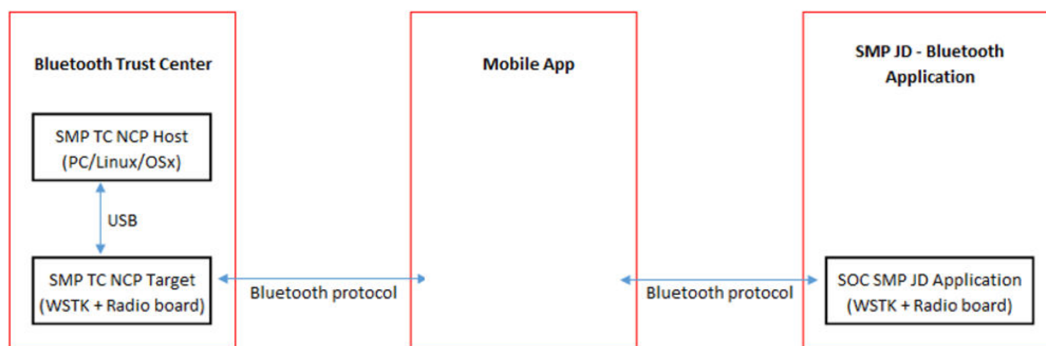


Figure 8.1. Three Bluetooth Applications

In addition, two zigbee applications must be built: the trust center and joining device. The trust center requires a fourth WSTK and radio board with a chip that is running a suitable NCP image.

- **SwitchedMultiprotocolTrustCenter:** This can be generated using Simplicity Studio and built on a POSIX host. It is a sample application presented when building a host application. An NCP application must be loaded onto a device to interact with this host application.

- **SwitchedMultiprotocolJoiningDevice**: This is also built using Simplicity Studio. It is also presented as a sample application when building for a SoC. This image will be converted to a GBL and sent to the joining device using Bluetooth's OTA transfer mechanism, as shown later.

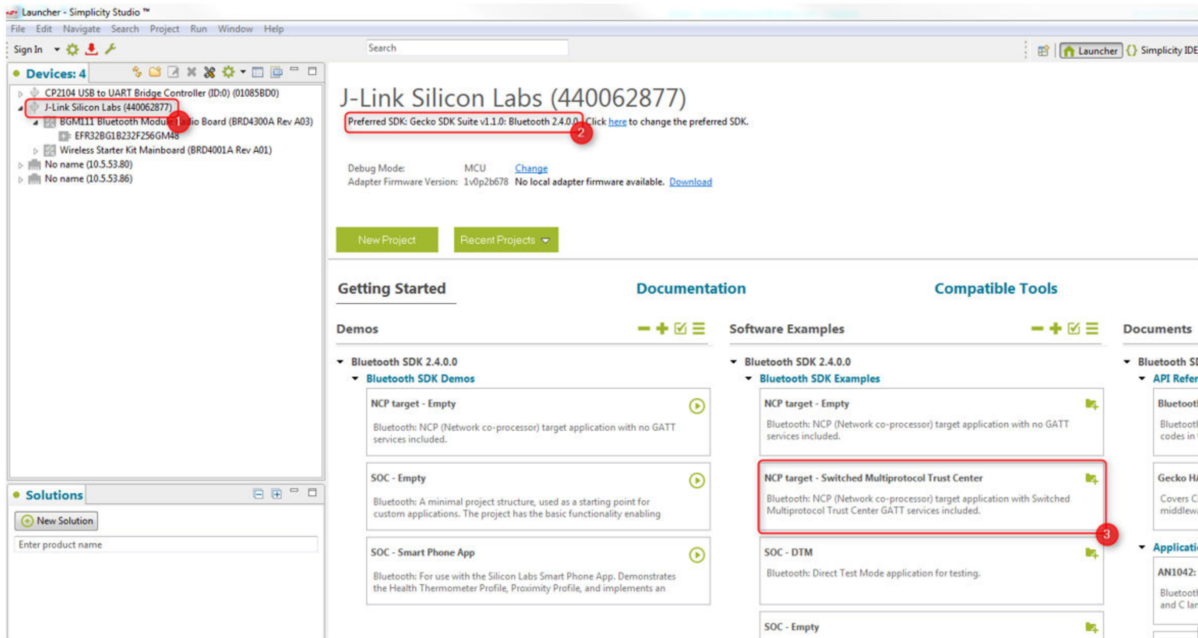
Both trust center applications (Trust Center Bluetooth Interface and SwitchedMultiprotocolTrustCenter) must be run on the same host system. This is due to the fact that the two processes must send MPSI messages to each other using system resources.

8.2 Flashing Applications to Devices

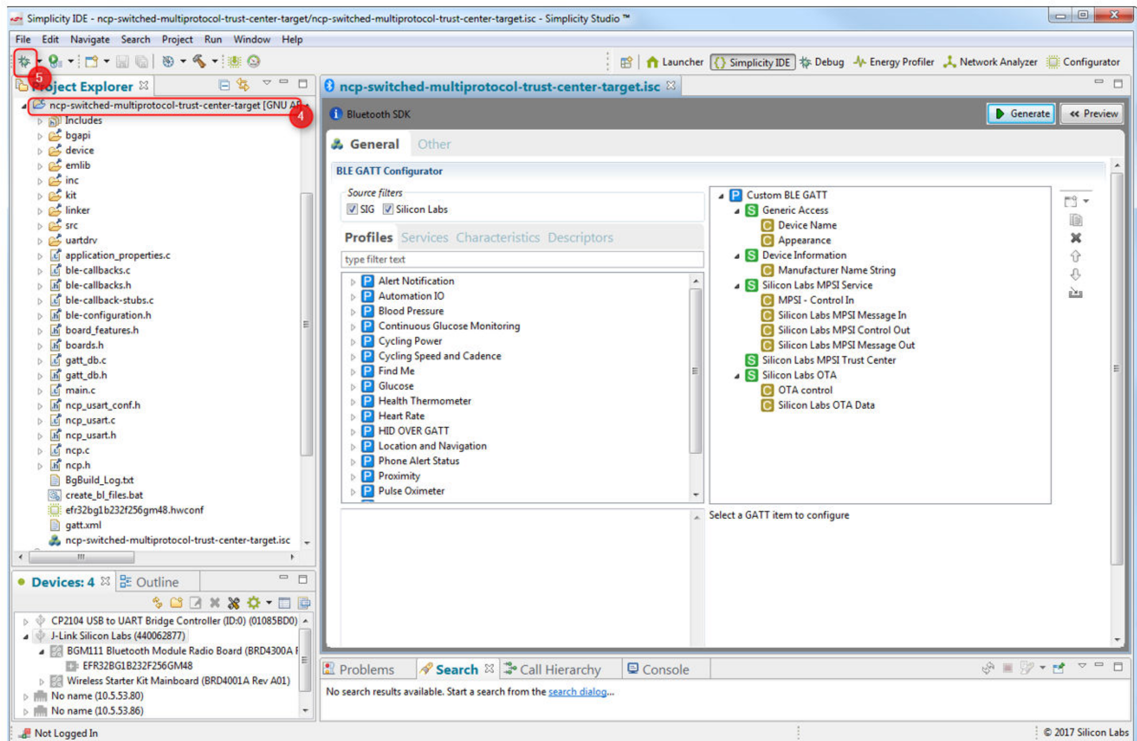
The test system needs three test devices (where a device is a WSTK + radio board). Each of them has to be flashed separately with the appropriate application image, according to section 8.1 Overview. As stated before, the Bluetooth and zigbee trust center applications must be running on the same host.

To flash the NCP target "NCP target – Switched Multiprotocol Trust Center":

1. Connect your device (WSTK + radio board), start Simplicity Studio, and select the device chosen to be the Trust Center.
2. Verify Bluetooth is installed in the Gecko SDK.
3. Click 'NCP target – Switched Multiprotocol Trust Center' in the Software Examples column.



4. The project is automatically created. Click on the project name in the Project Explorer.
5. Click the Debug button to build the application and download it to the device.



The NCP target image will be downloaded to the selected device. Now you can control the device from your PC.

To flash the "Switched Multiprotocol Joining Device" Bluetooth SoC application, follow the instructions in section 7. Implementing Switched Multiprotocol. Flash the Bluetooth application into the internal flash, or reboot from slot 0 after the zigbee application starts as described in section 7.7 Switching between Zigbee and Bluetooth Applications.

To flash an NCP image for the zigbee SwitchedMultiprotocolTrustCenter application, download to the target either a prebuilt or configured NCP binary. Prebuilt NCP images can be found in the EmberZNet installation folder. Configured NCP applications can be created using the xNCP framework in Studio.

In this example, the SwitchedMultiprotocolJoiningDevice is sent over OTA to the Joining Device and then booted.

8.3 Building Host Applications

The host application controlling the NCP target is provided as source code under

```
C:\SiliconLabs\SimplicityStudio\v4\developer\sdks\gecko_sdk_suite\v1.0\app\bluetooth_2.3\examples_ncp_host\switched_multipr
_trust_center
```

and

```
C:\SiliconLabs\SimplicityStudio\v4\developer\sdks\gecko_sdk_suite\v1.0\app\bluetooth_2.3\examples_ncp_host\switched_multipr
_mobile_app
```

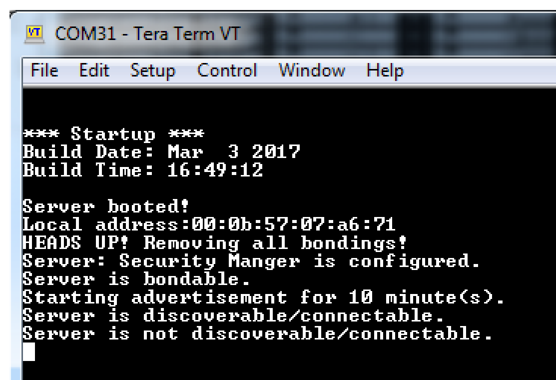
Either build the application on your Linux PC or Windows PC using Cygwin, for example, or on a Raspberry Pi by following the instructions:

1. Power on the Raspberry Pi, connect to it either with a keyboard/monitor or with SSH.
2. Copy the Bluetooth SDK directory (for example C:\SiliconLabs\SimplicityStudio\v4\developer\sdks\gecko_sdk_suite\v1.0\protocol\bluetooth_2.3\) to the Raspberry Pi (for example, ~/BLE/ble-sdk) either using a USB drive or SSH.
3. Browse to 'ble-sdk/app/bluetooth_dev/examples_ncp_host/switched_multipr_trust_center'.
4. Run 'make'.
5. The Trust Center host application should be built at this point.
6. The zigbee host image should be built on the same host by going into the Simplicity Studio project directory and running 'make.'

8.4 Running the Test Applications

8.4.1 Joining Device

The "Switched Multiprotocol Joining Device" Bluetooth application is a standalone application. After reset, the bootloader checks the application image, and then starts it. Connect to the WSTK with a USB cable. A new – virtual – COM port is shown among the available COM ports on your computer. Connect to it with a terminal application. The following should be seen after reset:



At this point you should see the device advertising itself as SLJDxxxx.

8.4.2 Trust Center

The trust center application needs an 'NCP target – Switched Multiprotocol Trust Center' application running on the radio board. After flashing it to the device the host application has to be started. The executable application can be found in:

```
ble-sdk/app/bluetooth_dev/examples_ncp_host/switched_multipr_trust_center/exe
```

Identify the communication port that is opened for the connected device (for example COM31 or /dev/ttyACMx). Run the application as follows:

```
./switched_multipr_trust_center COMport 115200
```

You should see the following in the command line:

```
$ ./switched_multipr_trust_center.exe COM31 115200
MPSI IPC error: failed to create or get message queue (errno 88)


*** Startup ***
Build Date: Mar  4 2017
Build Time: 21:02:59

Server booted!
Local address:00:0b:57:07:a6:71
HEADS UP! Removing all bondings!
Server: Security Manger is configured.
Server is bondable.
Starting advertisement for 10 minute(s).
Server is discoverable/connectable.
```

At this point you should see the device advertising itself as SLTCxxxx.

The trust center host applications (that is, Bluetooth and zigbee) communicate over inter-process communication (IPC). The MPSI IPC error shown above suggests that the application cannot create the necessary queue for this communication mechanism. This can happen if the application runs on a device that is not capable of handling the IPC mechanism such as Windows.

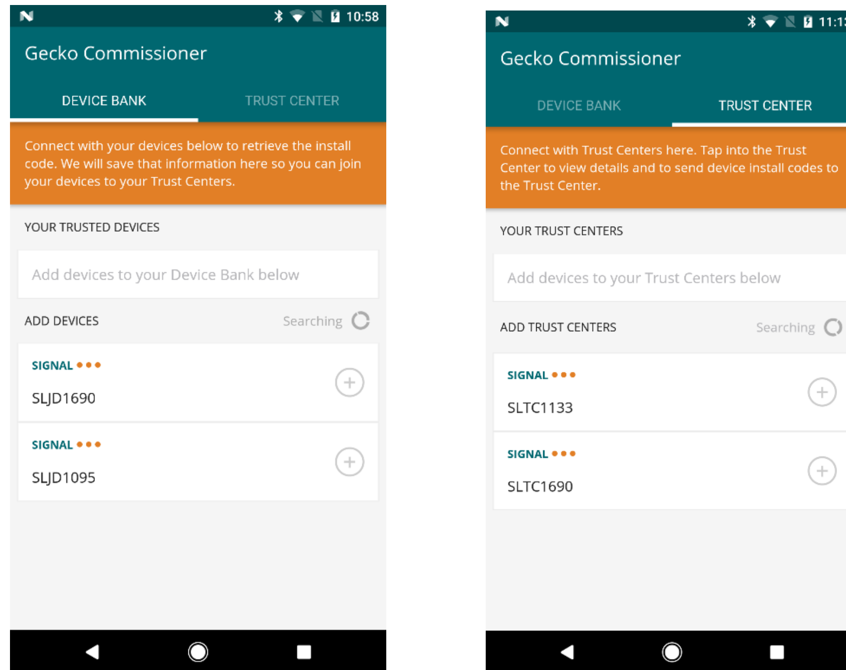
The zigbee trust center is started in a similar fashion. Once an appropriate NCP image is loaded onto the device and the host application is built, the host application can interface the NCP.

```
$ ./build/exe/SwitchedMultiprotocolTrustCenter -p /dev/ttyACM1
Reset info: 11 (SOFTWARE)
ezsp ver 0x05 stack type 0x02 stack ver. [0.0.0 Alpha 1 build 0]
Ezsp Config: set source route table size to 0x0007:Success: set
Ezsp Config: set security level to 0x0005:Success: set
Ezsp Config: set address table size to 0x0002:Success: set
Ezsp Config: set TC addr cache to 0x0002:Success: set
Ezsp Config: set stack profile to 0x0002:Success: set
Ezsp Config: set MAC indirect TX timeout to 0x1E00:Success: set
Ezsp Config: set max hops to 0x001E:Success: set
Ezsp Config: set tx power mode to 0x8000:Success: set
Ezsp Config: set supported networks to 0x0001:Success: set
Ezsp Policy: set binding modify to allow for valid endpoints
EMBER_NETWORK_UP 0x0000
SwitchedMultiprotocolTrustCenter>
```

8.4.3 Mobile App

The only configuration necessary is to install the Mobile Application onto a target device.

The Mobile App scans Bluetooth beacons and shows two sets of devices. Joining devices are listed under the Device Bank tab, while Trust Centers are shown under the Trust Center tab.



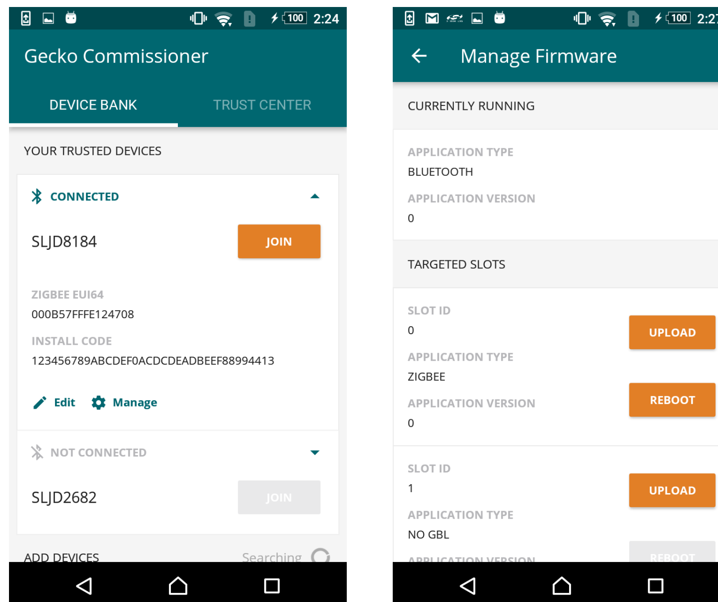
In order to connect to the Joining Device, tap the plus sign next to a discovered device. The mobile application will try to bond to the device. The Joining Device must confirm the bonding, by first accepting the connection and then verifying the passkey.

Similarly for the Trust Center, from the Mobile App, identify the Trust Center of interest and tap the plus sign to begin bonding. The Trust Center should then confirm the bonding and the passkey.

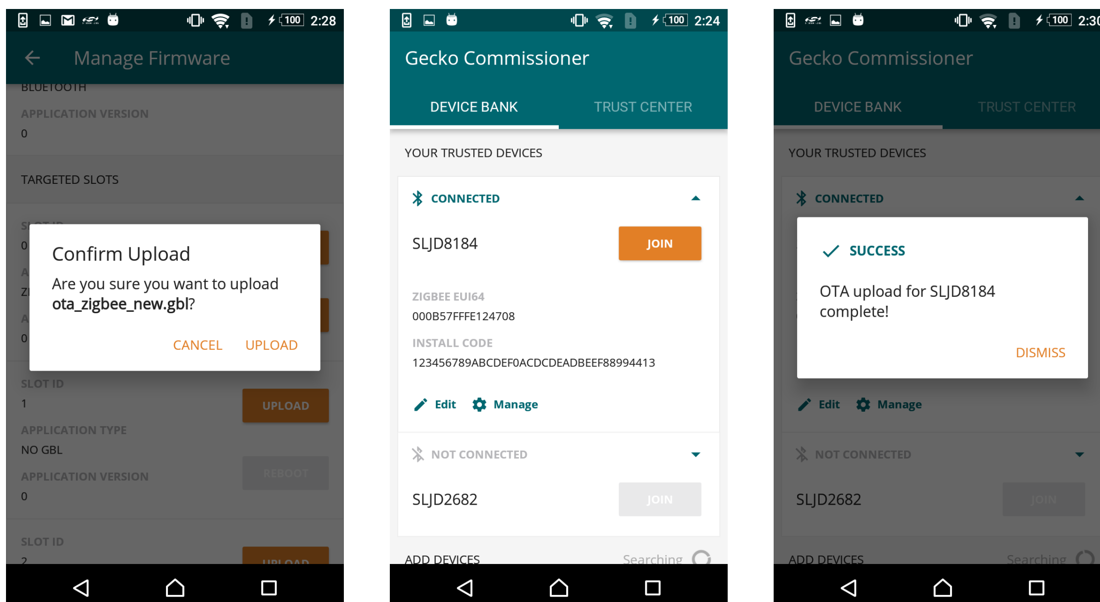
8.5 OTA File Upload

Using the Mobile App, an image can be streamed to a target device over the OTA process.

The user begins by connecting to a joining device, and then tapping [**Manage**]. A new screen is presented that shows the number of slots on the target device and what images, if any, are present.



After tapping [**Upload**], the user is instructed to choose a file for upload. Once the file is chosen, the user is prompted to confirm. Upon confirmation, the OTA process begins. A progress bar below the target device on the Device Bank tab shows current OTA progress. During the OTA process, management of the device is restricted.

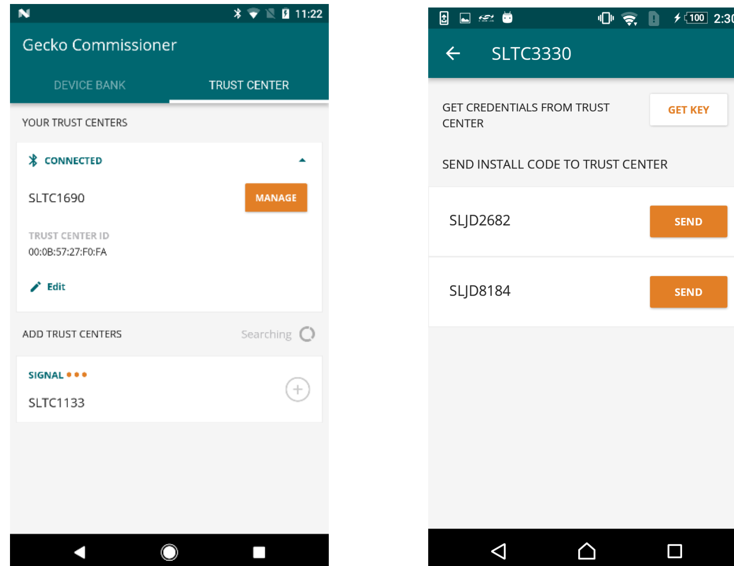


8.6 Commissioning

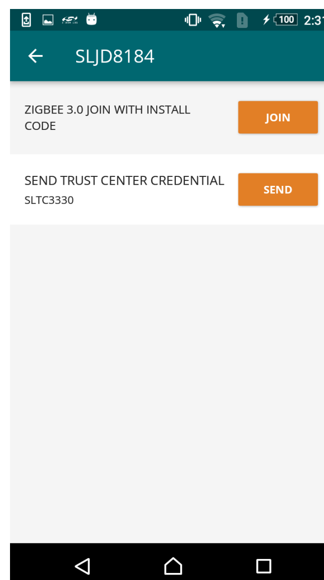
Once the Mobile App is connected to the Trust Center and to the Joining device, the three devices are able to communicate with MPSI messages. Transactions over MPSI can be initiated by tapping appropriate controls on the Mobile App.

Method 1: Having the Joining Devices send their install codes to the Trust Center

- Tap [**Manage**] next to a Trust Center. Identify a Joining Device and then tap [**Send**]. This fetches the zigbee install code from the Joining Device and relays it to the Trust Center. It then instructs the Trust Center to open the network for joining.



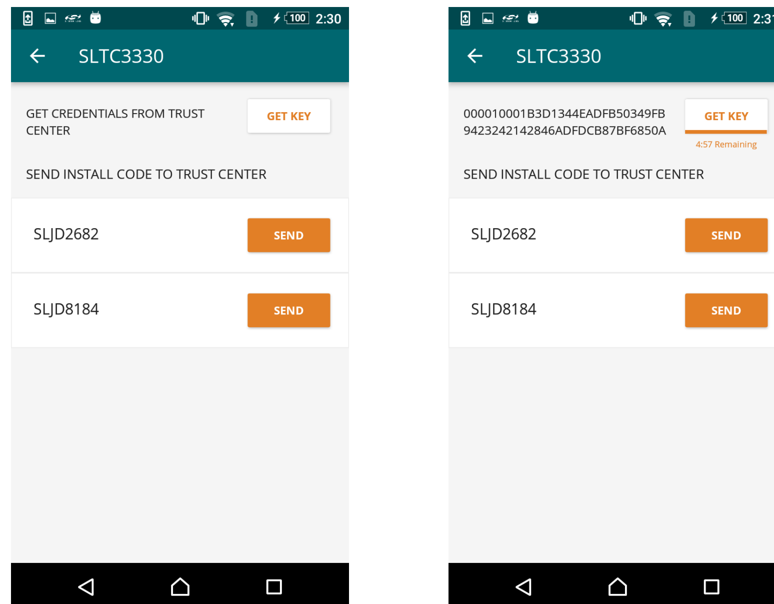
- Tap [**Manage**] next to a Joining Device. Tapping [**Join**] will cause the Joining Device to boot into zigbee and initiate joining using its install code.



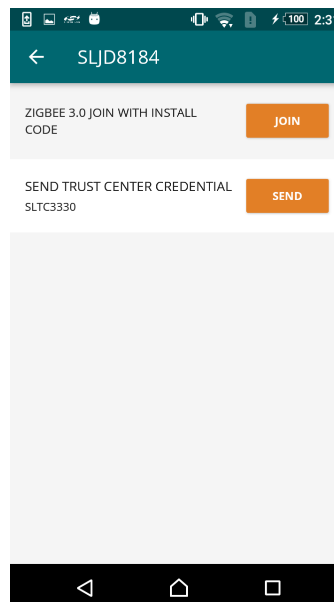
After rebooting the Joining Device in zigbee mode, the zigbee application finds the "initiate joining" MPSI message stored in the flash, and executes it. The Trust Center is already prepared to allow the device to connect to the zigbee network.

Method 2: Having the Trust Center generate and send network credentials to the Joining Devices

- Tap [**Manage**] next to a Trust Center. Tapping [**Get Key**] will cause the Trust Center to generate a random joining key that any device can use to join the network. The MPSI response that the Trust Center sends to the Mobile App also contains the current network's channel mask and zigbee extended PAN ID, so that the Joining Device can use them when scanning for networks. The key returned has a timer of five minutes, which the Mobile App displays in a timer after the user taps [**Get Key**].



- Tap [**Manage**] next to a Joining Device. Tap [**Send**] to relay the previously-retrieved Trust Center joining credentials to the Joining Device. The Joining Device will then reboot and attempt to join the network using the supplied joining credentials.



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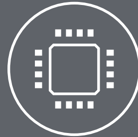

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