USER'S GUIDE

AMOTA Example

Ultra-Low Power Apollo SoC Family

A-SOCAP3-UGGA04EN v1.3

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Revision History

Revision	Date	Description
0.1	December 20, 2016	Draft created
0.2	December 30, 2016	Added OTA profile and app description
0.3	January 12, 2017	Add storage type definition
0.4	February 17, 2017	Added Apollo2 supported description
0.5	March 24, 2017	Updated according to setting changes
1.0	May 5, 2017	Created for AmbiqSuite SDK Re. 1.2.8
1.1	November 27, 2017	Created for AmbiqSuite SDK Rel 1.2.11
1.2	April 12, 2022	Updated template
1.3	January 3, 2023	Updated document part number

Reference Documents

Document ID	Description

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SECTION

1

Introduction

This document describes the firmware Over-The-Air (OTA) update example using Bluetooth Low Energy 4.2 for Apollo[1] and Apollo2 series SoCs as well as the firmware running inside of the HCI controller. The example project consists of the following parts to complete the function:

- Program running on the Apollo/Apollo2 series SoCs.
  - AMOTA Application (freertos_amota)
  - Bootloader (exactle_fit_amota_multi_boot)
  - OTA Bluetooth Low Energy Service (amota)
  - Bluetooth Low Energy stack (Arm Cordio BTLE Stack)
- Firmware running on Bluetooth Low Energy HCI controller device (EM9304)
- Smartphone APP on iOS or Android system. (OTA Demo)
- akefile to generate binary files for APP to load.

The purpose of the example is to provide a reference for firmware update of the SoC and the HCI controller over Bluetooth Low Energy communication while the application is still running. Data transfer is in background operation of the application and can be paused and resumed during the progress. Data being transferred is verified by each communication package as well as a whole image once the transfer is complete. Data received can be stored either inside the empty area of the internal flash (if there is enough space left in the internal flash of the SoC) or into the external serial flash. After the complete image is received and stored correctly, the system will keep operating from the existing firmware until a system reset is triggered. The new image will be loaded into the target internal flash by the bootloader after a system reset, and executed automatically if checked available.

[1] Apollo support will be provided as soon as EM9304 device is supported with the apollo1_evb.

SECTION

2

System Description

This section of the document describes the system of the OTA example project in general. The example is developed, compiled, and tested with Keil Arm compiler V5.17 and Eclipse Mars 1 Release.

2.1 Features

- Functions during OTA
  - Robust to communication disturbances.
    Continue update progress after re-connection.
  - Side-by-side firmware update.
    The system update progress is executed while application is running, providing a "silent update" experience to the end user.
- Proprietary OTA service on top of Bluetooth Low Energy stack.
  - RF IC always works in HCI controller mode and does not require image switching.
- High speed communication
  - Firmware data transfer at a speed of > 3KB / sec with iOS and Android.
    (Target version: iOS 10 and Android 6.0)
- Error handling
  - CRC checking is applied to each data packet received as well as to the whole image after the completion of the data transfer.
  - Packet will be requested to be re-transmitted by the central device (smartphone) if there is error happened during the communication.
- Firmware version information is transmitted and stored.
- Image storage

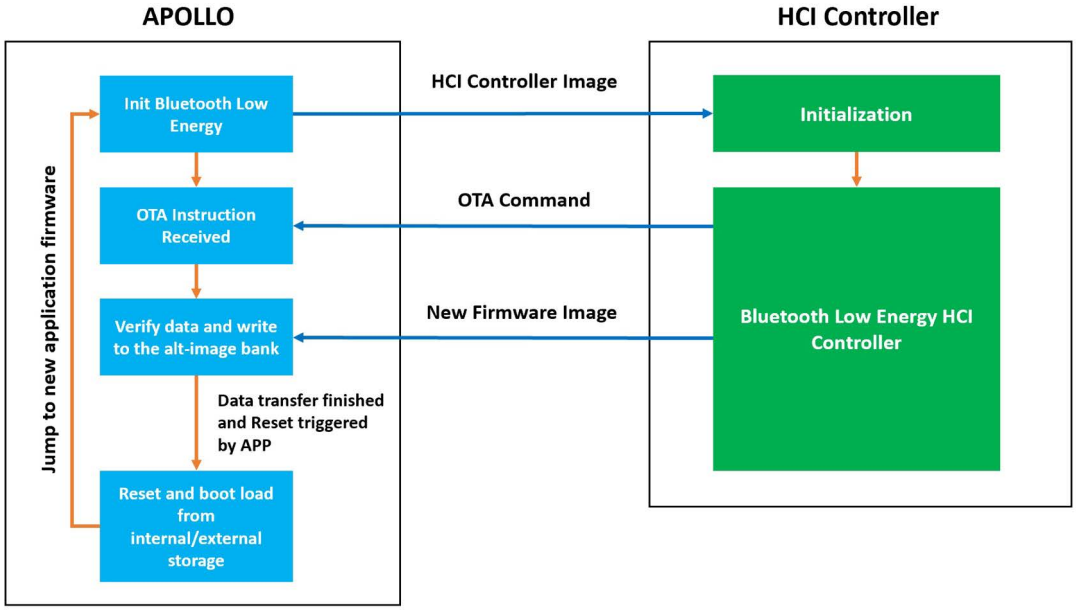
  - Image can be selected to be stored either in internal flash or external storage, enabling larger image size to be updated.
- Update of the Bluetooth Low Energy stack itself
  - Since the image is transferred as one entity containing the Bluetooth Low Energy stack as well as the OTA service itself, this OTA update flow allows user to update the Bluetooth Low Energy stack as well as the OTA service to be updated.
- Encrypted image data (extended feature)
  - Image being transferred and stored can be encrypted and decrypted during the boot process.
- Data type can be specified (extended feature)
  - Type of the data being transferred and stored can be specified as application firmware or plain data providing the possibility to update only the data arrays inside the firmware without updating the rest of the code.

Note: Extended features are not included in version 1.0 of the example project.

2.2 System Architecture and Operation Flow

A high-level system architecture and operation flow is illustrated in the diagram below:

Figure 2-1: System Architecture and Operation Flow



The Bluetooth Low Energy stack used in this example is the Arm Cordio BTLE stack (e.g., Wicentric Bluetooth Low Energy Stack, or exact LE Stack) software version 2.1. The upper layers (above and including HCI host layer) of the stack is running on the Apollo/Apollo2 series SoCs as a part of the application firmware. This leaves the

BTLE module working as a standard HCI controller. This architecture utilizes the ultra-low operating power feature of the Apollo/Apollo2 series SoCs for the Bluetooth Low Energy communication as much as possible to further reduce overall system power consumption, as well as providing a flexibility of choosing the external RF controller.

As the application firmware gets boots up, the lower level software driver will send the standard HCI controller image to the RF controller, and the Bluetooth Low Energy communication can be started once HCI controller and the stack are initialized.

Since the stack and the HCI controller static image are parts of the application firmware, they can be updated during the OTA progress.

For further information on the Arm Cordio BTLE stack, refer to the documents located in the directory of:
\AmbiqMicro\AmbiqSuite\third_party\exactle\docs\pdf

The example starts to broadcast with standard services (heart rate, device information and battery) once loaded. When a central device connects to the example device, AMOTA service can be discovered, and data transfer can be triggered according to the pre-defined meta data description. For more information of the AMOTA service, refer to *Section 2.5 AMOTA Service on page 16*.

During data transfer, application code can keep running. This example uses a binary counter that turns on and off the LED arrays on the Apollo/Apollo2 series SoCs EVB to indicate the operating status of the application code. Data received is stored into internal flash or external serial flash according to the user specification.

Once the data transfer is completed, the AMOTA service will update the flash flag page located at a fixed memory address (default: 0x3C00 for Apollo SoC and 0x4000 for Apollo2 SoC) to mark a valid new image is available for the bootloader to load. User can make the choice of whether to trigger a POI reset to the SoC or keep running the old application code.

After a system reset, bootloader checks the flash flag page information and loads the available new image into the target memory address. Once verification passes, the new image gets executed from the bootloader. For details about bootloader, check *Section 2.4 Bootloader and Flash Flag Page on page 13*.

2.3 SoC Memory Map

The SoC memory map is shown Figure 2-2.

Figure 2-2: Apollo SoC Memory Map

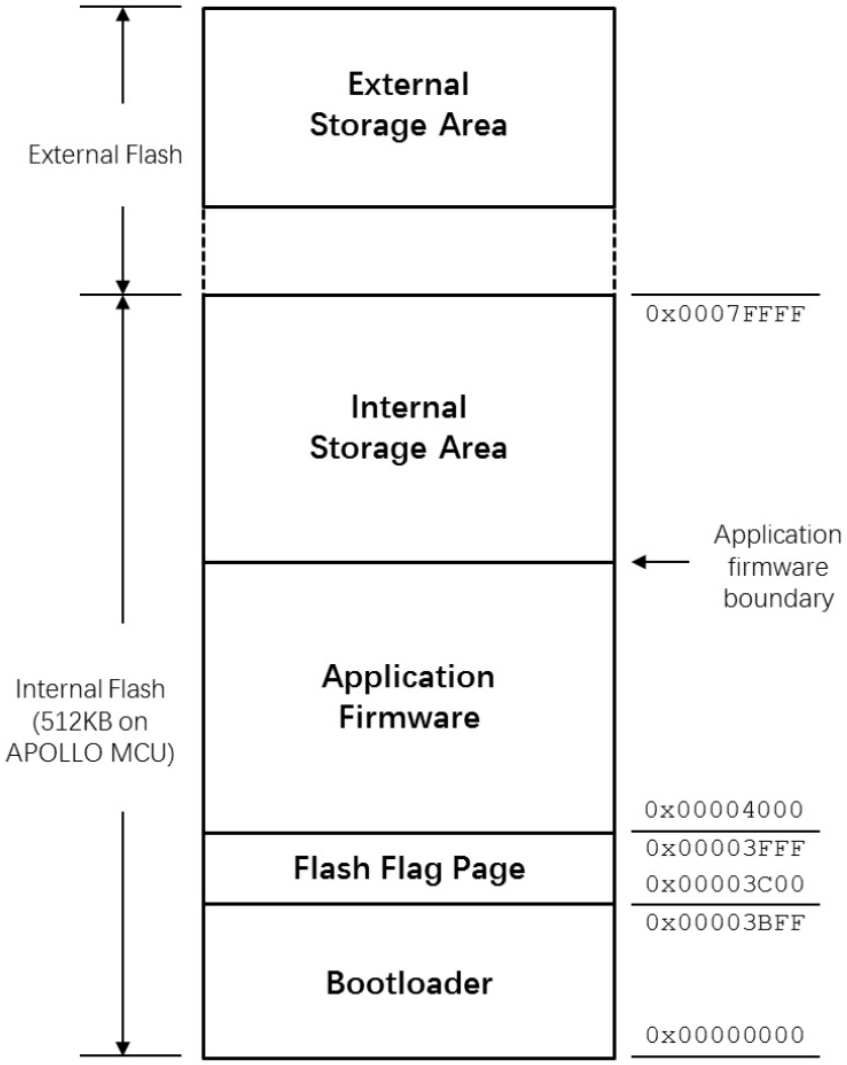
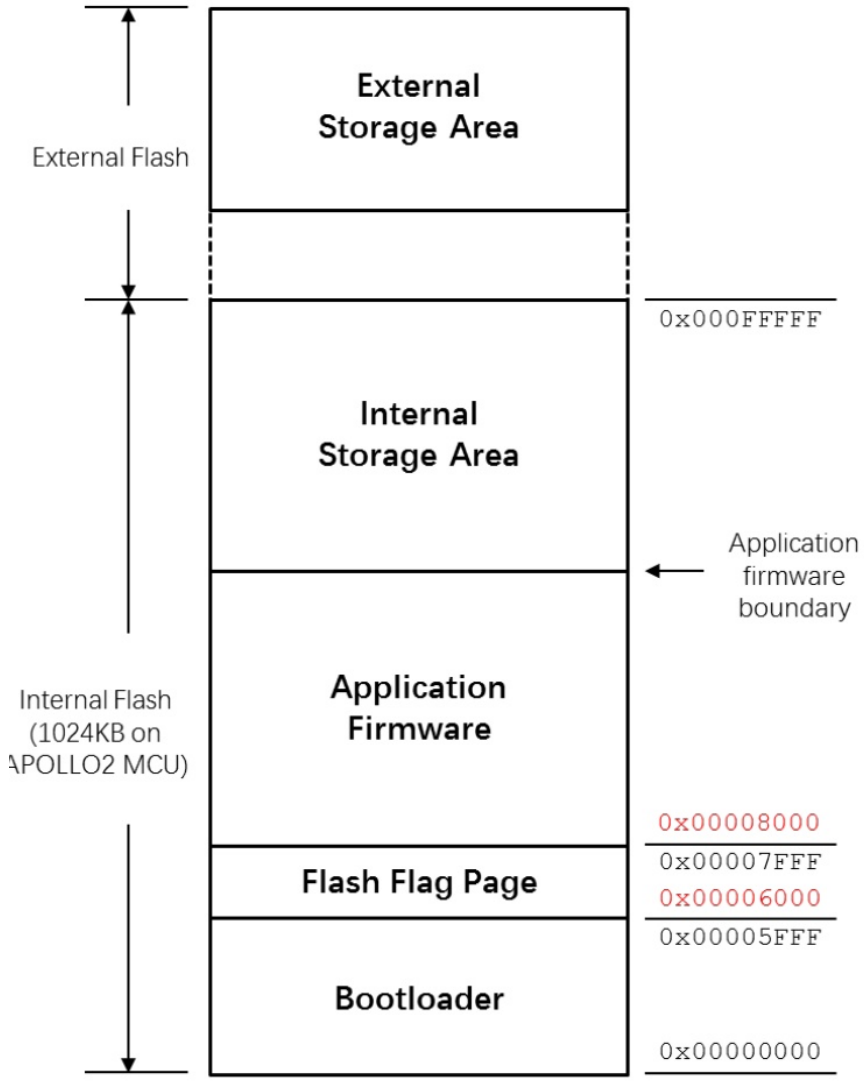


Figure 2-3: Apollo2 SoC Memory Map



Taking Apollo as example, the first 16K bytes of the internal flash is mapped to the bootloader (15K bytes) and flash flag page (1K bytes). By default, flash flag page is fixed starting from 0x3C00. Application firmware can be mapped right after the flash flag page starting from 0x4000 (default), or any other address above. Application firmware boundary is the end of the application code aligned with the internal flash page size (which is 2048 bytes for Apollo SoC). If the data received is to be stored inside the internal flash, user has to ensure that the space left inside the internal flash starting from the application firmware boundary is sufficient to hold the data. If not, it is recommended to store the data received inside the external storage device.

Checking the space left inside the internal flash is done by API provided along with the example project.

For above mentioned memory mapping, with Apollo2 SoC, the addresses are different due to the size of the flash page on Apollo2 is 8K bytes. For Apollo2, the default flash flag page starting address is mapped to 0x6000, and the application load starting address is mapped to 0x8000.

2.4 Bootloader and Flash Flag Page

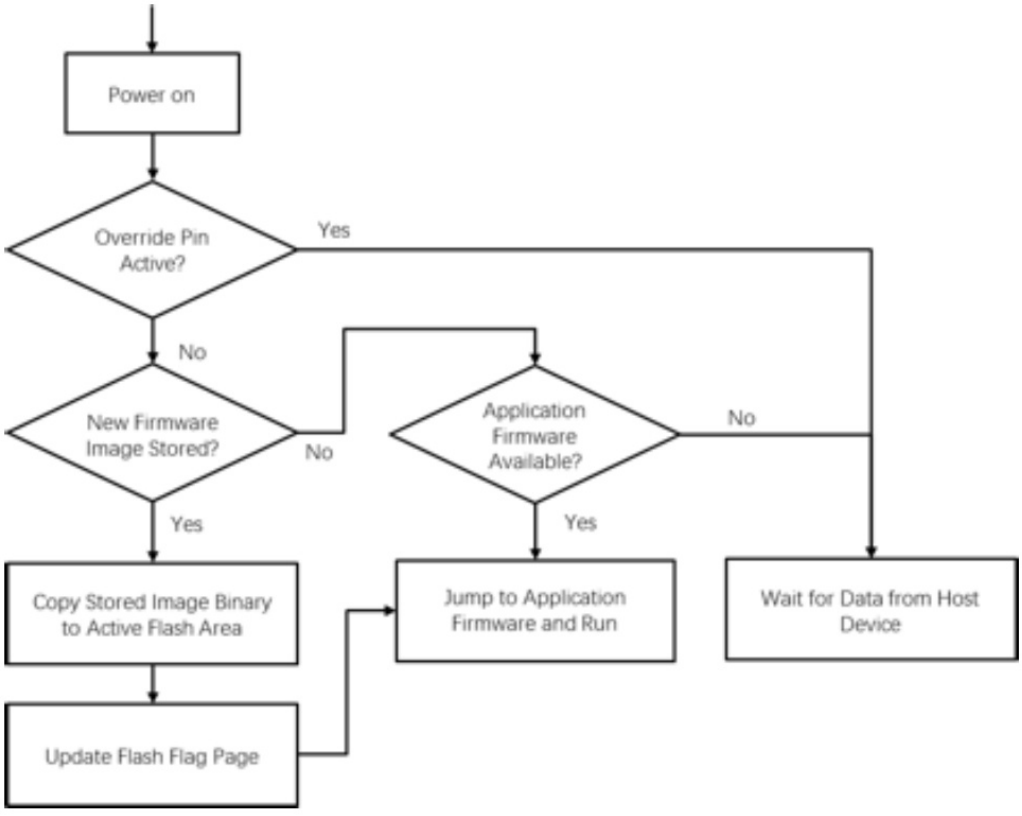
2.4.1 Bootloader

Bootloader of this example is built based on multi_boot example of the SDK. For more information of multi_boot, check MultiProtocolBootloader.pdf in the folder: **\AmbiqMicro\AmbiqSuite\docs\app_notes\bootloader**

This section only describes the modification made on multi_boot as well as the extended flash flag page settings.

The modified boot sequence is shown in Figure 2-4:

Figure 2-4: Boot Sequence



After checking the override pin, the bootloader checks the ui32Options flag stored in flash flag page (address offset 0x1C) to determine whether there is a new image stored in internal or external flash. If there is, the bootloader will first check the availability of the stored image by calculate and compare the CRC of the stored data with the CRC inside the flash flag page (ui32CRC, address offset 0x08), and load the image into the target link address (pui32LinkAddress, address offset 0x00) if the image is valid.

Storage type of the new image is specified by user when generating the OTA binary file. The smartphone APP is also able to set the target storage option.

Bootloader is a standalone project besides the application. It is located at:
`\Ambiqsuite\boards\apollo_evk_base\examples\multi_boot`

2.4.2 Flash Flag Page

This example project utilizes a modified flash flag page data structure which is shown in Table 2-1:

Table 2-1: Flash Flag Page

Symbol	Length (bytes)	Address Offset	Description
pui32LinkAddress	4	0x00	Starting address where the image was linked to run. This value shall not be small than 0x4000.
ui32NumBytes	4	0x04	Length of the executable image in bytes.
ui32CRC	4	0x08	CRC-32 Value for the full image.
ui32OverrideGPIO	4	0x0C	Override GPIO number. Can be used to force a new image load.
ui32OverridePolarity	4	0x10	Active polarity for the override pin. 0: Logic low; 1: Logic high If the selected GPIO input value matches active polarity, bootloader is forced to load new image from external host via serial communication.
pui32StackPointer	4	0x14	Stack pointer location. This value shall not be smaller than starting address of the internal SRAM.
pui32ResetVector	4	0x18	Reset vector location. This value shall not be smaller than pui32LinkAddress
ui32Options	4	0x1C	Boot Options. 0x01: New image available in internal flash. 0x02: New image available in external flash. Other: No new image available.
ui32Version	4	0x20	Version Information of the Current Image
ui32VersionNewImage	4	0x24	Version Information of the New Image (Not used in this example)

Table 2-1: Flash Flag Page *(Continued)*

Symbol	Length (bytes)	Address Offset	Description
pui32StorageAddressNewImage	4	0x28	Starting address where the new image was stored.
ui32TotalNumBytesNewImage	4	0x2C	Length of the new image being received in bytes. (Not used in this example)
ui32StoredNumBytesNewImage	4	0x30	Bytes already received and stored. (Not used in this example)
ui32CRCNewImage	4	0x34	CRC-32 Value for the new image being received. (Not used in this example)
bEncrypted	4	0x38	Use to determine whether the image is encrypted. 0: image is not encrypted. 1: image is encrypted

The flash flag page is by default located at 0x3C00 (0x4000 for Apollo2) of the internal flash, however it is possible for user to specify the start address of the flash flag page to the last page in the internal flash. E.g. 0x7F800 for a device with 512KB internal flash. This can be done by setting the following macro to 1.

Figure 2-5: Setting Macro at line 46

```
40 //*****************************************************************************
41 //
42 // Ignore the configured location, and use the last available flash page as the
43 // flag page.
44 //
45 //*****************************************************************************
46 #define USE_LAST_PAGE_FOR_FLAG              1
47
```

The macro is located at line 46 of **`..\AmbiqSuite\\boards\apollo_evk_base\examples\multi_boot\src\multi_boot_config.h`**.

After changing to this setting is made, both multi_boot and freertos_amota projects have to be re-built to work with the new setting.

NOTE: Using the last page of flash as the flash flag page will significantly increase the binary file size of the "combined" binary (boot + application + flash flag page information), due to the gap between the end of the application firmware and the flash flag page is filled with 0xFF in the binary file generated.

2.5 AMOTA Service

The following section describes the AMOTA service that is implemented in this example to perform the key function of the OTA process.

2.5.1 Service Declaration

The service UUID of Ambiq Micro OTA (AMOTA) service is defined as below:
`00002760-08C2-11E1-9073-0E8AC72E1001`

> **NOTE:** Base UUID of Bluetooth SIG is 00000000-0000-1000-8000-00805F9B34FB. All customized 128-bit UUIS should be less than base UUID.

2.5.2 Service Characteristics Definitions

Rx: 00002760-08C2-11E1-9073-0E8AC72E0001
Tx: 00002760-08C2-11E1-9073-0E8AC72E0002

Table 2-2: Characteristics

Characteristic	Requirements	Mandatory Properties	Security Permissions	Description
Characteristic Rx	M	Write	None	Data from client
Characteristic Rx User Description	N	Read	None	Value read by client
Characteristic Tx	M	Notify	None	Value notification to client
Characteristic Tx Client Characteristic Configuration descriptor	M	Read	None	Value notification configuration

2.5.3 Characteristics

The following characteristics are defined in the AMOTA Service. Only one instance of each characteristic is permitted within this service.

Table 2-3: Characteristics Defined in the AMOTA Service

Characteristic Name	Mandatory Properties	Security Permission
Received Data Characteristic	Write Command	None
Send Data Characteristic	Notify	None

Characteristic Descriptors:

Characteristic User Description. This characteristic descriptor defines the AM OTA version with read permission property.

Client Characteristic Configuration Descriptor:

The notification characteristic will start to notify if the value of the CCCD (Client Characteristic Configuration Descriptor) is set to 0x0001 by client. The send data characteristic will stop notifying if the value of the CCCD is set to 0x0000 by client.

2.5.4 Service Behaviors

The following are the service behaviors:

1. OTA client sends firmware header/meta info to server by amota packet format.
2. Server replies with received byte counters.
3. OTA client starts to send firmware data by amota packet format.
4. Server replies with received byte counters.
5. OTA client sends verify command to ask server to calculate the whole firmware checksum.
6. Server replies checksum result to client.
7. Client sends reset command to server (APP behavior).
8. Server sends reset command response to server before reset (APP behavior).

AMOTA Packet Format

Length: two bytes (data + checksum)
Cmd: 1 byte
Data: 0 ~ 512 bytes
Checksum: 4 bytes

Table 2-4: Partner Contact Information

Length	Command	Data	Checksum
Two bytes	1 byte	0 ~ 512 bytes	4 bytes

Commands:

```
/* amota commands */
typedef enum
{
   AMOTA_CMD_UNKNOWN,
   AMOTA_CMD_FW_HEADER,
   AMOTA_CMD_FW_DATA,
   AMOTA_CMD_FW_VERIFY,
   AMOTA_CMD_FW_RESET,
   AMOTA_CMD_MAX
}eAmotaCommand;
```

Firmware Header Information:
Amota packet header (two bytes length + 1 byte cmd)

amotaHeaderInfo_t

encrypted: 4 bytes
fwStartAddr: 4 bytes
fwLength: 4 bytes
fwCrc: 4 bytes
secInfoLen: 4 bytes
resvd1: 4 bytes
resvd2: 4 bytes
resvd3: 4 bytes
version: 4 bytes
fwDataType: 4 bytes
storageType: 4 bytes
resvd3: 4 bytes
Amota packet checksum (4 bytes)

Firmware Data Packet
Amota packet header (two bytes length + 1 byte cmd)
Data: 0 ~ 512 bytes
Amota packet checksum (4 bytes)

Firmware Verify Command
Amota packet header (two bytes length + 1 byte cmd)
Amota packet checksum (4 bytes)

Target Reset Command
Amota packet header (two bytes length + 1 byte cmd)
Amota packet checksum (4 bytes)

Command Response Format
Length: 2 bytes (data + status)
Cmd: 1 byte
Status: 1 byte
Data: 0 ~ 16 bytes

```
/* amota status */
typedef enum
{
   AMOTA_STATUS_SUCCESS,
   AMOTA_STATUS_CRC_ERROR,
   AMOTA_STATUS_INVALID_HEADER_INFO,
   AMOTA_STATUS_INVALID_PKT_LENGTH,
   AMOTA_STATUS_INSUFFICIENT_BUFFER,
   AMOTA_STATUS_INSUFFICIENT_FLASH,
   AMOTA_STATUS_UNKNOWN_ERROR,
   AMOTA_STATUS_FLASH_WRITE_ERROR,
   AMOTA_STATUS_MAX
}eAmotaStatus;
```

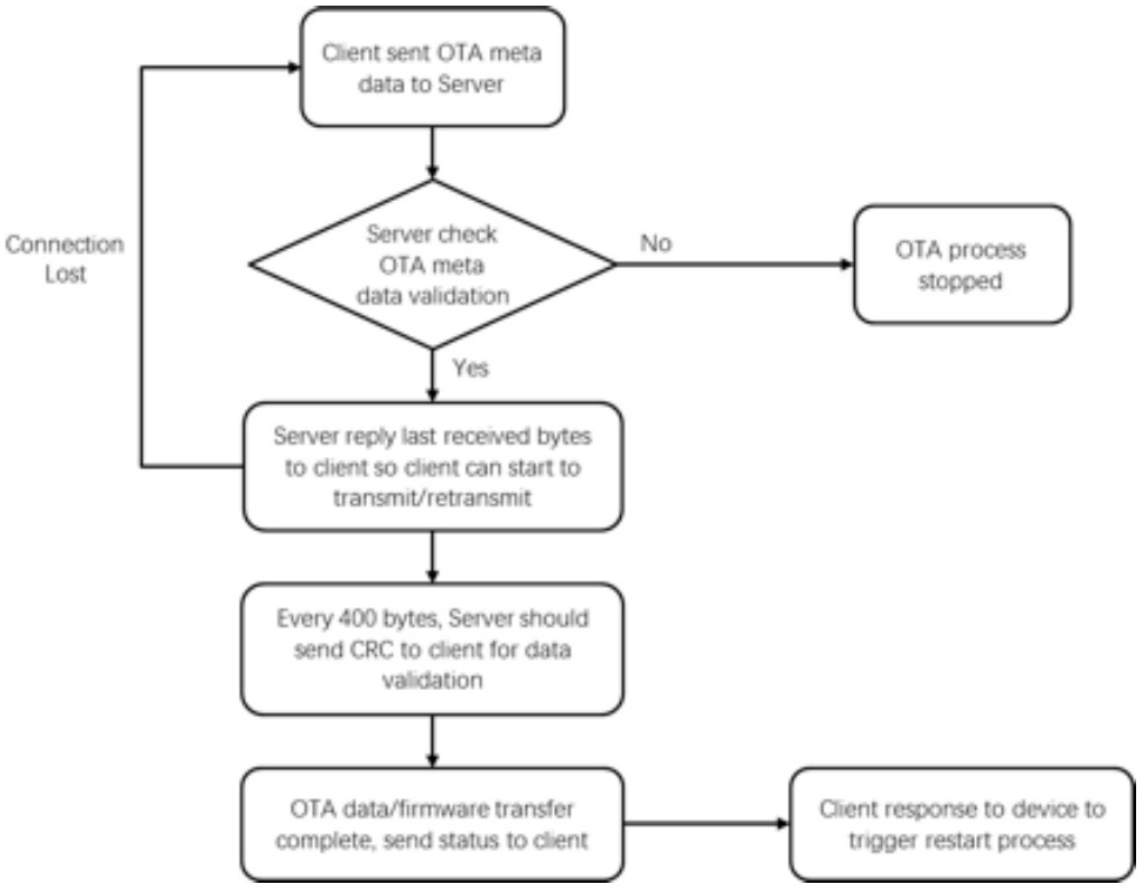
Firmware Header Info Response and Firmware Data Response

Amota packet header (two bytes length + 1 byte cmd)
Status: 1 byte
Received packet counter: 4 bytes

Firmware Verify and Target Reset Response

Amota packet header (two bytes length + 1 byte cmd)
Status: 1 byte

Figure 2-6: OTA Service Flow



- Create services
  - svc_amotas.c
  - svc_amotas.h
- Profile and OTA logic implementation
  - amotas_main.c
  - amotas_api.h
- Initialize in application
  - Set AmotasCfg_t

- Add AMOTAS_TX_CH_CCC_HDL in attsCccSet_t
- Register callback in FitStart()
  - SvcAmotasCbackRegister(NULL, amotas_write_cback);
- Add service in FitStart()
  - SvcAmotasAddGroup();
- Call amotas_proc_msg() in fitProcMsg() for event DM_CONN_OPEN_IND
- Add amotas_start() and amotas_stop() in function fitProcCccState()

SECTION

3

Getting Started

3.1 Folder Directory

The example project comes with the folder structure shown in Figure 3-1 and Figure 3-2 on page 22.

Figure 3-1: Folder Structure - Apollo2 OTA Example Project

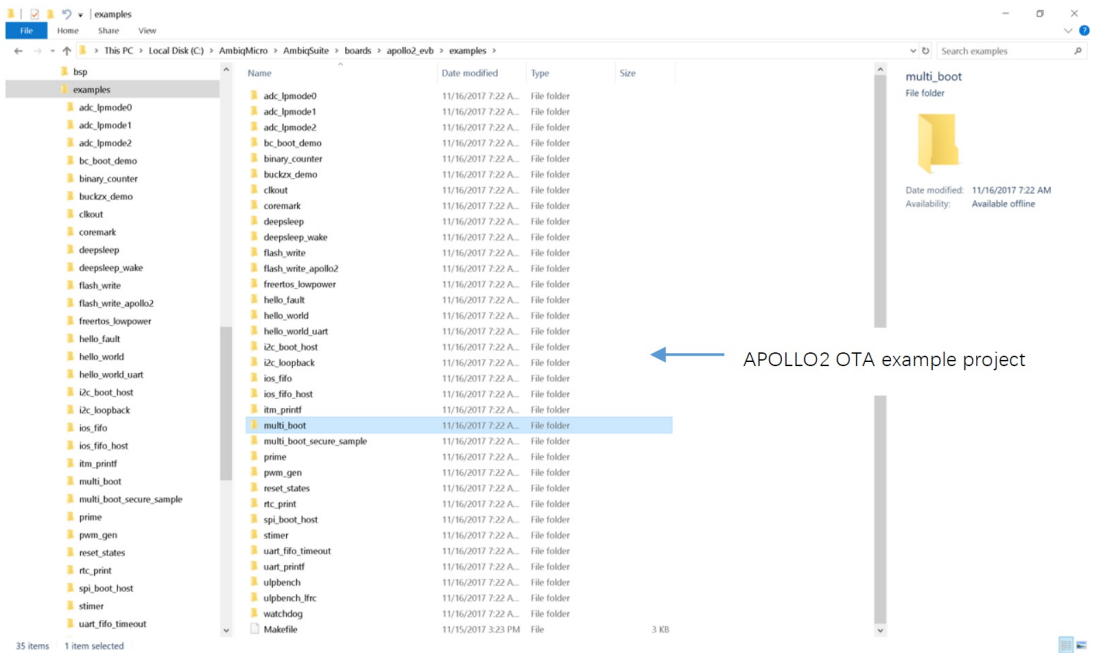
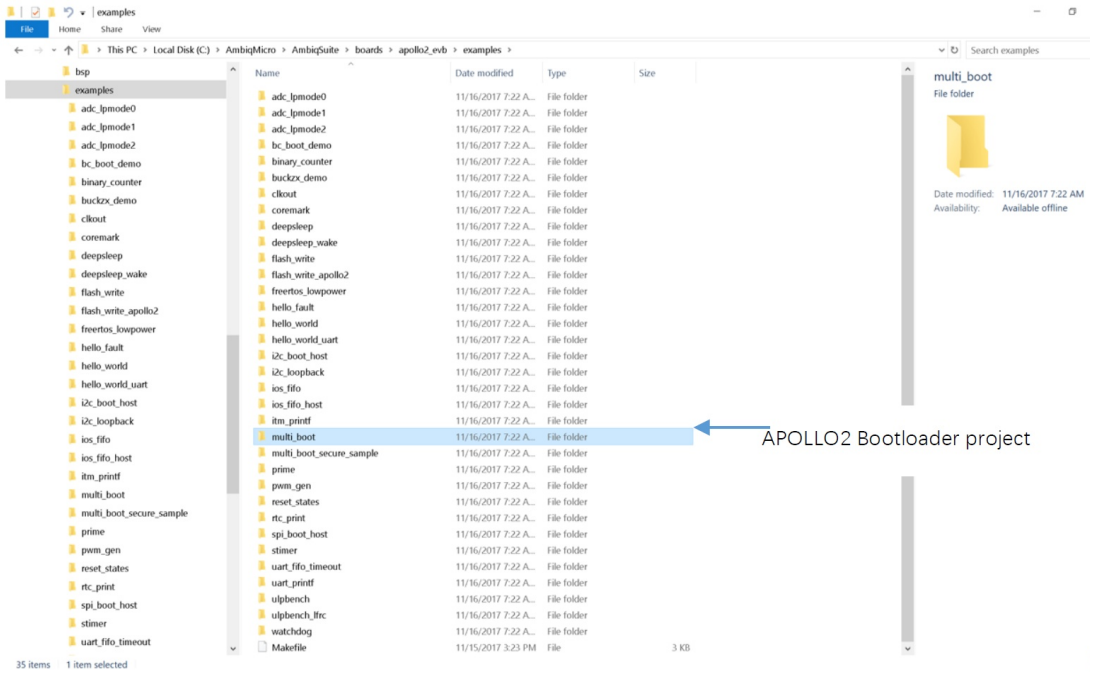


Figure 3-2: Folder Structure - Apollo2 Bootloader Project



3.2 Development Environment

- **Hardware**

  This example runs on APOLLO+EM9304 shield board and Apollo2 Blue EVB, make sure you have one available to run the example.

  For details of the EVKs, check:
  ..\AmbiqMicro\AmbiqSuite\docs\boards\apollo_evk\apollo_evk_users_guide.pdf.

  Otherwise, modifications need to be done according to the hardware setup in the BSP of both **exactle_fit_amota_multi_boot** and **freertos_amota** folders.

- **Software**

  – Install the latest AmbiqSuite.
  – Install Python 3.x to run the helper scripts for OTA binary file generation and combination.
  – Install Keil MDK-ARM Plus Version 5.20 or later for code generation and debug.

- **iOS:**

  – Install iTunes PC tool for iOS device APP installation and file sharing.
  – Visit our APP page on Apple AppStore at:
  https://itunes.apple.com/us/app/ambiqota/id1190453962?mt=8

Or simply search for "Ambiq OTA" in the AppStore to install.

- **Android:**
  - Install our Ambiq OTA app directly from the APK located at: **..\AmbiqMicro\AmbiqSuite\tools\amota**

3.3 Run the Example

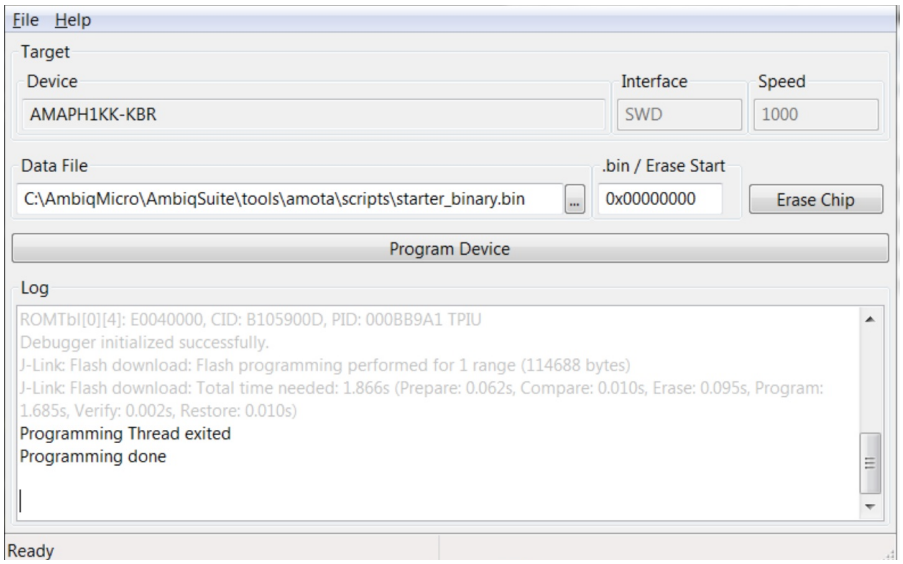
Use the following procedure to run the example:

1. Navigate to the **/AmbiqSuite/tools/amota/scripts** folder.
2. Run **make** in this folder.

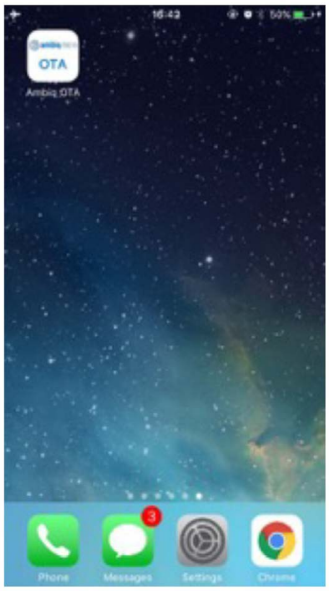
> **NOTE:** It will take a while to build all the required binaries for Apollo and Apollo2 Blue EVB.
>
> There are four binaries generated from the above step:
> - **starter_binary_apollo1.bin** - used to load into Apollo1 based board.
> - **starter_binary_apollo2_blue.bin** - used to load into Apollo2 Blue EVB.
> - **update_binary_apollo1.bin** - which must be uploaded into smartphone app to transfer it over the air to Apollo based EVB.
> - **update_binary_apollo2_blue.bin** - which must be uploaded into smartphone app to transfer it over the air to Apollo2 Blue EVB.

```
$ make
python3 bootloader_binary_combiner.py --bootbin "../../../boards/apollo2_evb_em9304/exampl
es/exactle_fit_amota_multi_boot/keil/bin/exactle_fit_amota_multi_boot.bin" --appbin "../..
/../boards/apollo2_evb_em9304/examples/freertos_amota/keil/bin/freertos_amota.bin" --flag-
addr 0x6000 --load-address 0x8000 -o starter_binary
boot_size  12868
pad_length  19900
load_address  0x8000 ( 32768 )
app_size  0x13dd0 ( 81360 )
crc =  0x4742cde0
python3 ota_binary_converter.py --appbin "./binary_counter.bin" --load-address 0x8000 -o u
pdate_binary
pad_length  48
load_address  0x8000 ( 0x8000 )
app_size  0x19e8 ( 6632 )
crc =  0x4147fa8d
app_ver 0 ( 0x0 )
bin_type 0 ( 0x0 )
str_type 0 ( 0x0 )
```

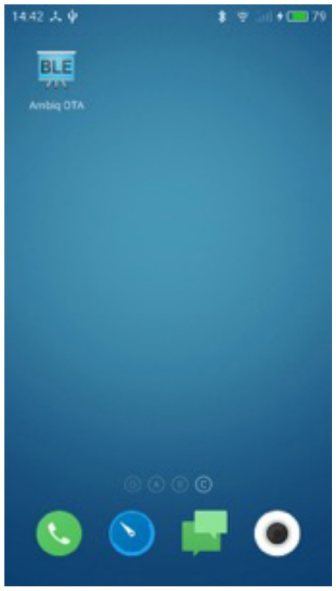
3. Load the **starter_binary_apollo1.bin** or **starter_binary_apollo2_blue.bin** into the target SoC using the J-Link Flash as follows:



4. Press the reset button to start the application.
5. Complete one of the following procedures:
   - **iOS** - Install the iOS APP from Apple AppStore by searching for Ambiq OTA. Once the APP is installed successfully, it will be shown on the home screen.
   - **Android** - Install the APK from the **..\tools\amota** folder. Once the APK is installed successfully, it will be shown on the home screen.



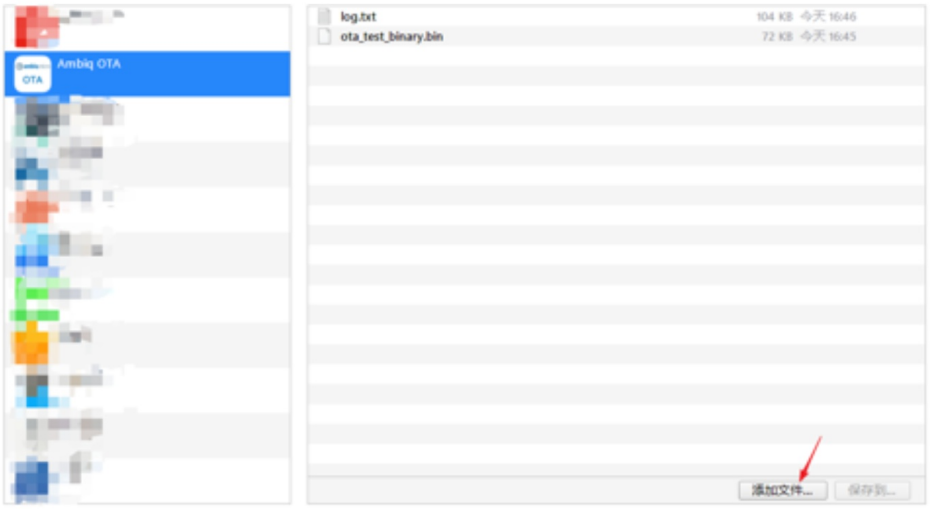
iOS



Android

6. Load the **update_binary_apollo1.bin** and **update_binary_apollo2_blue.bin** into the APP:

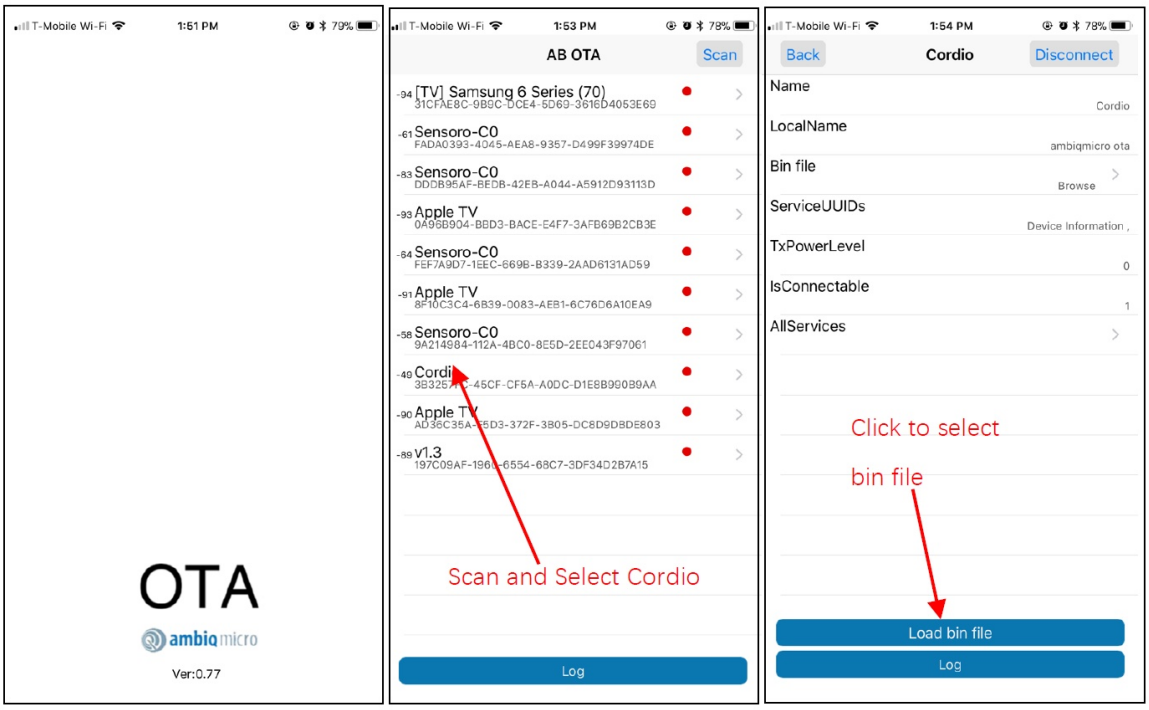
   - **iOS** - Connect the smart phone with PC, start iTunes and load the binary file into OTA APP. With iTunes.

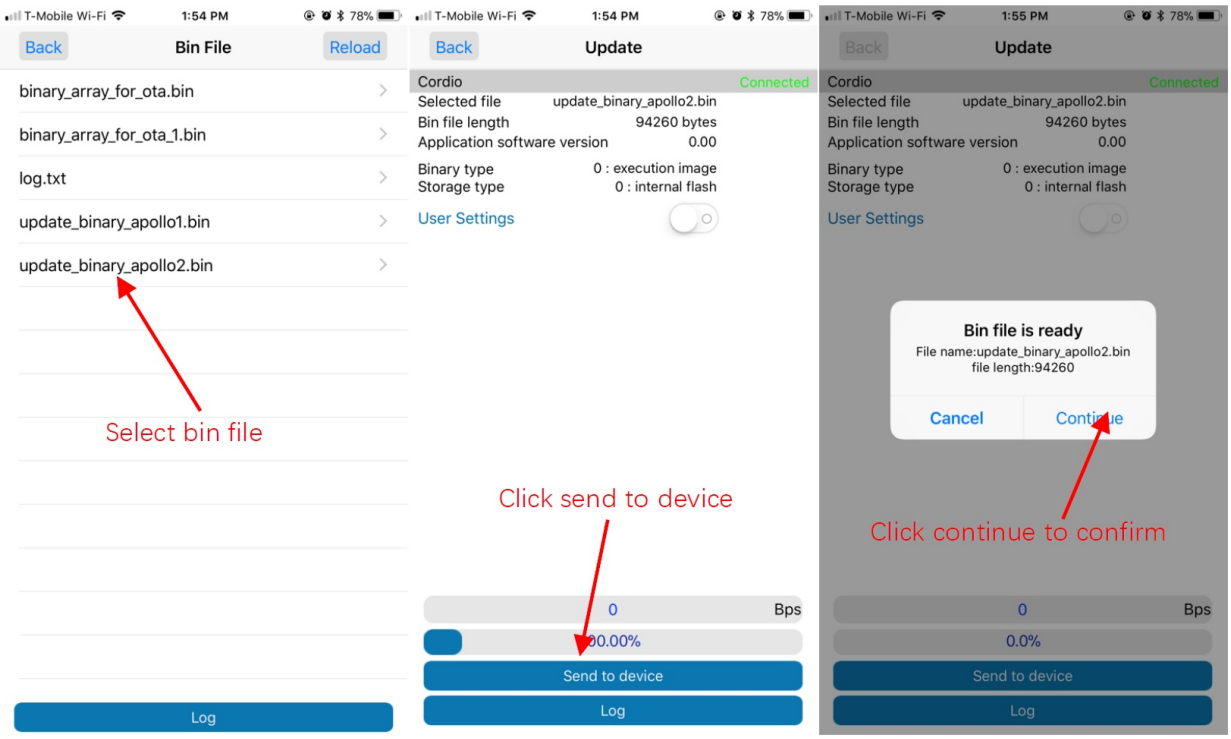


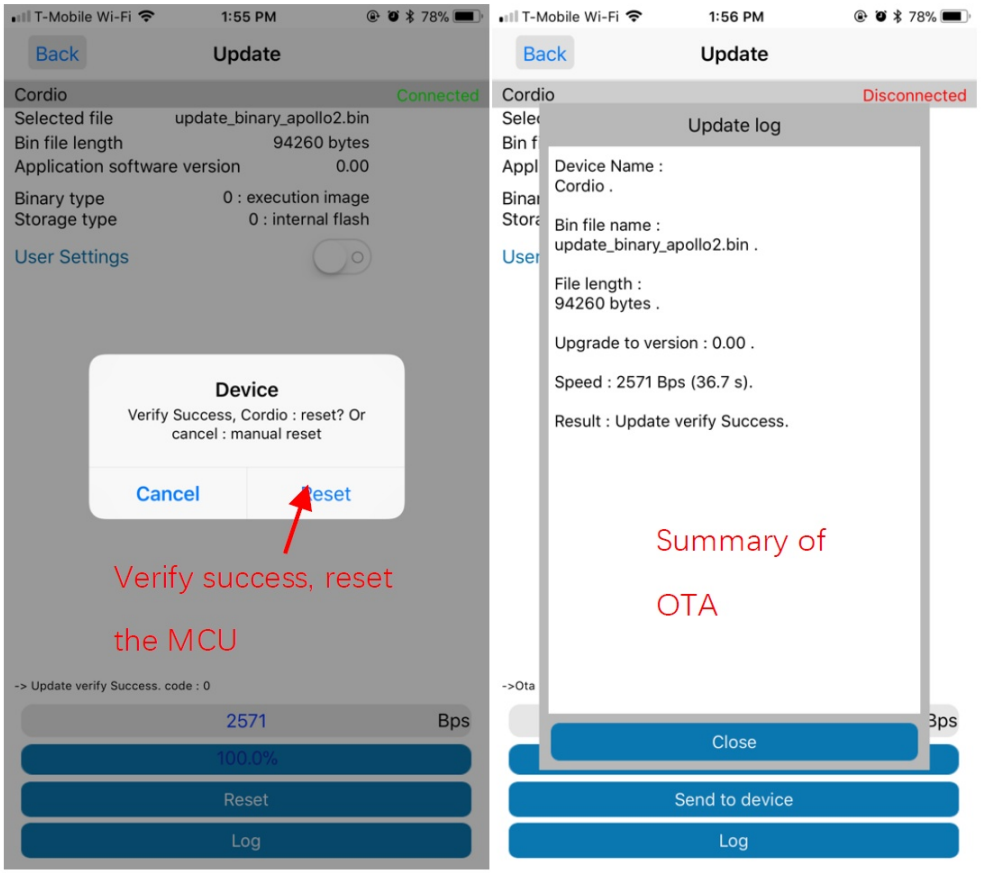
   - **Android** - Enable the USB storage media device when the smart phone is connected to PC and move the target binary file into any visible storage directory (e.g., **..\storage\emulated\0\Debug\ota_binary**).

7. Start OTA APP from smart phone and send the update_binary_apollo1.bin or update_binary_apollo2_blue.bin via Bluetooth Low Energy.

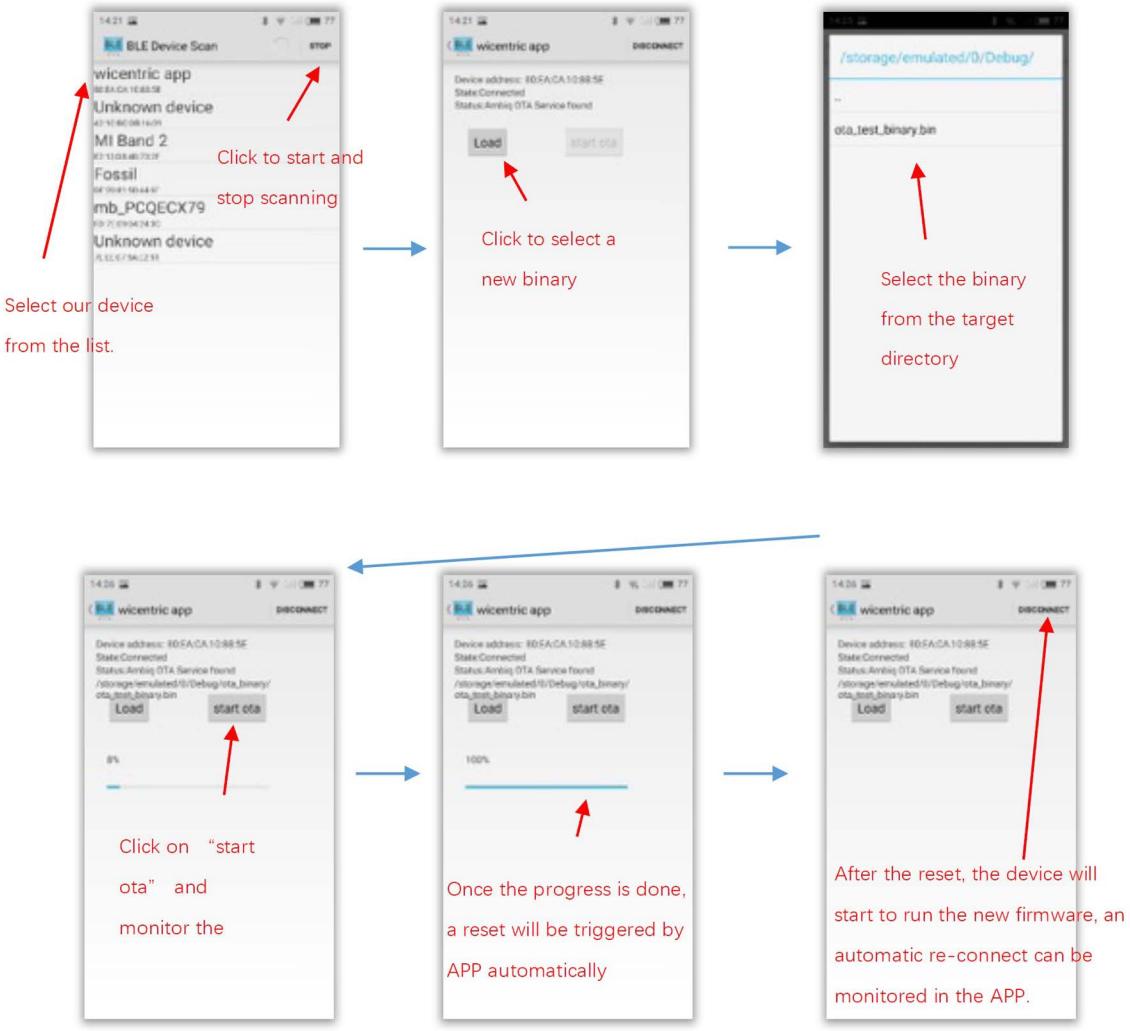
   - **With iOS**




Back
Bin File
Reload
binary_array_for_ota.bin
binary_array_for_ota_1.bin
log.txt
update_binary_apollo1.bin
update_binary_apollo2.bin
Select bin file
Log
Back
Update
Cordio
Connected
Selected file update_binary_apollo2.bin
Bin file length 94260 bytes
Application software version 0.00
Binary type 0 : execution image
Storage type 0 : internal flash
User Settings
Click send to device
0
Bps
0.00%
Send to device
Log
Bin file is ready
File name:update_binary_apollo2.bin
file length:94260
Cancel
Continue
Click continue to confirm
0.0%


Back
Update
Cordio
Connected
Selected file update_binary_apollo2.bin
Bin file length 94260 bytes
Application software version 0.00
Binary type 0 : execution image
Storage type 0 : internal flash
User Settings
Device
Verify Success, Cordio : reset? Or cancel : manual reset
Cancel
Reset
Verify success, reset the MCU
-> Update verify Success. code : 0
2571
Bps
100.0%
Reset
Log
Disconnected
Update log
Device Name : Cordio .
Bin file name : update_binary_apollo2.bin .
File length : 94260 bytes .
Upgrade to version : 0.00 .
Speed : 2571 Bps (36.7 s).
Result : Update verify Success.
Summary of OTA
Close
Send to device

- **With Android**



Once reset command is sent to SoC, the SoC resets and enters bootloader, it will take several seconds to load the new image into the flash.

After the new image is up and running, the LED array will blink the binary counter with a sub pattern, which indicates the operation is successfully done.

SECTION

4

Characteristics

4.1 For Apollo SoC

Table 4-1: Apollo SoC Characteristics

	Item	Typ.	Unit	Remark
Data Transfer Speed	Storage in internal flash	4.9	KB/s	with iOS App V0.51
	Storage in external flash	4.8	KB/s	with iOS App V0.51
Resource Consumption	Bootloader code size	10.27	KB	
	Bootloader RAM size	5.2	KB	
	Flash flag page	1	KB	224 bytes
	OTA project code size	89.70	KB	
	OTA project RAM size	7.27	KB	2KB stack
Execution Timing	Boot from internal flash	1.98	sec	89.70KB image
	Boot from external flash	2.45	sec	89.70KB image@8MHz
	Flash write to internal flash	4.8	msec	512bytes
	Flash write to external flash	6.4	msec	256bytes @ 8MHz

4.2 For Apollo2 Blue SoC

Table 4-2: Apollo2 Blue SoC Characteristics

	Item	Typ.	Unit	Remark
Data Transfer Speed	Storage in internal flash	4.9	KB/s	with iOS App V0.51
	Storage in external flash	3.4	KB/s	with iOS App V0.51
Resource Consumption	Bootloader code size	14.96	KB	
	Bootloader RAM size	17.60	KB	Buffer for 1 flash page
	Flash flag page	8	KB	224 bytes
	OTA project code size	89.85	KB	
	OTA project RAM size	7.8	KB	2KB stack
Execution Timing	Boot from internal flash	0.624	sec	91.32KB image
	Boot from external flash	1.01	sec	91.32KB image@8MHz
	Flash write to internal flash	1.8	msec	512bytes
	Flash write to external flash	4.1	sec	256bytes @ 8MHz

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