



INGCHIPS SDK User Guide

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Welcome

Welcome to use *INGCHIPS* 918xx/9186xx Software Development Kit.

INGCHIPS 918xxx/9186xx are BLE 5.x full feature SoC solutions. This manual will give you an in-depth view on BLE development with 918xx/9186xx from software perspective.

Chapter 1

Introduction

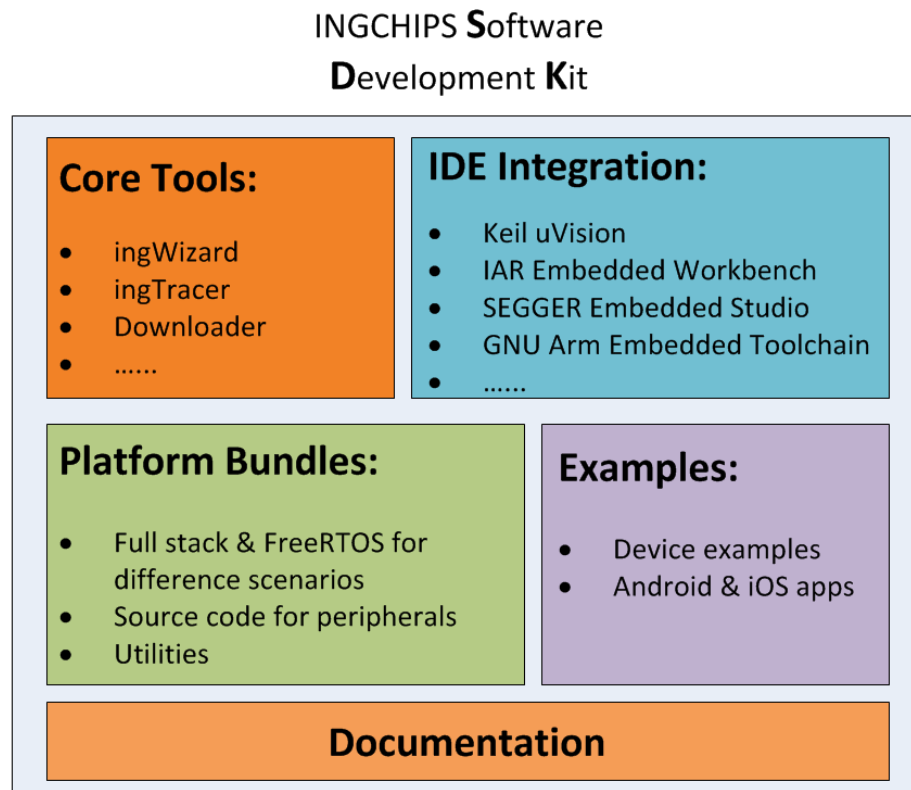


Figure 1.1: SDK Overview

INGCHIPS software development kit has following major components (see Figure 1.1):

1. Core Tools

Provide project wizard, flash loader and other functionalities. These tools make BLE development easy and seamless.

2. Language & IDE Integration

Support Keil μ Vision¹, IAR Embedded Workbench², Rowley Crossworks for ARM³, and SEGGER Embedded Studio for ARM⁴. All IDE/Toolchain settings are configured by core tools properly and automatically. GNU Arm Embedded Toolchain⁵ is also supported.

3. Platform Bundles

Provide different bundles for different application scenarios (such as typical, and extension). Each bundle contains full stack & (optional) FreeRTOS binary, and C header files. Source codes for accessing peripherals are also provided.

4. Examples

Provide a rich set of BLE device examples and corresponding Android and iOS referencing applications.

5. Documentation

User guide (this document), API reference, and application notes are also provided.

1.1 Scope

This document covers platform overall architecture, core tools and platform APIs.

1.2 Architecture

There are two variants of bundles, one with built-in FreeRTOS (RTOS Bundles), and one without built-in RTOS (“NoOS” Bundles).

1.2.1 RTOS Bundles

ING918xx/ING9186xx software architecture is shown in Figure 1.2. Bootloader is stored in ROM and can't be modified, while platform and app executable are stored in flash. Platform executable is provided for each bundle. BLE stack, FreeRTOS and some SoC functionality are compiled into this single platform executable. When system starts up, platform executable initializes, then loads the primary app executable.

A secondary app can only be asked to execute programmatically. It is possible to download several secondary apps, and to switch between them programmatically. After reset, platform will load the primary app executable as usual. Entry address of the primary app is managed by SDK tools, while entry addresses of secondary apps can be configured manually.

¹<https://www.keil.com/>

²<https://www.iar.com/iar-embedded-workbench/>

³<https://www.crossworks.com/index.htm/>

⁴<https://www.segger.com/products/development-tools/embedded-studio/>

⁵<https://developer.arm.com/open-source/gnu-toolchain/gnu-rm>

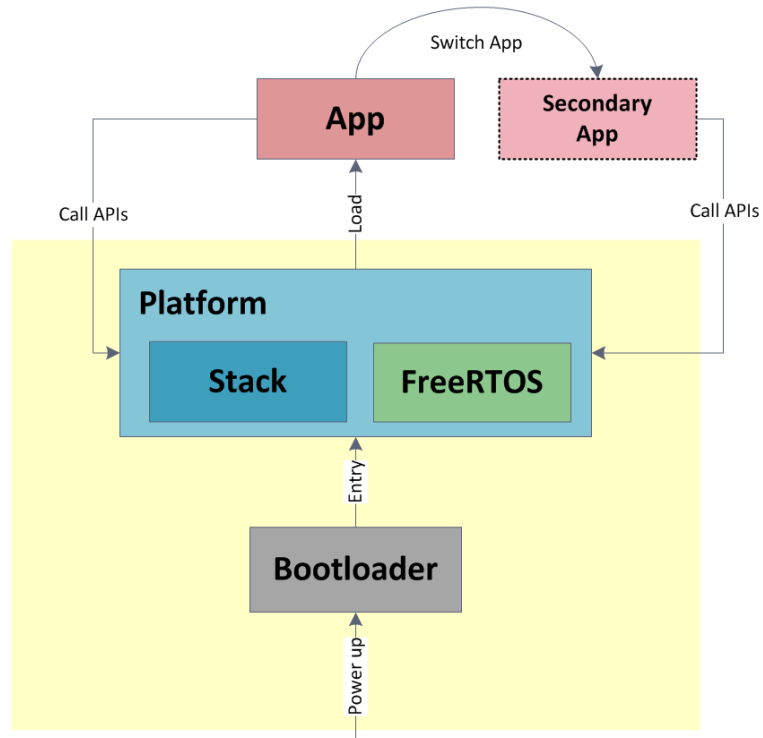


Figure 1.2: Architecture

1.2.1.1 Apps built with c

App executable's main function is named `app_main`, where app gets initialized:

```
int app_main(void)
{
    ...
    return 0;
}
```

`app_main` should always return 0.

Platform, BLE stack and FreeRTOS APIs are all declared in corresponding c header files. To use these APIs, just include the necessary header files.

1.2.1.2 Other Languages

Languages can also be used to build apps, for example:

- Rust⁶

⁶<https://ingchips.github.io/blog/2022-09-24-use-rust/>

- Nim⁷
- Zig⁸

1.2.2 “NoOS” Bundles

When developers want to use other RTOS, or use features that are missing in those RTOS bundles, developers can choose the “NoOS” bundles.

A generic RTOS interface is defined, and developers should provide an implementation of this interface to platform binaries through the returning value of `app_main`:

```
uintptr_t app_main(void)
{
    ...
    return (uintptr_t)os_impl_get_driver();
}
```

1.3 Abbreviations & Terminology

Table 1.1: Abbreviations

Abbreviation	Notes
ATT	Attribute Protocol
BLE	Bluetooth Low Energy
FOTA	Firmware Over-The-Air
IRQ	Interrupt Request
GAP	Generic Access Profile
GATT	Generic Attribute Profile
RAM	Random Access Memory
ROM	Read Only Memory
SDK	Software Development Kit

Table 1.2: Terminology

Terminology	Notes
Flash Memory	An electronic non-volatile computer storage medium

⁷SDK example: *Smart Home Hub*.

⁸SDK example: *Central FOTA*.

Terminology	Notes
FreeRTOS	A real-time operating system kernel

1.4 References

1. Host API Reference
2. Bluetooth SIG⁹
3. FreeRTOS¹⁰
4. Mastering the FreeRTOS™ Real Time Kernel¹¹

⁹<https://www.bluetooth.com/>

¹⁰<https://freertos.org>

¹¹https://www.freertos.org/Documentation/161204_Mastering_the_FreeRTOS_Real_Time_Kernel-A_Hands-On_Tutorial_Guide.pdf

Chapter 2

Tutorials

Following step-by-step tutorials show the basic usage of core tools and concepts of the SDK.

2.1 Hello World

In this tutorial, we are going to create a device which is advertising its name, “Hello, ”.

Start Wizard from start menu and select menu item Project -> New Project This brings up the project wizard. This first page shown by the wizard is Development Tool (see Figure 2.1).

2.1.1 Development Tool Page

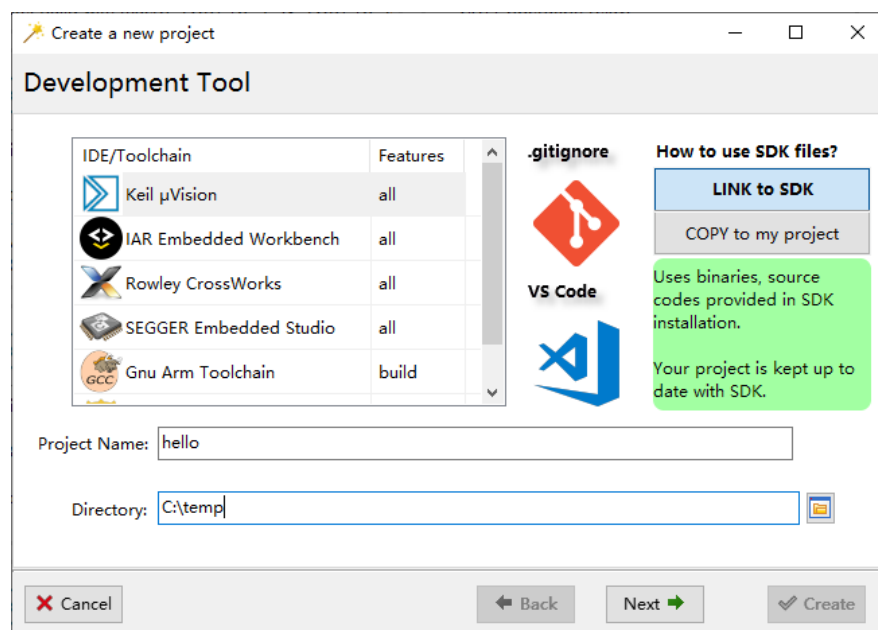


Figure 2.1: Choose Project Type

On this page (Figure 2.1):

1. Choose IDE/Toolchain
2. Choose a project name
3. Choose where to store your project

Wizard provides below handy functionality:

- If `Git` is used for software configuration management, select `Setup .gitignore`;
- If `Visual Studio Code` is the preferred code editor, select `Setup Visual Studio Code`.

Then press `Next` to proceed to the next page, `Choose Chip Series`.

2.1.2 Choose Chip Series Page

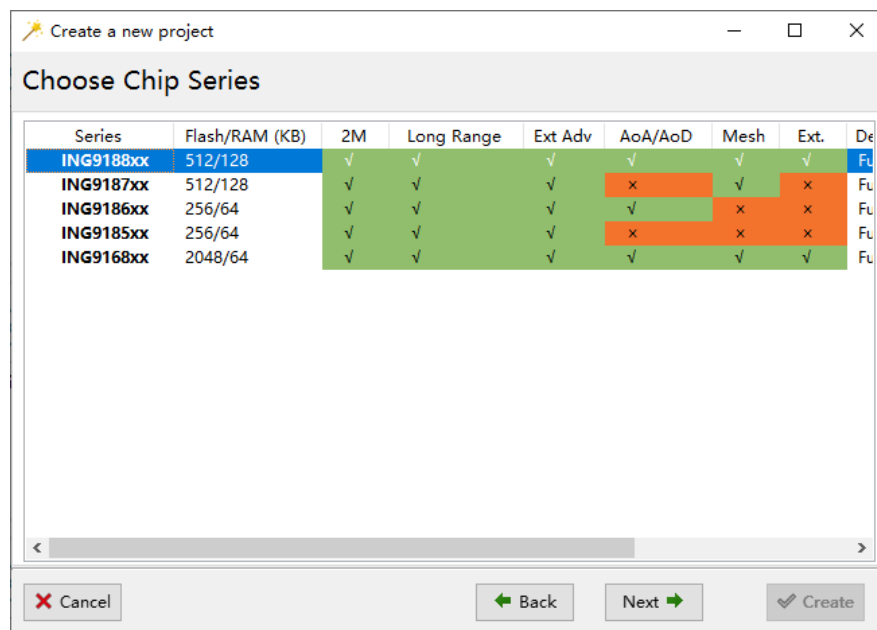


Figure 2.2: Choose Chip Series

On this page (Figure 2.2), choose the target chip series of the project. Then press `Next` to proceed to the next page, `Choose Project Type`.

2.1.3 Choose Project Type Page

On this page (Figure 2.3), select `Typical`.

Then press `Next` to proceed to the next page, `Role of Your Device`.

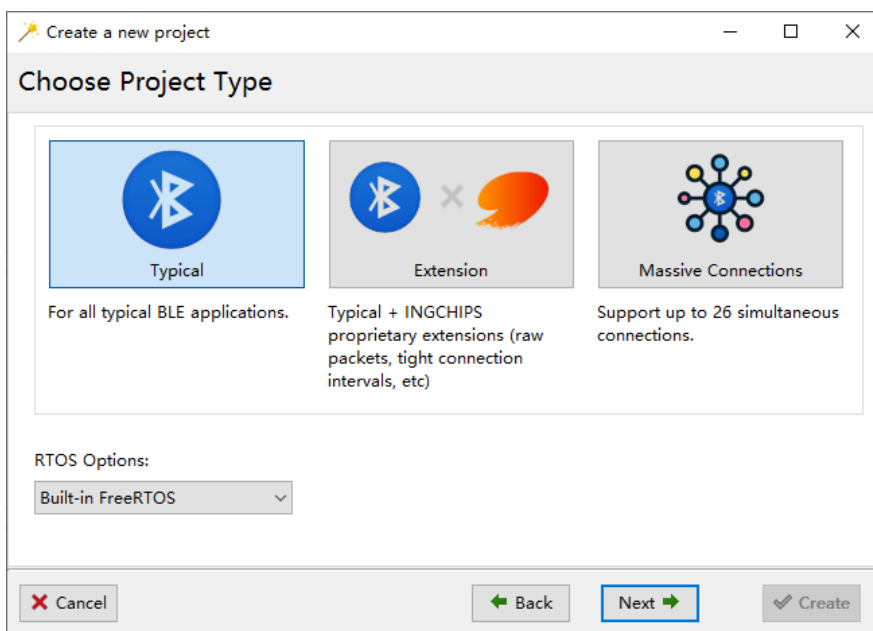


Figure 2.3: Choose Project Type

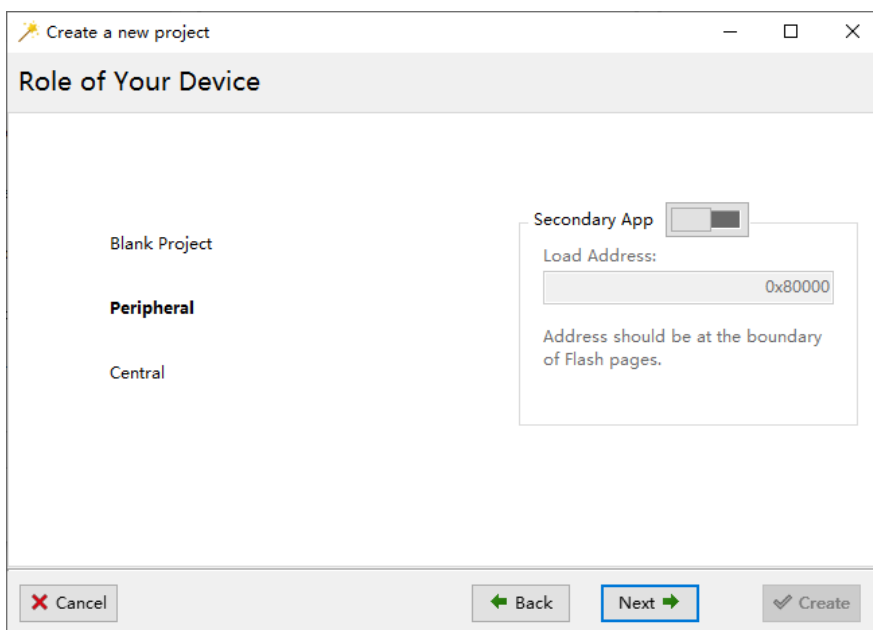


Figure 2.4: Role of Your Device

2.1.4 Role of Your Device Page

On this page (Figure 2.4), just select Peripheral, and press Next to proceed to the next page, Peripheral Setup.

2.1.5 Peripheral Setup Page

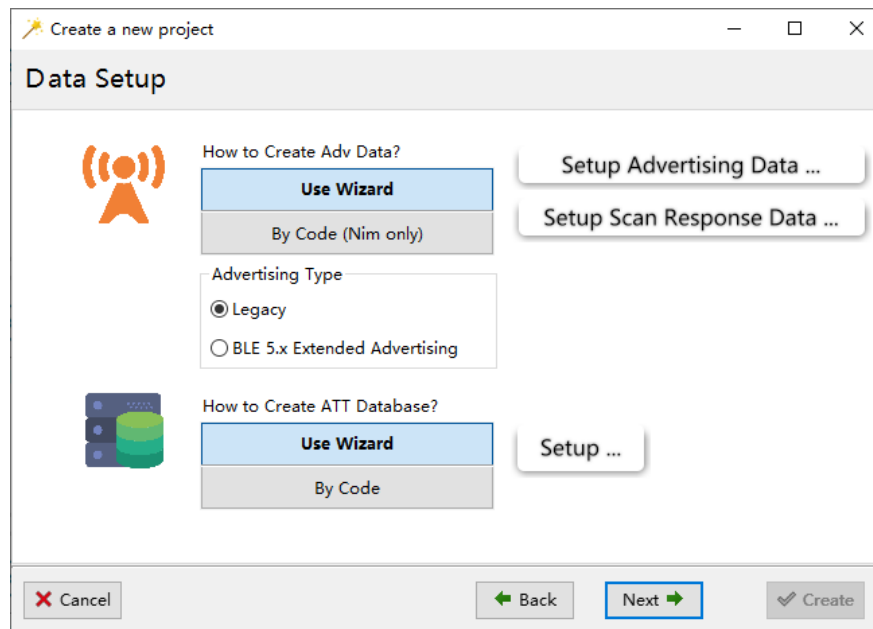


Figure 2.5: Peripheral Setup

On this page (Figure 2.5), select Legacy advertising.



Phones that support BLE 5.x extended advertising are still rare at present (`r Sys.Date()`) even if BLE 5.0 is declared as “supported”, so we use legacy advertising for better compatibility. Furthermore, legacy advertising can be changed to BLE 5.x extended advertising by toggling a single bit later.

Click Setup Advertising Data button, which will bring up the advertising data editor (Figure 2.6). In the editor, type name to quickly search for the GAP advertising item 09 - «Complete Local Name», and click Add to add it into our device’s advertising data.

Click the newly added 09 - «Complete Local Name» item, then fill in “Hello, ” in the data editor shown below and press Enter. Data Preview will be updated and the whole advertising data is shown in raw bytes with a few comments on each item. Obviously, Chinese characters are encoded in UTF-8 properly.

Now, click OK to go back to project wizard, and press Next to proceed to the next page Security & Privacy.

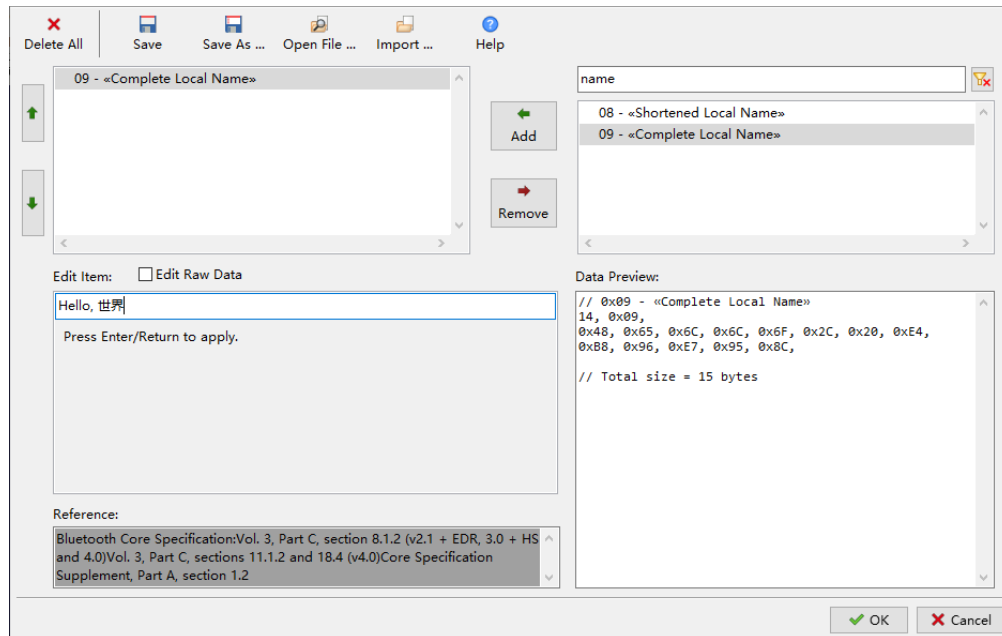


Figure 2.6: Edit Advertising Data

2.1.6 Security & Privacy Page

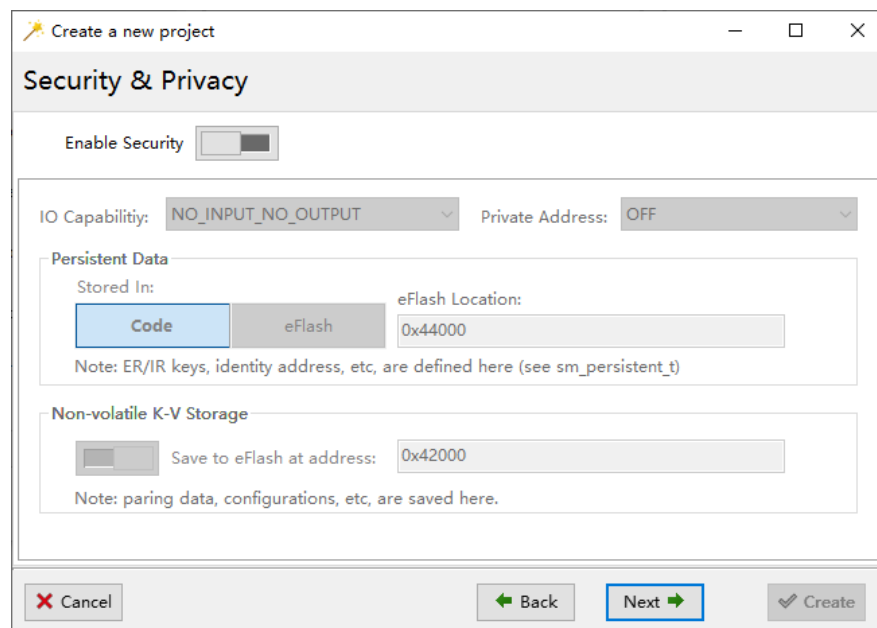


Figure 2.7: Firmare Over-The-Air

Leave all options as default (Figure 2.7), and press Next to proceed to the next page Firmare Over-The-Air.

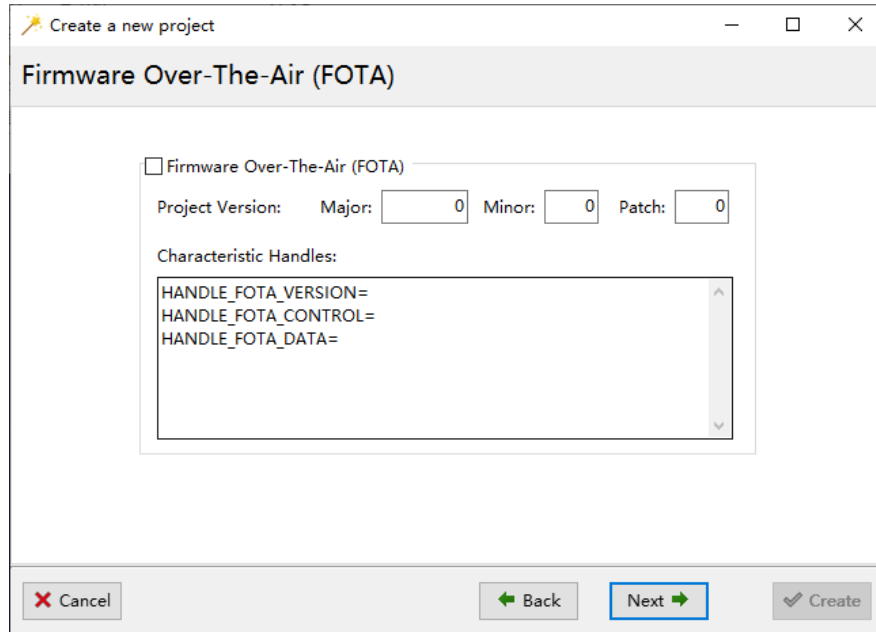


Figure 2.8: Firmare Over-The-Air

2.1.7 Firmare Over-The-Air Page

Leave all options as default (Figure 2.8), and press Next to proceed to the last page Common Functions.

2.1.8 Common Functions Page

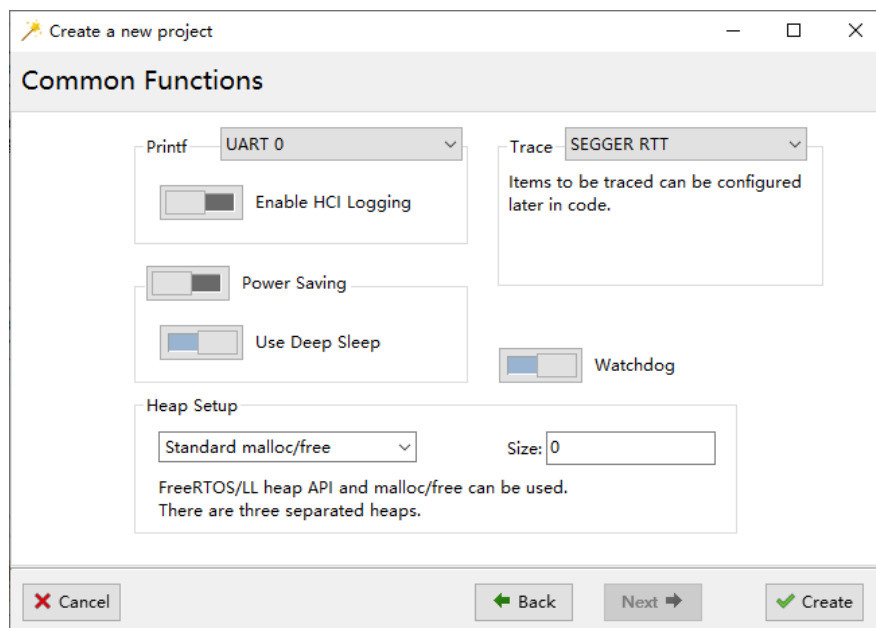


Figure 2.9: Common Functions

On this page (Figure 2.9), we also accept the default settings and press Create. Now your project is created (Figure 2.10), and ready for building and downloading.

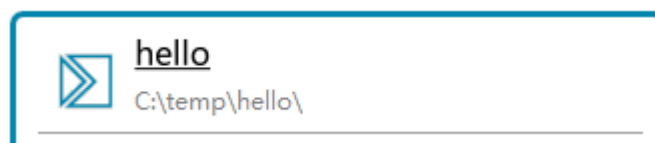


Figure 2.10: "Hello, " is Ready

2.1.9 Build your project

Back to the main window of wizard (Figure 2.10), click on your project to open it. Build your project in IDE.

2.1.10 Download

To download your project, back to wizard (Figure 2.10), right click on your project, and select Download to Flash from the popup menu to start the downloader (Figure 2.11).

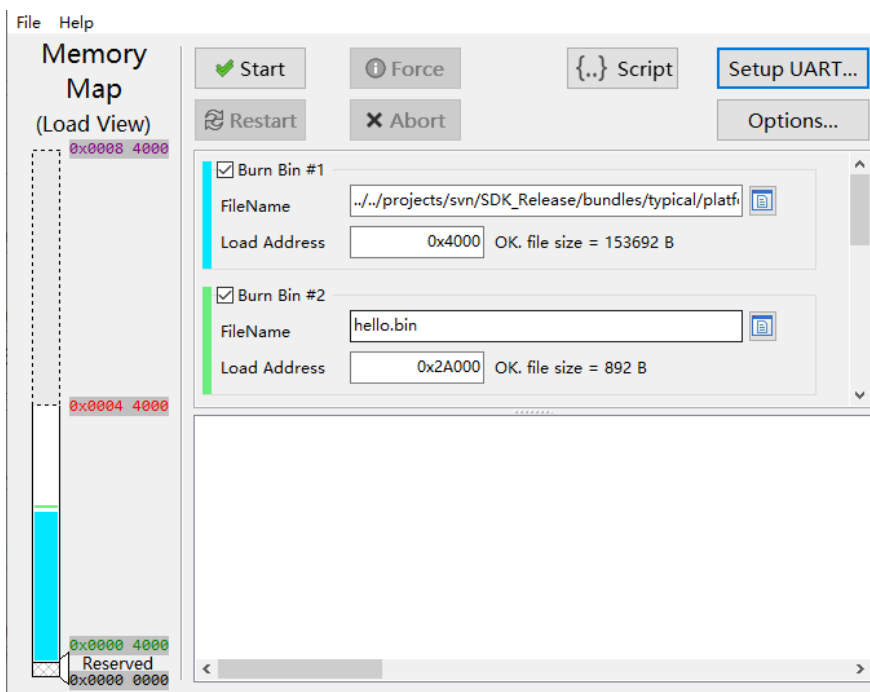


Figure 2.11: Download to Flash

All settings in the downloader are ready except the UART port number. In the downloader, configure the correct UART port and then click Start.

Once downloaded, check if you can find a device named "Hello, " by LightBlue, INGdemo (Figure 2.12) or other apps. Note that, this device may not be listed in the Bluetooth menu of system settings at present.

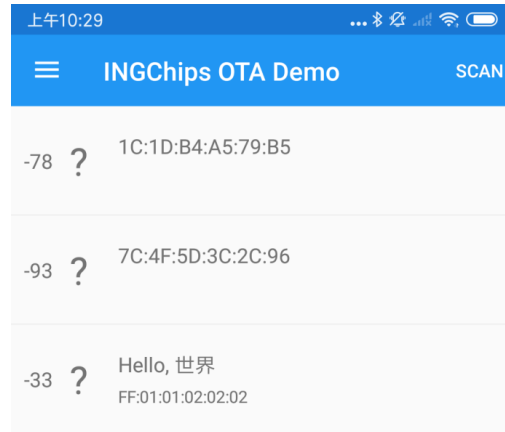


Figure 2.12: Hello,

2.2 iBeacon

In this tutorial, let's make an iBeacon. iBeacon is a protocol developed by Apple¹ and introduced at the Apple Worldwide Developers Conference in 2013. Beacons are a class of Bluetooth low energy (BLE) devices that broadcast their identifier to nearby portable electronic devices. This technology enables smartphones, tablets and other devices to perform actions when in close proximity to an iBeacon device.

Firstly, get a iBeacon scanning app from App Store. We will use an app called `Locate` in this tutorial. `Locate` has a list of preconfigured proximity UUIDs, which includes an all 0s Null UUID. We will use this Null UUID².

2.2.1 Setup Advertising Data

There are two items in iBeacon advertising packet.

1. Flags

Value is fixed to 0x06, i.e. two bits are set, LE General Discoverable Mode & BR/EDR Not Supported.

2. Manufacturer Specific Data

The contents of this item is shown in Table 2.1

¹<https://developer.apple.com/ibeacon/>

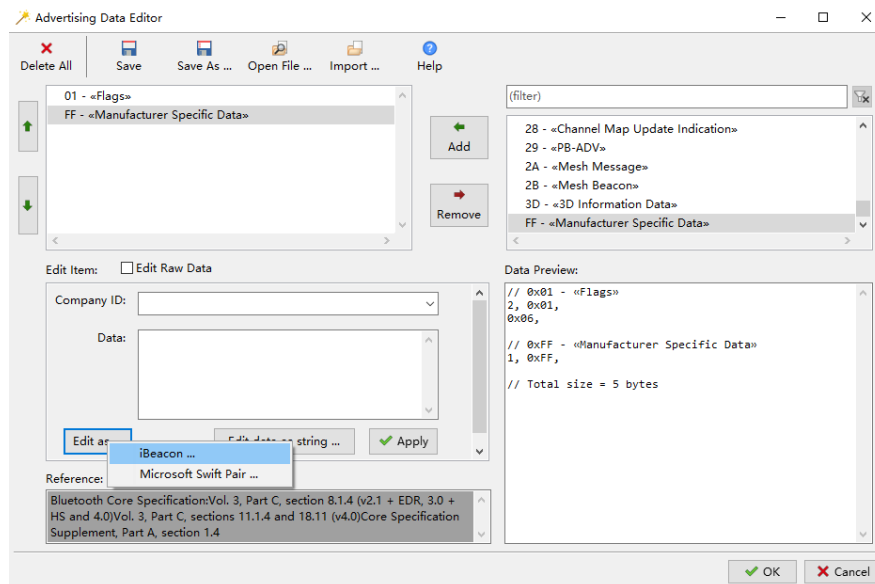
²Note that UUID is not allowed to be all 0s in final products.

Table 2.1: iBeacon Manufacturer Specific Data

Size in Bytes	Name	Value	Notes
2	Company ID	0x004C	Company ID of Apple, Inc
2	Beacon Type	0x1502	Value defined by Apple
16	Proximity UUID		User defined value
2	Major		Group ID
2	Minor		ID within a group
1	Measured Power	in dBm	Measured by an iPhone 5s at a 1 meter distance

In order to make an iBeacon device, we can just follow the same steps as in the Hello World example, with only one exception that we need to configure the advertising package according to the specification.

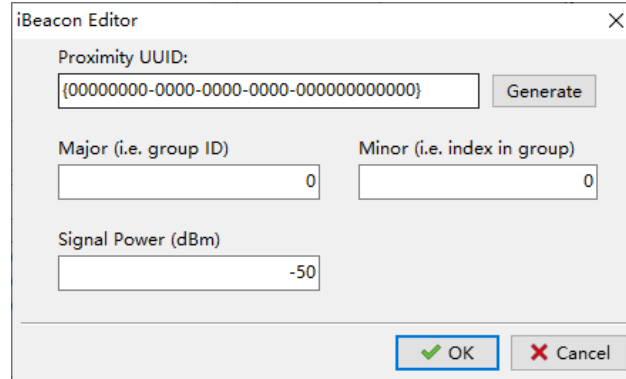
In the advertising data editor, add 0x01 - «Flags» and 0xFF - «Manufacturer Specific Data». Click 0x01 - «Flags», check LE General Discoverable Mode and BR/EDR Not Supported. Click 0xFF - «Manufacturer Specific Data», then the Edit as button, a menu pops up and select iBeacon ... (Figure 2.13) to open iBeacon manufacturer specific data editor (Figure 2.14).


Figure 2.13: Edit iBeacon Advertising Data

Signal power can be set to any reasonable value (such as -50dBm), and we will calibrate it later with the help of the Locate app.

2.2.2 Try It

Let's select GNU Arm Embedded Toolchain as our development environment on Choose Project Type page, and the wizard will make everything ready (Figure 2.15).



The iBeacon Editor dialog box contains the following fields and buttons:

- Proximity UUID:** A text field containing the placeholder string {00000000-0000-0000-0000-000000000000} and a **Generate** button.
- Major (i.e. group ID):** A text field containing the value 0.
- Minor (i.e. index in group):** A text field containing the value 0.
- Signal Power (dBm):** A text field containing the value -50.
- Buttons:** **OK** (with a green checkmark) and **Cancel** (with a red X).

Figure 2.14: Edit iBeacon Manufacturer Specific Data

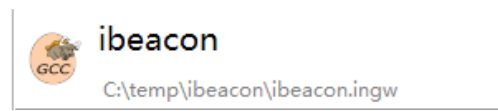


Figure 2.15: iBeacon Ready for GNU Arm Toolchain

Click on the project to open a console, type `make3` to build it. Back to Wizard, follow the same steps to download it. Now we are able to find our newly created iBeacon in Locate. (Figure 2.16)

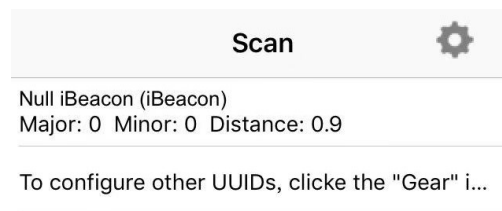


Figure 2.16: iBeacon in Locate app

Tap on our device then we can calibrate signal power or check distance in real-time as shown in Figure 2.17.

Once signal power is calibrated, we can right click on our project in Wizard, and select **Edit Data -> Advertising** menu item to edit its advertising data with same editor that we are getting familiar with. After advertising data is updated, rebuild the project and check if the distance is more accurate.



According to the specification, proximity beacons must use a non connectable undirected advertising PDU, using a fixed 100ms advertising interval. In this tutorial, we are not going to touch the code, so advertising parameters are not touched, either. To make these parameters fully meet the specification, please refer to the corresponding host GAP APIs.

³Makefile follows the syntax of GNU make.

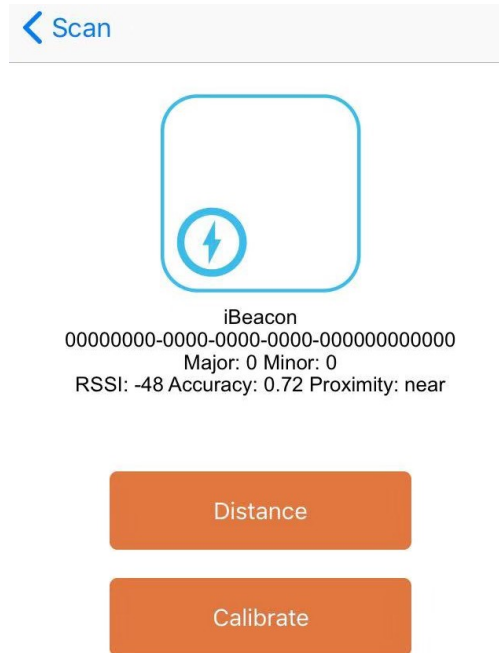


Figure 2.17: iBeacon Detailed Information in Locate app

2.3 Thermometer

In this tutorial, we are going to make a *serious* BLE device, a thermometer. Bluetooth SIG has already defined a GATT service called Health Thermometer⁴. This SDK contains a reference app called INGdemo, which can be deployed to an Android or iOS device. Using INGdemo, we can check Bluetooth devices' advertising data, and if health thermometer service is found in a device, INGdemo can connect to it and read temperature.

In this tutorial, you will learn how to:

- Broadcast supported services
- Configure a GATT profile
- Respond to the read request of a GATT characteristic

2.3.1 Setup Advertising Data

Again, we follow the same steps as in the Hello World example, and on the Peripheral Setup page, we declare the thermometer service and create a GATT profile. Add following three items into the advertising data:

1. Flags

⁴https://www.bluetooth.com/specifications/gatt/viewer?attributeXmlFile=org.bluetooth.service.health_thermometer.xml

2.3. THERMOMETER

Value is fixed to 0x06, i.e. two bits are set, LE General Discoverable Mode & BR/EDR Not Supported.

2. Complete List of 16-bit Service Class UUIDs

Add one service 0x1809 - Health Thermometer as shown in Figure 2.18.

3. Complete Local Name

Let's name our device as "AccurateOne".

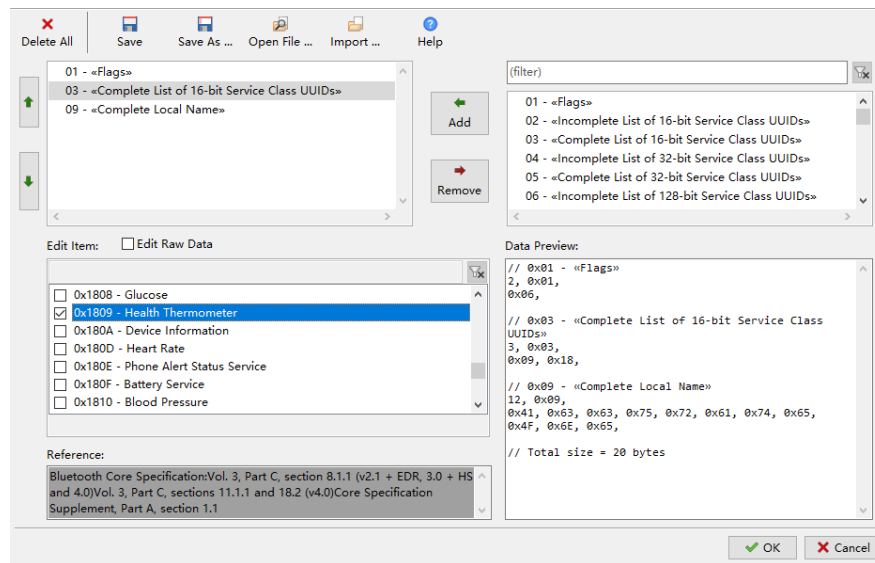


Figure 2.18: Thermometer Advertising Data

2.3.2 Setup GATT Profile

Back to the Peripheral Setup page and click Setup ATT database ... to open the GATT profile editor. Add two service, General Access (0x1800) and Health Thermometer (0x1809). Delete all non-mandatory characteristics of General Access service. For Health Thermometer service, keep two characteristics, i.e. temperature measurement and temperature type, and delete the other two.

Next, edit each characteristic's value:

1. Device Name of General Access:

Right click on the characteristic, select Edit String Value ... menu, and set the value to "AccurateOne".

2. Appearance of General Access:

Right click on the characteristic, select Help and the editor will open the corresponding document on Bluetooth SIG website. Find the value for general thermometer (0x0300), then click the Edit button and input 0x00, 0x03 into the data field.

3. Temperature Measurement of Health Thermometer

Check the document on Bluetooth SIG website. click the `Edit` button and input five 0s (0, 0, 0, 0, 0) into the data field. Here the first byte contains the flags showing that the following measurement is a `FLOAT` value in units of Celsius. Check `read` and `dynamic` properties (Figure 2.19).

`FLOAT` type is IEEE-11073 32-bit float. Basically, it has a 24-bit mantissa, and an 8-bit exponent (the most significant byte) in base 10.

4. Temperature Type of Health Thermometer

Check the document on Bluetooth SIG website. Set it to any valid value by click the `Edit` button.

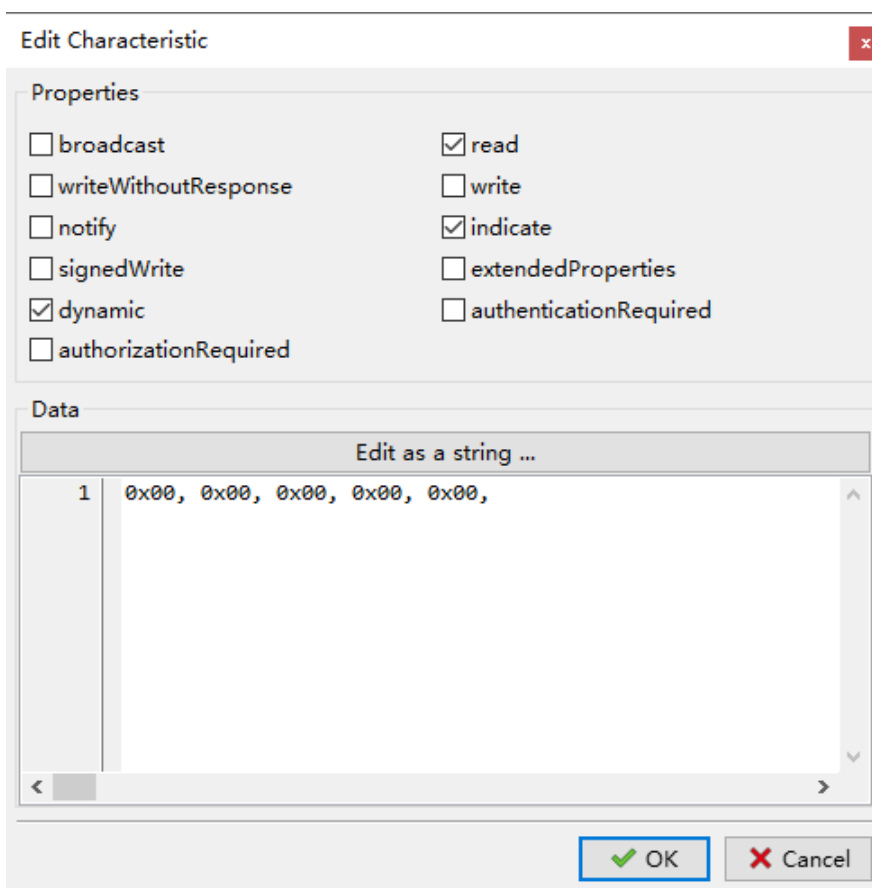


Figure 2.19: Edit Temperature Measurement

2.3.3 Write the Code

After project is created, open `profile.c` in IDE, and the temperature measurement characteristic handling function `att_read_callback` is automatically generated by wizard.

```
static uint16_t att_read_callback(hci_con_handle_t connection_handle,
                                uint16_t att_handle, uint16_t offset,
                                uint8_t * buffer, uint16_t buffer_size)
{
    switch (att_handle)
    {
        case HANDLE_TEMPERATURE_MEASUREMENT:
            if (buffer)
            {
                // add your code
                return buffer_size;
            }
            else
                return 1; // TODO: return required buffer size

        default:

            return 0;
    }
}
```

att_read_callback will be called twice or more when app reads a characteristic that has dynamic property: one for querying required buffer size, and one for reading data. If data is large, att_read_callback might be called more times, each reading a part of data specified by offset.

As discussed above, define a temperature measurement type:

```
typedef __packed struct gatt_temperature_meas
{
    uint8 flags;
    sint32 mantissa:24;
    sint32 exponent:8;
} gatt_temperature_meas_t;

static gatt_temperature_meas_t temperature_meas = {0};
```

Now, we can complete the above case HANDLE_TEMPERATURE_MEASUREMENT clause:

```
case HANDLE_TEMPERATURE_MEASUREMENT:
    if (buffer)
    {
        // simulate an "accurate" thermometer
```

```

    temperature_meas.mantissa = rand() % 100;
    // output data
    memcpy(buffer, ((uint8 *)&temperature_meas) + offset, buffer_size);
    return buffer_size;
}
else
    return sizeof(gatt_temperature_meas_t);

```

Build & download project, then connect to “AccurateOne” device in INGdemo app. Check if temperature changes randomly each time Refresh button is pressed (Figure 2.20).

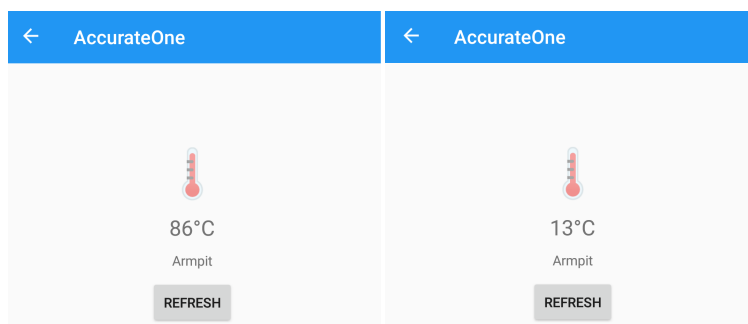


Figure 2.20: Refresh Temperature Measurement



A thermometer (a server) can use notification or indication procedure to notify (without acknowledge) or indicate (with acknowledge) a characteristic value, see [Thermometer with Notification]. In this example, “AccurateOne” does not use these two procedures, and sends its measurement passively.

2.3.4 Notification

2.4 Thermometer with FOTA

In this tutorial, we are going to add Firmware Over-The-Air update feature into our thermometer. This SDK provides a FOTA reference design that is workable out-of-the-box. To make FOTA work, at least three parties are involved, a device, an app, and an HTTP server. The INGdemo app is already there, so in this tutorial, we will focus on the device and HTTP server.

2.4.1 Device with FOTA

Follow the same steps as in the previous Thermometer example to create a new project, say “ota”.

When editing advertising data, we can import data created in previous example by clicking `Open File...` button of the editor. Advertising data is stored in `$(ProjectPath)/data/advertising.adv`. Let's change device's name to "Clickety Click".

When editing GATT profile database, we can import data created in previous example by clicking `Open File...` button of the editor. GATT profile data is stored in `$(ProjectPath)/data/gatt.profile`. Select `INGChips Service` from the drop-down menu of `Add Service` button, and add "INGChips FOTA Service". At present, we are not going to consider security issues, so delete the "FOTA Public Key" characteristics. Next, edit characteristics value of this service:

1. FOTA Version:

This identifies the full version number of our project. As shown in flash downloader, a whole project is composed by two binaries, one is from SDK bundle, called platform binary, and the other one is built from our project, called the app binary. FOTA version contains two sub-versions, one for each binary. Each sub-version contains three fields:

- Major: A 16-bit field.
- Minor: A 8-bit field.
- Patch: Another 8-bit field.

Each bundle has its own version (so as the platform binary), using the same numbering scheme, which can be found on SDK page of `Environment Options` dialog (use menu item `Tools -> Environment Options` to open this dialog). Suppose platform version is 1.0.1⁵, and we would like our app's version to be 1.0.0, then we set this characteristic's value to (Fig 2.21):

```
0x0001, 0, 1 // platform version
0x0001, 0, 0, // app version
```

2. FOTA Control

This is control point during update. Set its value to 0 (i.e. `OTA_STATUS_DISABLED`), which is the initial status of FOTA.

Click OK to close GATT profile editor. (Note: do not click `Save`, unless you want to change the file `$(ProjectPath)/data/gatt.profile` that is opened in editor.)

Back to project wizard, press `Next` to proceed to the next page `Firmware Over-The-Air`. On this page, let's check FOTA. Note that characteristics handles related to FOTA is generated automatically by inspecting the GATT profile. Then finish remaining steps on project wizard.

Open our brand-new project "ota", copy the code from previous example to make our thermometer respond to `Refresh` in `INGdemo` app.

Next, let's make a new version.

⁵Apps can report a different version in FOTA. It is not required to be same as in `Environment Options`.

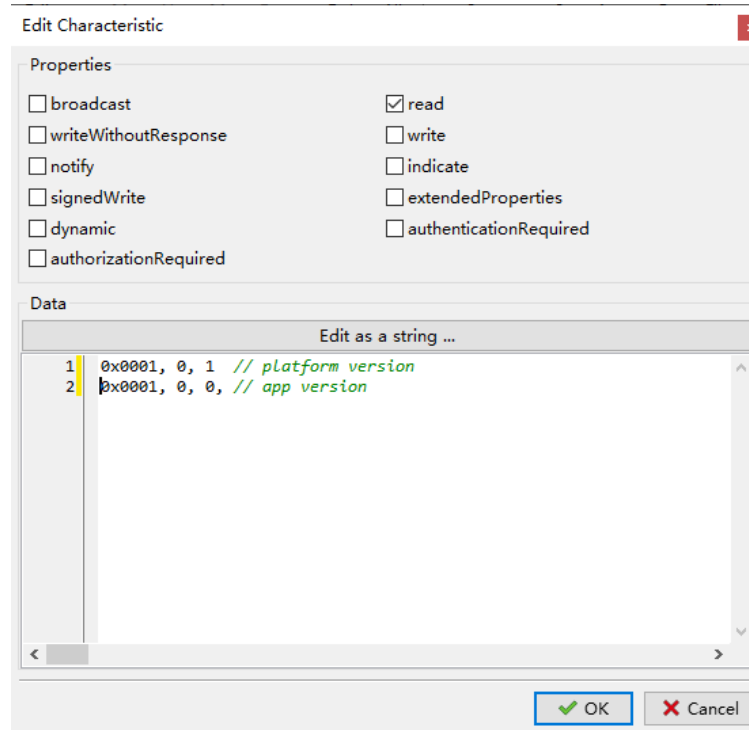


Figure 2.21: Configure FOTA Version

2.4.2 Make a New Version

New version of our “ota” will have a new name “Barba Trick”, and app version number is upgraded to 2.0.0. These data are saved in advertising and profile data respectively, so right click on the project and use editors to update it. After data is updated, use Save As ... to save data to another file in the same directory, for example, update advertising data and save it to \$(ProjectPath)/data/advertising_2.adv, and updated profile to \$(ProjectPath)/data/gatt_2.profile.

Use macro V2 to control the actual advertising and profile data:

```
const static uint8_t adv_data[] = {
#ifdef V2
    #include "../data/advertising.adv"
#else
    #include "../data/advertising_2.adv"
#endif
};

.....

const static uint8_t profile_data[] = {
#ifdef V2
```

```
#include "../data/gatt.profile"
#else
#include "../data/gatt_2.profile"
#endif
};
```

Rebuild the project with macro `v2` defined, copy `ota.bin` and `platform.bin` (in `SDK_DIR/sdk/bundles/typical`) to an empty directory, say `ota_app_v2`.

Create a file named `manifest.json` in `ota_app_v2`, with follow data in it:

```
{
  "platform": {
    "version": [1,0,1],
    "name": "platform.bin",
    "address": 16384
  },
  "app": {
    "version": [2,0,0],
    "name": "ota.bin",
    "address": 163840
  },
  "entry": 16384,
  "bins": []
}
```

Those addresses can be found in Environment Options. `entry` value is fixed to `0x4000`, i.e. 16384. Note that `json` do not accept the popular `0xabcd` hexadecimal literals. `INGdemo` can download additional binaries specified by `bins` to device. In this case, we don't have such binaries, so this field is left as an empty array.

Then create a `readme` file for this update with some information about this update in it.

Now the FOTA package is ready. Make a `ota_app_v2.zip` ZIP archive of the whole `ota_app_v2` directory. Note that `ota_app_v2` should not be made into a sub-directory in `ota_app_v2.zip`. Table 2.2 summarize the files in the ZIP archive.

Table 2.2: FOTA Package Summary

File Name	Notes
<code>readme</code>	Some information about this update
<code>manifest.json</code>	Meta information
<code>platform.bin</code>	Platform binary

File Name	Notes
ota.bin	App binary

Back to IDE, rebuild the project leaving macro `v2` undefined, then download the project.

2.4.3 FOTA Server

INGdemo app needs a FOTA server URL, defined in `class Thermometer.FOTA_SERVER`. Move `ota_app_v2.zip` to HTTP server's document directory, and create a `latest.json` file, which contains information about latest version. Its content is:

```
{
  "app": [2,0,0],
  "platform": [1,0,1],
  "package": "ota_app_v2.zip"
}
```

Make sure that these two files can be accessed through URL (`FOTA_SERVER + latest.json`) and (`FOTA_SERVER + ota_app_v2.zip`).

2.4.4 Try It

Connect to “Clickety Click” in INGdemo, click Update (Figure 2.22). Since `platform.bin` is up-to-date, only `app.bin` need to be updated, the whole update completes in a short time. Return to the main page, scan again and check if our new version works, a device named “Barba Trick” appearing. Connect to “Barba Trick”, firmware is up-to-date now.



This tutorial gives an example on FOTA implementation. Users are free to design a new FOTA solution, from version definition to FOTA service and characteristics. It also possible to develop a dedicated secondary app for FOTA.

Security must be considered.

2.5 iBeacon Scanner

We already know to how to make iBeacon devices. In this tutorial, we are going to create an iBeacon scanner.

A scanner plays a central role in Bluetooth pico network. As always, we create a new project named “iscanner” in Wizard (Fig 2.23). On Role of Your Device page, select *Central*. A central

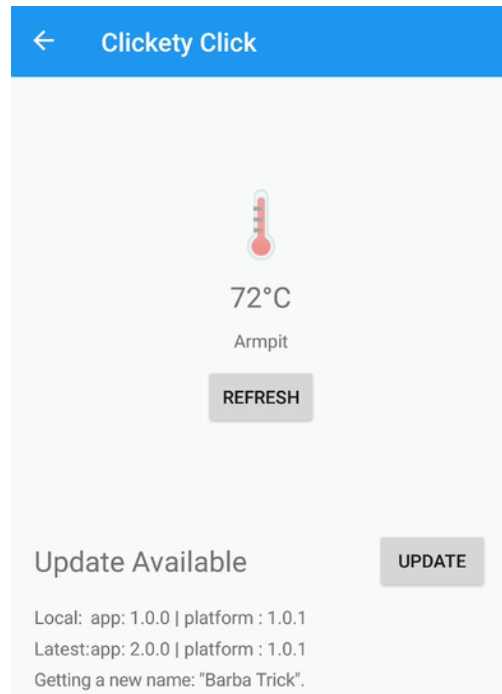


Figure 2.22: Update Available for "Clickety Click"

device almost always scans for something then performs other actions, and our new project wizard automatically adds codes to start scanning.



Figure 2.23: "iscanner" Created for IAR Embedded Workbench

Open this new project in IDE, and navigate to function `user_packet_handler`. We can see there is an event called `HCI_SUBEVENT_LE_EXTENDED_ADVERTISING_REPORT`:

```
case HCI_SUBEVENT_LE_EXTENDED_ADVERTISING_REPORT:
{
    const le_ext_adv_report_t *report = decode_hci_le_meta_event(packet,
        le_meta_event_ext_adv_report_t)->reports;
    // ...
}
break;
```

Each time this event is received, we can check if the advertising report contains `0xFF` - «Manufacturer Specific Data», and if it is an iBeacon packet. With the knowledge of making an iBeacon device, it is straight forward to define an iBeacon packet type in C.


```
typedef __packed struct ibeacon_adv
{
    uint16_t apple_id;
    uint16_t id;
    uint8_t uuid[16];
    uint16_t major;
    uint16_t minor;
    int8_t ref_power;
} ibeacon_adv_t;

#define APPLE_COMPANY_ID      0x004C
#define IBEACON_ID            0x1502
```

`__packed` is an extended keyword to specify a data alignment of 1 for a data type. Fortunately, it is supported by both *ARM* and *IAR* compilers. Alternatively, one can use `#pragma pack` directive:

```
#pragma pack (push, 1)
typedef struct ibeacon_adv
{
    ...
} ibeacon_adv_t;
#pragma pack (pop)
```

Before proceeding, let's create a helper function that converts an UUID to a string.

```
const char *format_uuid(char *buffer, uint8_t *uuid)
{
    sprintf(buffer, "{%02X%02X%02X%02X-%02X%02X-%02X%02X-"
        "%02X%02X-%02X%02X%02X%02X%02X%02X}",
        uuid[0], uuid[1], uuid[2], uuid[3],
        uuid[4], uuid[5], uuid[6], uuid[7], uuid[8], uuid[9],
        uuid[10], uuid[11], uuid[12], uuid[13], uuid[14], uuid[15]);
    return buffer;
}
```

2.5.1 Distance Estimation

The received signal strength indication (RSSI) is reported together with advertising data. Generally, the intensity of electromagnetic waves radiating from a point source is inversely proportional to the square of the distance from the source. The well known equation for free space loss is:

$$Loss = 32.45 + 20\log(d) + 20\log(f)$$

Where d is in km, f in MHz and $Loss$ in dB. By comparing RSSI and measured power at a distance of 1 meter (ref_power), we can grossly estimate the distance between the scanner and beacon using the free space loss equation:

```
double estimate_distance(int8_t ref_power, int8_t rssi)
{
    return pow(10, (ref_power - rssi) / 20.0);
}
```

Now, we are able to make a fully functional iBeacon scanner in less than twenty lines:

```
uint8_t length;
ibeacon_adv_t *p_ibeacon;
char str_buffer[80];
const le_ext_adv_report_t *report;
.....
case HCI_SUBEVENT_LE_EXTENDED_ADVERTISING_REPORT:
    report = decode_hci_le_meta_event(packet,
                                      le_meta_event_ext_adv_report_t->reports;
    p_ibeacon = (ibeacon_adv_t *)ad_data_from_type(report->data_len,
                                                    (uint8_t *)report->data, 0xff, &length);

    if ((length != sizeof(ibeacon_adv_t))
        || (p_ibeacon->apple_id != APPLE_COMPANY_ID)
        || (p_ibeacon->id != IBEACON_ID))
        break;

    printf("%s %04X,%04X, %.1fm\n",
           format_uuid(str_buffer, p_ibeacon->uuid),
           p_ibeacon->major, p_ibeacon->minor,
           estimate_distance(p_ibeacon->ref_power, report->rssi));
    break;
```

Use the Locate app to transmit iBeacon signal, and check if our device can found it (Figure 2.24). Finally, since RSSI value fluctuates, one can add a low pass filter on RSSI to make the estimation more stable.



Note that the size of this app's binary increases dramatically. This is mainly because that Cortex-M3 don't have a hardware floating-point unit and floating-point operations are all performed by library functions. *Think twice* before using floating-point operations.

```
[14:00:53.135] {2F234454-CF6D-4A0F-ADF2-F4911BA9FFA6} 0000,0000, 2.8m
[14:00:53.184] {2F234454-CF6D-4A0F-ADF2-F4911BA9FFA6} 0000,0000, 4.0m
[14:00:53.232] {2F234454-CF6D-4A0F-ADF2-F4911BA9FFA6} 0000,0000, 3.5m
[14:00:53.296] {2F234454-CF6D-4A0F-ADF2-F4911BA9FFA6} 0000,0000, 2.8m
```

Figure 2.24: iBeacon Scan Result

2.5.2 Concurrent Advertising & Scanning

As an exercise, we can merge iBeacon project with this one, and check if our device can send iBeacon signals while keeps scanning for other iBeacon devices.



Bluetooth radio uses TDD (Time Division Duplex) topology in which data transmission occur in one direction at one time and data reception occur at another time, and it's impossible to receive its own iBeacon signal.

2.6 Notification & Indication

A server can use notification or indication procedure to notify (without acknowledge) or indicate (with acknowledge) a characteristic's value. Now, let's add notification and indication features to our thermometer we have created in a previous tutorial.

To notify or indicate a characteristic's value, we use `att_server_notify` and `att_server_indicate` respectively. These APIs must be called within the Bluetooth stack (Host) task.

Unsolicited notifications and indication may be triggered by a timer or interrupts, i.e. by sources outside of Bluetooth stack task. To call these Bluetooth stack APIs, inter-task communication mechanism based on RTOS messages is provided.

2.6.1 Inter-task Communication

`btstack_push_user_msg` can be used to send a message into Bluetooth stack stack:

```
uint32_t btstack_push_user_msg(uint32_t msg_id, void *data, const uint16_t len);
```

This message will be passed to your `user_packet_handler` under event ID `BTSTACK_EVENT_USER_MSG`:

```
static void user_packet_handler(uint8_t packet_type, uint16_t channel,
                               uint8_t *packet, uint16_t size)
{
    uint8_t event = hci_event_packet_get_type(packet);
```

```

btstack_user_msg_t *p_user_msg;
if (packet_type != HCI_EVENT_PACKET) return;

switch (event)
{
// .....
case BTSTACK_EVENT_USER_MSG:
    p_user_msg = hci_event_packet_get_user_msg(packet);
    user_msg_handler(p_user_msg->msg_id, p_user_msg->data,
                    p_user_msg->len);

    break;
// .....
}
}

```

Here, we delegate the handling of the user message to another function `user_msg_handler`. Note that `user_msg_handler` is running in the context of Bluetooth stack task, and we are allowed to call those Bluetooth stack APIs now.

Event `BTSTACK_EVENT_USER_MSG` is broadcasted to all HCI event callback functions.

2.6.2 Timer

Now let's make our thermometer "AccurateOne" to update its value once per second. Firstly, create a timer in initialization, such as in `app_main` or `setup_profile`.

```

TimerHandle_t app_timer = 0;

uint32_t setup_profile(void *data, void *user_data)
{
    app_timer = xTimerCreate("app",
                             pdMS_TO_TICKS(1000),
                             pdTRUE,
                             NULL,
                             app_timer_callback);

    // ...
}

```

Timer callback function is defined as:

```
#define USER_MSG_ID_REQUEST_SEND 1
static void app_timer_callback(TimerHandle_t xTimer)
{
    if (temperture_notify_enable | temperture_indicate_enable)
        btstack_push_user_msg(USER_MSG_ID_REQUEST_SEND, NULL, 0);
}
```

This timer is started when we get HCI_SUBEVENT_LE_ENHANCED_CONNECTION_COMPLETE in HCI_EVENT_LE_META, and stopped when we get HCI_EVENT_DISCONNECTION_COMPLETE.

Here temperture_notify_enable and temperture_indicate_enable are two flags initialized as 0s and set to 1 in att_write_callback:

```
static int att_write_callback(hci_con_handle_t connection_handle,
                             uint16_t att_handle, uint16_t transaction_mode,
                             uint16_t offset, uint8_t *buffer, uint16_t buffer_size)
{
    switch (att_handle)
    {
        case HANDLE_TEMPERATURE_MEASUREMENT + 1:
            handle_send = connection_handle;
            switch (*(uint16_t *)buffer)
            {
                case GATT_CLIENT_CHARACTERISTICS_CONFIGURATION_INDICATION:
                    temperture_indicate_enable = 1;
                    break;
                case GATT_CLIENT_CHARACTERISTICS_CONFIGURATION_NOTIFICATION:
                    temperture_notify_enable = 1;
                    break;
            }
            return 0;
        // ...
    }
}
```

Here we store connection_handle to a global variable handle_send which will be used later. The last piece of code is to handle message USER_MSG_ID_REQUEST_SEND in user_msg_handler:

```
static void user_msg_handler(uint32_t msg_id, void *data, uint16_t size)
{
    switch (msg_id)
    {
```

```

case USER_MSG_ID_REQUEST_SEND:
    att_server_request_can_send_now_event(handle_send);
    break;
}
}

```

And report temperature in ATT_EVENT_CAN_SEND_NOW:

```

...
case ATT_EVENT_CAN_SEND_NOW:
    temperature_meas.mantissa = rand() % 100;
    if (temperture_notify_enable)
    {
        att_server_notify(handle_send,
                          HANDLE_TEMPERATURE_MEASUREMENT,
                          (uint8_t*)&temperature_meas,
                          sizeof(temperature_meas));
    }

    if (temperture_indicate_enable)
    {
        att_server_indicate(handle_send,
                           HANDLE_TEMPERATURE_MEASUREMENT,
                           (uint8_t*)&temperature_meas,
                           sizeof(temperature_meas));
    }
    break;
...

```

Try to rebuild and download the project, and check if the temperature value shown in INGdemo changes once per second.



There is a fully functional thermometer example, a.k.a thermo_ota, supporting FOTA, notification and indication.

2.7 Throughput

BLE 5.0 introduces a new uncoded PHY with a sampling rate at 2M.

2.7.1 Theoretical Peak Throughput

Maximum payload length is 251 bytes for a Data Physical Channel PDU. Using 2M PHY, it takes 1048 μ s to transmit. And an empty Data Physical Channel PDU takes 44 μ s to transmit.

To achieve maximum throughput on one direction, length of all PDUs on this direction should be 251 bytes, while on the other direction, all PDUs should be empty. So, the transmission of 251 bytes takes a total duration of

$$1048 + 44 + 150 * 2 = 1392(\mu s)$$

Therefore, the theoretical peak throughput provided by link layer is

$$251 * 8 / 1392 * 1000000 \approx 1442.528(kbps)$$

For an app working above GATT, I2CAP and ATT all have their own overhead. Typically, GATT has a maximum effective payload of (251 - 7 =) 244 bytes. So, GATT could provide a theoretical peak throughput of

$$244 * 8 / 1392 * 1000000 \approx 1402.298(kbps)$$

2.7.2 Test Throughput

There are a pair of examples in SDK for throughput testing (Figure 2.25).

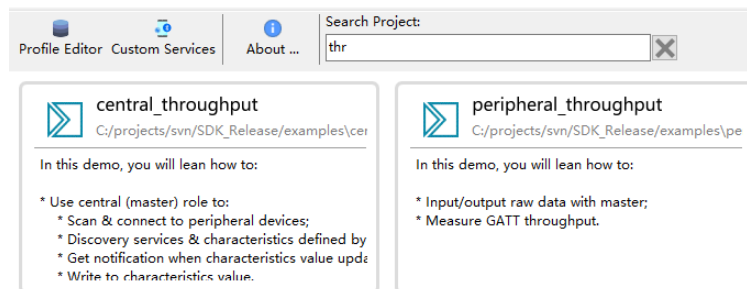


Figure 2.25: Examples for Throughput Testing

2.7.2.1 Test against INGdemo

Download peripheral_throughput. Use INGdemo to connect to ING Tpt, and open throughput testing page. On this page, we can test throughput from master to slave, from slave to master, or on both directions simultaneously.

Figure 2.26 shows that using a common low end Android phone with 2M PHY support, we can achieve a 1M+ bps throughput over the air.

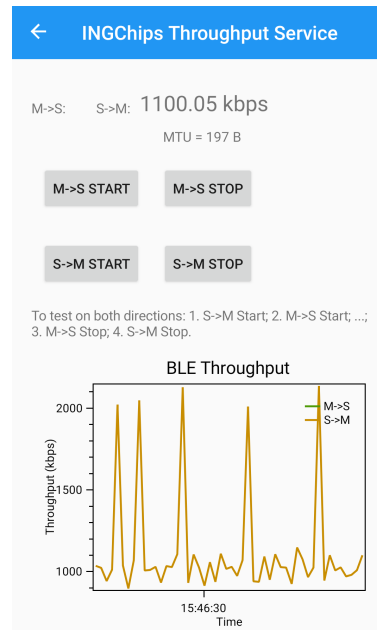


Figure 2.26: Throughput on an Android Phone

2.7.2.2 Test against Our Own App

Example `central_throughput` demonstrates the typical procedure for a BLE central device:

1. Scan and connect to a device that has throughput service declared in its advertising
2. Discover throughput service;
3. Discover characteristics of the service;
4. Discover descriptors of characteristics.

INGChips Throughput Service has two characteristics.

- Generic Output

By this characteristic, peripheral device send data to central device.

This characteristic has a `Client Characteristic Configuration` descriptor.

- Generic Input

By this characteristic, central device send data to peripheral device.

Download `central_throughput` to another board. This app has a UART command line interface to host computer. Connect to a host computer, type “?” to check supported commands. This app connects to `peripheral_throughput` automatically. Input command `start s->m` or `start m->s` to start testing throughput from peripheral to central, or from central to peripheral, receptively.

Figure 2.28 shows that using two boards, we have achieved a stable throughout at 1.2M+ bps over the air.


```
?
commands:
h/?      show this
start dir start throughput test on dir
stop dir  stop throughput test on dir

note: dir = s->m, or m->s
start s->m
```

Figure 2.27: Command interface

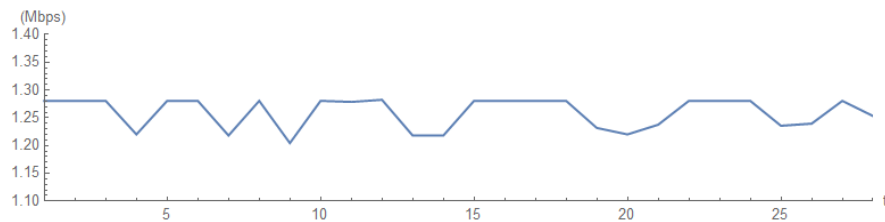


Figure 2.28: Throughput Between Boards



This throughput is tested over the air, a little bit lower than theoretical peak value, but much more practical.

2.8 Dual Role & BLE Gateway

In this tutorial, we are going to create a BLE gateway, which collects data from several peripheral devices and reports data to a central device. When collecting data, this gateway is a central device, while reporting data, it is a peripheral device, i.e., our app has two roles.

More specifically, our gateway only supports to collect data from thermometers. Let call it a `smart_meter`.

`smart_meter` uses a generic string based output service for report data to a central device, such as the `INGdemo` running on a smart phone. It also has a UART control interface connecting to a host computer.



Checkout the example `peripheral_console` for how to do string input & output.

Full functional `smart_meter` app is also provided as an example. Take this example as an reference while creating your own.

Now, let's create this BLE gateway.

2.8.1 Use wizard to create a peripheral app

Use GUI editor to edit advertising data, naming our app as "ING Smart Meter".

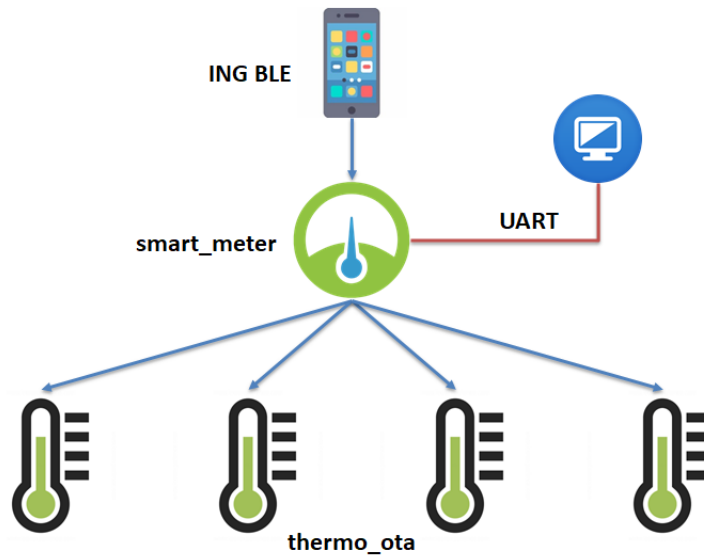


Figure 2.29: Smart Meter Overview

Use GUI editor to edit GATT Profile. Add INGChips Console Service into GATT Profile (Figure 2.30).

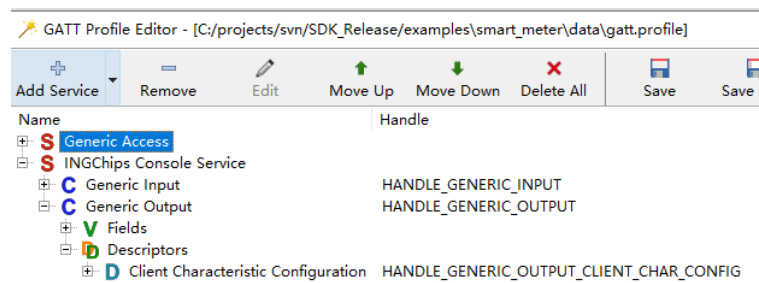


Figure 2.30: Smart Meter GATT Profile

2.8.2 Define Thermometer Data

A thermometer is identified by its device address and `id`. Each thermometer uses its own connection identified by `conn_handle`.

```
typedef struct slave_info
{
    uint8_t      id;
    bd_addr_t    addr;
    uint16_t     conn_handle;
    gatt_client_service_t      service_thermo;
    gatt_client_characteristic_t temp_char;
}
```

```
gatt_client_characteristic_descriptor_t temp_desc;  
gatt_client_notification_t temp_notify;  
} slave_info_t;
```

Define four thermometers.

2.8.3 Scan for Thermometers

Call two GAP APIs to start scanning. Once a device is found, check whether its device address is one of the thermometers. If so, stop scanning and call `gap_ext_create_connection` to connect.

After connection established, if there is any thermometer not connected, then start scanning again.

2.8.4 Discover Services

After connection established, call `gatt_client` APIs to discover its services.

These APIs follow a similar logic like Android, iOS.

2.8.5 Data Handling

Subscribe to thermometer's Temperature Measurement characteristic. When a new measurement is received, convert the value into a string and report it to a host computer. If our app is already connected to a central device, forward this information to it through GATT characteristic.

2.8.6 Robustness

To make our app more *robust*:

- If disconnected from a thermometer, then start scanning;
- If disconnected from a central device, then start advertising.

2.8.7 Prepare Thermometers

We can use example `thermo_ota` as thermometers. But we need to configure different address for each one.

We can write a simple script for downloader to generate these addresses automatically:

```
procedure OnStartBin(const BatchCounter, BinIndex: Integer;  
                    var Data: TBytes; var Abort: Boolean);  
begin  
    if BinIndex <> 6 then Exit;  
    Data[0] := BatchCounter;  
end;
```

For further information on downloader scripting, see Scripting & Mass Production.

2.8.8 Test

Input command `start` on host computer to start our app (start scanning & advertising). Use `INGdemo` to connect to a device named “ING Smart Meter” and check temperature measurements.

Turn off and on one or more thermometers, and our app should be able to reconnect to them.

2.9 Start from Examples

`Wizard` main interface displays all the examples included with the SDK. Developers can directly modify the examples and see the effects. When the SDK is reinstalled, these modifications will be overwritten. If developers need to develop a project based on an example, you can select “Copy this Example ...” from the popup menu to fully copy the example to another location.

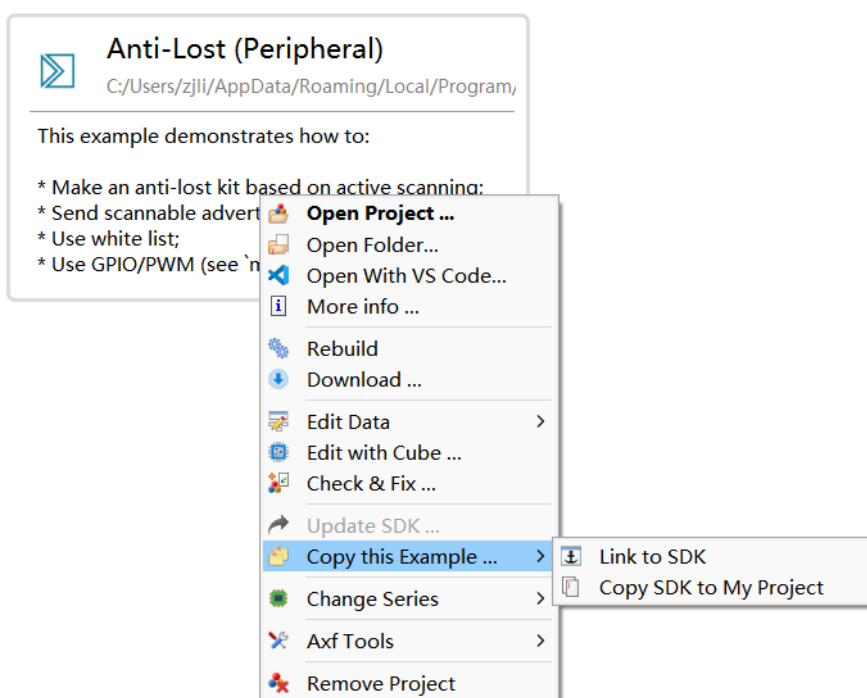


Figure 2.31: Copy an SDK Example

Chapter 3

Core Tools

SDK core tools play an important role in the BLE device development.

3.1 Wizard

Wizard is the recommended entry point in the whole development life cycle. With it, we can create & open project, edit project data, and migrate projects, etc.

1. Create Project

Wizard's new project wizard assists the creation of new projects. We can select favourite IDE, peripheral role, edit advertising and profile data, enable FOTA and logging, etc.

Once a project is created, following files are also created, used by Wizard but not IDE, and they should not be deleted, or Wizard will not function properly:

- `$(ProjectName).ingw`

This file shares the same name with the project with an extension `.ingw`. It contains crucial information about the project and SDK. Without this information, it becomes impossible to do migration.

2. Advertising Data Editor

This editor helps us to generate advertising data. It can also be opened from main menu `Tools -> Advertising Data Editor`

3. GATT Profile Editor (or GATT/ATT Database Editor)

This editor helps us to build GATT profile data. It can also be opened from main menu `Tools -> Profile Database Editor`

This editor supports three type of services, SIG defined services, *INGChips* defined services and user defined services. To add an user defined service, it must be create beforehand (see below).

4. Manage Custom Services

This editor can be opened from main menu Tools -> Manage Custom GATT Services We can add, delete and edit custom services.

Custom Services and characteristics are all named with a prefix which is deduced from company name initialized when installing SDK, and updatable through Environment Options.

5. Migration

In case a new version of SDK is installed, ROM and RAM used by platform might be changed, so projects settings need to be updated accordingly. This process is automated by right click on a project and select Check & Fix Settings



Always remember to backup your project before perform a migration, either by committing all changes into version control system or making a full backup.

3.2 Downloader

3.2.1 Introduction

This downloader downloads up-to six images (binaries) to flash through UART connection. It cooperate with bootloader. Bootloader can be made into flash downloading mode either by:

- Asserting boot pin¹ (this is used in the vast majority of cases),
- Setting entry point which is stored Flash to an invalid address (Only on ING918).

When ING918 is powered on, bootloader checks above conditions. If any conditions are true, bootloader sends the handshaking message. When ING916 is made into flash downloading mode, bootloader will check GPIO15: if its level is high, USB port is also enabled.

User can download any files, although typically these files are generated by IDE tools. The load address of image (binary) must be aligned at flash erasable unit boundary (EFLASH_ERASABLE_SIZE).

- ING918: each erasable unit is a page

The load address of image (binary) must be aligned at flash page boundary. Each flash page has 8192 (0x2000) bytes. Flash starts from 0x4000, so the load address should be $0x4000 + X * 0x2000$, where X is an integer.

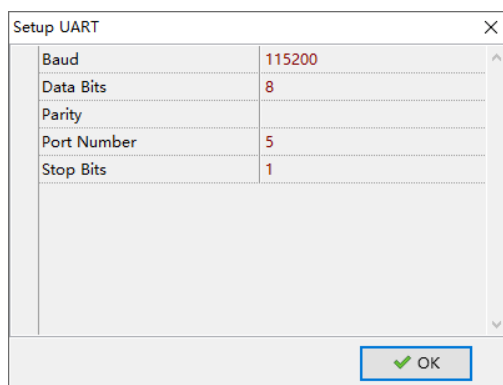
- ING918: each erasable unit is a sector

The load address of image (binary) must be aligned at flash sector boundary. Each flash sector has 4096 (0x1000) bytes. Flash starts from 0x2000000, so the load address should be $0x2000000 + X * 0x1000$, where X is an integer.

¹ING918 has a dedicated boot pin, while ING916 reuses GPIO0.

Downloader complains if the load address is not correct. Note that when this downloader is started from Wizard, binaries have already been correctly configured.

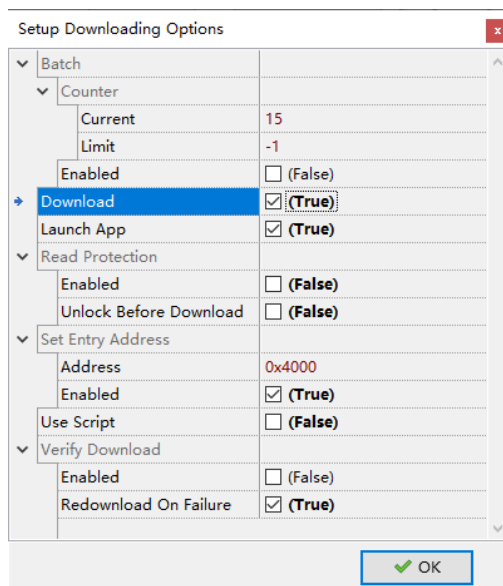
Click Setup UART ... or Setup Port ... to configure communication port (Figure 3.1). Users need to set Port Number to the value shown in Windows Device Manager, for example, if “COM9” is used, then set Port to COM9, or simply 9. For chips that support downloading through USB, Port can be set to USB to select the default USB device. Baud rate can be set to a value larger than 115200, such as 460800, 921600, etc, to achieve a faster download speed. The maximum supported baud rate is 921600. Due to the limitation of internal flash characters, there isn’t any further significant improvement for baud rate larger than 512000. Other fields should be left unchanged.



Setup UART	
Baud	115200
Data Bits	8
Parity	
Port Number	5
Stop Bits	1
<input type="button" value="OK"/>	

Figure 3.1: Configure UART

The whole downloading procedure is composed of several steps, such as downloading, verification, set entry address, and launching app. These steps can be configured by clicking Options (Figure 3.2).



Setup Downloading Options	
Batch	
Counter	
Current	15
Limit	-1
Enabled	<input type="checkbox"/> (False)
Download	<input checked="" type="checkbox"/> (True)
Launch App	<input checked="" type="checkbox"/> (True)
Read Protection	
Enabled	<input type="checkbox"/> (False)
Unlock Before Download	<input type="checkbox"/> (False)
Set Entry Address	
Address	0x4000
Enabled	<input checked="" type="checkbox"/> (True)
Use Script	<input type="checkbox"/> (False)
Verify Download	
Enabled	<input type="checkbox"/> (False)
Redownload On Failure	<input checked="" type="checkbox"/> (True)
<input type="button" value="OK"/>	

Figure 3.2: Downloader Options

Entry address specifies the entry point of the program. For ING918, if platform binary is used,

entry address must be set to `0x4000` which is also the load address of platform binary. For ING916, entry address is ignored if the address is not in the range of RAM.

If “Verify Download” is enabled, then data will be read back and compare with origin file to ensure data is correctly downloaded. Data blocks are CRC checked, so “Verify Download” can be kept disabled on a regular basis. If downloading keeps failing on specific address, then we can enable it to double check if flash is malfunctioned. In this case, when mismatch is found, read-back data will be stored to a file.

When “Batch” mode is enabled, downloader will keep waiting for bootloader handshaking, and once received handshaking, downloading starts; after downloading completes, downloader will start waiting again. When “Batch” mode is disabled, downloader will no longer wait for handshaking after downloading completes.

Click `Start` to start downloading, or rather start waiting for handshaking. Bootloader sends handshaking message only once, and if chips are already powered up, it may be too late to receive handshaking. In this case, we can click `Force` to skip handshaking and start downloading immediately.

3.2.2 Scripting & Mass Production

This downloader supports powerful scripting, making it suitable for mass production. In the script, two event handlers (functions) are required to be defined.

- `OnStartRun`

This event handler gets called when each round of downloading starts;

- `OnStartBin`

This event handler gets called when a binary starts downloading. Here, binary data can be modified on-the-fly before it is written into flash.

When “Batch” mode is enabled, this downloader keeps a counter which is increased by 1 after downloading finishes. This counter is shown as `Counter.Current` shown in Figure 3.2. There is also a variable called `Counter.Limit`. In “Batch” mode, before a new round of downloading starts, `Counter.Current` is checked against this limit, if it is *larger* than limit, “Batch” mode stops automatically. For example, if `Counter.Current` and `Counter.Limit` are set to 10 and 13 respectively, then “Batch” mode will run for 4 rounds in total, with `Counter.Current` equals to 10, 11, 12 and 13. After “Batch” mode stops, `Counter.Current` equals to 14.

The language used for scripting is *RemObjects Pascal Script*², which is quite similar to C, and easy to develop. Below is an simple but working example, in which, the batch round number (`BatchCounter`) is written to a fixed location in the binary.

²<https://github.com/remobjects/pascalscript>

```
// we can use constants
const
    BD_ADDR_ADDR = $1;

// BatchCounter is just Counter.Current
procedure OnStartRun(const BatchCounter: Integer; var Abort: Boolean);
begin
    // Use *Print* for logging and debugging
    Print('OnStartRun %d', [BatchCounter]);
    // we can abort downloading by assigning True to *Abort*
    // Abort := True;
end;

procedure OnStartBin(const BatchCounter, BinIndex: Integer;
    var Data: TBytes; var Abort: Boolean);
begin
    // Note that BinIndex counts from 1 (not 0), just as shown on GUI
    if BinIndex <> 2 then Exit;
    // We can modify binary data before it is downloaded into flash
    Data[BD_ADDR_ADDR + 0] := BatchCounter and $FF;
    Data[BD_ADDR_ADDR + 1] := (BatchCounter shr 8) and $FF;
    Data[BD_ADDR_ADDR + 2] := (BatchCounter shr 8) and $FF;
end;
```

3.2.3 Flash Read Protection

To protect illegal access of data & program stored in flash, 918xx has a read-protection mechanism. Once read-protection is enabled, JTAG/SW and this downloader can not be able to access flash any more. To re-enable JTAG/SW debugging functionality and downloading, the read-protection must be turned off by a procedure called *unlock*. Flash data is erased in this procedure.

Once the app is ready to ship, and it is decided that data & program must be protected from illegal access, just enable “Read Protection” as shown in Figure 3.2. To download program into a read protected, check *Unlock Before Download* option. As flash data is erased during *unlocking*, do not forget to re-download platform binary.

All configurations are stored in an *ini* file.

3.2.4 Python Version

SDK also provides a Python version downloader (*icsdw.py*). It’s open source and easy to be integrated with other tools.

3.3. TRACER

This version is written in Python 3. It uses PySerial³ package to access serial port, so run “pip install pyserial” to install the package.

Python downloader shares the same *ini* file with only one exception: Scripting. The GUI downloader stores *RemObjects Pascal* source code with key named “*script*” in section “*options*”, while the python version stores the path to a user module. The path can be a full path or a relative path (relative to the location of the *ini* file).

In the user module, two methods are required to be defined to handle events as in the GUI downloader, `on_start_run` & `on_start_bin`. Below is an example, in which, the batch round number (`batch_counter`) is written to a fixed location in #2 binary.

```
# return abort_flag
def on_start_run(batch_counter: int):
    return False

# return abort_flag, new_data
def on_start_bin(batch_counter: int, bin_index: int, data: bytes):
    if bin_index != 2:
        return False, data
    ba = bytearray(data)
    addr = batch_counter.to_bytes(4, 'little')
    ba[1:5] = addr
    return False, bytes(ba)
```

3.3 Tracer

Tracer is the visual tool for inspecting recorded Trace data introduced in Debugging & Tracing.

To limit items drawn on screen, Tracer breaks trace data into frames. Each frame has a length of 5sec. When a frame is selected, besides the current frame, the previous and the next one are also shown for continuity.

Graph shows all trace data visually. By clicking an item in **Graph**, detailed information is decoded and shown in **Message Decoder** and **Message Hex Viewer**. **Graph** supports some of CAD operations, such as zooming, panning, measuring, etc. Checkout menu Help -> About for detailed information. (Figure 3.3)

To help analyzing app & high layer issues, ingTrace can generate MSC (message sequence chart) for each connection. While **Graph** emphasizes on timing between events, MSC emphasizes on procedure and fits better for protocol analysis. Message can be decoded by clicking on the [+] mark (Figure 3.4).

³<https://pypi.org/project/pyserial/>

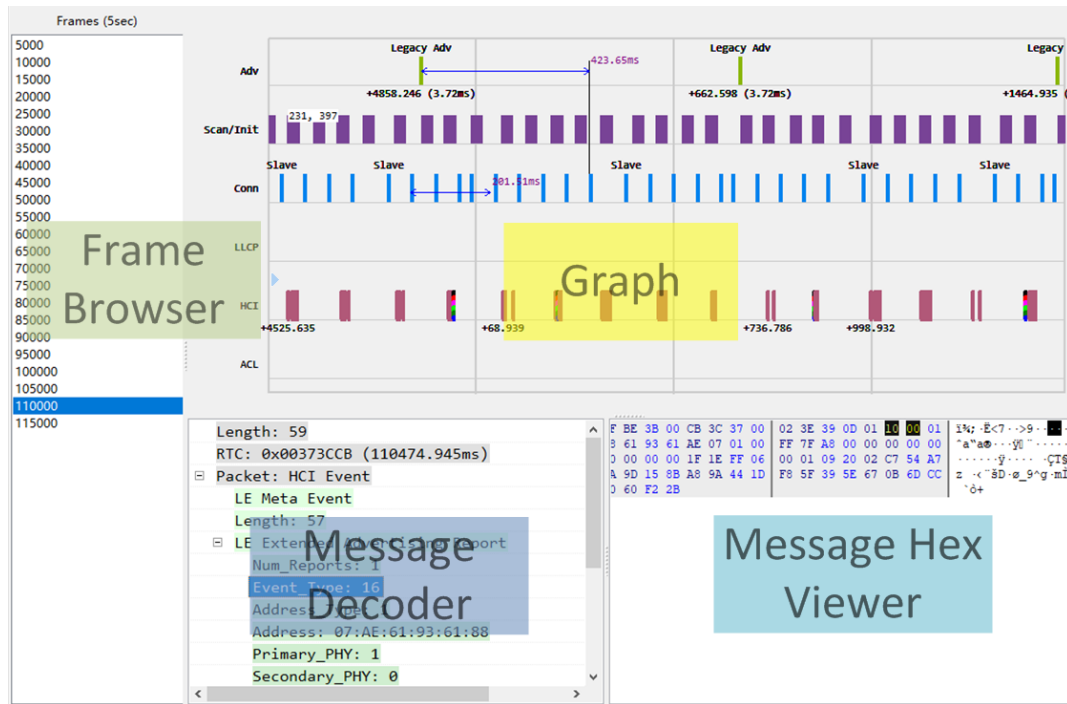


Figure 3.3: Tracer Main UI

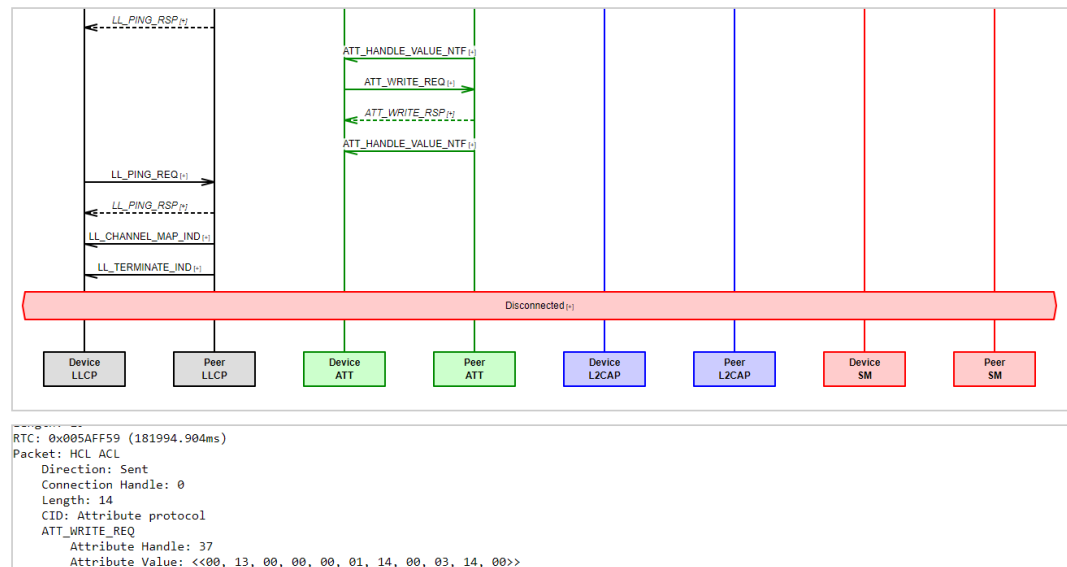


Figure 3.4: MSC Generated by Tracer

3.4 Axf Tool

Axf Tool is a command line tool analyzing executables and memory dump, which can be invoked from popup menu on a project in Wizard. It has several functionalities:

- **stack-usage:** Statically analyze stack usage, and report call chains with top N maximum stack depth.
- **bt-api-thread-safety:** Audit the usage of Bluetooth API, and check thread confinement.
- **call-stack:** Try to recover call stack from memory dump.
- **history:** Give a brief history of BLE activities.
- **check-heap:** Try to check for errors in heaps.
- **check-task:** Runtime check of FreeRTOS tasks with the help of dump.

Use `axf_tool.exe help {function}` to get help on a specific functionality.

Chapter 4

Dive Into SDK

This chapter discusses some important topics that are critical to use SDK efficiently.

4.1 Memory Management

There are mainly three type of memory management methods:

1. Statically allocated global variables
2. Dynamically allocated and freed on stack
3. Manually allocated and freed on heap



RAM is shared between platform and user applications. When a new project is created by wizard, RAM settings is configured properly. Developers are not suggested to modify these settings.

4.1.1 Global Variables

This is the *recommended* way to define variables that have a full life span in the app. They are allocated in the fixed location and their content can be checked easily in debugger.

4.1.2 Using Stack

For variables that are only used within a limited scope, such as a function, we can allocate them on stack.

Care must be taken that size of stack is limited, and it might overflow if too much memory is allocated.

1. The `app_main` function & interrupts serving routines shares the same global stack with platform's `main` function.

For RTOS bundles, this stack is defined in platform binaries as 1024 bytes, and can be replaced by a user defined one with the help of `platform_install_isr_stack`.

For “NoOS” bundles, this stack is defined in app binary as usual.

2. Callback functions registered into Bluetooth stack shares the same task stack with the stack task, whose size is defined as 1024 bytes, and about half is left to be used by app.
3. Developers can create new tasks by calling RTOS APIs. In these cases, stack size should be carefully examined.



Use tools to check required stack maximum depth of functions.

4.1.3 Using Heap

Generally, heap is not a recommended way for memory management in embedded applications. There are several cons included but not limited to:

- Space Overhead
Some bytes are *wasted* to store extra information and extra program.
- Time Overhead
It costs cycles to allocate and free memory blocks.
- Fragmentation

Based on these considerations, the heap used by `malloc` & `free` has been totally disabled by setting its size to 0. If such heap is *TRULY* required, it can be re-enabled by changing its size to a proper value when creating projects. Be sure to check follow alternatives before using `malloc` & `free`:

- Use global variables
- Use memory pool¹
This is probably the choice for most cases.
- Use FreeRTOS's heap and memory functions, `pvPortMalloc` & `pvPortFree`

Note that this heap is used by platform & FreeRTOS itself, and it may not have too much free space left for apps. The standard `malloc` & `free` can be configured to be overridden and backed by `pvPortMalloc` & `pvPortFree` when setting up heap in Wizard. Once overridden, the allocator from `libc` is omitted, and `malloc` & `free` are implemented by `pvPortMalloc` & `pvPortFree` respectively.

¹https://en.wikipedia.org/wiki/Memory_pool

4.2 Multitasking

It is recommend to have a check on *Mastering the FreeRTOS™ Real Time Kernel*. Some tips:

1. Do not do too much processing in interrupt handlers, but defer it to tasks as soon as possible
2. Callback functions registered into Bluetooth stack are executed in the context of the stack task, so do not do too much processing in these functions either
3. Use message passing function `btstack_push_user_msg` or other special functions² to get synchronized with Bluetooth stack (see Inter-task Communication)

4.3 Interrupt Management

To create traditional ISR for interrupts, apps only need to register callback functions through a platform API `platform_set_irq_callback`.

Apps can use following APIs to modify interrupts configuration and states:

- `NVIC_SetPriority`

Note that the highest allowed priority is `configLIBRARY_MAX_SYSCALL_INTERRUPT_PRIORITY + 2`, i.e. that priority parameter must be *larger* than or *equal* to this value, indicating a *lower* or *equal* priority.

- `NVIC_EnableIRQ`
- `NVIC_DisableIRQ`
- `NVIC_ClearPendingIRQ`
- etc...

4.4 Power Management

In most case, platform manages the power saving feature of ING918xx/ING9186xx SoC automatically and tries the minimize the power consumption in all circumstances, with only one exception, *deep sleep*.

In deep sleep, all components, except those required for power saving control and real-time clocks, are powered down. Some peripherals may be used by apps, and platform does not know how to configure them. So, apps have to get involved in the waking up process after deep sleep. Platform will also check with app if deep sleep is allowed, and fall back to less aggressive power saving modes when deep sleep is not allowed.

²`btstack_push_user_runnable`. See *Thread Safety in Developer's Guide for Bluetooth LE*.

To use deep sleep, two callback functions are needed, see `platform_set_evt_callback`. To ease development & debug, power saving can be turned on or off by calling `platform_config`.

Besides the above automatic power management schema, apps can also shutdown the whole system and reboot after a specified duration. In shutdown state the whole system has the least power consumption. See `platform_shutdown`. In shutdown state, a portion of data can be kept optionally at the cost of a little more power consumption. In case of only a little piece of data needs to be kept, SDK provides a pair of APIs for this, `platform_write_persistent_reg` and `platform_read_persistent_reg`.

4.5 CMSIS API

SDK tries to encapsulate CMSIS APIs to ease the development. Be careful when calling these APIs in apps as it may affect the platform program.

Following operations are strictly forbidden:

1. Changing the vector table offset register.
2. Modify configurations of internal interrupts.

4.6 Debugging & Tracing

Besides online debugging, SDK provides two methods to assist debugging.

1. `printf`

`printf` is the most convenient way to check program's behaviour. Wizard can generate necessary code to use `printf`.

2. Trace

Internal state & HCI messages can be recorded through this trace mechanism. Wizard can generate necessary code to use trace, too. There are several types of trace data, which are predefined and can't be changed. Which types of trace data are going to be recorded is programmable. Use

Tracer to view the recorded trace data.

Table 4.1: Comparison of `printf` and Trace

Debug Option	Pros	Cons
<code>printf</code>	Universal	<i>slow</i>
Trace	Binary data, fast	Data types are predefined

Both `printf` and trace can be directed to UART ports or SEGGER RTT³. Table 4.2 is a comparison of these two transport options.

Table 4.2: Comparison of UART and SEGGER RTT

Transport Option	Pros	Cons
UART	Universal, easy to use	Slower, consume more CPU cycles
SEGGER RTT	Fast	J-Link is required, hard to capture power up log

4.6.1 Tips on SEGGER RTT

- Use J-LINK RTT Viewer to view `printf` outputs in real-time.
- Use J-LINK RTT Logger to record trace outputs to files.

This logger will ask for the settings of RTT. Device name is “CORTEX-M3”. Target interface is “SWD”. RTT Control Block address is the address of a variable named `_SEGGER_RTT`, which can be found in `.map` file. RTT channel index is 0. Blow is a sample session.

```
-----
Device name. Default: CORTEX-M3 >
Target interface. > SWD
Interface speed [kHz]. Default: 4000 kHz >
RTT Control Block address. Default: auto-detection > 0x2000xxxx
RTT Channel name or index. Default: channel 1 > 0
Output file. Default: RTT_<ChannelName>_<Time>.log >

-----
Connected to:
  J-Link ...
  S/N: ...

Searching for RTT Control Block...OK. 1 up-channels found.
RTT Channel description:
  Index: 0
  Name: Terminal
  Size: 500 bytes.

Output file: .....log

Getting RTT data from target. Press any key to quit.
```

³<https://www.segger.com/products/debug-probes/j-link/technology/about-real-time-transfer/>

Alternatively, this tool can be called from command line. Address of `_SEGGER_RTT` can be specified by a range, and the tool will search for it automatically. For examples,

```
JLinkRTTLogger.exe -If SWD -Device CORTEX-M3 -Speed 4000
-RTTSearchRanges "0x20005000 0x8000"
-RTTChannel 0
file_name
```

4.6.2 Memory Dump

We are committed to delivery high quality platform binary. If an assertion or hard fault had occurred in platform binary, it is suggested to create a full memory dump and save all registers. Check out Developers' Guide for addresses of all memory regions. After a dump is got, use Axf Tool to analyze it. If the problem can not be resolved, contact technical support.

Memory can be dumped through debuggers:

- Keil μ Vision

In debug session, open the Command Window, use `save` to save each memory region. Take ING918xx as an example:

```
save sysm.hex 0x20000000,0x2000FFFF
save share.hex 0x400A0000,0x400AFFFF
```

- J-Link Commander

Once connected, use `regs` to shows all current register values, and `savebin` to save target memory into binary file. Take ING918xx as an example:

```
savebin sysm.bin 0x20000000 0x10000
savebin share.bin 0x400A0000 0x10000
```

- IAR Embedded Workbench

In debug session, open a Memory window, and select "Memory Save ..." from popup menu.

- Rowley Crossworks for ARM & SEGGER Embedded Studio for ARM

In debug session, open a Memory window, for each memory region:

1. Fill in the start address and size;
2. Use "Memory Save ..." from popup menu.

- GDB (GNU Arm Embedded Toolchain)

In GDB debug session, use `dump` command to save each memory region.

Memory can be also dumped by a piece of specific code. For example, in the event handler of `PLATFORM_CB_EVT_ASSERTION`, dump all memory data to UART.

Chapter 5

Platform API Reference

This chapter describes the platform API.

5.1 Configuration & Information

5.1.1 `platform_config`

Configure some platform functionalities.

5.1.1.1 Prototype

```
void platform_config(const platform_cfg_item_t item,  
                    const uint32_t flag);
```

5.1.1.2 Parameters

- `const platform_cfg_item_t item`

Specify the item to be configured. It can be one of following values:

- `PLATFORM_CFG_LOG_HCI`: Print host controller interface messages. Default: Disabled. Only available on ING918. HCI logging is only intended for a quick check on BLE behavior. Please consider using tracing (see Debugging & Tracing).
- `PLATFORM_CFG_POWER_SAVING`: Power saving. Default: Disabled.
- `PLATFORM_CFG_TRACE_MASK`: Bit map of selected trace items. Default: 0.

```
typedef enum
{
    PLATFORM_TRACE_ID_EVENT           = 0,
    PLATFORM_TRACE_ID_HCI_CMD         = 1,
    PLATFORM_TRACE_ID_HCI_EVENT       = 2,
    PLATFORM_TRACE_ID_HCI_ACL         = 3,
    PLATFORM_TRACE_ID_LLCP            = 4,
    //..
} platform_trace_item_t;
```

- PLATFORM_CFG_RT_RC_EN: Enable/Disable real-time RC clock. Default: Enabled.
- PLATFORM_CFG_RT_OSC_EN: Enable/Disable real-time crystal oscillator. Default: Enabled.
- PLATFORM_CFG_RT_CLK: Real-time clock selection. Flag is platform_rt_clk_src_t. Default: PLATFORM_RT_RC

```
typedef enum
{
    PLATFORM_RT_OSC,           // External real-time crystal oscillator
    PLATFORM_RT_RC             // Internal real-time RC clock
} platform_rt_clk_src_t;
```

For ING918, When modifying this configuration, both RT_RC and RT_OSC should be **enabled** and **run**:

- * For RT_OSC, wait until status of RT_OSC is OK;
- * For RT_RC, wait 100µs after enabled.

And wait another 100µs before disabling the unused clock.

- PLATFORM_CFG_RT_CLK_ACC: Configure real-time clock accuracy in ppm.
- PLATFORM_CFG_RT_CALI_PERIOD: Real-time clock auto-calibration period in seconds. Default: 3600 * 2 (2 hours).
- PLATFORM_CFG_DEEP_SLEEP_TIME_REDUCTION: Sleep time reduction (deep sleep mode) in micro seconds. ING918 Default: ~550µs.
- PLATFORM_CFG_SLEEP_TIME_REDUCTION: Sleep time reduction (other sleep mode) in micro seconds. ING918 Default: ~450µs.
- PLATFORM_CFG_LL_DBG_FLAGS: Link layer flags. Combination of bits in ll_cfg_flag_t. Check out *Programmers' Guide on Bluetooth Low Energy*¹ for details.
- PLATFORM_CFG_LL_LEGACY_ADV_INTERVAL: Link layer legacy advertising intervals for high duty cycle (higher 16bits) and normal duty cycle (lower 16bits) in micro seconds. Default for high duty cycle: 1250; default for normal duty cycle: 1500.

¹https://ingchips.github.io/application-notes/pg_ble_stack_cn/index.html

- PLATFORM_CFG_RTOS_ENH_TICK: Enable enhanced ticks for RTOS. Default: Disabled. When enabled, ticks becomes more accurate when peripherals are generating interrupt requests frequently.
- PLATFORM_CFG_LL_DELAY_COMPENSATION: Delay compensation for Link Layer. When system runs at a lower frequency, more time (in μs) is needed by Link Layer to schedule RF tasks. For example, if ING916 runs at 24MHz, a compensation of $\sim 2500 \mu\text{s}$ is needed.
- PLATFORM_CFG_24M_OSC_TUNE: 24M OSC tuning. Not available for ING918. For ING916, tuning value may vary in $0x16 \sim 0x2d$.
- PLATFORM_CFG_ALWAYS_CALL_WAKEUP: Always trigger PLATFORM_CB_EVT_ON_DEEP_SLEEP_WAKEUP event no matter if deep sleep procedure is completed or aborted (failed). Default for ING918: Disabled for backward compatibility. Default for ING916: Enabled.
- PLATFORM_CFG_FAST_DEEP_SLEEP_TIME_REDUCTION: Sleep time reduction for fast deep sleep mode in micro seconds. Not available for ING918. This configuration must be less or equal to PLATFORM_CFG_DEEP_SLEEP_TIME_REDUCTION. When equal to PLATFORM_CFG_DEEP_SLEEP_TIME_REDUCTION, fast deep sleep mode is not used. Default for ING916: $\sim 2000 \mu\text{s}$.
- PLATFORM_CFG_AUTO_REDUCE_CLOCK_FREQ: Automatically reduce CPU clock frequency in these circumstances:
 - * The default IDLE procedure,
 - * When entering sleep modes.Not available for ING918. Default for ING916: Enabled.

- `const uint32_t flag`

To disable or enable an item. It can be one of following values:

- PLATFORM_CFG_ENABLE
- PLATFORM_CFG_DISABLE

5.1.1.3 Return Value

Void.

5.1.1.4 Remarks

Void.

5.1. CONFIGURATION & INFORMATION

5.1.1.5 Example

```
// On ING918, Enable HCI logging  
platform_config(PLATFORM_CFG_LOG_HCI, PLATFORM_CFG_ENABLE);
```

5.1.2 platform_get_version

Get version number of platform.

5.1.2.1 Prototype

```
const platform_ver_t *platform_get_version(void);
```

5.1.2.2 Parameters

Void.

5.1.2.3 Return Value

Pointer to platform_ver_t.

5.1.2.4 Remarks

Platform version number has three parts, major, minor and patch:

```
typedef struct platform_ver  
{  
    unsigned short major;  
    char minor;  
    char patch;  
} platform_ver_t;
```

5.1.2.5 Example


```
const platform_ver_t *ver = platform_get_version();  
printf("Platform version: %d.%d.%d\n", ver->major, ver->minor, ver->patch);
```

5.1.3 platform_read_info

Read platform information.

5.1.3.1 Prototype

```
uint32_t platform_read_info(const platform_info_item_t item);
```

5.1.3.2 Parameters

- const platform_info_item_t item

Information item.

- PLATFORM_INFO_RT_OSC_STATUS: Read status of real-time crystal oscillator. Value 0: not OK; Non-0: OK.

For ING916: this clock become running **after** selected as real time clock source.

- PLATFORM_INFO_RT_CLK_CALI_VALUE: Read current real time clock calibration result.
- PLATFORM_INFO_IRQ_NUMBER: Get the underline IRQ number of a platform IRQ.
For example, get the underline IRQ number of UART0:

```
platform_read_info(  
    PLATFORM_INFO_IRQ_NUMBER + PLATFORM_CB_IRQ_UART0)
```

5.1.3.3 Return Value

Value of the information item.

5.1.3.4 Remarks

Void.

5.1.3.5 Example

```
platform_read_info(PLATFORM_INFO_RT_OSC_STATUS);
```

5.1.4 platform_switch_app

Switch to a secondary app.

5.1.4.1 Prototype

```
void platform_switch_app(const uint32_t app_addr);
```

5.1.4.2 Parameters

- `const uint32_t app_addr`
Entry address of the secondary app.

5.1.4.3 Return Value

Void.

5.1.4.4 Remarks

When calling this function, the code after it will not be executed.

5.1.4.5 Example

```
platform_switch_app(0x80000);
```

5.2 Events & Interrupts

5.2.1 platform_set_evt_callback_table

Register a callback function table for all platform events.

5.2.1.1 Prototype

```
void platform_set_evt_callback_table(  
    const platform_evt_cb_table_t *table);
```

5.2.1.2 Parameters

- `const platform_evt_cb_table_t *table`
Address of the callback function table.

5.2.1.3 Return Value

Void.

5.2.1.4 Remarks

This function shall only be called in `app_main`. If `platform_set_evt_callback` is used, this function shall not be used.

Comparing to `platform_set_evt_callback`, use this function can save a block of RAM of `sizeof(platform_evt_cb_table_t)` bytes.

5.2.1.5 Example

```
static const platform_evt_cb_table_t evt_cb_table =  
{  
    .callbacks = {  
        [PLATFORM_CB_EVT_HARD_FAULT] = {  
            .f = (f_platform_evt_cb)cb_hard_fault,  
        },  
        [PLATFORM_CB_EVT_PROFILE_INIT] = {  
            .f = setup_profile,  
        },  
        // ...  
    }  
};  
  
int app_main()
```

```
{  
    // ...  
    platform_set_evt_callback_table(&evt_cb_table);  
    // ...  
}
```

5.2.2 platform_set_irq_callback_table

Register a callback function table for all platform interrupt requests.

5.2.2.1 Prototype

```
void platform_set_irq_callback_table(  
    const platform_irq_cb_table_t *table);
```

5.2.2.2 Parameters

- `const platform_irq_cb_table_t *table`
Address of the callback function table.

5.2.2.3 Return Value

Void.

5.2.2.4 Remarks

This function shall only be called in `app_main`. If `platform_set_irq_callback` is used, this function shall not be used.

Comparing to `platform_set_irq_callback`, use this function can save a block of RAM of `sizeof(platform_irq_cb_table_t)` bytes.

5.2.2.5 Example

```
static const platform_irq_cb_table_t irq_cb_table =
{
    .callbacks = {
        [PLATFORM_CB_IRQ_UART0] = {
            .f = (f_platform_irq_cb)cb_irq_uart,
            .user_data = APB_UART0
        },
        // ...
    }
};

int app_main()
{
    // ...
    platform_set_irq_callback_table(&irq_cb_table);
    // ...
}
```

5.2.3 platform_set_evt_callback

Registers callback functions to platform events.

5.2.3.1 Prototype

```
void platform_set_evt_callback(platform_evt_callback_type_t type,
                              f_platform_evt_cb f,
                              void *user_data);
```

5.2.3.2 Parameters

- platform_evt_callback_type_t type
Specify the event type to which the callback function is registered. It can be one of following values:
 - PLATFORM_CB_EVT_PUTC: Output ASCII character event
When platform want to output ASCII characters for logging, this event is fired. Parameter void *data passed into the callback function is casted from char *.
Wizard can automatically generate code that redirects platform log to UART if Print to UART is checked on Common Function when creating a new project.

- PLATFORM_CB_EVT_PROFILE_INIT: Profile initialization event

When host initializes, this event is fired to request app to initialize GATT profile.

Wizard can automatically generate code for this event when creating a new project.

- PLATFORM_CB_EVT_ON_DEEP_SLEEP_WAKEUP: Wakeup from deep sleep event

When waking up from deep sleep, this event is fired. During deep sleep, peripheral interfaces (such as UART, I2C, etc) are all powered off. So, when waking up, these interfaces might need to be re-initialized.

Wizard can automatically generate code for event if Deep Sleep is checked on Common Function when creating a new project.

Parameter `void *data` passed into the callback function is casted from `platform_wakeup_call_info_t *`.

RTOS is not resumed yet, some RTOS APIs are not usable; Some platform APIs (such as `platform_get_us_time`) might be unusable either.

- PLATFORM_CB_EVT_ON_IDLE_TASK_RESUMED: OS is fully resumed from power saving modes.

The callback is invoked after `PLATFORM_CB_EVT_ON_DEEP_SLEEP_WAKEUP` if its reason is `PLATFORM_WAKEUP_REASON_NORMAL`. For NoOS variants, the callback is invoked by `platform_os_idle_resumed_hook()`. This event is different with `PLATFORM_CB_EVT_ON_DEEP_SLEEP_WAKEUP`:

- * all OS functionalities are resumed (For NoOS variants, this depends on the proper use of `platform_os_idle_resumed_hook()`)
- * all platform APIs are functional
- * callback is invoked in the idle task.

Parameter `void *data` is always `NULL`.

- PLATFORM_CB_EVT_QUERY_DEEP_SLEEP_ALLOWED: Query if deep sleep is allowed event

When platform prepares to enter deep sleep mode, this event is fired to query app if deep sleep is allow at this moment. Callback function can reject deep sleep by returning 0, and allow it by returning a non-0 value.

Wizard can automatically generate code for event if Deep Sleep is checked on Common Function when creating a new project.

- PLATFORM_CB_EVT_HARD_FAULT: Hard fault occurs

When hard fault occurs, this event is fired. Parameter `void *data` passed into the callback function is casted from `hard_fault_info_t *`. If this callback is not defined, CPU enters a dead loop when hard fault occurs.

- PLATFORM_CB_EVT_ASSERTION: Software assertion fails

When software assertion fails, this event is fired. Parameter `void *data` passed into the callback function is casted from `assertion_info_t *`. If this callback is not defined, CPU enters a dead loop when assertion occurs.

- PLATFORM_CB_EVT_LLE_INIT: Link layer engine initialized.

When link layer engine initialized, this event is fired.

- PLATFORM_CB_EVT_HEAP_OOM: Out of memory.
When allocation on heap fails (heap out of memory), this event is fired. If this event is fired and no callback is defined, CPU enters a dead loop.
- PLATFORM_CB_EVT_TRACE: Trace output.
When a trace item is emitted, this event is fired. Apps can define a callback function for this event to save or log trace output. param to the callback is casted from platform_trace_evt_t * (See Debugging & Tracing).

```
typedef struct
{
    const void *data1;
    const void *data2;
    uint16_t len1;
    uint16_t len2;
} platform_evt_trace_t;
```

A trace item is a combination of data1 and data2. Note:

1. len1 or len2 might be 0, but not both;
2. If callback function finds that it can't output data of size len1 + len2, then, both data1 & data2 should be discarded to avoid trace item corruption.

- PLATFORM_CB_EVT_EXCEPTION: Hardware exceptions.
Parameter void *data is casted from platform_exception_id_t *.
- PLATFORM_CB_EVT_IDLE_PROC: Customized IDLE procedure.
See “Programmer’s Guide - Power Saving”².
- PLATFORM_CB_EVT_HCI_RECV: Take over HCI and isolate the built-in Host completely.
When defined:

- * HCI events and ACL data are passed to this callback;
- * PLATFORM_CB_EVT_PROFILE_INIT is ignored.

Parameter void *data is casted from const platform_hci_recv_t *. See also platform_get_link_layer_intf.

- PLATFORM_CB_EVT_BEFORE_DEEP_SLEEP: Platform is entering deep sleep mode
When platform decides to enter deep sleep mode, this event is emitted. Apps can take this opportunity to configure peripherals. The callback function shall be simple and return as soon as possible.
Parameter void *data is casted from platform_sleep_category_b_t, representing the selected sleep mode.

- f_platform_evt_cb f

The callback function registered to event type. f_platform_evt_cb is:

²https://ingchips.github.io/application-notes/pg_power_saving_en/

```
typedef uint32_t (*f_platform_evt_cb)(void *data, void *user_data);
```

- void *user_data

This is passed to callback function's user_data unchanged.

5.2.3.3 Return Value

Void.

5.2.3.4 Remarks

It is not required to register callback functions to each event.

If no callback function is registered to PLATFORM_CB_EVT_PUTC event, all platform log including platform_printf is discarded.

If no callback function is registered to PLATFORM_CB_EVT_PROFILE_INIT event, BLE device's profile is empty.

If no callback function is registered to PLATFORM_CB_EVT_ON_DEEP_SLEEP_WAKEUP event, app will not be notified when waking up from deep sleep.

If no callback function is registered to PLATFORM_CB_EVT_QUERY_DEEP_SLEEP_ALLOWED event, deep sleep is *disabled*.

5.2.3.5 Example

```
uint32_t cb_putc(char *c, void *dummy)
{
    // TODO: output char c to UART
    return 0;
}

.....

platform_set_evt_callback(PLATFORM_CB_EVT_PUTC, (f_platform_evt_cb)cb_putc,
                          NULL);
```

5.2.4 platform_set_irq_callback

Registers callback functions to interrupt requests.

Developers do not need to define IRQ handlers in apps, but use callback functions instead.

5.2.4.1 Prototype

```
void platform_set_irq_callback(platform_irq_callback_type_t type,  
                              f_platform_irq_cb f,  
                              void *user_data);
```

5.2.4.2 Parameters

- platform_irq_callback_type_t type

Specify the IRQ type to which the callback function is registered. Values vary for different chip families. Take ING918 as an example:

```
PLATFORM_CB_IRQ_RTC,  
PLATFORM_CB_IRQ_TIMER0,  
PLATFORM_CB_IRQ_TIMER1,  
PLATFORM_CB_IRQ_TIMER2,  
PLATFORM_CB_IRQ_GPIO,  
PLATFORM_CB_IRQ_SPI0,  
PLATFORM_CB_IRQ_SPI1,  
PLATFORM_CB_IRQ_UART0,  
PLATFORM_CB_IRQ_UART1,  
PLATFORM_CB_IRQ_I2C0,  
PLATFORM_CB_IRQ_I2C1
```

- f_platform_irq_cb f

The callback function registered to IRQ type. f_platform_irq_cb is:

```
typedef uint32_t (*f_platform_irq_cb)(void *user_data);
```

- void *user_data

This is passed to callback function's user_data unchanged.

5.2.4.3 Return Value

Void.

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5.2.4.4 Remarks

When a callback function is registered to an IRQ, the IRQ is enabled automatically. See also `platform_enable_irq`.

5.2.4.5 Example

```
uint32_t cb_irq_uart0(void *dummy)
{
    // TODO: add UART0 IRQ handling code
    return 0;
}

.....

platform_set_irq_callback(
    PLATFORM_CB_IRQ_UART0,
    cb_irq_uart0,
    NULL);
```

5.2.5 `platform_enable_irq`

Enable or disable a specified IRQ.

5.2.5.1 Prototype

```
void platform_enable_irq(
    platform_irq_callback_type_t type,
    uint8_t flag);
```

5.2.5.2 Parameters

- `platform_irq_callback_type_t type`:
The IRQ to be configured.
- `uint8_t flag`:
Enable (1) or disable (0).

5.2.5.3 Return Value

Void.

5.2.5.4 Remarks

“Enabling” or “disabling” an interrupt here is from the perspective of CPU. Take UART as an example, UART itself has to be configured to generate interrupts for Rx, Tx, or timeout, which is out of the scope of this function.

5.2.5.5 Example

To enable the interrupt request from UART0:

```
platform_enable_irq(  
    PLATFORM_CB_IRQ_UART0,  
    1);
```

5.3 Clocks

See also “The Real-time Clock”³ in “Programmer’s Guide - Power Saving”⁴.

5.3.1 platform_calibrate_rt_clk

Calibrate real-time clock and get the calibration value.

5.3.1.1 Prototype

```
uint32_t platform_calibrate_rt_clk(void);
```

5.3.2 platform_rt_rc_auto_tune

Automatically tune the internal real-time RC clock, and get the tuning value.

For ING918, this function tunes the internal real-time RC clock to 50kHz⁵. For others, it tunes the internal real-time RC clock to 32768Hz.

³https://ingchips.github.io/application-notes/pg_power_saving_en/ch-api.html#the-real-time-clock

⁴https://ingchips.github.io/application-notes/pg_power_saving_en/

⁵Starting from v8.4.6. For elder version, 32768Hz is used.

5.3.2.1 Prototype

```
uint16_t platform_rt_rc_auto_tune(void);
```

5.3.2.2 Parameters

Void.

5.3.2.3 Return Value

The 16-bits tuning value.

5.3.2.4 Remarks

This function must be called if the app enables power saving mode, and the real-time RC clock is used as the clock source.

This operation costs ~250ms. It is recommended to call this once and store the returned value for later usage.

5.3.2.5 Example

```
// the simplest example: call this function in the  
// callback function of 'PLATFORM_CB_EVT_PROFILE_INIT'  
// without saving the returned value.  
uint32_t setup_profile(void *user_data)  
{  
    platform_rt_rc_auto_tune();  
    ...  
}
```

5.3.3 platform_rt_rc_auto_tune2

Automatically tune the internal real-time RC clock to a specific frequency, and get the tuning value.

5.3.3.1 Prototype

```
uint16_t platform_rt_rc_auto_tune2(  
    uint32_t target_frequency);
```

5.3.3.2 Parameters

- `uint32_t target_frequency`
Target frequency in Hertz.

5.3.3.3 Return Value

The 16-bits tuning value.

5.3.4 `platform_rt_rc_tune`

Tune internal the real-time RC clock with the tune value.

5.3.4.1 Prototype

```
void platform_rt_rc_tune(uint16_t value);
```

5.3.4.2 Parameters

- `uint16_t value`
Value used to tune the clock (returned by `platform_rt_rc_auto_tune`, or `platform_rt_rc_auto_tune2`)

5.3.4.3 Return Value

Void.

5.3.4.4 Remarks

void.

5.3.4.5 Example

```
platform_rt_rc_tune(value);
```

5.4 RF

5.4.1 platform_set_rf_clk_source

Select RF clock source. This function is for internal use.

5.4.2 platform_set_rf_init_data

Customize RF initialization data. This function is for internal use.

5.4.3 platform_set_rf_power_mapping

Power level is represented by an index internally. There is a power mapping table which lists the actual Tx power level of an index. Take ING918 as an example, power index is in a range of [0..63], and power mapping table is an array of 64 entries, each entry giving the Tx power level in 0.01 dBm.

For applications that need better power level control, actual power level can be measured for each index. Update the mapping with this function, then the stack can determine the proper index for a request power level.

5.4.3.1 Prototype

```
void platform_set_rf_power_mapping(  
    const int16_t *rf_power_mapping);
```

5.4.3.2 Parameters

- `const int16_t *rf_power_mapping`
The new power mapping table.

5.4.3.3 Return Value

Void.

5.4.3.4 Remarks

Void.

5.4.3.5 Example

```
static const int16_t power_mapping[] =
{
    -6337, // index 0: -63.37dBm
    // ...
    603    // index 63: 6.03dBm
};

platform_set_rf_power_mapping(
    power_mapping);
```

5.4.4 platform_patch_rf_init_data

Patch part of the internal RF initialization data. This function is for internal use.

5.5 Memory & RTOS

5.5.1 platform_call_on_stack

Call a function on a separate dedicated stack. This is useful when a function that uses a lot of stack needs to be called, occasionally.

5.5.1.1 Prototype

```
void platform_call_on_stack(
    f_platform_function f,
    void *user_data,
    void *stack_start,
    uint32_t stack_size);
```

5.5.1.2 Parameters

- `f_platform_function f`
The function to be called.
- `void *user_data`
User data to be passed to `f`.
- `void *stack_start`
Start (lowest) address of the dedicated stack.
- `uint32_t stack_size`
Size of the dedicated stack in bytes.

5.5.1.3 Return Value

Void.

5.5.1.4 Remarks

Although `stack_size` is provided, this function does not protect the stack from overwritten by `f`.

5.5.2 platform_get_current_task

Get the current task from which this API is called.

5.5.2.1 Prototype

```
platform_task_id_t platform_get_current_task(void);
```

5.5.2.2 Parameters

Void.

5.5.2.3 Return Value


```
typedef enum
{
    PLATFORM_TASK_CONTROLLER,
    PLATFORM_TASK_HOST,
    PLATFORM_TASK_RTOS_TIMER,
} platform_task_id_t;
```

5.5.2.4 Remarks

This API is only available in bundles with built-in RTOS.

5.5.3 platform_get_gen_os_driver

Get the generic OS driver. For “NoOS” variants, driver provided by app is returned; for bundles with built-in RTOS, an emulated driver is returned.

5.5.3.1 Prototype

```
const void *platform_get_gen_os_driver(void);
```

5.5.3.2 Parameters

Void.

5.5.3.3 Return Value

Return value is casted from `const gen_os_driver_t *`. Developers can cast the return value back to `const gen_os_driver_t *` and use API in it.

5.5.3.4 Remarks

`gen_os_driver_t` is an abstract layer over RTOS. Using API in it instead of RTOS API can make apps cross RTOS (independent of underlying RTOS).

5.5.4 platform_get_heap_status

Get current heap status, such as available size, etc.

5.5.4.1 Prototype

```
void platform_get_heap_status(platform_heap_status_t *status);
```

5.5.4.2 Parameters

- platform_heap_status_t *status
Heap status.

5.5.4.3 Return Value

Void.

5.5.4.4 Remarks

Heap status is defined as:

```
typedef struct
{
    uint32_t bytes_free;           // total free bytes
    uint32_t bytes_minimum_ever_free; // minimum of bytes_free from startup
} platform_heap_status_t;
```

5.5.4.5 Example

```
platform_heap_status_t status;
platform_get_heap_status(&status);
```

5.5.5 platform_get_task_handle

Get RTOS handle of a specific platform task.

5.5.5.1 Prototype

```
uintptr_t platform_get_task_handle(  
    platform_task_id_t id);
```

5.5.5.2 Parameters

- platform_task_id_t id
Platform task ID.

5.5.5.3 Return Value

Task handle if such task is known to platform else 0. For example, in the case of “NoOS” variants, platform does not know the handle of PLATFORM_TASK_RTOS_TIMER, so 0 is returned.

5.5.6 platform_install_task_stack

Install a new RTOS stack for a specific platform task.

Use this to enlarge stack when the default stack size is not enough for internal tasks. For example, user developed RTOS timer callbacks might require a larger stack space.

Developers can check RTOS documentation for how to check stack usages. For example, uxTaskGetStackHighWaterMark in FreeRTOS is used to query how close a task has come to overflowing the stack space allocated to it.

5.5.6.1 Prototype

```
void platform_install_task_stack(  
    platform_task_id_t id,  
    void *start,  
    uint32_t size);
```

5.5.6.2 Parameters

- platform_task_id_t id
Task identifier.

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- void *start

Start (lowest) address of the stack. Address shall be properly aligned for underlying CPU.

- uint32_t size

Size of the new stack in bytes.

5.5.6.3 Return Value

Void.

5.5.6.4 Remarks

This function shall only be called in `app_main`.

For NoOS variants, RTOS stacks can be replaced (modify its size, etc) when implementing the generic OS interface.

5.5.7 platform_install_isr_stack

Install a new stack for ISR.

5.5.7.1 Prototype

```
void platform_install_isr_stack(void *top);
```

5.5.7.2 Parameters

- void *top

Top of the new stack, which must be properly aligned for the underlying CPU.

5.5.7.3 Return Value

Void.

5.5.7.4 Remarks

In case apps need a much larger stack than the default one in ISR, a new stack can be installed to replace the default one.

This function is only allowed to be called in `app_main`. The new stack is put into use after `app_main` returns.

5.5.7.5 Example

```
uint32_t new_stack[2048];
...
platform_install_isr_stack(new_stack + sizeof(new_stack) / sizeof(new_stack[0]));
```

5.6 Time & Timers

API for reading current time (timer counter):

- platform_get_timer_counter
- platform_get_us_time

API for using timers with 625µs resolution:

- platform_set_abs_timer
- platform_set_timer
- platform_delete_timer

API for using timer with 1µs resolution:

- platform_create_us_timer
- platform_cancel_us_timer

Both types of timers can be used with power saving, i.e. it just works as expected when power saving is enabled. A comparison of of these two types of timers is shown in Table 5.1.

Table 5.1: Two Types of Platform Timers

Type	625µs resolution	1µs resolution
Callback	Invoked from a task-like context	Invoked from an ISR
Identifier	Callback function pointer	Timer handle

5.6.1 platform_cancel_us_timer

Cancel a platform timer previously created by platform_create_us_timer.

5.6.1.1 Prototype

```
int platform_cancel_us_timer(  
    platform_us_timer_handle_t timer_handle);
```

5.6.1.2 Parameters

- `platform_us_timer_handle_t timer_handle`
Handle of the timer.

5.6.1.3 Return Value

This function returns 0 if the specified time is canceled successfully. Otherwise, a non-0 value is returned, which also means the callback function of the timer is executing.

5.6.2 `platform_create_us_timer`

Setup a single-shot platform timer with 1 microsecond (μ s) resolution.

5.6.2.1 Prototype

```
platform_us_timer_handle_t platform_create_us_timer(  
    uint64_t abs_time,  
    f_platform_us_timer_callback callback,  
    void *param);
```

5.6.2.2 Parameters

- `uint64_t abs_time`
When `platform_get_us_timer() == abs_time`, the callback is invoked.
- `f_platform_us_timer_callback callback`
The callback function. The signature is:

```
typedef void * (* f_platform_us_timer_callback)(  
    platform_us_timer_handle_t timer_handle,  
    uint64_t time_us,  
    void *param);
```

Where, `timer_handle` is the returned value of `platform_create_us_timer`, i.e., `time_us` is current value of `platform_get_us_timer` when invoking the callback, and `param` is the user parameter when creating this timer.

- `void *param`
User parameter.

5.6.2.3 Return Value

This function returns a handle of the created timer. A non-NULL value is returned when the timer is successfully created. Otherwise, NULL is returned.

5.6.2.4 Remarks

Although `abs_time` is in microsecond (μ s), callback is **not guaranteed** to be invoked with such resolution.

This type of timers are much like `platform_set_timer`, except that:

1. resolution is higher;
2. callback is invoked in the context of an ISR.

DO NOT call `platform_create_us_timer` again in callback.

5.6.3 platform_delete_timer

Delete a previously platform timer created by `platform_set_timer` or `platform_set_abs_timer`.

5.6.3.1 Prototype

```
void platform_delete_timer(f_platform_timer_callback callback)
```

5.6.3.2 Parameters

- `f_platform_timer_callback callback`
The callback function, which is also an identifier for the timer.

5.6.3.3 Return Value

Void.

5.6.3.4 Remarks

When calling this function, the callback might already be queued for invoking in the task. Therefore, the callback might still be invoked after this function is called.

5.6.4 platform_get_timer_counter

Read the counter of platform timer at 625 μ s resolution.

5.6.4.1 Prototype

```
uint32_t platform_get_timer_counter(void);
```

5.6.4.2 Parameters

Void.

5.6.4.3 Return Value

A full 32 bits value represents current counter, which is roughly `platform_get_us_time() / 625`.

5.6.5 platform_get_us_time

Read the internal time counting from BLE initialization.

5.6.5.1 Prototype

```
int64_t platform_get_us_time(void);
```

5.6.5.2 Parameters

Void.

5.6.5.3 Return Value

Value of the internal time counter counting at 1 μ s. This counter wraps around every ~21.8 years.

5.6.5.4 Remarks

This counter restarts after shutdown.

5.6.5.5 Example

```
uint64_t now = platform_get_us_time();
```

5.6.6 platform_set_abs_timer

Setup a single-shot platform timer triggered at an absolute time with 625µs resolution.

5.6.6.1 Prototype

```
void platform_set_abs_timer(  
    f_platform_timer_callback callback,  
    uint32_t abs_time);
```

5.6.6.2 Parameters

- `f_platform_timer_callback callback`
The callback function when the timer expired, and is called in a RTOS task-like⁶ context, but not an ISR.
- `uint32_t abs_time`
when `platform_get_timer_counter() == abs_time`, callback is invoked. If `abs_time` just passes `platform_get_timer_counter()`, callback is invoked immediately, for example, `abs_time` is `platform_get_timer_counter() - 1`.

5.6.6.3 Return Value

Void.

5.6.6.4 Remarks

This function always succeeds, except when running out of memory.

⁶It's called from the Controller task if existing.

5.6.6.5 Example

Use this function to emulate a periodic timer.

```
#define PERIOD 100
static uint32_t last_timer = 0;

void platform_timer_callback(void)
{
    last_timer += PERIOD;
    platform_set_abs_timer(platform_timer_callback, last_timer);

    // do periodic job
    // ...
}

last_timer = platform_get_timer_counter() + PERIOD;
platform_set_abs_timer(platform_timer_callback, last_timer);
```

5.6.7 platform_set_timer

Setup a single-shot platform timer after a delay from “now” with 625µs resolution.

5.6.7.1 Prototype

```
void platform_set_timer(
    f_platform_timer_callback callback,
    uint32_t delay);
```

5.6.7.2 Parameters

- f_platform_timer_callback callback

The callback function when the timer expired, and is called in a RTOS task-like context, but not an ISR.

- uint32_t delay

Time delay before the timer expires (unit: 625µs).

Valid Range: 0~0x7ffffff. When delay is 0, the timer is cleared.

5.6.7.3 Return Value

Void.

5.6.7.4 Remarks

This function always succeeds, except when running out of memory.

`platform_set_timer(f, 100)` is equivalent to:

```
platform_set_abs_timer(f,  
    platform_get_timer_counter() + 100);
```

`platform_set_timer(f, 0)` is equivalent to:

```
platform_delete_timer(f);
```

but not

```
platform_set_abs_timer(f,  
    platform_get_timer_counter() + 0);
```

Since callback is also the identifier of the timer, below two lines defines only a timer expiring after 200 units but not two separate timers:

```
platform_set_timer(f, 100);  
platform_set_timer(f, 200); // update the timer, but not creating a new one
```

If `f` is used once again in `platform_set_abs_timer`, then the timer is updated again:

```
platform_set_abs_timer(f, ...);
```

5.7 Utilities

5.7.1 platform_hrng

Generate random bytes by using hardware random-number generator.

5.7.1.1 Prototype

```
void platform_hrng(uint8_t *bytes, const uint32_t len);
```

5.7.1.2 Parameters

- `uint8_t *bytes`
Random data output.
- `const uint32_t len`
Number of random bytes to be generated.

5.7.1.3 Return Value

Void.

5.7.1.4 Remarks

Time consumption to generate a fix length of data is undetermined.

5.7.1.5 Example

```
uint32_t strong_random;  
platform_hrng(&strong_random, sizeof(strong_random));
```

5.7.2 platform_rand

Generate a pseudo random integer by internal PRNG.

5.7.2.1 Prototype

```
int platform_rand(void);
```

5.7.2.2 Parameters

Void.

5.7.2.3 Return Value

A pseudo random integer in range of 0 to RAND_MAX.

5.7.2.4 Remarks

Seed of the internal PRNG is initialized by HRNG at startup. This function can be used as a replacement of `rand()` in standard library.

5.7.2.5 Example

```
printf("rand: %d\n", platform_rand());
```

5.7.3 platform_read_persistent_reg

Read value from the persistent register. See also `platform_write_persistent_reg`.

5.7.3.1 Prototype

```
uint32_t platform_read_persistent_reg(void);
```

5.7.3.2 Parameters

Void.

5.7.3.3 Return Value

The value written by `platform_write_persistent_reg`.

5.7.3.4 Remarks

Void.

5.7.3.5 Example

```
platform_read_persistent_reg();
```

5.7.4 platform_reset

Reset platform (SoC).

5.7.4.1 Prototype

```
void platform_reset(void);
```

5.7.4.2 Parameters

Void.

5.7.4.3 Return Value

Void.

5.7.4.4 Remarks

When calling this function, the code after it will not be executed.

5.7.4.5 Example

```
if (out-of-memory)
    platform_reset();
```

5.7.5 platform_shutdown

Bring the whole system into shutdown state, and reboot after a specified duration. Optionally, a portion of memory can be retained during shutdown, and apps can continue to use it after reboot.

Note that this function will NOT return except that shutdown procedure fails to initiate. Possible causes for failures include:

1. External wake-up signal is issued;
2. Input parameters are not proper;
3. Internal components are busy.

5.7.5.1 Prototype

```
void platform_shutdown(const uint32_t duration_cycles,  
                      const void *p_retention_data,  
                      const uint32_t data_size);
```

5.7.5.2 Parameters

- `const uint32_t duration_cycles`
Duration (measured in cycles of real-time clock) before power on again (reboot). The minimum duration is 825 cycles (about 25.18ms). If 0 is used, the system will stay in shutdown state until external wake-up signal is issued.
- `const void *p_retention_data`
Pointer to the start of data to be retained. Only data within SYSTEM memory can be retained. This parameter can be set to NULL when `data_size` is 0.
- `data_size`
Size of the data to be retained. Set to 0 when memory retention is not needed.

5.7.5.3 Return Value

Void.

5.7.5.4 Remarks

Void.

5.7.5.5 Example

```
// Shutdown the system and reboot after 1s.  
platform_shutdown(32768, NULL, 0);
```

5.7.6 platform_write_persistent_reg

Write a value to the persistent register. This value is kept even in power saving, shutdown mode, or when switching to another app.

Only a few bits are saved as shown in Table 5.2.

Table 5.2: Persistent Register Bit Size

Chip Family	Register Size (bit)
ING918	4
ING916	5

5.7.6.1 Prototype

```
void platform_write_persistent_reg(const uint8_t value);
```

5.7.6.2 Parameters

- `const uint8_t value`
The value.

5.7.6.3 Return Value

Void.

5.7.6.4 Remarks

Void.

5.7.6.5 Example

```
platform_write_persistent_reg(1);
```

5.8 Debugging & Tracing

5.8.1 platform_printf

The printf function stored in platform binary.

5.8.1.1 Prototype

```
void platform_printf(const char *format, ...);
```

5.8.1.2 Parameters

- `const char *format`
Format string.
- `...`
Variable arguments for format string.

5.8.1.3 Return Value

Void.

5.8.1.4 Remarks

There are pros & cons to use this function.

Pros:

- This function is located in platform binary, app binary size can be saved.

Cons:

- Output is directed PLATFORM_CB_EVT_PUTC event, so its callback function must be defined.

5.8.1.5 Example

```
platform_printf("Hello world");
```

5.8.2 platform_raise_assertion

Raise a software assertion.

5.8.2.1 Prototype

```
void platform_raise_assertion(const char *file_name, int line_no);
```

5.8.2.2 Parameters

- `const char *file_name`
File name where the assertion occurred.
- `int line_no`
Line number where the assertion occurred.

5.8.2.3 Return Value

Void.

5.8.2.4 Remarks

Void.

5.8.2.5 Example

```
if (NULL == ptr)  
    platform_raise_assertion(__FILE__, __LINE__);
```

5.8.3 platform_trace_raw

Output a block of raw data to TRACE. ID is PLATFORM_TRACE_ID_RAW.

5.8.3.1 Prototype

```
void platform_trace_raw(  
    const void *buffer,  
    const int byte_len);
```

5.8.3.2 Parameters

- const void *buffer
Pointer of the buffer.
- const int byte_len
Length of data buffer in bytes.

5.9 Others

5.9.1 platform_get_link_layer_intf

Get link layer driver API.

5.9.1.1 Prototype

```
const platform_hci_link_layer_intf_t *  
platform_get_link_layer_intf(void);
```

5.9.1.2 Parameters

Void.

5.9.1.3 Return Value

The driver interface platform_hci_link_layer_intf_t *.

5.9.1.4 Remarks

This API exposes the Controller HCI interface. This driver interface is only available when PLATFORM_CB_EVT_HCI_RECV is defined, in which case, the built in Host is disabled.

5.9.2 sysSetPublicDeviceAddr

Set the public address of device.

The public address of a BLE device is a 48-bit extended unique identifier (EUI-48) created in accordance with the IEEE 802-2014 standard⁷.



INGCHIPS 91x *DO NOT* have public addresses. This function should *ONLY* be used for debugging or testing, and *NEVER* be used in final products.

5.9.2.1 Prototype

```
void sysSetPublicDeviceAddr(const unsigned char *addr);
```

5.9.2.2 Parameters

- const unsigned char *addr

New public address.

5.9.2.3 Return Value

Void.

5.9.2.4 Remarks

In order to avoid potential issues, this function should be called before calling any GAP functions. It is recommended to call this function in app_main or PLATFORM_CB_EVT_PROFILE_INIT event callback function.

⁷<http://standards.ieee.org/findstds/standard/802-2014.html>

5.9.2.5 Example

```
const unsigned char pub_addr[] = {1,2,3,4,5,6};  
sysSetPublicDeviceAddr(pub_addr);
```


Chapter 6

Revision History

Version	Notes	Date
1.0	Initial release	2020-07-28
1.1	Add Python downloader	2020-10-10
1.2	Update API descriptions	2020-07-05
1.2.1	Update memory dump section	2020-08-02
1.2.2	Fix typos, other minor updates	2020-09-08
1.2.3	Fix order of versions in “Device With FOTA” and typo	2020-09-09
1.2.4	Fix outdated information in tutorials	2020-10-20
1.2.5	Update for “NoOS” bundles	2020-11-15
1.2.6	Add ING9168xx	2022-01-10
1.2.7	Minor fixes	2022-07-30
1.2.8	Add <code>btstack_push_user_runnable</code>	2022-10-31
1.2.9	Add information about <code>Axf Tool</code>	2023-10-23
1.3.0	Fix some errors	2024-05-28
1.4.0	Update Platform API	2025-01-20

