

Introduction

This application note is written to guide designers through the steps required to build specific Bluetooth® Low Energy (BLE) or 802.15.4 applications based on STM32WB Series microcontrollers. It groups together the most important information and lists the aspects to be addressed.

To fully benefit from the information in this document and to develop an application, the user must be familiar with STM32 microcontrollers, BLE technology, 802.15.4 OpenThread protocol and 802.15.4 MAC layer, and has to understand system services such as low power management and task sequencing.

Contents

1	References	10
2	List of acronyms and abbreviations	11
3	Software overview	12
3.1	Supported stacks	12
3.2	BLE application	14
3.3	Building a BLE application on top of the HCI layer interface	15
3.4	Thread application	16
3.5	MAC 802_15_4 application	16
3.6	BLE and Thread application in concurrency	16
4	STM32WB software architecture	17
4.1	Main principles	17
4.2	Memory mapping	18
4.3	Shared peripherals	19
4.4	Sequencer	26
4.4.1	Implementation	26
4.4.2	Interface	26
4.4.3	Detailed interface and behavior	27
4.5	Timer server	29
4.5.1	Implementation	30
4.5.2	Interface	30
4.5.3	Detailed interface and behavior	30
4.6	Low power manager	32
4.6.1	Implementation	33
4.6.2	Interface	33
4.7	Flash memory management	33
4.7.1	CPU2 timing protection	34
4.7.2	CPU1 timing protection	36
4.7.3	Conflict between RF activity and Flash memory management	36
4.8	Debug information from CPU	37
4.8.1	GPIO	37

4.8.2	SRAM2	38
4.9	FreeRTOS low power	38
5	System initialization	41
6	Step by step design of a BLE application	42
6.1	Initialization phase	42
6.2	Advertising phase (GAP peripheral)	42
6.3	Discoverable and connectible phase (GAP central)	43
6.4	Services and characteristic configuration (GATT server)	44
6.5	Service and characteristic discovery (GATT client)	45
6.6	Security (pairing and bonding)	46
6.6.1	Security modes and level	47
6.6.2	Security commands	47
6.6.3	Security information commands	48
6.7	Privacy feature	49
6.8	How to use the 2 Mbps feature	50
6.9	How to update connection parameters	50
6.10	Write or read long local or distant values	50
6.10.1	Write long distant value	50
6.10.2	Read long distant value	52
6.10.3	Write long local value	53
6.10.4	Read long local value	53
6.11	Event and error code description	54
7	BT-SIG and proprietary GATT-based BLE application	55
7.1	Transparent mode - Direct test mode (DTM)	55
7.1.1	Purpose and scope	55
7.1.2	Transparent mode application principle	56
7.1.3	Configuration	56
7.1.4	RF certification - Application implementation	58
7.2	Heart rate sensor application	58
7.2.1	How to use STM32WB heart rate sensor application	59
7.2.2	STM32WB heart rate sensor application - Middleware application	60
7.3	STMicroelectronics proprietary advertising	64

7.4	Proprietary P2P application	67
7.4.1	P2P server specification	67
7.4.2	How to use the P2P server application	69
7.4.3	P2P server application - Middleware application	69
7.4.4	P2P client application - Middleware application	72
7.5	FUOTA application	77
7.5.1	CPU1 user Flash memory mapping	77
7.5.2	BLE FUOTA application startup	78
7.5.3	BLE FUOTA services and characteristics specification	79
7.5.4	Flow description example to upload new CPU1 application binary	80
7.5.5	Application example with smart phone	82
7.5.6	How to use the reboot request characteristics	85
7.5.7	Power failure recovery mechanism for CPU1 application	87
7.6	Application tips	87
7.6.1	How to set Bluetooth device address	87
7.6.2	How to add a task to the sequencer	89
7.6.3	How to use the timer server	90
7.6.4	How to start the BLE stack - SHCI_C2_BLE_Init()	90
7.6.5	How to maximize data throughput	95
7.6.6	How to add a custom BLE service	95
8	Building a BLE application on top of the HCI layer interface	97
9	Thread	98
9.1	Overview	98
9.2	How to start	98
9.3	Thread configuration	99
9.4	Architecture overview	99
9.5	Inter core communication	100
9.6	OpenThread API	101
9.7	Usage of the OpenThread APIs	102
9.7.1	OpenThread instance	102
9.7.2	OpenThread call back management	102
9.8	System commands for Thread applications	103
9.8.1	Non-volatile Thread data	104
9.8.2	Low-power support	105

10	Step by step design of an OpenThread application	106
10.1	Initialization phase	106
10.2	Set-up the Thread network	106
10.3	CoAP request	106
10.3.1	Creating an otCoapResource	107
10.3.2	Sending a CoAP request	107
10.3.3	Receiving a CoAP request	107
10.4	Commissioning	108
10.5	CLI	108
10.6	Traces	109
11	STM32WB OpenThread application	110
11.1	Thread_Cli_Cmd	110
11.2	Thread_Coap_DataTransfer	110
11.3	Thread_Coap_Generic	110
11.4	Thread_Coap_Multiboard	110
11.5	Thread_Commissioning	111
11.6	Thread_FTD_Coap_Multicast	111
11.7	Thread_SED_Coap_Multicast	111
11.8	Thread FUOTA	112
11.8.1	Principle	112
11.8.2	Memory mapping	112
11.8.3	Thread FUOTA protocol	115
11.8.4	FUOTA application startup procedure	116
11.8.5	Applications	117
12	MAC IEEE Std 802.15.4-2011	119
12.1	Overview	119
12.2	Architecture	119
12.3	API	119
12.4	How to start	120
12.4.1	Board configuration	120
12.4.2	MAC radio protocol processor CPU2 firmware	121
12.4.3	MAC application processor firmware	121
12.4.4	Output	122

12.4.5	MAC IEEE Std 802.15.4-2011 system	123
12.4.6	Integration recommendations	123
13	Annexes	126
13.1	Detailed flow of the device initialization	126
13.2	Mailbox interface	128
13.2.1	Interface API	129
13.2.2	Detailed interface behavior	130
13.3	Mailbox interface - Extended	134
13.3.1	Interface API	134
13.3.2	Detailed interface and behavior	135
13.4	ACI interface	140
13.4.1	Detailed interface and behavior	141
13.5	STM32WB system commands and events	146
13.5.1	Commands	146
13.5.2	Events	147
13.6	BLE - Set 2 Mbps link	147
13.7	BLE - Connection update procedure	148
13.8	BLE - Security procedure	150
13.8.1	LE security mode1 level 3	150
13.8.2	LE security mode1 level 4	152
13.8.3	LE security mode1 level 4 - Key-press notification	154
13.8.4	Privacy enabled	156
13.9	BLE - Link layer data packet	158
13.10	Thread overview	158
13.10.1	Introduction	158
13.10.2	Main characteristics	159
13.10.3	Layers	159
13.10.4	Mesh topology	161
13.10.5	Thread configuration	162
14	Conclusion	164
15	Revision history	165

List of tables

Table 1.	Stacks supported by STM32WB Series microcontrollers	12
Table 2.	Semaphores	19
Table 3.	Interface functions	26
Table 4.	Interface functions	30
Table 5.	Interface functions	33
Table 6.	Advertising phase API description	43
Table 7.	GAP central APIs	43
Table 8.	GATT client APIs	45
Table 9.	Security commands	48
Table 10.	Security information commands	48
Table 11.	2 Mbps feature commands	50
Table 12.	Proprietary connection data	50
Table 13.	Direct test mode functions	56
Table 14.	Heart rate service functionalities	61
Table 15.	HR sensor application control	64
Table 16.	AD structure according to the Bluetooth 5 Core specification Vol. 3 part C	65
Table 17.	STM32WB manufacturer specific data	65
Table 18.	Group B features - Bit mask	65
Table 19.	Device ID Enum	65
Table 20.	P2P service and characteristic UUIDs	68
Table 21.	P2P specification	68
Table 22.	P2P service functionalities	70
Table 23.	FUOTA service and characteristics UUID	79
Table 24.	Base address characteristics specification	80
Table 25.	File upload confirmation reboot Request characteristics specification	80
Table 26.	Raw data characteristics specification	80
Table 27.	Reboot request characteristics specification	80
Table 28.	MO firmwares available for Thread	98
Table 29.	Files for Thread configuration	99
Table 30.	Interface APIs	129
Table 31.	Interface APIs	134
Table 32.	BLE transport layer interfaces	140
Table 33.	System interface commands	146
Table 34.	User system events	147
Table 35.	Document revision history	165

List of figures

Figure 1.	Protocols supported by STM32WB Series microcontrollers	13
Figure 2.	STM32WB Series microcontroller BLE HCI layer model	14
Figure 3.	BLE application and wireless firmware architecture	15
Figure 4.	Memory mapping	18
Figure 5.	Timing for entering/exiting Stop mode on CPU1	21
Figure 6.	Algorithm to enter Stop mode on CPU1	22
Figure 7.	Algorithm to exit Stop mode on CPU1	23
Figure 8.	Algorithm to use RNG on CPU1	24
Figure 9.	Algorithm to use USB on CPU1	25
Figure 10.	Algorithm to write/erase data in the Flash memory.	35
Figure 11.	CPU1 and Flash memory operation versus PESD bit	36
Figure 12.	System initialization	41
Figure 13.	Write long distant value	51
Figure 14.	Read long distant value	52
Figure 15.	Write long local value	53
Figure 16.	Read long local value	53
Figure 17.	GATT-based BLE application	55
Figure 18.	Transparent mode with P-NUCLEO-WB55 board and ST-LINK VCP	57
Figure 19.	Transparent mode with P-NUCLEO-WB55 board and level shifter	58
Figure 20.	Simple setup with BLE RF tester and P-NUCLEO board	58
Figure 21.	Heart rate profile structure	59
Figure 22.	Simple setup with BLE RF tester and P-NUCLEO board	59
Figure 23.	Smart phone - ST BLE sensor with heart rate application	60
Figure 24.	Heart rate project - Interaction between middleware and user application	64
Figure 25.	P2P server to client demonstration	67
Figure 26.	P2P server to ST BLE sensor smart phone application	67
Figure 27.	P2P server/client communication sequence	68
Figure 28.	P2P server connected to ST BLE sensor smart phone application	69
Figure 29.	P2P server software communication	72
Figure 30.	P2P client software communication	77
Figure 31.	FUOTA memory mapping	78
Figure 32.	FUOTA startup procedure	79
Figure 33.	FUOTA process with heart rate	81
Figure 34.	P2P server - Application firmware selection	83
Figure 35.	P2P server - Application firmware update	84
Figure 36.	Heart rate sensor notification	85
Figure 37.	User option bytes setting	99
Figure 38.	Software architecture with BLE and Thread stacks	100
Figure 39.	OpenThread functions calls	101
Figure 40.	OpenThread callback	101
Figure 41.	OpenThread stack API directory structure	102
Figure 42.	OpenThread callback management	103
Figure 43.	Storage on non-volatile data	104
Figure 44.	Configurable CLI UART (LPUART or USART)	108
Figure 45.	Traces for Thread applications	109
Figure 46.	Thread FUOTA network topology	112
Figure 47.	OTA server (Thread_Ota_Server) Flash memory mapping	113
Figure 48.	FUOTA client Flash memory mapping initial state	113

Figure 49.	FUOTA server Flash memory mapping after CPU1 binary transfer	114
Figure 50.	FUOTA server Flash memory mapping after CPU2 binary transfer	114
Figure 51.	Thread FUOTA protocol	115
Figure 52.	FUOTA startup procedure	116
Figure 53.	Update procedure	117
Figure 54.	MAC 802.15.4 software architecture	119
Figure 55.	MAC API dedicated to application core	120
Figure 56.	Option bytes configuration for MAC 802.15.4	120
Figure 57.	MAC 802.15.4 simple application	121
Figure 58.	MAC 802.15.4 applications - Directory structure	122
Figure 59.	Coordinator start	123
Figure 60.	Node start, requesting association, and data send	123
Figure 61.	Coordinator receiving association request and data	123
Figure 62.	MAC 802.15.4 layer abstraction	124
Figure 63.	Traces on MAC 802.15.4 application	125
Figure 64.	System initialization	126
Figure 65.	System ready event notification	127
Figure 66.	BLE initialization	128
Figure 67.	Transport layer initialization	130
Figure 68.	BLE channel initialization	131
Figure 69.	BLE command sent by the mailbox	132
Figure 70.	ACL data sent by the mailbox	132
Figure 71.	System command sent by the mailbox	133
Figure 72.	BLE and system user event received by the mailbox	133
Figure 73.	System transport layer initialization	135
Figure 74.	System command sent by the system transport layer	136
Figure 75.	System user event reception flow	138
Figure 76.	shci_resume_flow() usage example	139
Figure 77.	BLE transport layer initialization	141
Figure 78.	ACI command flow	142
Figure 79.	BLE user event receive flow	144
Figure 80.	hci_resume_flow() usage example	145
Figure 81.	2 Mbps set-up flow	148
Figure 82.	Master initiates the connection update with HCI command	149
Figure 83.	Slave initiates the connection update with L2CAP command	149
Figure 84.	LE security mode1 level 3 key distribution feature	150
Figure 85.	LE security mode1 level 3 pairing feature exchange	151
Figure 86.	LE security mode1 level 3 pairing request and response feature	152
Figure 87.	LE security mode1 level 4	153
Figure 88.	LE security mode1 level 4	153
Figure 89.	LE security mode1 level 4	154
Figure 90.	LE security mode1 level 4 - Key-press notification (1/2)	155
Figure 91.	LE security mode1 level 4 - Key-press notification (2/2)	156
Figure 92.	Privacy enabled	157
Figure 93.	Data packet breakdown	158
Figure 94.	Application GATT data format	158
Figure 95.	Thread protocol letters	159
Figure 96.	6LoWPAN packet fragmentation	160
Figure 97.	Thread network topology	162
Figure 98.	Link with the external world	162
Figure 99.	Thread device roles	163

1 References

- [1] UM2550⁽¹⁾ Getting started with STM32CubeWB for STM32WB Series
- [2] RM0434⁽¹⁾ Multiprotocol wireless 32-bit MCU Arm[®]-based Cortex[®]-M4 with FPU, Bluetooth[®] Low-Energy and 802.15.4 radio solution
- [3] AN5270⁽¹⁾ STM32WBx5 Bluetooth[®] Low Energy (BLE) wireless interface
- [4] UM2442⁽¹⁾ Description of STM32WB HAL and low-layer drivers
- [5] UM2288⁽¹⁾ STM32CubeMonitor-RF software tool for wireless performance measurements
- [6] AN5185⁽¹⁾ ST firmware upgrade services for STM32WB Series
- [7] Bluetooth[®] specification Bluetooth Core Specification (v4.0, v4.1, v4.2, v5.0)
- [8] MAC IEEE Std 802.15.4-2011 Specification of the 802_15_4 MAC standard
- [9] Thread specification Thread specification V1.1 (Thread Group)

1. Available on www.st.com.

2 List of acronyms and abbreviations

ACI	Application command interface
ATT	Attribute protocol
BLE	Bluetooth® Low Energy
CLI	Command line interface
CoAP	Constrained application protocol
CPU1	Cortex®-M4 core
CPU2	Cortex®-M0+ core
D2D	Device to device
DUT	Device under test
FUOTA	Firmware update over the air
FUS	Firmware upgrade service
GAP	Generic access profile
GATT	Generic attribute profile
HCI	Host controller interface
L2CAP	Logical link control adaptation layer protocol
LTK	Long-term key
OTA	Over the air
PDU	Protocol data unit
P2P	Peer to peer
RFU	Reserved for future use
SIG	Special interest group
SM	Security manager
UUID	Universally unique identifier

3 Software overview

3.1 Supported stacks

The STM32WB Series microcontrollers are based on Arm^{®(a)} cores.

Select CPU2 firmware to load based on the target application.

The STM32WB Series microcontroller ecosystem supports different stacks (see [Table 1](#)), controlled by the application through specific interfaces, as shown in [Figure 1](#).

As shown in [Figure 2](#), CPU2 may provide a BT HCI standard interface and a different BLE stack can run on CPU1.

Table 1. Stacks supported by STM32WB Series microcontrollers

Stacks supported	Associated firmware
BLE	stm32wb5x_BLE_Stack_fw.bin stm32wb5x_BLE_HCI_Layer_fw.bin
Thread	stm32wb5x_Thread_FTD_fw.bin stm32wb5x_Thread_MTD_fw.bin
BLE and Thread	stm32wb5x_BLE_Thread_fw.bin
MAC 802_15_4	stm32wb5x_Mac_802_15_4_fw.bin

arm

a. Arm is a registered trademark of Arm Limited (or its subsidiaries) in the US and/or elsewhere.

Figure 1. Protocols supported by STM32WB Series microcontrollers

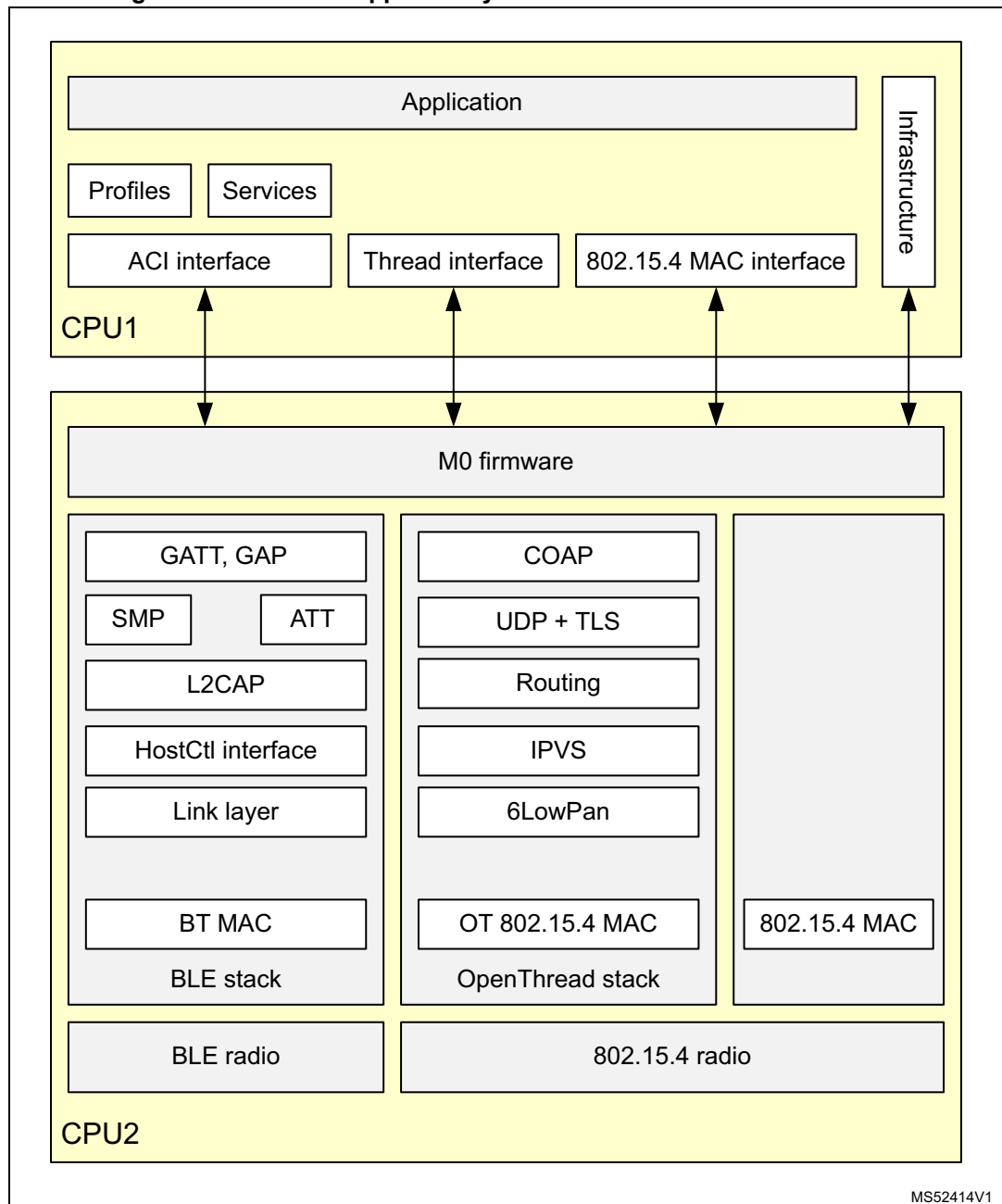
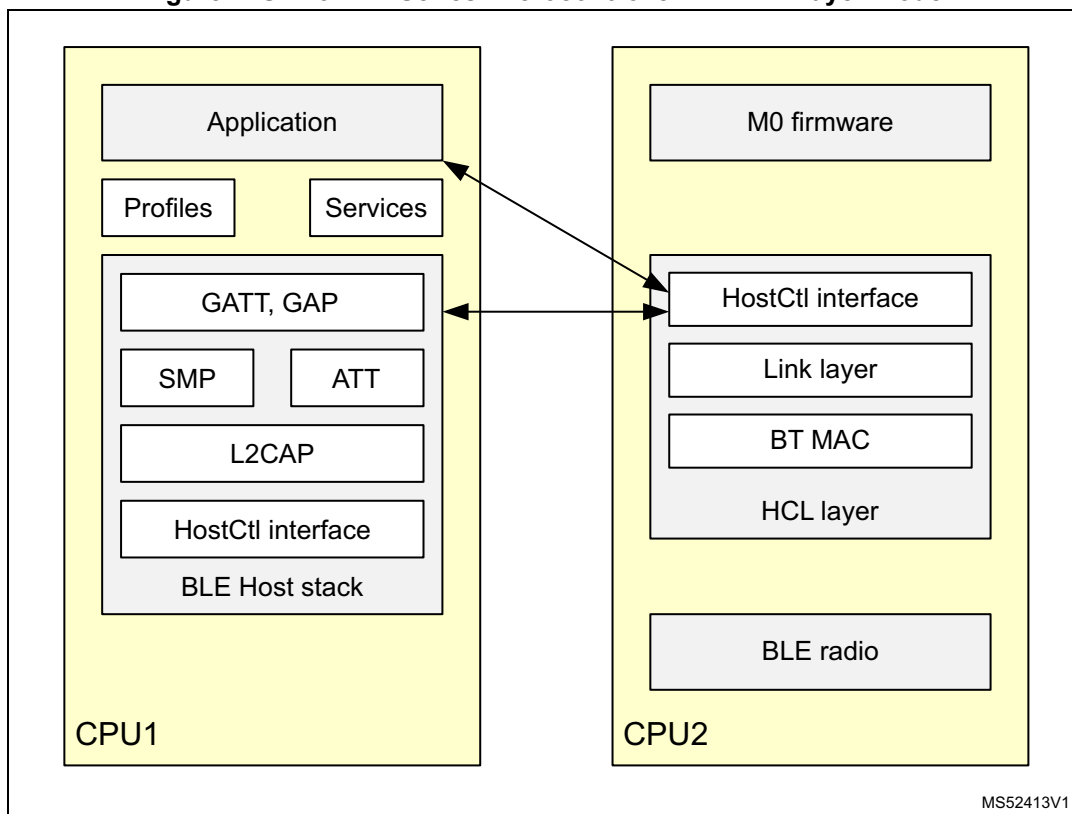


Figure 2. STM32WB Series microcontroller BLE HCI layer model



3.2 BLE application

The STM32WB architecture separates the BLE profiles and application, running on the application CPU1, from the real-time aspects residing in the BLE peripheral.

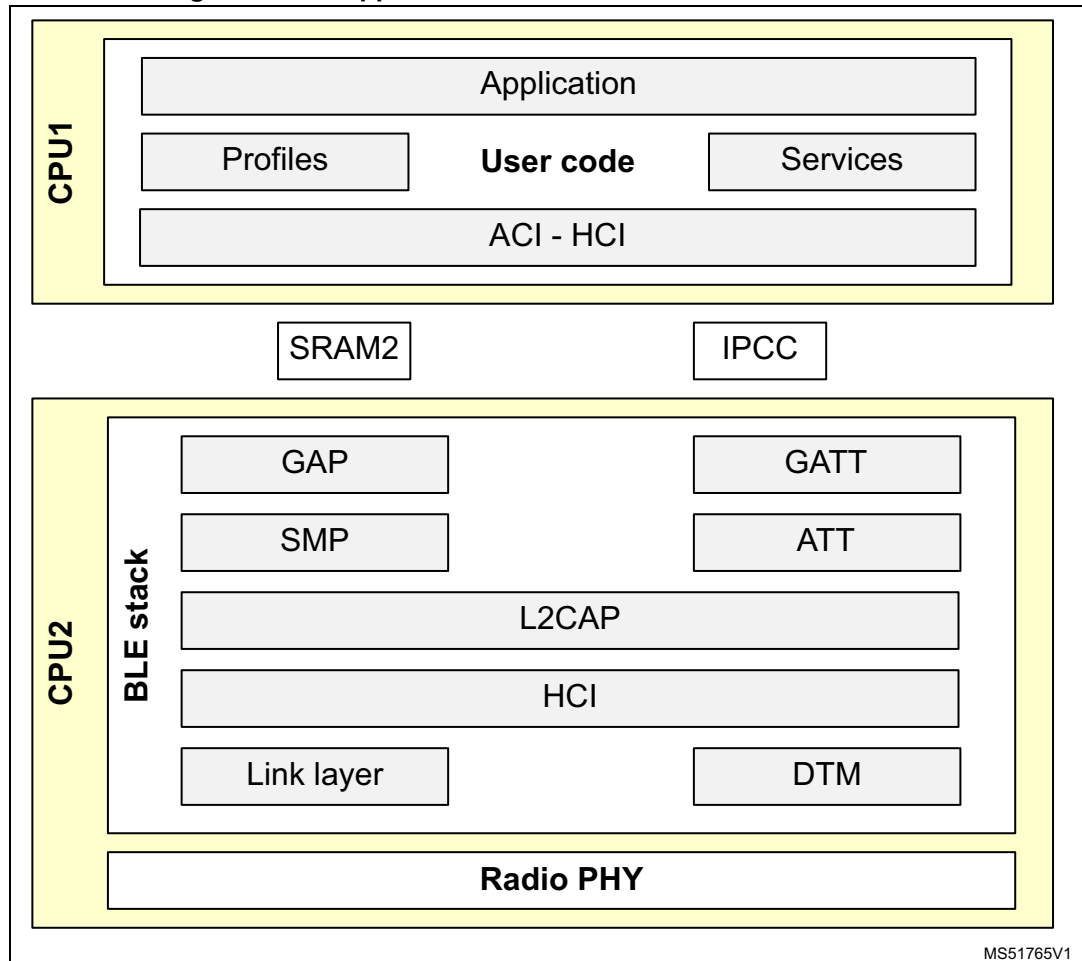
The BLE peripheral incorporates a CPU2 processor containing the stack handling the link layer up to the GAP and the GATT layers. It also incorporates the physical 2.4 GHz radio.

The application CPU1 collects and computes the data to be transferred to the BLE.

CPU2 contains the LE controller and the LE host needed to manage all real time link layer and radio PHY interaction which includes:

- Low power manager to control Low-power mode
- Debug trace to output information about activities
- Mailbox / IPCC to interface the BLE stack (LL, GAP, GATT)

Figure 3. BLE application and wireless firmware architecture



3.3 Building a BLE application on top of the HCI layer interface

CPU2 may be used as a BLE HCI layer co-processor. In that case, the user either implements its own HCI application or uses an existing open source BLE host stack.

Most BLE host stacks use a UART interface to communicate with a BLE HCI co-processor. The equivalent physical layer on STM32WB Series microcontroller is the mailbox, as described in [Section 13.2: Mailbox interface](#).

The mailbox provides an interface for both the BLE channel and the System channel. The BLE host stack is responsible for building the command buffer to be sent over the BLE channel on the mailbox and must provide an interface to report events received over the mailbox. In addition to the BLE host stack adaptation over the mailbox, the user must notify the mailbox driver when an asynchronous packet can be released.

The System channel is not handled by a BLE host stack. The user has to implement a custom transport layer to build the system command buffer to be sent to the mailbox driver and to manage the event received from the mailbox (including the notification to release an asynchronous buffer to the mailbox driver), or it may use the mailbox extended driver (as described in [Section 13.3: Mailbox interface - Extended](#)) that provides an interface on top of

the transport layer responsible for building the system command buffer and to manage the system asynchronous event.

The BLE_TransparentMode project may be used as an example to build an application on top of a BLE HCI layer co-processor using the mailbox as described in [Section 11.2: Thread_Coap_DataTransfer](#).

3.4 Thread application

The OpenThread stack runs on CPU2 core and exports a set of APIs on CPU1 side in order to build a complete Thread application. Three CPU2 firmwares support the Thread protocol:

- **sm32wb5x_Thread_FTD_fw**: In this case, the device supports all Thread roles except the border router (e.g. Leader, Router, End device, Sleepy end device).
- **stm32wb5x_Thread_MTD_fw**: In this case, the device can act only as an end device or sleepy end device). This configuration saves on memory space compared to the FTD one.
- **stm32wb5x_BLE_Thread_fw**: In this case, the device supports both Thread (FTD) and BLE in static concurrent mode (refer to [Section 3.6](#) for more details).

3.5 MAC 802_15_4 application

When downloading the STM32wb5x_Mac_802_15_4_fw CPU2 firmware, CPU1 can access directly the 802_15_4 MAC layer and build its own application on top of it.

3.6 BLE and Thread application in concurrency

The STM32WB Series microcontroller supports a “static concurrent mode” (also named “switched mode”).

Both stacks (BLE and Thread) are embedded in the stm32wb5x_BLE_Thread_fw CPU2 firmware that is available from www.st.com. Switch from one protocol to the other is done through a system application command. In this mode, the system disables the operational protocol before activating the other one. The STM32WB device switches from BLE to Thread after completely stopping the BLE stack, and vice versa. These transitions can take several seconds, as the network needs to be reattached each time.

4 STM32WB software architecture

4.1 Main principles

- All the code running on CPU2 is delivered as an encrypted binary
- Black box for customer perspective
- All the code running on CPU1 is delivered as source code
- Communication between CPUs is done via “mailbox”

The standard STM32Cube delivery package includes STM32WB resources such as:

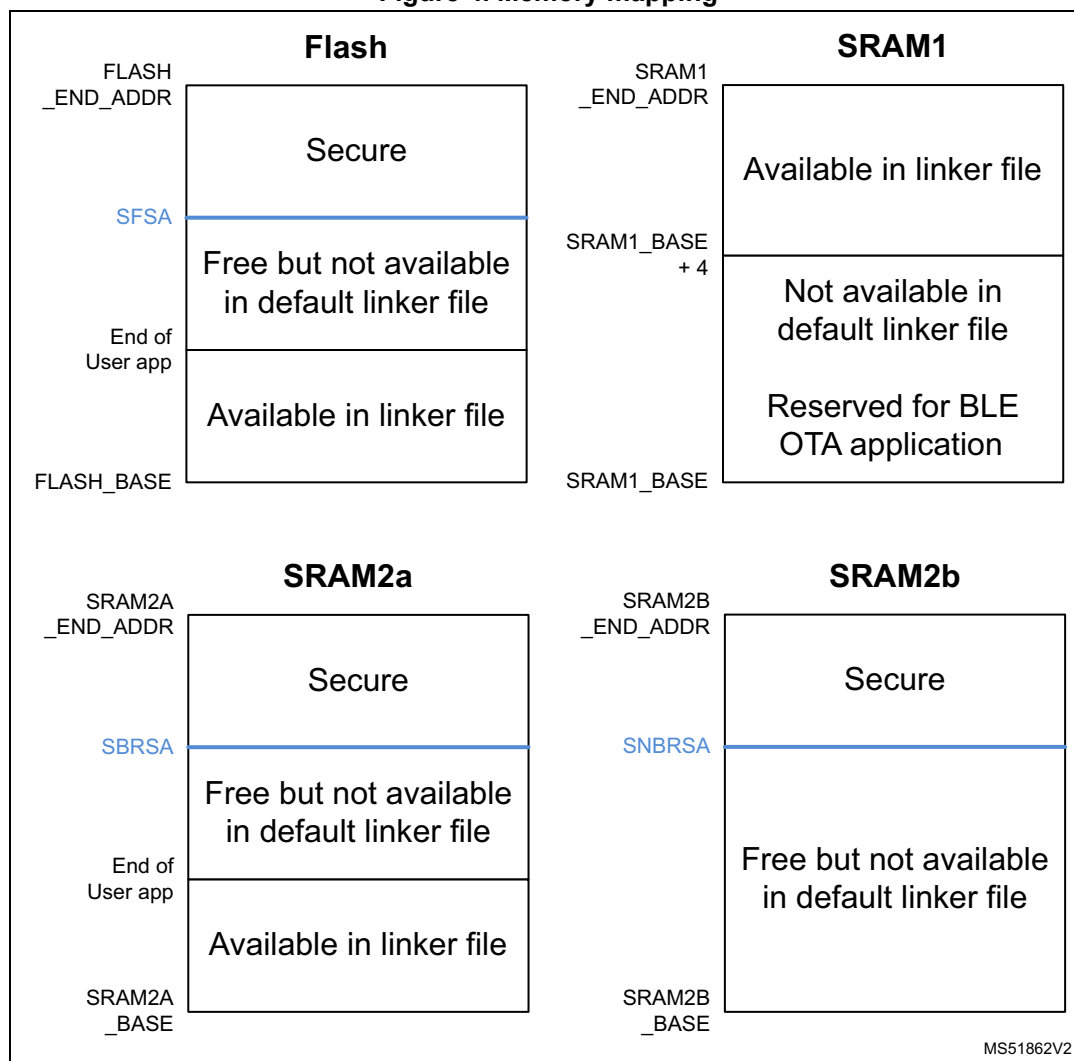
- HAL/LL to access the hardware registers
- BSP
- Middleware (such as FreeRTOS, USB devices).

In addition, the following application provide efficient system integration:

- A sequencer to execute the tasks in background and enter Low-power mode when there is no activity
- A timer server to provide virtual timers running on RTC (in Stop and Standby modes) to the application.

4.2 Memory mapping

Figure 4. Memory mapping



The Flash, SRAM2a and SRAM2b memories contain a secure section, which cannot be read nor written by CPU1. The secure start address for each memory can be read from the option byte, indicated in blue in [Figure 4](#):

- SFSA for the Flash memory
- SBRSA for the SRAM2a (retained in Standby)
- SNBRSA for the SRAM2b.

These option bytes are only written by the FUS running on CPU2. This is done on each CPU2 update installed by the FUS.

The user application must take into account that the available memory may vary between different versions of the RF stack. The available space for the user application can be obtained from the release notes for STM32WB coprocessor wireless binaries. The install address for the RF stack is also the boundary address for the user Flash memory area.

Ensure that some margin is included in CPU2 domain to support updates during the product lifetime.

The boundary granularity is 4 Kbytes for the Flash memory and 1 Kbyte for both SRAM2a and SRAM2b.

The linker file is identical to all delivered BLE/Thread applications (except for BLE_Thread_Static, BLE_HeartRate_ota and BLE_p2pServer_ota). The available memories are chosen to fit all provided applications. For applications like BLE, where CPU2 memory requirements are smaller, it is possible to update the linker file to allocate more memory to the application.

To optimize the available memory for a dedicated application, the linker file has to be updated inline with the following guidelines:

- Flash memory: the end of available memory address can be moved up to the SFSA address. When a CPU2 update is required, there must be enough free memory just below the secure memory to upload a new encrypted CPU2 FW update. The size of the memory required depends on CPU2 FW to be updated (BLE, Thread or concurrent BLE/Thread), see [\[1\]](#).
- SRAM1: the first unavailable 32 bits in the linker file are only required for the BLE_OTA application. For all other applications, the start address can be moved from SRAM1_BASE + 4 to SRAM1_BASE.
- SRAM2a: the end of available memory address can be moved up to the SBRSA address. When CPU2 update support required, there must be some free sectors just below the secure memory to support new CPU2 FW updates requiring more sectors to be secure.
- SRAM2b: The SRAM2b is not part of the linker file because it is all secure for any FW CPU2 supporting the Thread protocol. For BLE only applications, the linker file may be updated with a new section to map RW data into the SRAM2B from SRAM2B_BASE up to the SNBRSA address. When CPU2 update support required, there must be some free sectors just below the secure memory to support new CPU2 FW updates requiring more sectors to be secure.

STOP2 is the deepest low power mode supported when RF is active. When the user application has to enter Standby mode, it must first stop all RF activities, and fully re-initialize CPU2 when coming out of Standby mode. The user application may use the full non secure SRAM2a to store its own content (that needs to be retained in Standby mode).

4.3 Shared peripherals

All peripherals concurrently accessible by both CPUs are protected by hardware semaphores. Before accessing these peripherals, the associated semaphore must first be taken, and released afterwards.

Table 2. Semaphores

Semaphore	Purpose
Sem0	RNG - All registers
Sem1	PKA - All registers
Sem2	FLASH - All registers

Table 2. Semaphores (continued)

Semaphore	Purpose
Sem3	RCC_CR RCC_EXTCFGR RCC_CFGR RCC_SMPSCR
Sem4	Clock control mechanism for the Stop mode implementation
Sem5	RCC_CRRCR RCC_CCIPR
Sem6	Used by CPU1 to prevent CPU2 from writing/erasing data in Flash memory
Sem7	Used by CPU2 to prevent CPU1 from writing/erasing data in Flash memory

If the application needs to use semaphores for inter task control, it is recommended to start using Sem31 downwards to be compatible with future wireless firmware updates on CPU1, where new features may be added requiring additional semaphores.

Sem0 is used to share the RNG IP between the two CPUs. The semaphore is taken by the CPU2 for a time interval depending upon the required RNG number to be generated and upon the RNG source clock speed. To relax the latency to get RNG numbers, it is recommended to generate at startup a pool of RNG numbers and fill the pool in a low priority task when some numbers are retrieved by the application to keep it full. The usage of Sem0 is shown in [Figure 8](#).

Sem 0 can be used in the USB use case too. When the USB is not used anymore and needs to be switched off by the application, Sem 0 must be taken before switching off the CLK48 clock. This is required because USB and RNG share the same clock, and CPU2 could use RNG at the same time when CPU1 needs to switch off the USB (see [Figure 9](#)).

Sem1 is used to share the PKA IP between the two CPUs.

Sem2 is used to share the FLASH IP between the two CPUs. The semaphore is taken by the CPU2 for a time interval depending upon the number of data to be written in the Flash memory and upon the number of sectors to erase. BLE stack writes to Flash memory the pairing information (when bonding is enabled) and the GATT attribute cache.

Sem3 is used for the low power management. It must not be locked for more than 500 μ s by the CPU1 when there is BLE RF activity. The algorithm is detailed in [Figure 6](#) and [Figure 7](#).

Sem4 is used to handle race condition on the switch of the system clock when a CPU exits low power mode while the other one enter low power mode. The algorithm is detailed in [Figure 6](#) and [Figure 7](#).

Sem3 and Sem4 are used in the examples to enter/exit Stop mode.

The user must ensure that the algorithms shown in [Figure 6](#) and [Figure 7](#) are executed before and after wake-up from Stop mode. These routines (see [Figure 5](#)) are usually implemented inside the IDLE task of sequencer or RTOS. The implementation takes advantage of the fact that when WFI is called from critical section, the MCU wakes up upon interrupt request, but instead of executing ISR it continues to execute the next instruction after WFI. Only after exiting the critical section the ISR is executed.

```
PRIMASK = 1; // Mask all interrupts (enter critical section)
PWR_EnterStopMode()
WFI
PWR_ExitStopMode()
PRIMASK = 0; // Unmask all interrupts (exit critical section)
```

Figure 5. Timing for entering/exiting Stop mode on CPU1

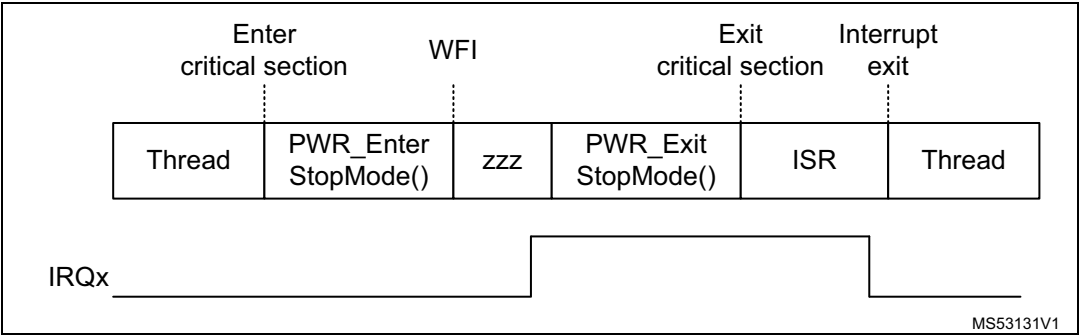


Figure 6. Algorithm to enter Stop mode on CPU1

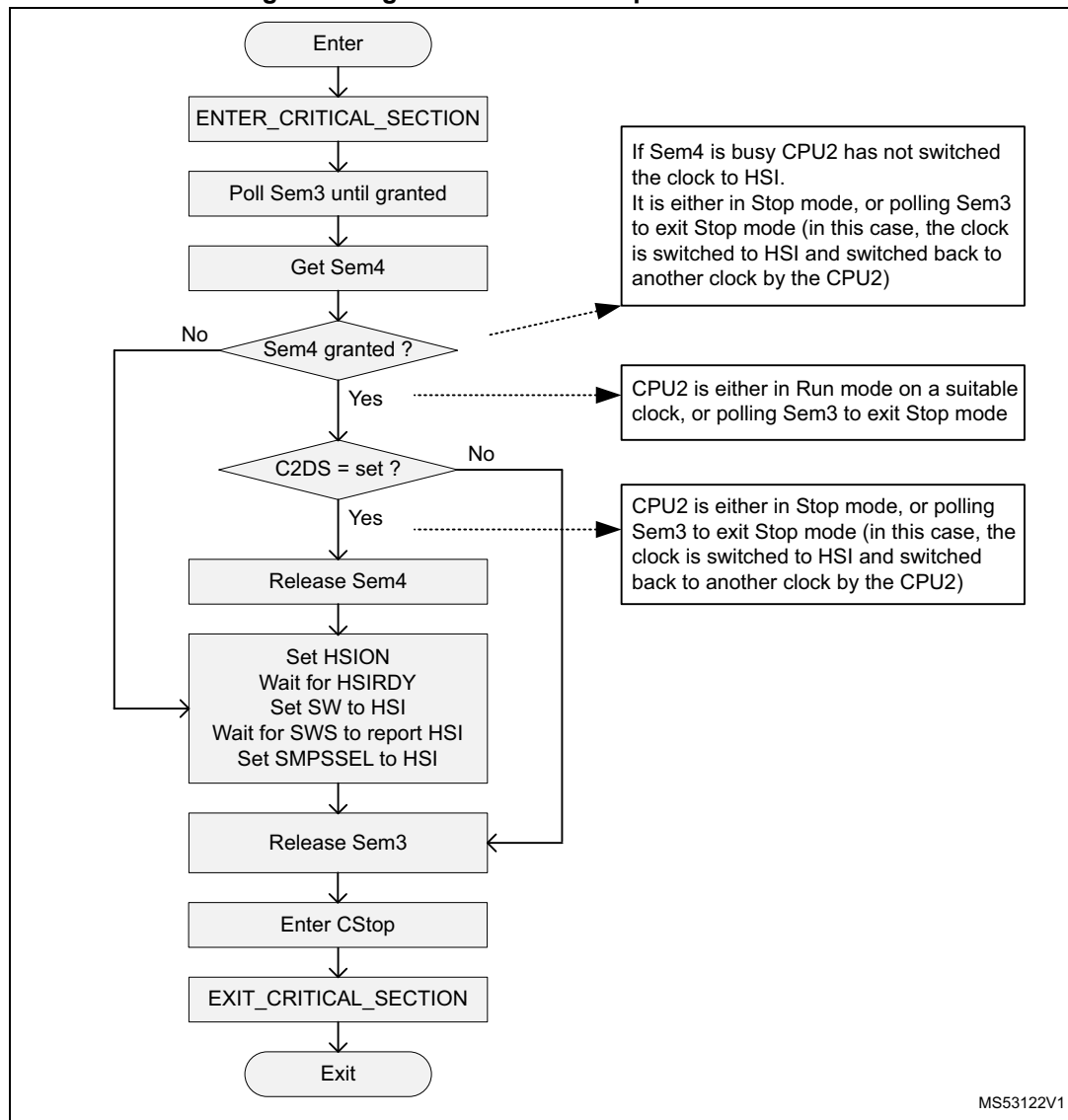
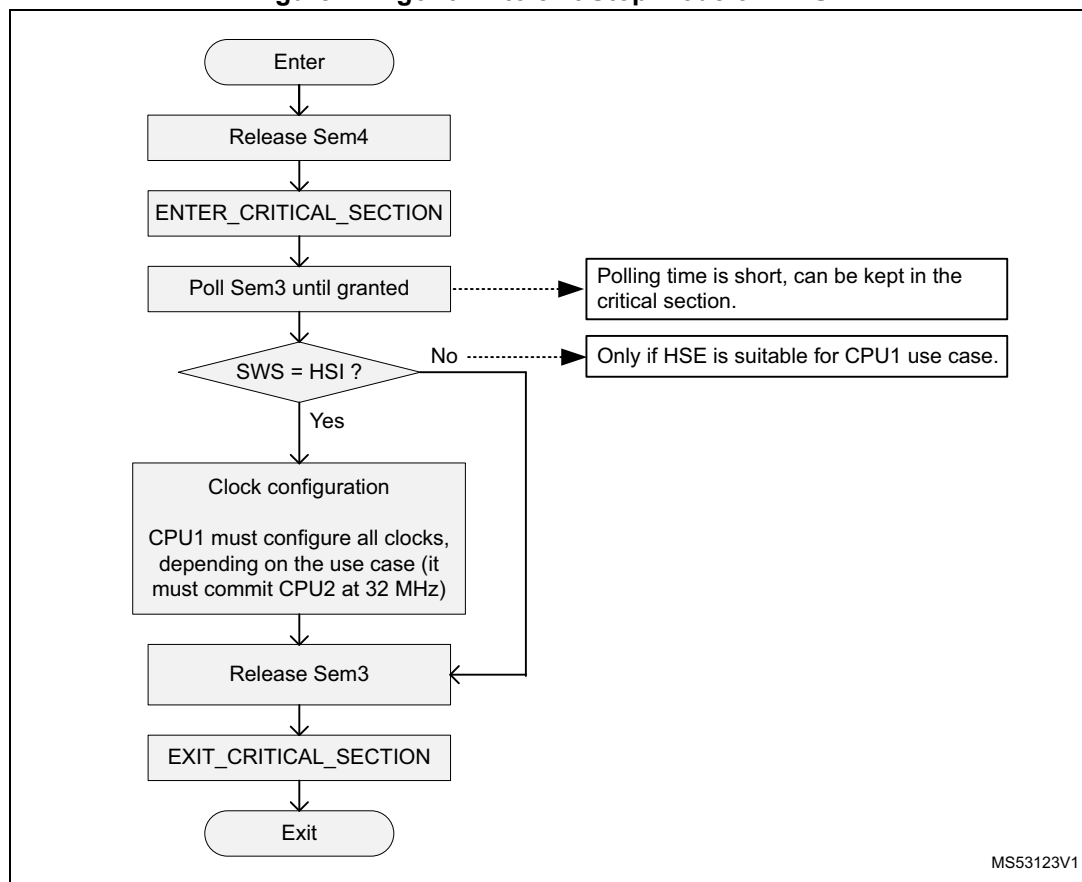


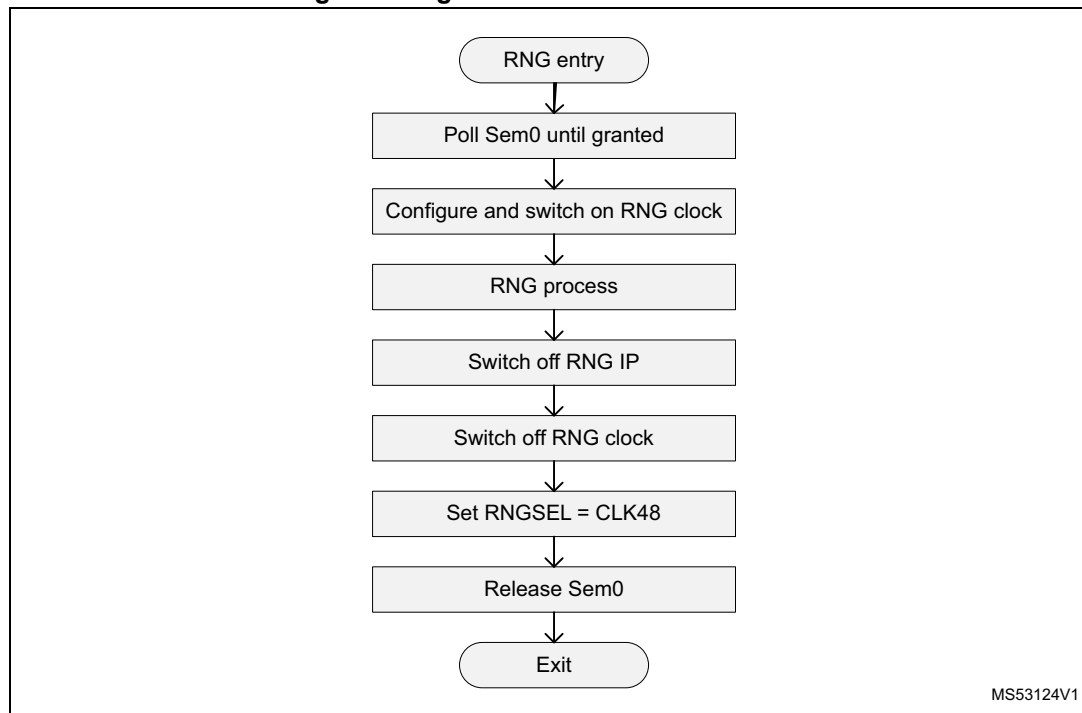
Figure 7. Algorithm to exit Stop mode on CPU1



Sem5 is used to control the RNG/USB CLK48 source clock. The CPU2 updates or switches off the clock only when the RNG IP (Sem0) is used.

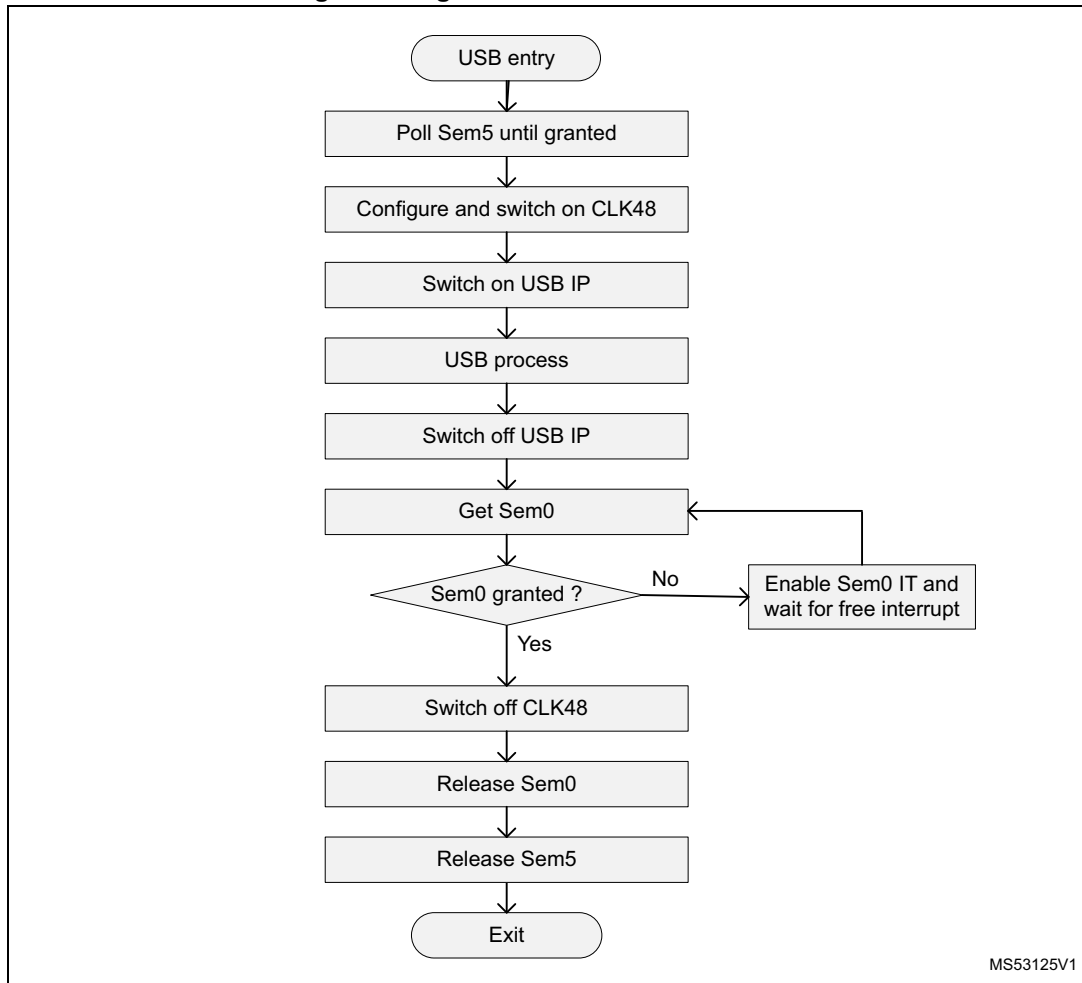
To avoid a race condition with the CPU2, when the CPU1 needs to switch off the clock it must always first get Sem0, even if not using the RNG IP. This mechanism is shown in the BLE P-NUCLEO-WB55.USB dongle examples (see [Section 7.1.3: Configuration](#) and [Figure 9](#)). This does not impact the CPU2.

Figure 8. Algorithm to use RNG on CPU1



Note: *Sem5 is not taken because the CPU2 does not take it without taking first Sem0. This algorithm can be updated to take Sem5 before configuring the RNG clock source.*

Figure 9. Algorithm to use USB on CPU1



The USB and RNG IPs share the same source clock. Before switching off the clock, the USB driver must first check whether the CPU2 requires the clock or not. To avoid a race condition with the CPU2, the CPU1 must first get Sem0 (RNG semaphore, CPU2 does not use USB) before switching off the clock.

If Sem0 is busy, the CPU1 must wait for Sem0 to be free to switch off the clock. This is required because there can be a race condition when CPU1 releases the USB and CPU2 releases the RNG at the same time, leading to the oscillator to be kept on.

Sem6 is used to protect the CPU1 timing versus write/erase operations requested by the CPU2. The CPU1 shall get Sem6 to prevent the CPU2 or other CPU1 processes to either write or erase data in Flash memory. There is no time limit on how long the CPU1 can keep the semaphore, but, as long as the semaphore is taken, the CPU2 is unable to write either the pairing or client descriptor information in the memory.

CPU1 has to release Sem6 only if it can afford being stalled for the time required to finish the write or erase operation.

The CPU2 implements the algorithm described in [Figure 10](#), similarly to the CPU1. Before writing or erasing data in Flash memory, it tries to get Sem6 and, if successful, writes/erases

data and releases the semaphore. When the CPU1 needs to protect its timing, it polls Sem6 until it gets it.

Sem7 is used to protect the CPU2 timing versus write/erase Flash memory operation requested by CPU1. The CPU1 must get Sem7 before writing or erasing. Sem7 must be taken and released for each single write or erase operation, but for not more than 0.5 ms in addition to the write/erase timing. To comply with this requirement the code must be executed in the critical section. The algorithm is described in [Figure 10](#).

4.4 Sequencer

The sequencer executes registered functions one by one. It has the following features:

- supports up to 32 functions
- requests functions to be executed
- enables / disables the execution of a function
- provides a blocking interface based on the reception of an event.

The sequencer provides a simple background scheduling function. It provides a hook to implement a secure way Low-power mode (no event loss) when the sequencer does not have any pending tasks to be executed. It also provides an efficient mechanism for the application to wait for a specific event before moving forward. When the sequencer is waiting for a specific event, it provides a hook where the application may either enter Low-power mode or execute some other code.

4.4.1 Implementation

To use the sequencer, the application must:

- set the number of maximum of supported functions (this is done by defining a value for UTIL_SEQ_CONF_TASK_NBR)
- register a function to be supported by the sequencer with UTIL_SEQ_RegTask()
- start the sequencer by calling UTIL_SEQ_Run() to run a background while loop
- call UTIL_SEQ_SetTask() when a function needs to be executed.

4.4.2 Interface

Table 3. Interface functions

Function	Description
<code>void UTIL_SEQ_Idle(void);</code>	Called (in critical section - PRIMASK) when there is nothing to execute.
<code>void UTIL_SEQ_Run(UTIL_SEQ_bm_t mask_bm)</code>	Requests the sequencer to execute functions that are pending and enabled in the mask mask_bm.
<code>void UTIL_SEQ_RegTask(UTIL_SEQ_bm_t task_id_bm, uint32_t flags, void (*task)(void))</code>	Registers a function (task) associated with a signal (task_id_bm) in the sequencer. The task_id_bm must have a single bit set.
<code>void UTIL_SEQ_SetTask(UTIL_SEQ_bm_t task_id_bm,</code>	Requests the function associated with the task_id_bm to be executed. The task_prio is evaluated by the sequencer only when a function has finished. If several functions are pending at any one time, the one with the highest priority (0) is executed.

Table 3. Interface functions (continued)

Function	Description
<code>void UTIL_SEQ_PauseTask(UTIL_SEQ_bm_t task_id_bm)</code>	Disables the sequencer to execute the function associated with <code>task_id_bm</code> .
<code>void UTIL_SEQ_ResumeTask(UTIL_SEQ_bm_t task_id_bm)</code>	Enables the sequencer to execute the function associated with <code>task_id_bm</code> .
<code>void UTIL_SEQ_WaitEvt(UTIL_SEQ_bm_t evt_id_bm)</code>	Requests the sequencer to wait for a specific event <code>evt_id_bm</code> and does not return until the event is set with <code>UTIL_SEQ_SetEvt()</code> .
<code>void UTIL_SEQ_SetEvt(UTIL_SEQ_bm_t evt_id_bm)</code>	Notifies the sequencer that the event <code>evt_id_bm</code> occurred (the event must have been first requested).
<code>void UTIL_SEQ_EvtIdle(UTIL_SEQ_bm_t task_id_bm, UTIL_SEQ_bm_t evt_waited_bm)</code>	Called while the sequencer is waiting for a specific event.
<code>void UTIL_SEQ_ClrEvt(UTIL_SEQ_bm_t evt_id_bm)</code>	Clears the pending event.
<code>UTIL_SEQ_bm_t UTIL_SEQ_IsEvtPend(void)</code>	Returns the <code>evt_id_bm</code> of the pending event.

4.4.3 Detailed interface and behavior

The sequencer is a packaging of while loops to call functions when requested by the user:

```
while(1)
{
    if(task_id1)
    {
        task_id1 = 0;
        Fct1();
    }

    if (task_id2)
    {
        task_id2= 0;
        Fct2();
    }

    __disable_irq();
    If (! (task_id1 || task_id2))
    {
        UTIL_SEQ_Idle();
    }
    __enable_irq();
}
```

```
void UTIL_SEQ_Run(UTIL_SEQ_bm_t mask_bm)
```

Implements the body of the while (1) loop. The mask_bm parameter is the list of functions that the sequencer is allowed to execute. Each function is associated with one bit in that mask_bm. At the end of the startup, this API must be called in a while (1) loop with mask_bm = (~0) to allow the sequencer to execute any pending function.

```
void UTIL_SEQ_Idle( void )
```

Called under the critical section (set with the CortexM PRIMASK bit - all interrupts are masked) when the sequencer does not have any function to executed. This is where the application must enter the Low-power mode.

```
void UTIL_SEQ_RegTask(UTIL_SEQ_bm_t task_id_bm, uint32_t flags, void (*task)( void ))
```

Informes the sequencer to add the function task associated with the flag task_id_bm to its while loop.

```
void UTIL_SEQ_SetTask( UTIL_SEQ_bm_t task_id_bm , UTIL_SEQ_bm_t task_prio )
```

Sets the flag task_id_bm for the scheduler to call the associated function.

The task_prio is evaluated by the sequencer when it needs to decide which function to call next. This can be done only when the execution of the current function is finished. When several functions have their flag set, the one with the higher priority is executed (0 is the highest). This API may be called several times before the function is actually executed with a different priority. In that case, the sequencer records the highest priority. Whatever the number of API calls before the function is executed, the sequencer runs the associated function only once.

```
void UTIL_SEQ_PauseTask( UTIL_SEQ_bm_t task_id_bm ) :
```

Informes the sequencer not to execute the function associated with the flag task_id_bm even if it is set. If the API UTIL_SEQ_SetTask() is called after UTIL_SEQ_PauseTask(), the request is recorded but the function is not executed. The mask associated with UTIL_SEQ_PauseTask() is independent from the mask associated with void UTIL_SEQ_Run(UTIL_SEQ_bm_t mask_bm).

A function can be executed only when its flag is set and enabled in both masks (default case).

```
void UTIL_SEQ_ResumeTask( UTIL_SEQ_bm_t task_id_bm ) :
```

Cancels the request done by UTIL_SEQ_PauseTask(). If this API is called when no UTIL_SEQ_PauseTask() has been requested, it has no effect.

```
void UTIL_SEQ_WaitEvt( UTIL_SEQ_bm_t evt_id_bm )
```

When this API is called, it does not return until the associated evt_id_bm signal is set. Only one bit in the evt_id_bm 32-bit value needs to be set. While the sequencer is waiting for this event, it calls UTIL_SEQ_EvtIdle() in a while loop on the event evt_id_bm. This has to be used to replace all code where a polling is made on a flag before moving forward.

```
void UTIL_SEQ_SetEvt( UTIL_SEQ_bm_t evt_id_bm )
```

Must be called only when UTIL_SEQ_WaitEvt() has already been called. It sets the signal evt_id_bm the function UTIL_SEQ_WaitEvt() is waiting for. Calling this API before the UTIL_SEQ_WaitEvt() function makes the call to UTIL_SEQ_WaitEvt() return immediately as the flag is already set.

```
void UTIL_SEQ_EvtIdle(UTIL_SEQ_bm_t task_id_bm, UTIL_SEQ_bm_t
evt_waited_bm)
```

Called while the API void UTIL_SEQ_WaitEvt() is waiting for the signal to be set with UTIL_SEQ_SetEvt().

This API is weakly implemented in the sequencer to call UTIL_SEQ_Run(0), which means that while waiting for this event to occur, the function UTIL_SEQ_Idle() allows the system to enter Low-power mode while waiting for the flag.

The application may implement this API to pass parameters that are different from 0 to the UTIL_SEQ_Run(mask_bm). Each bit set to 1 in the mask_bm requests the sequencer to execute the function associated with this flag when it is set with UTIL_SEQ_SetTask(). This means that when the function UTIL_SEQ_WaitEvt() is called, while it is waiting for the requested event to return, it may either execute the unmasked functions when their flag is set, or call UTIL_SEQ_Idle() if no tasks is pending execution by the sequencer.

```
void UTIL_SEQ_ClrEvt( UTIL_SEQ_bm_t evt_id_bm )
```

This API may be called when, in some applications, the API UTIL_SEQ_WaitEvt() needs to be called while Evt is already set. In that case, the Evt must be cleared.

```
UTIL_SEQ_bm_t UTIL_SEQ_IsEvtPend( void ):
```

This API returns the Evt that is currently pending. When several UTIL_SEQ_WaitEvt() are nested, it returns the last one, which means the one that makes the deeper UTIL_SEQ_WaitEvt() to return to its caller.

4.5 Timer server

The timer server has the following features:

- Up to 255 virtual timers depending on available RAM capacity
- Single shot and repeated mode
- Stops a virtual timer and restarts it with a different timeout value
- Deletes a timer
- Timeout from 1 to $2^{32} - 1$ ticks

The timer server provides multiple virtual timers sharing the RTC wakeup timer. Each virtual timer may be defined as either single shot or a repeated timer. When a repeated timer comes to the end of a cycle, the user is notified and the virtual timer is automatically restarted with the same timeout. When a single shot timer ends, the user is notified and the virtual timer is set to the pending state (which means it is kept registered and may be restarted at any time). The user may stop a virtual timer and restart it with a different timeout value. When a virtual timer is no longer needed, the user must delete it to free the slot in the timer server.

The timer server can be used concurrently with the calendar.

4.5.1 Implementation

To use the timer server, the application must:

- Configure the RTC IP. When the calendar is required in the application, the RTC configuration must be compatible with the calendar settings requirement. When the calendar is not used, the RTC may be optimized for a Timer Server usage only.
- Initialize the timer server with `HW_TS_Init()`.
- Implement `HW_TS_RTC_Int_AppNot()` (optional). When not implemented, the timer callback is called in the RTC interrupt handler context.
- Create a virtual timer with `HW_TS_Create()`.
- Use the virtual timer with `HW_TS_Stop()`, `HW_TS_Start()`.
- Delete the virtual when not needed using `HW_TS_Delete()`.

4.5.2 Interface

Table 4. Interface functions

Function	Description
<code>void HW_TS_Init(HW_TS_InitMode_t TimerInitMode, RTC_HandleTypeDef *hrtc);</code>	Initializes the timer server.
<code>HW_TS_ReturnStatus_t HW_TS_Create(uint32_t TimerProcessID, uint8_t *pTimerID, HW_TS_Mode_t TimerMode, HW_TS_pTimerCb_t pTimerCallBack)</code>	Creates a virtual timer.
<code>void HW_TS_Stop(uint8_t TimerID)</code>	Stops a virtual timer.
<code>void HW_TS_Start(uint8_t TimerID, uint32_t timeout_ticks)</code>	Starts a virtual timer.
<code>void HW_TS_Delete(uint8_t TimerID)</code>	Deletes a virtual timer.
<code>void HW_TS_RTC_Wakeup_Handler(void);</code>	Timer server handler to be called from the RTC interrupt handler.
<code>uint16_t HW_TS_RTC_ReadLeftTicksToCount(void);</code>	Returns the number of ticks to count before the next interrupt.
<code>void HW_TS_RTC_Int_AppNot(uint32_t TimerProcessID, uint8_t TimerID, HW_TS_pTimerCb_t pTimerCallBack)</code>	Reports to the application that a virtual timer has expired.
<code>void HW_TS_RTC_CountUpdated_AppNot(void)</code>	Reports to the application that the number of ticks before the next interrupt has been updated by the timer server.

4.5.3 Detailed interface and behavior

The timer server provides virtual timers that run while the system is in Low-power mode down right down to Standby mode.

```
void HW_TS_Init(HW_TS_InitMode_t TimerInitMode, RTC_HandleTypeDef *hrtc) :
```

This command initializes the timer server based on the RTC IP configuration that must be made upfront.

TimerInitMode selects the timer server boot mode. When Standby mode is supported and the device wakes up from standby, set TimerInitMode to hw_ts_InitMode_Limited so that the timer server context is not reset. Otherwise, TimerInitMode must be set to hw_ts_InitMode_Full to run full initialization.

hrtc is the Cube HAL RTC handle.

```
HW_TS_ReturnStatus_t HW_TS_Create(uint32_t TimerProcessID,
uint8_t *pTimerId,
HW_TS_Mode_t TimerMode,
HW_TS_pTimerCb_t pTimerCallBack) :
```

pTimerId

This is the id returned by the timer server to the caller that needs to be used to Stop/Start/Delete the created timer.

TimerMode

The timer mode may be either in single shot or repeated mode. When in single shot mode, the timer is stopped when the timeout is reached. In repeated mode, it is restarted with the same previously programmed value at each timeout. This mode is fixed when the timer is created. To change the mode, the timer must be deleted and a new one must be created. Note that in this case, the new allocated pTimerId may be different.

pTimerCallBack

User callback on timeout.

TimerProcessID

This is defined by the user and is expected to be used in HW_TS_RTC_Int_AppNot(). When the timer is created, only the caller knows the Id that has been allocated. The TimerProcessID is returned in the HW_TS_RTC_Int_AppNot() with the pTimerCallBack so that relevant decision may be done when implementing HW_TS_RTC_Int_AppNot().

```
void HW_TS_Stop(uint8_t TimerID)
```

Stops the timer TimerID. It has no effect if the timer is not running. The timer TimerID must have been created. When the timer is stopped, the TimerID remains allocated in the timer server so that the same timer (with the same TimerMode and same pTimerCallBack) can be restarted with a different value.

```
void HW_TS_Start(uint8_t TimerID, uint32_t timeout_ticks)
```

Starts the timer TimerID with the timeout_ticks value. The value of the timeout_ticks depends on the configuration of the RTC IP. If the TimerID is already running, it is first stopped in the timer server and restarted with the new timeout_ticks value.

```
void HW_TS_Delete(uint8_t TimerID)
```

Deletes the TimerID from the timer server. The TimerID may be allocated to a new virtual timer. This API may be called on a running TimerID. In that case, it is first stopped and then deleted.

```
void HW_TS_RTC_Wakeup_Handler(void)
```

This interrupt handler must be called by the application in the RTC interrupt handler. This handler clears all required status flag in the RTC and EXTI peripherals.

```
uint16_t HW_TS_RTC_ReadLeftTicksToCount(void)
```

This API returns the number of ticks left to be counted before an interrupt is generated by the timer server. It may be used when the system needs to enter Low-power mode and decide which Low-power mode to apply, depending on when the next wakeup is expected.

When the timer is disabled (no timer in the list), it returns 0xFFFF.

```
void HW_TS_RTC_Int_AppNot(uint32_t TimerProcessID,  
uint8_t TimerID,  
HW_TS_pTimerCb_t pTimerCallBack)
```

This API must be implemented by the user application.

It notifies the application when a timer expires. This API is running in the RTC wakeup interrupt context and the application may prefer to call the pTimerCallBack as a background task depending on how much code is executed in the pTimerCallBack. As long as the TimerID is only known to the caller, the TimerProcessID may be used to identify to which module this pTimerCallBack belongs and the application may assess if it may be called in the RTC wakeup interrupt context or not.

```
void HW_TS_RTC_CountUpdated_AppNot(void) :
```

This API must be implemented by the user application.

This API notifies the application that the counter has been updated. This is expected to be used along with the HW_TS_RTC_ReadLeftTicksToCount () API. The counter may have been updated since the last call of HW_TS_RTC_ReadLeftTicksToCount () and before entering Low-power mode. This notification provides the application a way to solve the race condition to reevaluate the counter value before entering Low-power mode

4.6 Low power manager

The low power manager provides a simple interface to receive the input from up to 32 different users and computes the lowest possible power mode the system may use. It also provides hooks to the application before entering or on exit of low-power mode.

The Low power manager provides the following features:

- up to 32 users
- Stop mode and Off mode (standby and shutdown).
- Low-power mode selection
- Low-power mode execution
- callback when entering or exiting low-power mode
- Run mode not supported, when the application has to stay in this mode, it must not call UTIL_LPM_EnterModeSelected ().

4.6.1 Implementation

The low power manager can handle up to 32 users with different low-power mode requests.

To use the low power manager, the application must:

- create a user Id
- call either UTIL_LPM_SetOffMode() or UTIL_LPM_SetStopMode() at any time with the defined user Id to set the requested Low-power mode
- call void UTIL_LPM_EnterLowPower() in background.

4.6.2 Interface

Table 5. Interface functions

Function	Description
UTIL_LPM_ModeSelected_t UTIL_LPM_ReadModeSel(void)	Returns the selected Low-power mode that will be applied.
UTIL_LPM_SetOffMode(UTIL_LPM_bm_t lpm_id_bm, UTIL_LPM_State_t state)	Enables or disables the Off mode for any user at any time.
void UTIL_LPM_SetStopMode(UTIL_LPM_bm_t lpm_id_bm, UTIL_LPM_State_t state)	Enables or disables the Stop mode for any user at any time.
void UTIL_LPM_EnterLowPower(void)	Enters the selected Low-power mode.
void UTIL_LPM_EnterSleepMode(void)	API called before entering Sleep mode.
void UTIL_LPM_ExitSleepMode(void)	API called on exiting Sleep mode.
void UTIL_LPM_EnterStopMode(void)	API called before entering Stop mode.
void UTIL_LPM_ExitStopMode(void);	API called on exiting Stop mode.
void UTIL_LPM_EnterOffMode(void)	API called before entering off mode.
void UTIL_LPM_ExitOffMode(void);	API called on exiting off mode. This is called only if the MCU did not enter Off mode as expected.

4.7 Flash memory management

The STM32WB share one single bank between CPU1 and CPU2. When the Flash memory is either being written or erased, there is no way to fetch instruction from it.

When the CPU executes code from Flash memory, it stalls as soon as a write or erase operation is started.

When the CPU executes code from SRAM, the CPU is not stalled while a write or erase operation is ongoing (assuming it does not read data from Flash memory).

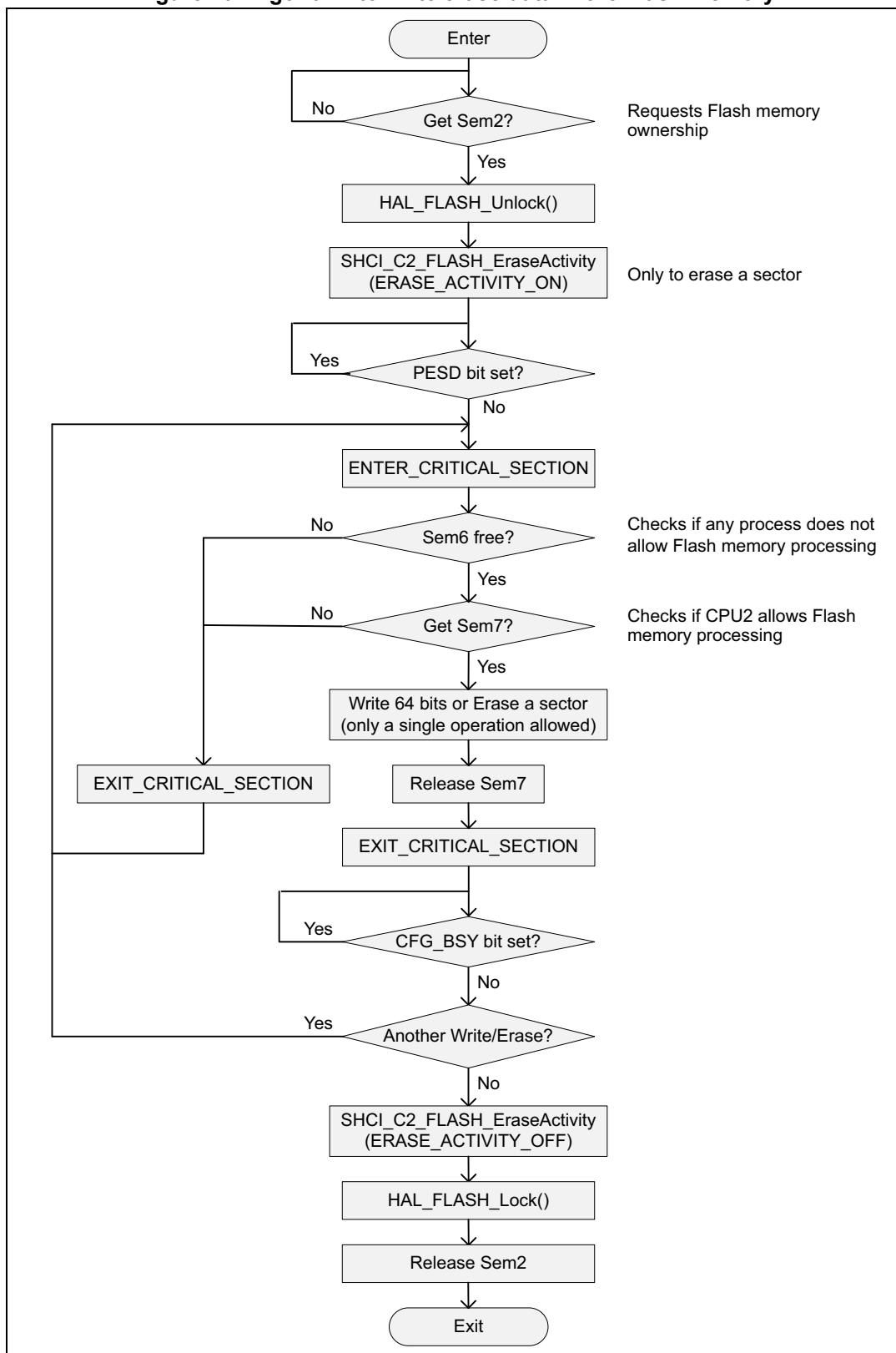
4.7.1 CPU2 timing protection

For security reason, CPU2 is prevented to execute any code from SRAM. To protect the CPU2 timing, it uses Sem7 to enable or disable Flash memory operation requests from CPU1.

The application on CPU1 must implement the algorithm shown in [Figure 10](#) to write or erase the Flash memory, and also implement in its own driver the following actions (outside the critical section defined in [Figure 10](#)):

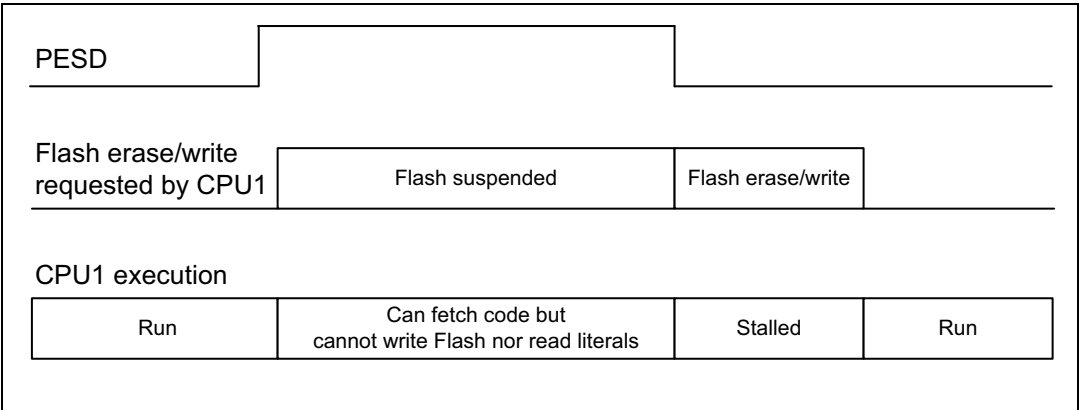
- Take Sem2 before any access to the Flash memory and release it when it no longer needs it to access the IP
- When the user driver needs to erase sectors, it must first send the command `SHCI_C2_FLASH_EraseActivity(ERASE_ACTIVITY_ON)`. When all concerned sectors are erased, it must send the command `SHCI_C2_FLASH_EraseActivity(ERASE_ACTIVITY_OFF)`, see [Section 4.7.1](#).
- When the CPU2 timing protections uses the PESD bit mechanism (which is the case by default, see [Section 4.7.1](#)), the FLASH driver must either poll the `CFGBSY` bit from the `FLASH_SR` register or read back the memory until the value is the one to be written.

Figure 10. Algorithm to write/erase data in the Flash memory



By default, CPU2 uses the PESD bit mechanism (from FLASH_SR register) to protect its BLE timing and not Sem7. The algorithm is still valid although checking Sem7 is useless. The drawback is that if the PESD bit is set by CPU2 at the same time when CPU1 starts a write or erase operation, CPU1 can fetch code but cannot read literals from the memory, even if the code to be executed requires this action. It is very difficult to control whether CPU1 will be stalled or not when the PESD mechanism is used. Additionally, there is no interrupt signal on PESD bit release by CPU2, so asynchronous software flow is not possible.

Figure 11. CPU1 and Flash memory operation versus PESD bit



The CPU2 use of PESD or Sem7 mechanism to protect the BLE timing is configurable by CPU1 with the system command `SHCI_C2_SetFlashActivityControl()`. Although it can be sent at any time, it is recommended to send it during the initialization phase.

By default, CPU2 protects its timing versus write operation requested by CPU1. When CPU1 needs to start an erase operation, it must first send the system command `SHCI_C2_FLASH_EraseActivity(ERASE_ACTIVITY_ON)`. When it does not expect to request erase operation anymore, it has to send the system command `SHCI_C2_FLASH_EraseActivity(ERASE_ACTIVITY_OFF)`. These commands do not need to be sent for each single erase operation. It is recommended to enable the protection before requesting the first erase operation and to send the disable protection after the last erase operation has been performed.

4.7.2 CPU1 timing protection

When CPU1 needs to make sure it will not be stalled due to Flash memory operation (write or erase) requested by CPU2, it must take Sem6. CPU2 does not request any Flash memory operation until Sem6 is released.

When Sem6 is taken, it means CPU2 is already in the process to execute a Flash memory operation (it is either close to be started or it has just finished). CPU1 must poll Sem6 to get it when it needs to prevent CPU2 to request any Flash memory operation.

CPU2 uses the same algorithm described in [Figure 10](#).

4.7.3 Conflict between RF activity and Flash memory management

Even if CPU1 does not use Sem6 to prevent CPU2 to start Flash memory operation, there are still some use cases when it is impossible for CPU2 to start the erase operation.

Flash memory write operation is always possible, but when the NVM is full on CPU2, a Flash memory write request may need an erase operation. In this case, the data are not written until the erase operation is executed.

When the CPU2 needs to protect its timing versus erase either because it has been notified by CPU1 with the command `SHCI_C2_FLASH_EraseActivity(ERASE_ACTIVITY_ON)` or because internally it needs to execute the Flash memory erase operation to erase some sectors in the NVM, any memory operation will be forbidden 25 ms before the radio activity until the end of it. To execute Flash memory erase operation when BLE is running, the application must make sure that there is some radio idle time longer than 25 ms.

- BLE advertising: the advertising interval must be longer than 25 ms + advertising packet length to be able to execute Flash memory erase operation.
- BLE connected: the connection interval must be longer than 25 ms + packet length in to be able to execute Flash memory erase operation.
- Data throughput use case: When data streaming packet is sent, the radio is kept active to send as much data as possible between two connection intervals. Therefore, the radio may not be in idle long enough to fit an erase operation. When the device is master, it may reduce the Connection Event Length parameter (with either the `aci_gap_create_connection()` or `aci_gap_start_connection_update()` command) to prevent the device filling completely the interval between two connection intervals. When the device is slave, it must request the master to increase the connection interval so that the data to be sent fit only part of the interval between two connections events.

The only cases when CPU2 needs to write data in Flash memory are:

- after the pairing phase to store the security information
- after a disconnection to store the GATT client descriptor information of the client that just disconnected, provided it was bonded.

4.8 Debug information from CPU

4.8.1 GPIO

It is possible to output on GPIOs most of the real time activity of CPU2 such as background tasks, interrupt handlers and BLE IP Core signals. Assignment of a signal to particular GPIO is fully configurable from the CPU1 side except for the BLE IP Core signals as they are driven by HW. Therefore, the BLE IP Core GPIOs must be enabled only if not used by the application. The full configuration is made in the file `app_debug.c` located in `\Core\Src` for each application.

HW signals

The `aRfConfigList[]` table holds the list of GPIO driven by the hardware according to the radio activity. There are four parameters for each signal to monitor:

```
{ GPIOA, LL_GPIO_PIN_9, 0, 0 }, /* DTB13 - Tx/Rx Start */
```

The first two parameters define the GPIO used (in this example, PA9 is used to output DTB13). These two parameters cannot be modified. To monitor the signal, the associated GPIO must be available on the board.

The third parameter is used to enable (1) or disable (0) the signal. All signals are set to 0 by default.

The fourth parameter is unused and shall be kept at 0.

To monitor a signal on the associated GPIO, the third parameter must be set to 1 and the BLE_DTB_CFG compiler switch at the top of the file must be set to 7.

The most useful signal is DTB13, which shapes all radio activity.

SW signals

The aGpioConfigList [] table holds the list of GPIO that are driven by the software. There are four parameters for each signal to monitor:

```
{ GPIOA, LL_GPIO_PIN_0, 0, 0}, /* BLE_ISR - Set on Entry / Reset on Exit */
```

The first two parameters define the GPIO used to output the signal. These are fully configurable. The user may select any GPIO unused in the application.

The third parameter is used to enable (1) or disable (0) the signal. All signals are set to 0 by default.

The fourth parameters is unused and must be kept to 0.

To monitor one signal on the associated GPIO, the third parameter must be set to 1.

4.8.2 SRAM2

Hardfault

When CPU2 enters the hardfault interrupt handler, it can output different information before running an infinite loop.

It can set a GPIO if enabled in app_debug.c - aGpioConfigList [].

It writes in SRAM2A the following data:

@SRAM2A_BASE: 0x1170FD0F	Keyword that identifies a hardfault issue
@SRAM2A_BASE + 4	Program counter value that generated the hardfault
@SRAM2A_BASE + 8	Link register value when the instruction that generated the hardfault has been executed
@SRAM2A_BASE + 12	Stack pointer value when the instruction that generated the hardfault has been executed

Security attack

When the buffers provided to the CPU2 to exchange data through the mailbox are not in the unsecure SRAM2, the CPU2 enters an infinite loop and writes the keyword 0x3DE96F61 @SRAM2A_BASE.

4.9 FreeRTOS low power

Whatever the stack running on CPU2, the FreeRTOS low power mode shares the same implementation on the CPU1 for all wireless applications.

The HAL tick is mapped to TIM17 to not collide with the systick reserved for FreeRTOS. The file `stm32wbxx_hal_timebase_tim.c` from `\Applications\BLE\BLE_HeartRateFreeRTOS\Core\Src` implements the HAL functions:

- `HAL_InitTick()`
- `HAL_SuspendTick()`
- `HAL_ResumeTick()`

The TIM17 user interrupt handler `HAL_TIM_PeriodElapsedCallback()` is implemented in `main.c` to increment the tick used by the HAL. This implementation may be customized to select another timer.

When FreeRTOS is in idle mode, the systick is switched off and replaced with a low power timer. The file `freertos_port.c` from `\Applications\BLE\BLE_HeartRateFreeRTOS\Core\Src` implements the tickless mode

- `vPortSuppressTicksAndSleep()` is reimplemented to support the tickless mode based on the low power mode available on STM32WB devices
- `vPortSetupTimerInterrupt()` is reimplemented to start a low power timer available on STM32WB devices

The current implementation is using the Timer server running on RTC. The timer selection may be changed by reimplementing the following functions:

- `LpTimerInit()` to initialize the low power timer to use.
- `LpTimerCb()` in case something more than just wakeup is required. In the current implementation, all actions done on wakeup are implemented on exit of low power mode in `vPortSuppressTicksAndSleep()` and not in the timer callback.
- `LpTimerStart()` to start the low power timer before entering low power mode.
- `LpGetElapsedTime()` to return how long the system has been in low power mode. This is required to update the systick used by FreeRTOS with `vTaskStepTick()`.

The low power mode is entered with `LpEnter()`. The current implementation is based on the Low power manager used in all BLE applications whether they are based on FreeRTOS or not. The implementation of `LpEnter()` may be customized.

BLE

The number of functions to be called in the background depends upon the application, which also determines if each function is called from a dedicated task or a single common task. The BLE architecture supports any combination.

Whatever the BLE application, there must be at least two function to be called in a task:

- **`hci_user_evt_proc()`**: when `hci_notify_asynch_evt()` is called from the middleware, this function must be called in the background. `hci_user_evt_proc()` must not be called inside `hci_notify_asynch_evt()` as it may be called from the IPCC interrupt context. There is no timing constraint between the time `hci_notify_asynch_evt()` is called from the middleware and the time when `hci_user_evt_proc()` is called in the background. However, in some data throughput use cases, the performance is better when the time is short enough to read the events at the same rate they are notified. When several `hci_notify_asynch_evt()` are received, the `hci_user_evt_proc()` function needs to be called only once from the background. It does not hurt to call several times

hci_user_evt_proc() from the background whereas there was only one or no notification with hci_notify_asynch_evt().

- **shci_user_evt_proc()**: the requirement is the same as for hci_user_evt_proc() with the associated notification shci_notify_asynch_evt(). Note that there is no currently data throughput on this system channel.

As long as it is not possible to send a BLE command while there is already one pending, or a system command while there is already one pending, the middleware provides hook so that the application may implement a semaphore mechanism.

When hci_cmd_resp_wait() is called from the middleware, a semaphore must be taken and released on reception of hci_cmd_resp_release(). The application must not return from hci_cmd_resp_wait() until the semaphore is released.

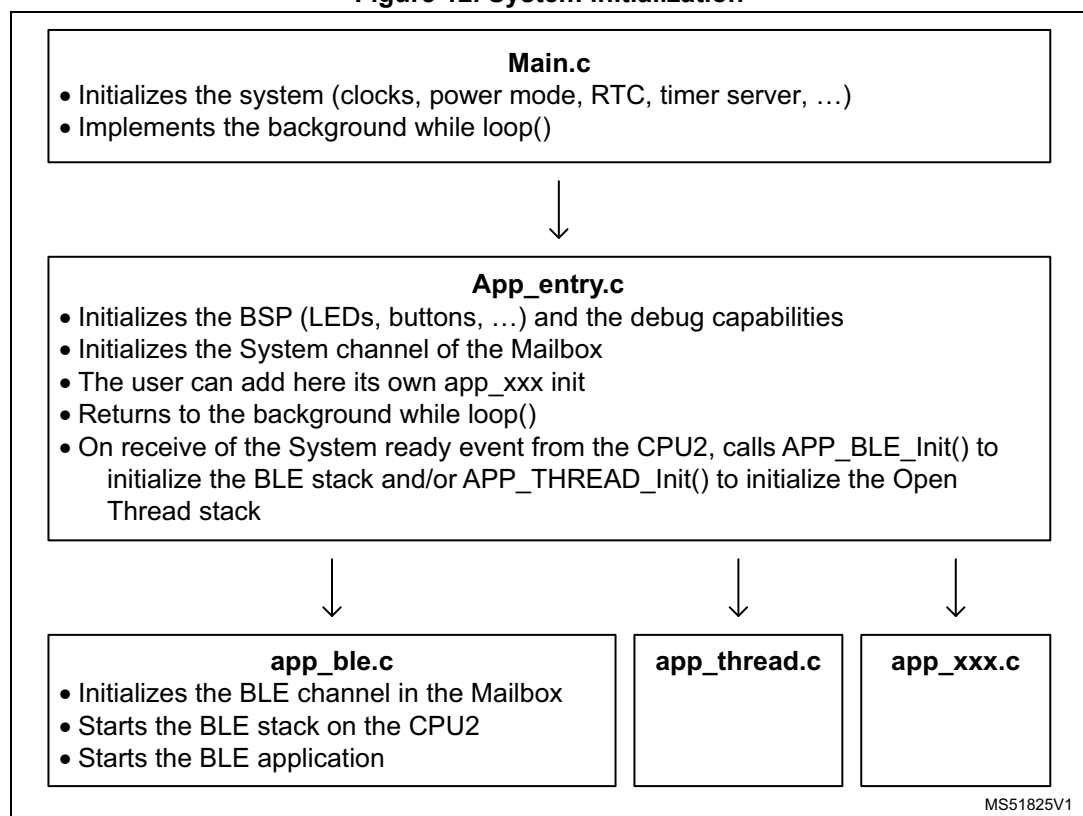
Another semaphore must be used to handle the same mechanism on the system channel with shci_cmd_resp_wait()/shci_cmd_resp_release().

5 System initialization

All applications begin with three sets of files (see [Figure 12](#)):

1. `main.c`: all HW configuration that is common to any application (the clock provided to the CPU2 must be always 32 MHz)
2. `app_entry.c`: all SW configuration and implementation that is common to any application
3. `app_ble.c` / `app_thread.c` / `app_xxx.c`: application dedicated files

Figure 12. System initialization



6 Step by step design of a BLE application

This section provides information and code examples on how to design and implement a BLE application on a STM32WB device.

6.1 Initialization phase

Several steps are mandatory to initialize the application.

- Initialize the device (HAL, reset device, clock and power configuration)
- Configure platform (buttons, LEDs)
- Configure hardware (UART, debug)
- Configure the BLE device public address (if used):
 - `aci_hal_write_config_data()` API
- Configure Tx Power
 - `aci_hal_set_tx_power_level()` API
- Init BLE GATT layer:
 - `aci_gatt_init()` API
- Init BLE GAP layer depending on the selected device role:
 - `aci_gap_init("role")` API
- Set the proper security I/O capability and authentication requirement (if BLE security is used):
 - `aci_gap_set_io_capability()` and `aci_gap_set_authentication_requirement()` APIs
- Define the required services, characteristics and characteristic descriptors if the device is a GATT server:
 - `aci_gatt_add_service()`, `aci_gatt_add_char()`, `aci_gatt_add_char_desc()` APIs
- Use sequencer to manage tasks and Low power

6.2 Advertising phase (GAP peripheral)

To establish a connection between a BLE GAP central (master) device and a BLE GAP peripheral (slave) device, the GAP discoverable mode has to be initiated on the peripheral device. The APIs in [Table 6](#) can be used.

Table 6. Advertising phase API description

API name	Description
<code>aci_gap_set_discoverable()</code>	Sets the device in general discoverable mode. The device is discoverable until the device issues the <code>aci_gap_set_non_discoverable()</code> API.
<code>aci_gap_set_limited_discoverable()</code>	Sets the device in a limited discoverable mode. The device is discoverable for a maximum period TGAP (lim_adv_timeout) of 180 seconds. The advertising can be disabled at any time by calling <code>aci_gap_set_non_discoverable()</code> API.
<code>aci_gap_set_direct_connectable()</code>	Sets the device in direct connectable mode. The device is in direct connectable mode only for 1.28 seconds. If no connection is established within this period, the device enters non-discoverable mode and advertising has to be enabled again explicitly.
<code>aci_gap_set_non_connectable()</code>	Puts the device into non-connectable mode
<code>aci_gap_set_undirect_connectable()</code>	Puts the device into undirected connectable mode.

6.3 Discoverable and connectable phase (GAP central)

To create a connection between two devices, the GAP central can discover the remote and then initiate a connection to the target device. It is also possible to initiate a direct connection to the specified device.

The APIs that can be used for the GAP discovery procedure are listed in [Table 7](#).

Table 7. GAP central APIs

API	Description
<code>aci_gap_start_limited_discovery_proc ()</code>	Starts the limited discovery procedure. The controller starts the active scanning. Only the devices in limited discoverable mode are returned to the upper layers.
<code>aci_gap_start_general_discovery_proc ()</code>	Starts the general discovery procedure. The controller starts active scanning.
The following APIs may be used in the procedure to establish the GAP connection	
<code>aci_gap_start_auto_connection_establish_proc ()</code>	Starts the auto connection procedure. The specified devices are added to the controller white list and initiate connection calls to the GAP controller using the initiator filter policy set to “use white list to determine which advertiser to connect to”.
<code>aci_gap_create_connection ()</code>	Starts the direct connection procedure. A create connection call is made to the controller by GAP with the initiator filter policy set to “ignore white list and process connectable advertising packets only for the specified device”.

Table 7. GAP central APIs (continued)

API	Description
<code>aci_gap_start_auto_connection_establish_proc()</code>	Starts the auto connection procedure. The specified devices are added to the controller white list and a create connection call is made to the controller by GAP with the initiator filter policy set to “use white list to determine which advertiser to connect to”.
<code>aci_gap_start_general_connection_establish_proc()</code>	Starts a general connection procedure. The device enables a controller scan with the scanner filter policy set to “accept all advertising packets” and from the scanning results, all the devices are sent to the upper layer using the event callback <code>hci_le_advertising_report_event()</code> .
<code>aci_gap_start_selective_connection_establish_proc()</code>	Starts a selective connection procedure. The GAP adds the specified device addresses into the white list and enables a controller scan with the scanner filter policy set to “accept packets only from devices in white list”. All the devices found are sent to the upper layer by the event callback <code>hci_le_advertising_report_event()</code> .
<code>aci_gap_terminate_gap_proc()</code>	Terminates the specified GAP procedure.

6.4 Services and characteristic configuration (GATT server)

To add a service and its related characteristics, a user application chooses from one of two profiles defined here:

- Standard profile defined by the Bluetooth SIG.
The user must follow the profile specification and services, and the characteristic specification documents to implement them using the related defined profile, services and characteristics 16-bit UUID (refer to Bluetooth SIG web page).
- Proprietary, non-standard profile.
The user must define custom services and characteristics. In this case, 128-bit UUIDs are required and must be generated by profile implementers (refer to UUID generator web page on www.famkruihof.net).

A service can be added using the following procedure:

```
aci_gatt_add_service(uint8_t Service_UUID_Type,
Service_UUID_t *Service_UUID,
uint8_t Service_Type,
uint8_t Max_Attribute_Records,
uint16_t *Service_Handle);
```

This procedure returns the pointer to the service handle (`Service_Handle`), which is used to identify the service within the user application. A characteristic can be added to this service using the following procedure:

```
aci_gatt_add_char(uint16_t Service_Handle,
uint8_t Char_UUID_Type,
Char_UUID_t *Char_UUID,
uint8_t Char_Value_Length,
uint8_t Char_Properties,
```

```
uint8_t Security_Permissions,
uint8_t GATT_Evt_Mask,
uint8_t Enc_Key_Size,
uint8_t Is_Variable,
uint16_t *Char_Handle);
```

This procedure returns the pointer to the characteristic handle (Char_Handle), which is used to identify the characteristic within the user application.

If the characteristic owner is in Notify or Indicate mode and enabled, the GATT server side must use the following API to send a notification or indication to the GATT client.

```
aci_gatt_update_char_value()
```

6.5 Service and characteristic discovery (GATT client)

Once two devices are connected, the application data exchange is based on GATT client-server architecture.

One device must implement the F and remove the GATT client.

The following APIs are used by the GATT client to discover services and characteristics, to enable/disable notification/indication to the GATT server, to write/read characteristics and to confirm GATT server Indication.

Table 8. GATT client APIs

API	Description
<code>aci_gatt_disc_all_primary_services ()</code>	<p>Starts the GATT client procedure to discover all primary services on the GATT server. It is used when a GATT client connects to a device and wants to find all the primary services provided on the device to determine what it can do.</p> <p>The procedure responses are given through the <code>aci_att_read_by_group_type_resp_event()</code> event callback</p>
<code>aci_gatt_disc_primary_service_by_uuid()</code>	<p>Starts the GATT client procedure to discover a primary service on the GATT server by using its UUID. It is used when a GATT client connects to a device and wants to find a specific service without the need for any other service.</p> <p>The procedure responses are given through the <code>aci_att_find_by_type_value_resp_event()</code> event callback</p>
<code>aci_gatt_find_included_services()</code>	<p>Starts the procedure to find all included services. It is used when a GATT client wants to discover secondary services once the primary services have been discovered.</p> <p>The procedure responses are given through the <code>aci_att_read_by_type_resp_event()</code> event callback.</p>

Table 8. GATT client APIs (continued)

API	Description
<code>aci_gatt_disc_all_char_of_service()</code>	Starts the GATT procedure to discover all the characteristics of a given service. The procedure responses are given through the <code>aci_att_read_by_type_resp_event()</code> event callback.
<code>aci_gatt_disc_char_by_uuid()</code>	Starts the GATT procedure to discover all the characteristics specified by a UUID. The procedure responses are given through the <code>aci_gatt_disc_read_char_by_uuid_resp_event()</code> event callback.
<code>aci_gatt_disc_all_char_desc()</code>	Starts the procedure to discover all characteristic descriptors on the GATT server. The responses are given through the <code>aci_att_find_info_resp_event()</code> event callback.

For all commands, the end of the procedure is indicated by `aci_gatt_proc_complete_event()` event callback .

6.6 Security (pairing and bonding)

The BLE security model includes five security features:

1. Pairing: process for creating one or more shared secret keys.
2. Bonding: act of storing the keys created during pairing for use in subsequent connections in order to form a trusted device pair.
3. Device authentication: verification to ensure two devices have the same keys.
4. Encryption: provides message confidentiality.
5. Message integrity: protects against message forgeries (4-byte message integrity check, or MIC)

BLE uses four pairing methods:

1. Just works
2. Out of band
3. Passkey entry
4. Numeric comparison (only secure connections) from Bluetooth 4.2

Method to determine computation of security keys:

- Legacy encryption - short temporary key (STK). STK is created to encrypt a connection. Then, if bonding, LTK will be used for subsequent connections.
- Secure connections - Long term key (LTK). LTK is created to encrypt the connection.

6.6.1 Security modes and level

LE security Mode 1 (Link layer):

- No security - level 1
- Unauthenticated pairing with encryption - level 2
- Authenticated pairing with encryption - level 3
- Authenticated LE secure connections pairing with encryption BT 4.2 - level 4

Authenticated pairing: pairing is performed with man In the middle (MITM) protection

Unauthenticated pairing: pairing is performed without MITM protection

LE security Mode 2 (ATT layer): not supported

- unauthenticated pairing with data signing
- authenticated pairing with data signing

6.6.2 Security commands

During the device initialization phase, the security properties can be initialized with the following commands:

```
aci_gap_set_io_capability()
```

Sets the IO capabilities of the device. This command has to be given only when the device is not in a connected state.

```
aci_gap_set_authentication_requirement()
```

Sets the authentication requirements for the device. This command has to be given only when the device is not in a connected state.

This command defines bonding mode information, MITM mode, LE secure connection support values, keypress notification support values, encryption key size, use or not of fixed pin, its value, and identity address type.

- SC_Support parameter defines the LE Secure connections support values.
 - 0x00: Secure connections pairing not supported (legacy pairing mode)
 - 0x01: Secure connections pairing supported but optional
 - 0x02: Secure connections pairing supported and mandatory (SC only mode)

Once the connection is established, the security procedure can be started:

- By the master with `aci_gap_set_pairing_req()`
 - Sends the SM pairing request to start a pairing process. The authentication requirements and IO capabilities must be set before issuing this command.
 - The `force_rebond` parameter value determines if the pairing request is sent even if the device was previously bonded.
- By the slave with `aci_gap_slave_security_req()`
 - Sends a slave security request to the master. This command has to be issued to notify the master of the security requirements of the slave. The master may encrypt the link, initiate the pairing procedure, or reject the request.
 - `aci_gap_pairing_complete_event` is returned after the pairing process is completed.

Depending on the SC_Support parameter value, the device answers to security requests with one of the commands listed in [Table 9](#).

Table 9. Security commands

Command	Description
<code>aci_gap_pass_key_resp()</code>	This command must be sent by the host in response to <code>aci_gap_pass_key_req_event</code> . The command parameter contains the pass key used during the pairing process if no fixed pin.
<code>aci_gap_numeric_comparison_value_confirm_yesno()</code>	This command allows the user to confirm or not the numerical comparison value shown through the <code>aci_gap_numeric_comparison_value_event</code> . When devices are bonded, the keys are stored in the non-volatile memory area (after BLE link disconnection). This means that if devices are previously bonded, and one of devices is unplugged, keys are not lost. When <code>aci_gap_set_pairing_req()</code> command is sent, with <code>force_rebond</code> parameter set to no force rebond, the pairing completes without any other exchange.
To clear the security database:	
<code>aci_gap_clear_security_db()</code>	All the devices in the security database are be removed.

6.6.3 Security information commands

Table 10. Security information commands

Command	Description
<code>aci_gap_get_bonded_devices()</code>	This command gets the list of the devices which are bonded. It returns the number of addresses and the corresponding address types and values.
<code>aci_gap_is_device_bonded()</code>	This command determines whether the device, whose address is specified in the command, is bonded. If the device uses a resolvable private address and has been bonded, then the command returns <code>ble_status_success</code> .
<code>aci_gap_get_security_level()</code>	This command can be used to get the current security settings of the device.
If keypress notification is supported, use:	
<code>aci_gap_passkey_input()</code>	This command permits to tell the stack the input type detected during passkey input.

Table 10. Security information commands (continued)

Command	Description
If OOB is supported, use:	
<code>aci_gap_set_oob_data()</code>	This command is sent by the user to input the OOB data arrived via OOB communication.
<code>aci_gap_get_oob_data()</code>	This command is sent by the user to get (extract from the stack) the OOB data generated by the stack itself.

6.7 Privacy feature

The BLE privacy feature reduces the ability to track a device over a period of time by changing the device address on a frequent basis.

The address of a device using the privacy mode can be resolved using the IRK (identity resolving key), which is one of the encryption keys exchanged during the pairing process.

Devices need first to be initialized with privacy disabled, then connected and paired.

Then, for privacy enabled on both devices, send on both sides:

```
Hci_reset()
aci_gap_init() - privacy enabled
aci_gap_add_devices_to_resolving_list()
```

This command is used to add one device to the list of address translations used to resolve Resolvable Private Addresses in the controller

From central side, send:

```
aci_gap_create_connection()

or

aci_gap_start_auto_connection_establish_proc()

or

aci_gap_start_general_connection_establish_proc() (then
aci_gap_create_connection) : own_address_type = resolvable private address,
peer_address_type = public or random
```

From peripheral side, send:

```
aci_gap_set_discoverable()

or

aci_gap_set_direct_connectable()

or

aci_gap_set_undirected_connectable()
own_address_type = resolvable private address
```

When the connection is established, the LE enhanced connection complete event is generated.

6.8 How to use the 2 Mbps feature

During the device initialization phase, the preferred TX_PHYS, RX_PHYS values can be initialized with the following command:

Table 11. 2 Mbps feature commands

Command	Description
HCI_LE_Set_default_Phy()	Specifies the preferred PHY to implement (for RX and TX), not linked to a connection. By default, the preferred PHY is 2M.
Once a connection is established (1M), the preferred PHY for TX and RX can be sent by each device:	
HCI_LE_Set_Phy()	Makes it possible for the host to specify the preferred values for a connection.
During a connection, the RX or TX PHY used can be read:	
HCI_LE_Read_Phy()	Reads the current PHY TX and RX for a connection.

When the command HCI_LE_Set_Phy() is used, event hci_le_phy_update_complete is received by the master.

6.9 How to update connection parameters

When a connection is established, it is possible to update connection parameters.

Table 12. Proprietary connection data

Command	Description
When the master device (central) is initiator of the update:	
aci_gap_start_connection_update()	Starts the connection update (only when role is master). On completion of the procedure, an HCI_LE_CONNECTION_UPDATE_COMPLETE_EVENT event is returned to the upper layer.
When the slave device (peripheral) is initiator of the update:	
aci_l2cap_connection_parameter_update_req()	Sends an L2CAP connection parameter update request from the slave to the master. An HCI_L2CAP_CONNECTION_UPDATE_RESP_EVENT event is raised when the master responds to the request (accepts or rejects it).

6.10 Write or read long local or distant values

6.10.1 Write long distant value

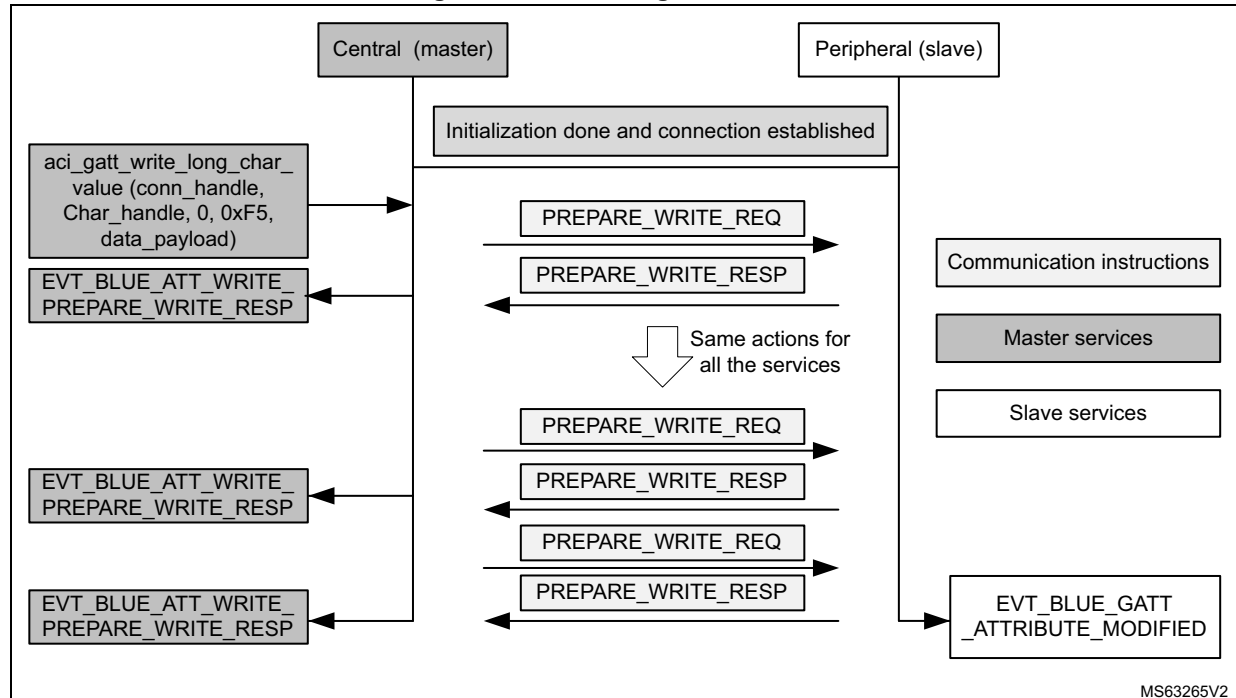
```
aci_gatt_write_long_char_value(conn_handle, RxCharHandle, offset,
chunk_size, (&payload)+offset)
```

Max data write length is 243 bytes.

On the server side, create a service aci_gatt_add_service.

Create a characteristic aci_gatt_add_char, with length max = 0xFF and property equal to CHAR_PROP_WRITE, as shown in [Figure 13](#).

Figure 13. Write long distant value

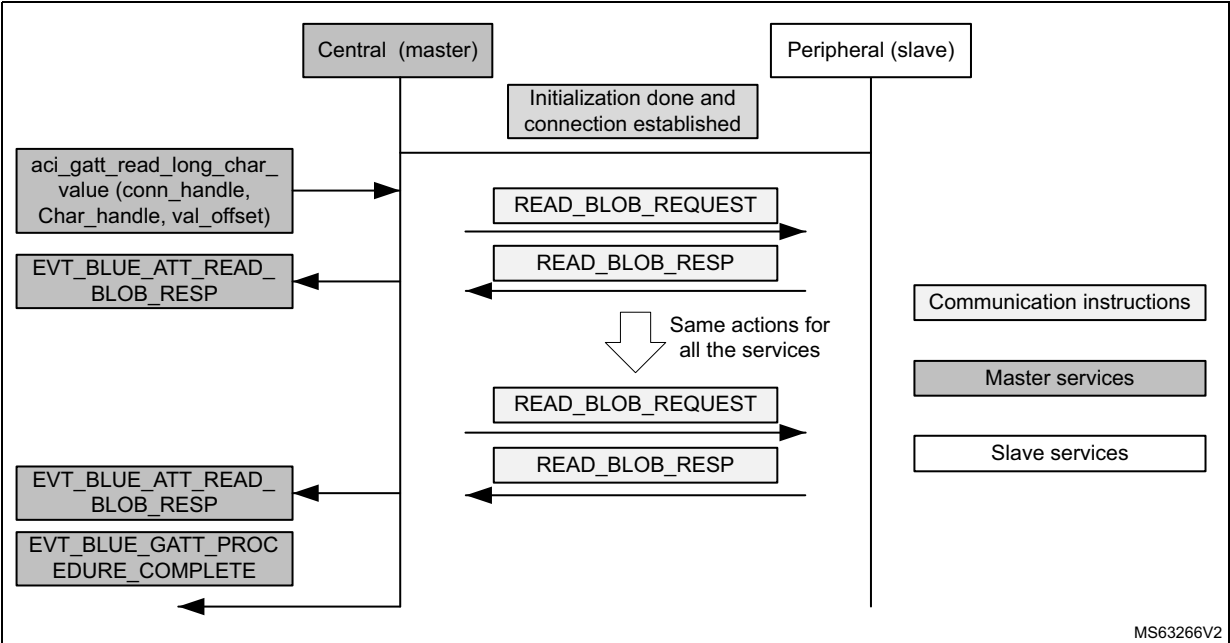


6.10.2 Read long distant value

```
aci_gatt_read_long_char_value(conn_handle, RxCharHandle, offset)
```

Max data read length is 243 bytes, as illustrated in [Figure 14](#).

Figure 14. Read long distant value



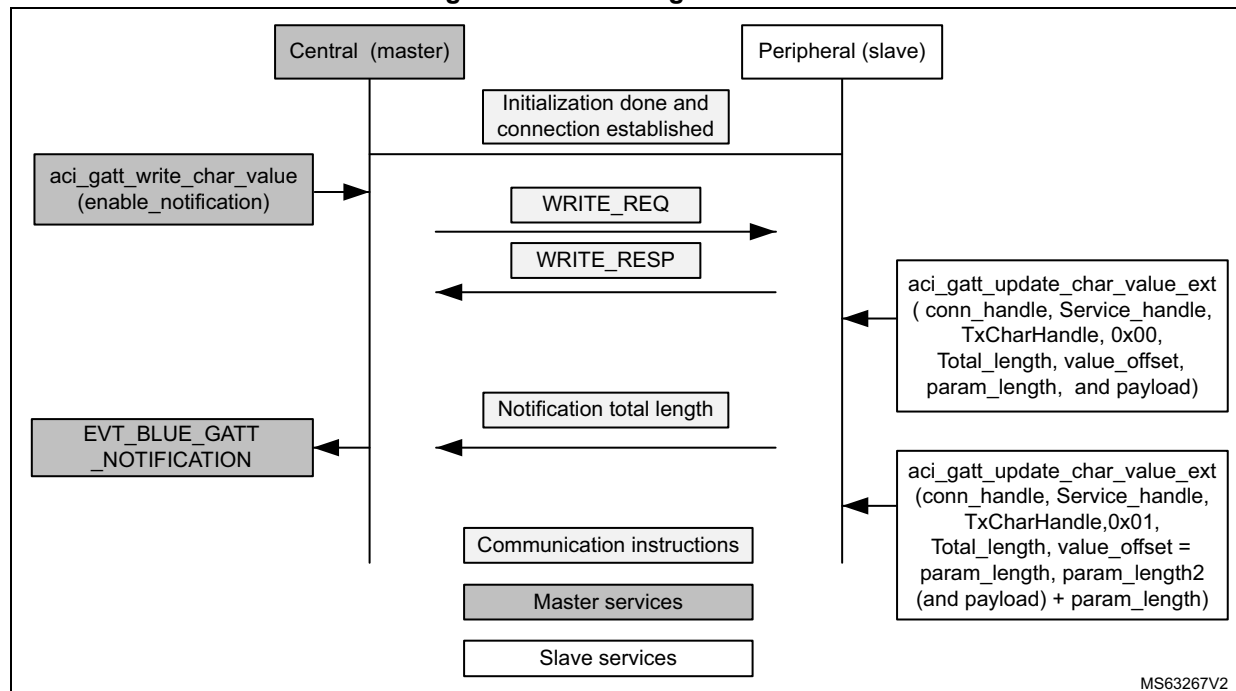
6.10.3 Write long local value

```
aci_gatt_update_char_value_ext(conn_handle_to_notify, service_handle,
char_handle, update_type, char_length, value_offset, value_length, value)
```

The maximum data write length is 243 bytes.

All data are sent if total length does not exceed (ATT_MTU – 3), as illustrated in [Figure 15](#).

Figure 15. Write long local value



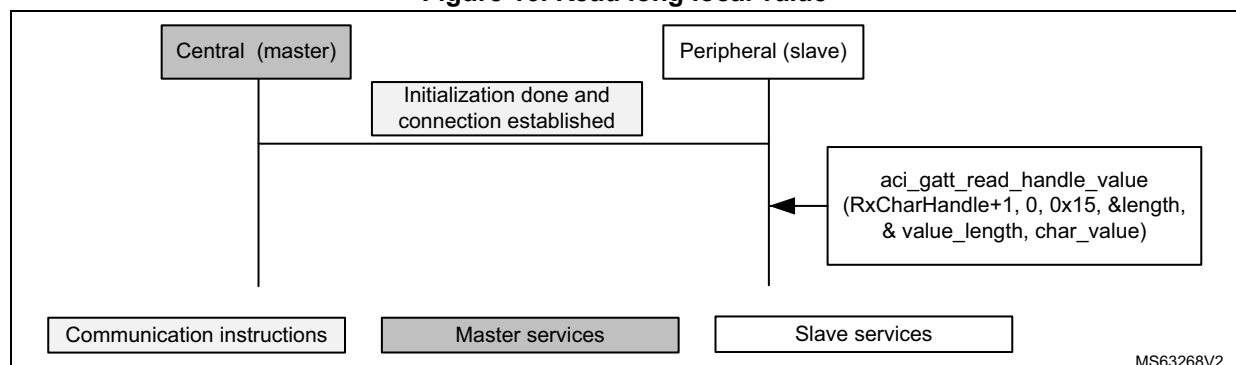
MS63267V2

6.10.4 Read long local value

```
aci_gatt_read_handle_value(RxCharHandle+1, offset,
value_length_requested, &length, &value_length, &value)
```

Value_length_requested cannot be greater than 243, when with one command it is not possible to read more than 243 bytes, an offset must be used (see [Figure 16](#)).

Figure 16. Read long local value



MS63268V2

6.11 Event and error code description

When a stack API is called, get the API return status and to monitor and track any potential error conditions.

BLE_STATUS_SUCCESS (0x00) is returned when the API is successfully executed.

All commands (HCI - ACI) are acknowledged by the `hci_command_status_event()`.

This command status event is used to indicate that the command described by the `Command_Opcode` parameter has been received, and that the BLE stack controller is currently performing the task for this command.

For any problem, the Status event parameters contains the corresponding error code (see [\[7\]](#), v5.0, Vol. 2, part D).

On the GATT client side, the GATT discovery procedure may fail due to several reasons. The `aci_gatt_error_resp_event()` is generated when an error response is received from the GATT server. This does not mean that the procedure ended with an error, but this error is part of the procedure itself.

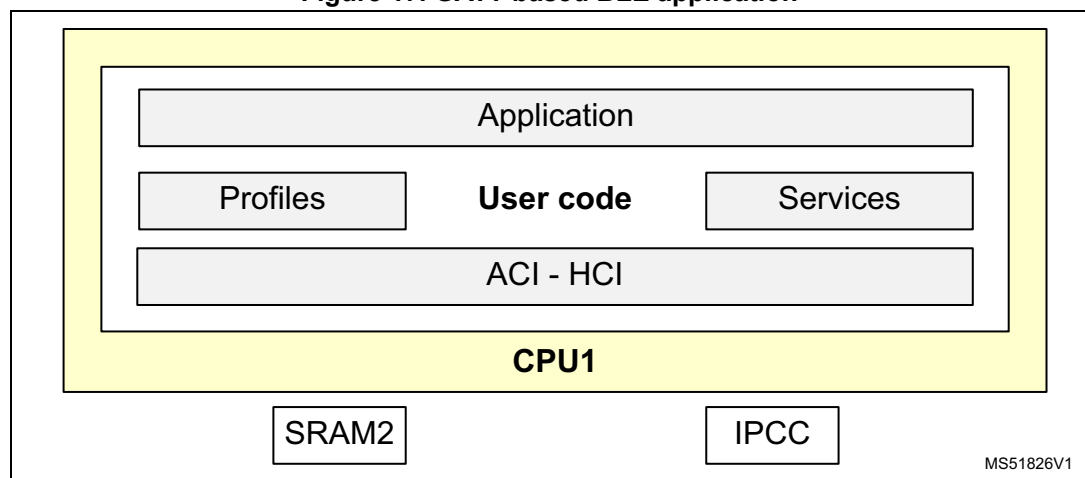
All GATT client procedures have to be completed with either a success or error on the `aci_gatt_proc_complete_event()`, so the GATT client can start a new procedure.

7 BT-SIG and proprietary GATT-based BLE application

This section describes the specification and implementation of the following applications running on CPU1:

- STM specific application
 - Transparent mode - Direct test mode
- BT-SIG GATT-based application
 - Heart rate sensor
- STMicroelectronics proprietary GATT-based application
 - P2P application (server / client)
 - FUOTA

Figure 17. GATT-based BLE application



7.1 Transparent mode - Direct test mode (DTM)

7.1.1 Purpose and scope

Among the set of HCI commands is a subset of commands used in order to enable direct test mode (DTM) as described in the Bluetooth Specification Core v5.0 Low Energy Controller Volume.

DTM is used to control the DUT and provides a report to the tester. According to the specification, the DTM must be set up using one of the two methods below:

1. Over HCI (the one implemented in STM32WB devices)
2. Through a 2-wire UART interface.

STM32WB supports the DTM as per Bluetooth Core Specification v5.0 [Vol. 6, Part F].

Here are the HCI test commands, which are fully compliant with the specifications:

- HCI_LE_Transmitter_Test
- HCI_LE_Enhanced_Transmitter_Test
- HCI_LE_Receiver_Test
- HCI_LE_Enhanced_Receiver_Test
- HCI_LE_Test_End

The number of the received test packets is a return value of the function HCI_LE_Test_End.

The additional available functions are listed in [Table 13](#).

Table 13. Direct test mode functions

Function	Description
aci_hal_le_tx_test_packet_number	This command provides the number of transmitted test packets during a DTM test.
aci_hal_set_tx_power_level	This command is used to set the TX output power. The ACI command set (see [3]) contains a complete description of the TX power level values.
aci_hal_tone_start	This command is used to generate a continuous waveform (CW) from the STM32WB radio.
aci_hal_tone_stop	This command is used to terminate the CW emission.

The command sequence below is a typical flow for enabling CW transmission from the STM32WB radio:

```
hci_reset
aci_hal_set_tx_power_level
aci_hal_tone_start
aci_hal_tone_stop
```

7.1.2 Transparent mode application principle

This firmware is used to:

- Receive commands on UART RX
- Transmit events on UART TX
- Communicate with the BLE stack via the IPCC.

No interpretation is done by CPU1 application firmware.

A set of commands/events has to go through the STM32WB UART to control BLE stack via Transparent mode application.

Level shifter, VCP ST-LINK or applicative VCP can be used to manage the TX and RX.

7.1.3 Configuration

STM32WB is seen as a 2-wire UART interface (TXD, RXD). CPU1 application to be used is "Ble_TransparentMode". This firmware does not interpret the command and event but just

communicates to the wireless BLE stack via the IPCC and the selected UART interface (USART1 or LPUART1).

The UART interface and configuration selection is done using `app_conf.h`:

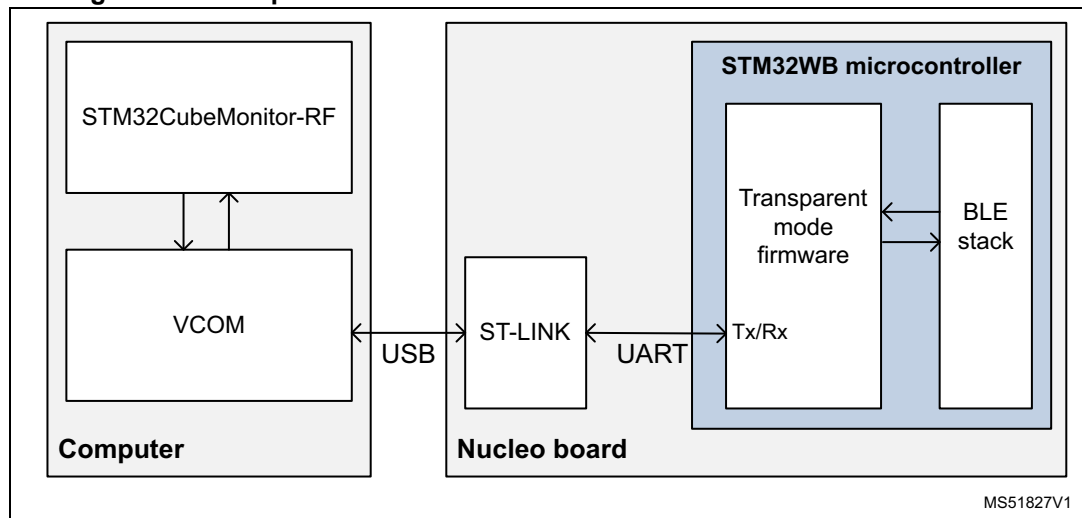
```
#define CFG_UART_GUI          hw_uart1
```

The P-NUCLEO-WB55 board includes the ST-LINK with Virtual COM port capability.

The following project is configured to communicate via the VCP of the ST-LINK:
 \Projects\ NUCLEO-WB55.Nucleo\Applications\BLE\Ble_TransparentMode.

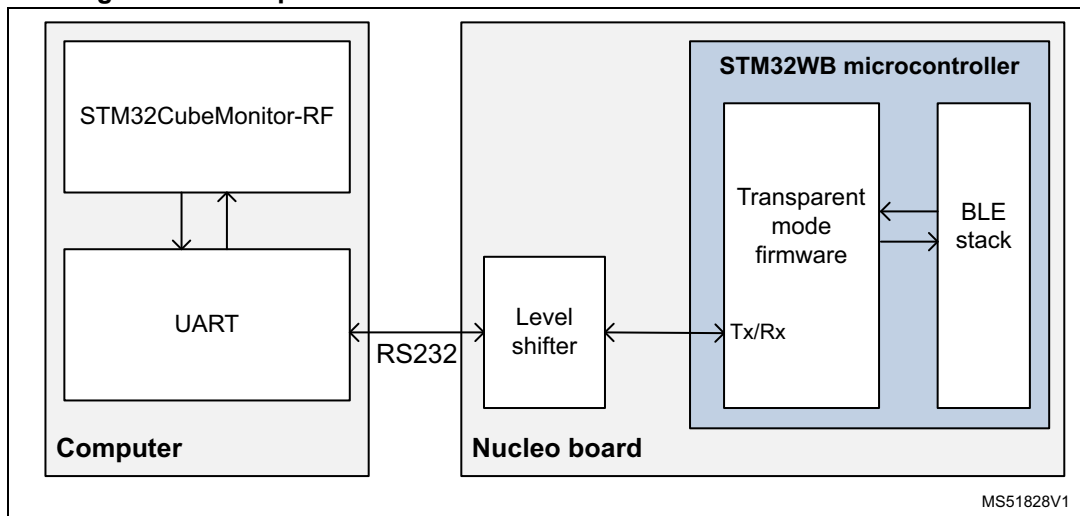
The UART1 (PB6, PB7) is connected to the P-NUCLEO-WB55 board ST-LINK VCP.

Figure 18. Transparent mode with P-NUCLEO-WB55 board and ST-LINK VCP



The P-NUCLEO-WB55 dongle board is provided without the ST-LINK. The project
 \Projects\ NUCLEO-WB55.USB Dongle\Applications\BLE\BLE_TransparentModeVCP
 includes Virtual COM port implementation in addition to the transparent mode feature.

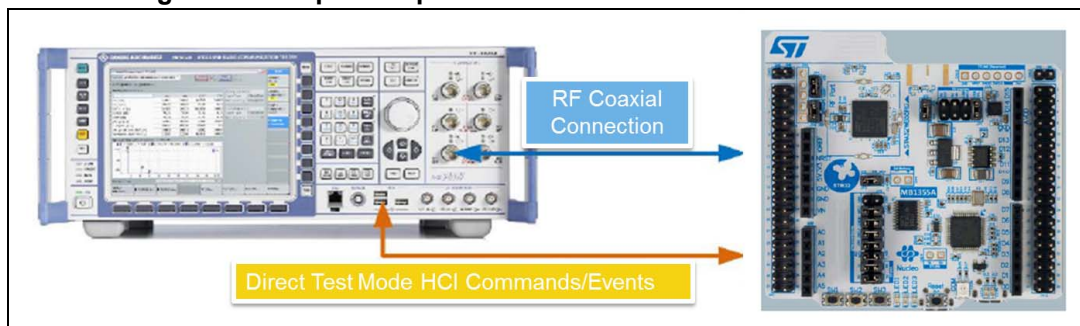
It is also possible to connect the STM3232WB UART interface directly to RS232 serial communication via a level shifter (not included on the NUCLEO-WB55RG board). This approach may be used to connect, among others, an RF tester.

Figure 19. Transparent mode with P-NUCLEO-WB55 board and level shifter

7.1.4 RF certification - Application implementation

The direct test mode (DTM) is specified by the Bluetooth SIG to provide a selection of different RF tests for BLE devices including remote control commands for the USB or RS232 interface.

BLE RF is placed in either continuous transmit or receive mode with or without modulation for RF evaluation. [Figure 20](#) illustrates a simple setup.

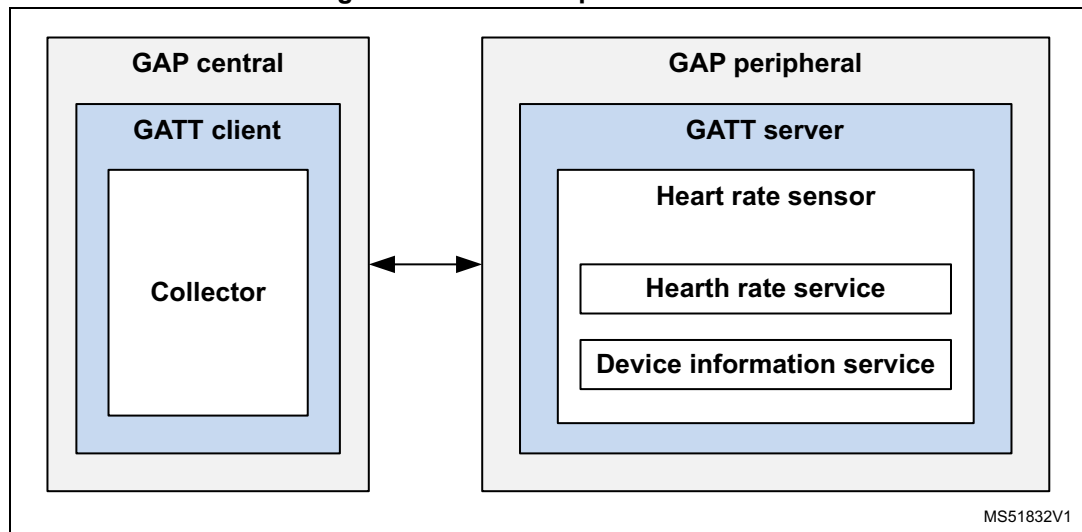
Figure 20. Simple setup with BLE RF tester and P-NUCLEO board

7.2 Heart rate sensor application

The heart rate profile is composed by two actions:

- Collector: GAP central and GATT client to receive heart rate measurement and other data
- Heart rate sensor: GAP peripheral and GATT server to provide heart rate measurement and other data.

Figure 21. Heart rate profile structure



The STM32WBCube_FW_WB_V1.0.0 release is provided with a heart rate sensor example.

This section describes the steps to create a Bluetooth SIG heart rate sensor application, aiming at transmitting heart rate from a sensor (for fitness application) each second and is composed of the following steps (illustrated in [Figure 22](#)):

- STM32WB user application initialization
- Heart rate service implementation - Middleware
- Heart rate sensor peripheral - User
- Heart rate sensor measurement update - User.

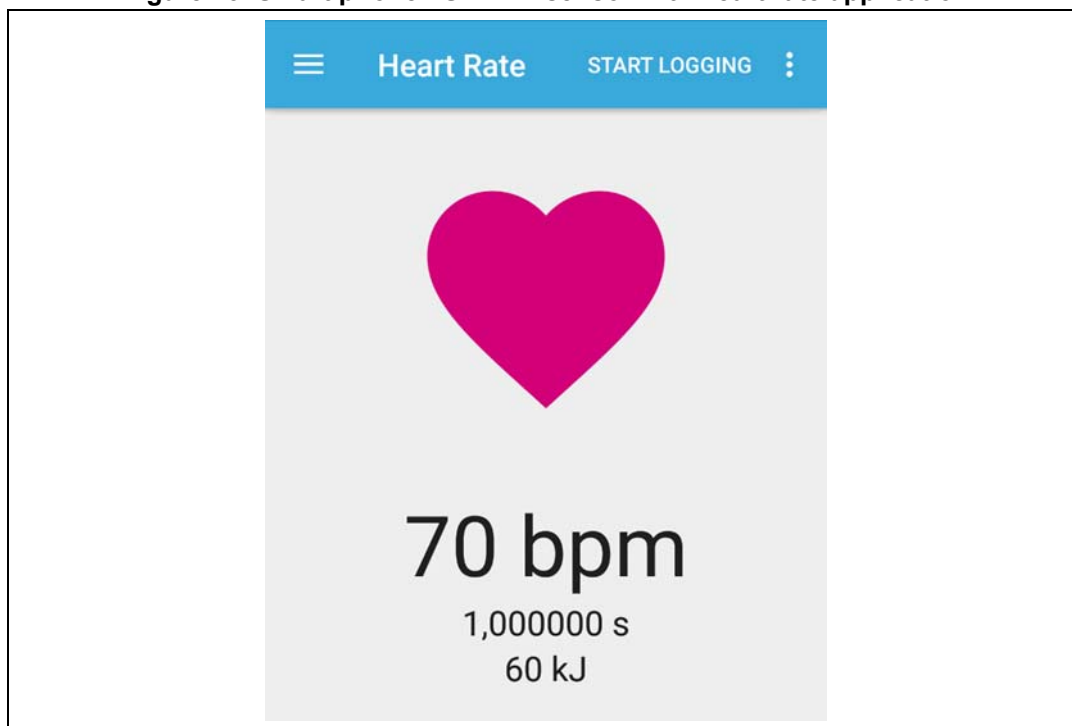
Figure 22. Simple setup with BLE RF tester and P-NUCLEO board



7.2.1 How to use STM32WB heart rate sensor application

- Open BLE_HeartRate project and follow readme.txt instructions
- Connect the ST BLE sensor mobile application to your heart rate application

Figure 23. Smart phone - ST BLE sensor with heart rate application



7.2.2 STM32WB heart rate sensor application - Middleware application

In Middlewares\STM32_WPAN\ble\core\Src\, the subfolder to insert BLE services is blesvc.

Warning: Do not modify the files in this folder.

- svc_ctl.c: Initializes the BLE stack and manages the services of the application (GATT events)
- hrs.c: used for the creation of:
 - A service and its characteristics for the application,
 - To update the service characteristics,
 - To receive the notification or write command and
 - to make a link between the BLE stack and the applicative.

For the application, the subfolder to create specific code is STM32_WPAN\app

- app_entry.c: Initializes the BLE Transport layer and the BSP (e.g. LEDs, buttons)
- app_ble.c: Initializes the GAP and manages the connection (e.g. advertising, scan)
- hrs_app.c: Initializes the GATT and manages the application

Heart rate service functionalities:
Middlewares\STM32_WPAN\ble\core\Src\blesvc\hrs.c

Table 14. Heart rate service functionalities

Function	Description
Service Init - HRS_Init()	<ul style="list-style-type: none"> Registers the heart rate event handle to the service controller Initializes the service UUID
aci_gatt_add_serv	<ul style="list-style-type: none"> Adds the heart rate service as primary service Initializes the heart rate measurement characteristic
aci_gatt_add_char	<ul style="list-style-type: none"> Adds the heart rate characteristic Initializes the body sensor location characteristic
aci_gatt_add_char	<ul style="list-style-type: none"> Adds the body sensor location characteristic Updates the heart rate measurement characteristic
aci_gatt_update_char_value	<ul style="list-style-type: none"> Updates the requested characteristics within the specified value Updates the body sensor location characteristic value
aci_gatt_update_char_value	<ul style="list-style-type: none"> Updates the requested characteristics within the specified value
HeartRate_Event_Handler(void *Event)	<ul style="list-style-type: none"> Manages the HCI Vendor Type Event
EVT_BLUE_GATT_WRITE_PERMIT_REQ	<ul style="list-style-type: none"> Server receives a Write command HR control point characteristic value Resets energy expended command then: Sends an aci_gatt_write_response() with an OK status. Notifies the HRS application to reset expended energy Or sends an aci_gatt_write_response() with an error.
EVT_BLUE_GATT_ATTRIBUTE_MODIFIED	<ul style="list-style-type: none"> HR measurement characteristic description value ENABLE or DISABLE notification Notifies HRS application of the measurement notification

The purpose of the service implementation is to:

- Register the heart rate services and selected characteristics with the BLE stack GATT database

```
/**
 * @brief Service Heart Rate initialization
 * @param None
 * @retval None
 */
void HRS_Init(void)
{
    REGISTER HEART RATE EVENT HANDLER
    • SVCCTL_RegisterSvcHandler(HearRate_Event_Handler);

    REGISTER HEART RATE SERVICE GATT DATABASE TO BLE STACK
    Add Heart Rate Service
    Add Heart Rate characteristics
```

```

Measurement Value (mandatory)
Body sensor Location (Optional)
Heart rate control point(Optional)
Add Over The Air Reboot Request characteristic (Optional)
}

```

- Manage the GATT event dedicated to the HR service

```

/**
 * @brief Heart Rate Service Event handler
 * @param Event: Address of the buffer holding the Event
 * @retval Ack: Return whether the GATT Event has been managed or not
 */
static SVCCTL_EvtAckStatus_t HearRate_Event_Handler(void *Event)
{
    MANAGE GATT EVENT FROM BLE STACK
    • EVT_BLUE_GATT_WRITE_PERMIT_REQ
    • EVT_BLUE_GATT_ATTRIBUTE_MODIFIED

    NOTIFY USER APPLICATION - HRS_Notification
    • HRS_RESET_ENERGY_EXPENDED_EVT
    • HRS_NOTIFICATION_ENABLED
    • HRS_NOTIFICATION_DISABLED
    • HRS_STM_BOOT_REQUEST_EVT
}

```

- Allow the application to update the characteristics to BLE stack GATT database

```

/**
 * @brief Characteristic update
 * @param UUID: UUID of the characteristic
 * @retval BodySensorLocationValue: The new value to be written
 */
tBleStatus HRS_UpdateChar(uint16_t UUID, uint8_t *pPayload)
{
    UPDATE BODY SENSOR LOCATION

    UPDATE HEART RATE MEASUREMENT VALUE
}

```

Service controller functionalities:**Middlewares\STM32_WPAN\ble\core\Src\blesvc\svc_ctl.c**

The SVCCTL_Init() has different function:

- Calls the initialization function of all the developed services
 - HR server - HRS_Init()
- Registers the service event handler
 - SVCCTL_RegisterSvcHandler()
 - Function receiving the GATT events from the svc_ctl.c and redirecting them to the application (hrs_app.c)
- Registers client event handler (not applicable to HR sensor project)
 - SVCCTL_RegisterClhHandler()

HR sensor application initialization:**Applications\BLE\BLE_HeartRate\STM32_WPAN\App\app_ble.c**

HR sensor peripheral initialization - APP_BLE_Init()

- Initializes the BLE stack on CPU2
 - SHCI_C2_BLE_Init()
- Initializes the HCI, GATT and GAP layers
 - Ble_Hci_Gap_Gatt_Init()
- Initializes the BLE Services
 - SVCCTL_Init()
- Calls heart rate server and device information application initialization
 - HRSAPP_Init()
 - DISAPP_Init()
- Configures and starts advertising: ADV parameters, Local name, UUID, ...
 - aci_gap_set_discoverable() - Sets the device in general discoverable mode
 - aci_gap_update_adv_data() - Adds information in advertising data packet
- Manages GAP Event - SVCCTL_App_Notification()
 - EVT_LE_CONN_COMPLETE

Provides the connection interval information, slave latency, Supervision timeout

- Provides the new information of the connection
 - EVT_LE_CONN_UPDATE_COMPLETE
- Informs the application about the link disconnection and the reason
 - EVT_DISCONN_COMPLETE
- Informs the application whether the link is encrypted
 - EVT_ENCRYPT_CHANGE

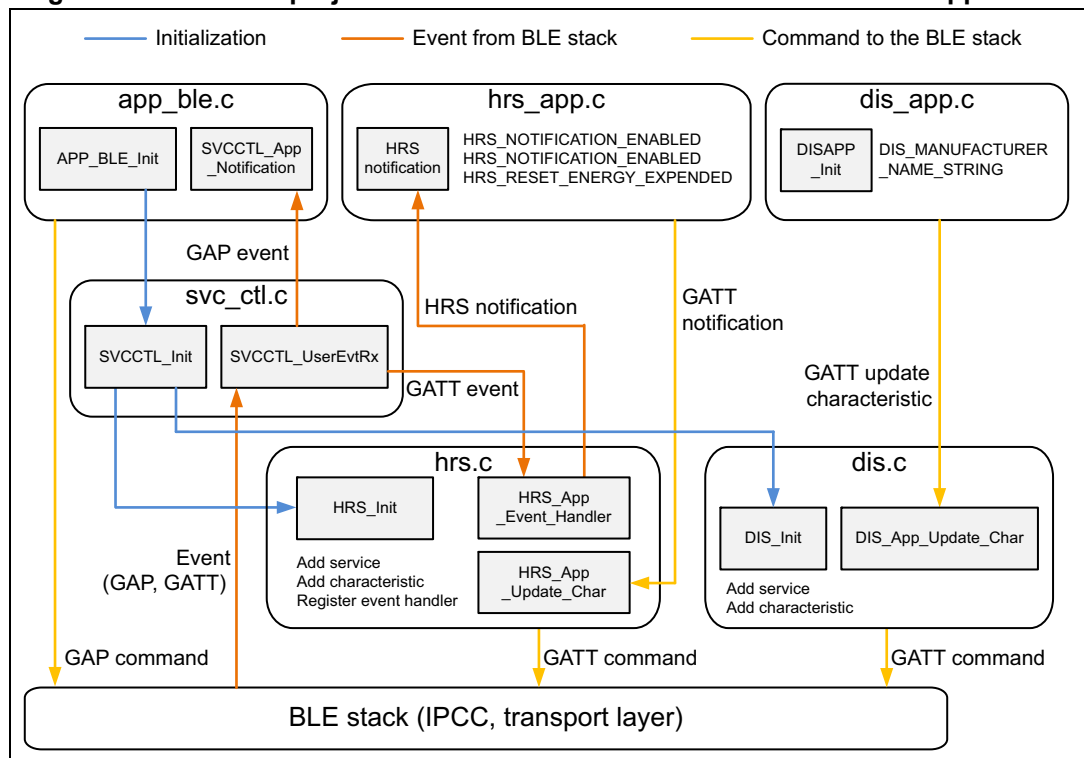
HR sensor application control:**Applications\BLE\BLE_HeartRate\STM32_WPAN\App\hrs_app.c**

The hrs_app.c file initializes the sensor application, creates timers

Table 15. HR sensor application control

Function	Description
HRSAPP_Init()	Receives and reacts to the internal events coming from the BLE stack at GATT level.
HRS_Notification()	Calls the service functions to update the characteristics (notify/write).
HRSAPP_Measurement()	-

Figure 24. Heart rate project - Interaction between middleware and user application



7.3 STMicroelectronics proprietary advertising

When the device is a peripheral, it advertises information such as Bluetooth address and advertising payload (0 to 31 bytes long).

The advertising information is represented by advertising data elements, standardized on the Bluetooth SIG:

- First byte: length of the element (excluding the length byte itself)
- Second byte: AD type - specifies what data is included in the element
- AD data: one or more bytes, the meaning of which is defined by AD type.

The AD type "0xFF" is used to provide manufacturer specific data.

The implementation of STMicroelectronics proprietary GATT-based applications such as P2P and FUOTA applications is proposed with the manufacturer specific AD type data. It is a way for the remote device (scanner) to filter the peripheral devices and access the requested application.

Table 16. AD structure according to the Bluetooth 5 Core specification Vol. 3 part C

Field name	Type	Len	Record size
TX_POWER_LEVEL	0x0A	2	3
COMPLETE_NAME	0x09	8	9
MANUF_SPECIFIC	0xFF	13	14
FLAGS	0x01	2	3

Table 17. STM32WB manufacturer specific data

Octect	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Name	Len	Type	Ver	DevID	Group A features	Group B features	Public device address (48 bits), optional							
Value	0x0D	0xFF	0x01	0XX	RFU	0XXXXX	0XXXXXXXXXXXXX							

Group B features

- Bit mask Thread: used to advertise the presence of the Thread switch characteristics.
- Bit mask OTA reboot request: used to advertise presence of the BLE reboot characteristics.

Table 18. Group B features - Bit mask

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RFU	Thread support	OTA reboot request	RFU												

Table 19. Device ID Enum

ID	HW
0x00	Generic
0x83	STM32WB P2P server 1
0x84	STM32WB P2P server 2
0x85	STM32WB P2P router
0x86	STM32WB FUOTA

The advertising procedure is managed at user application level in the app_ble.c.

Here is an example for BLE_p2p Server project advertising startup.

```
/* Local name to be advertised */
static const char local_name[] = { AD_TYPE_COMPLETE_LOCAL_NAME, 'P', '2',
    'P', 'S', 'R', 'V', '1' };

/* manufacturer data & legacy data to be advertised */
uint8_t manuf_data[14] = {
    sizeof(manuf_data)-1, AD_TYPE_MANUFACTURER_SPECIFIC_DATA,
```

```
    0x01/*SKD version */,  
    CFG_DEV_ID_P2P_SERVER1 /* STM32WB - P2P Server 1*/,  
    0x00 /* GROUP A Feature */,  
    0x00 /* GROUP A Feature */,  
    0x00 /* GROUP B Feature */,  
    0x00 /* GROUP B Feature */,  
    0x00, /* BLE MAC start -MSB */  
    0x00,  
    0x00,  
    0x00,  
    0x00,  
    0x00, /* BLE MAC stop */  
};  
  
/* Local device BD address*/  
const uint8_t *bd_addr;  
bd_addr = SVCCTL_GetBdAddress();  
  
/* BLE MAC update for Advertising manufacturer data*/  
manuf_data[ sizeof(manuf_data)-6] = bd_addr[5];  
manuf_data[ sizeof(manuf_data)-5] = bd_addr[4];  
manuf_data[ sizeof(manuf_data)-4] = bd_addr[3];  
manuf_data[ sizeof(manuf_data)-3] = bd_addr[2];  
manuf_data[ sizeof(manuf_data)-2] = bd_addr[1];  
manuf_data[ sizeof(manuf_data)-1] = bd_addr[0];  
  
/* Put the GAP peripheral in general discoverable mode:  
Advertising_Type: ADV_IND(undirected scannable and connectable);  
Advertising_Interval_Min;  
Advertising_Interval_Max;  
Own_Address_Type: PUBLIC_ADDR (public address: 0x00);  
Adv_Filter_Policy: NO_WHITE_LIST_USE (no whit list is used);  
Local_Name_Length  
Local_Name:  
Service_Uuid_Length: 0 (no service to be advertised);  
Service_Uuid_List: NULL;  
Slave_Conn_Interval_Min: 0 (Slave connection internal minimum value);  
Slave_Conn_Interval_Max: 0 (Slave connection internal maximum value).  
*/  
result = aci_gap_set_discoverable(ADV_IND,  
    CFG_FAST_CONN_ADV_INTERVAL_MIN,  
    CFG_FAST_CONN_ADV_INTERVAL_MAX,  
    PUBLIC_ADDR,  
    NO_WHITE_LIST_USE, /* use white list */  
    sizeof(local_name), (uint8_t*) local_name,
```

```

0,
NULL,
0, 0);

/* Update Advertising data with manufacturer specific information*/
result = aci_gap_update_adv_data(sizeof(manuf_data), (uint8_t*)
manuf_data);

```

The result is always compared to BLE_STATUS_SUCCESS (0x00).

7.4 Proprietary P2P application

Three components can be used to demonstrate the different data communication types:

1. P2P server project
2. P2P client project
3. Smart phone application.

The combination of the different components results in the demonstrations shown in figures [Figure 25](#) and [Figure 26](#).

Figure 25. P2P server to client demonstration

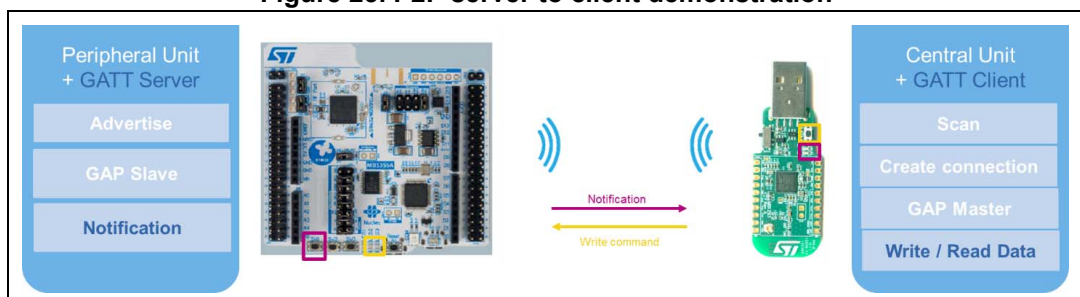
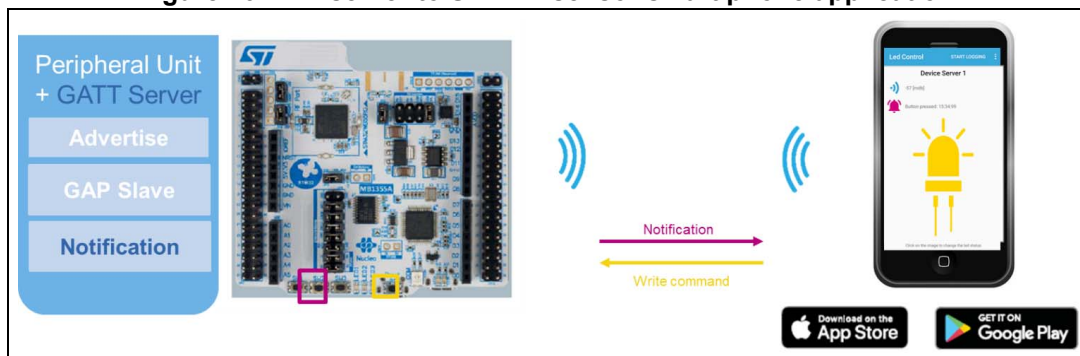


Figure 26. P2P server to ST BLE sensor smart phone application



7.4.1 P2P server specification

The P2P server application must be used to demonstrate point to point communication. It acts as a peripheral device with the following GATT service and characteristics.

Table 20. P2P service and characteristic UUIDs

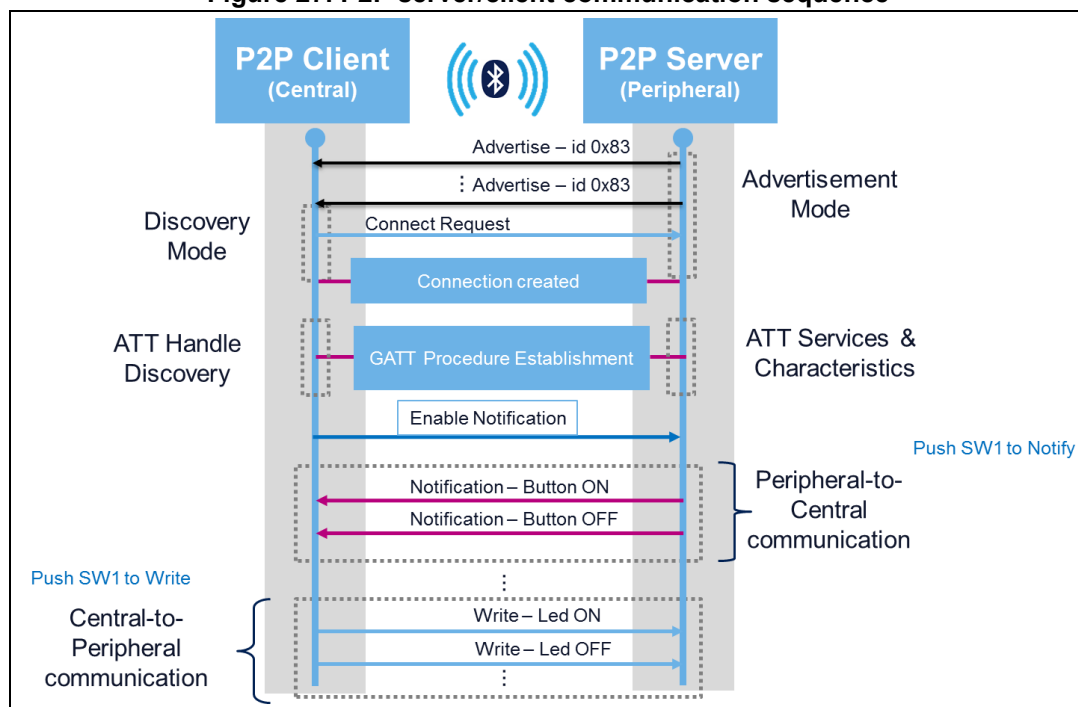
Groups	Service	Characteristic	Size	Mode	UUID
LED button control	P2P service	-	-	-	0000FE40-cc7a-482a-984a-7fed5b3e58f
	-	Write	2	Read / Write	0000FE41-8e22-4541-9d4c-21edae82ed19
	-	Notify	2	Notify	0000FE42-8e22-4541-9d4c-21edae82ed19

Table 21. P2P specification

Write	Octets LSB	0	1
	Name	Device selection	LED control
	Value	– 0x01: P2P server 1 – 0x02: P2P server 2 – 0x0x: P2P server x – 0x00: All	– 0x00 LED off – 0x01 LED on – 0x02 Thread switch
Notify	Octets LSB	0	1
	Name	Device selection	Button
	Value	– 0x01: P2P server 1 – 0x02: P2P server 2 – 0x0x: P2P server x	– 0x00 switch off – 0x01 switch on

To be used, a GAP central and GATT client device must discover and connect to the P2P server application. [Figure 27](#) explains the data exchange procedure.

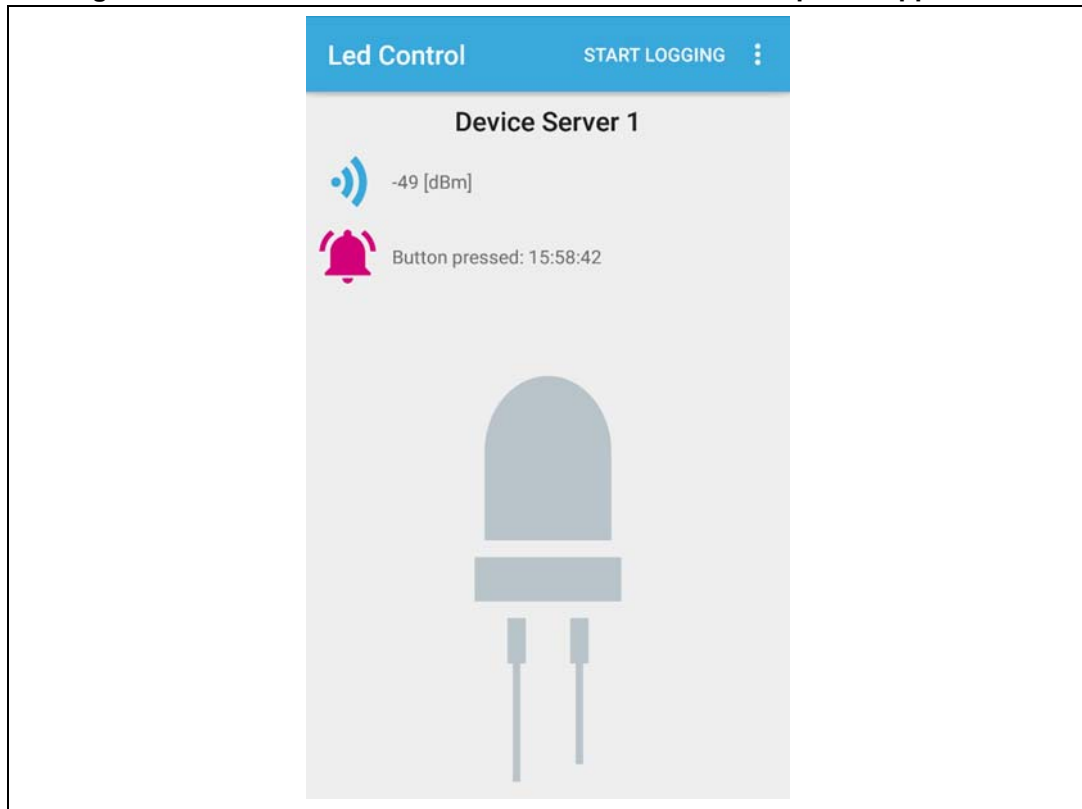
Figure 27. P2P server/client communication sequence



7.4.2 How to use the P2P server application

1. Flash your P-NUCLEO-WB55 board with the ble_P2P_Server project
2. Once flashed, connect the ST BLE sensor mobile application to your board, and use SW1 button to notify the smart phone.

Figure 28. P2P server connected to ST BLE sensor smart phone application



7.4.3 P2P server application - Middleware application

The P2P service and characteristics are created using the p2p_stm.c file.

p2p_stm.c: creates the service and the characteristics in the application to update the characteristics, to receive the notification or write command, and to make a link between the BLE wireless stack and the applicative part.

In the application, the subfolder to create specific code is “User”

- app_entry.c: initializes the BLE Transport layer and the BSP (e.g. LEDs, buttons)
- app_ble.c: initializes the GAP and manage the connection (e.g. advertising, scan)
- p2p_server_app.c: initializes the GATT and manage the application.

P2P service functionalities:**Middlewares\STM32_WPAN\ble\core\Src\blesvc\p2p_stm.c****Table 22. P2P service functionalities**

Function	Description
Service Init - P2PS_STM_Init() ()	<ul style="list-style-type: none"> – Register PeerToPeer_Event_Handler to Service controller – Initializes Service UUID aci_gatt_add_serv - adds P2P service as Primary services – Initializes P2P write characteristic aci_gatt_add_char - adds Write characteristic – Initializes P2P Notify characteristic aci_gatt_add_char - adds Notify characteristic – Updates notification characteristic - P2PS_STM_App_Update_Char() aci_gatt_update_char_value - updates the notify characteristics with a value aligned with the specification
PeerToPeer_Event_Handler (void *Event) - manages HCI Vendor Type Event:	EVT_BLUE_GATT_ATTRIBUTE_MODIFIED <ul style="list-style-type: none"> – Receives the configuration of the Descriptor value of the Notify characteristics – ENABLE or DISABLE notification – Informs the application, P2PS_STM__NOTIFY_ENABLED_EVT or P2PS_STM_NOTIFY_DISABLED_EVT – Receives data on the write characteristic and Informs P2P application P2PS_STM_WRITE_EVT – Receives data on the Reboot request characteristic and informs P2P application (to be used for FUOTA procedure) P2PS_STM_BOOT_REQUEST_EVT

P2P server application control:**Applications\BLE\BLE_p2pServer\STM32_WPAN\App\p2p_server_app.c**

The p2p_server_app.c file

Initializes the P2P server application, Create Timers

P2PS_APP_Init()

Receives and reacts to the internal events coming from the BLE stack at GATT level.

P2PS_STM_App_Notification ()

```

void P2PS_STM_App_Notification(P2PS_STM_App_Notification_evt_t
*pNotification)
{
Switch (pNotification->P2P_Evt_Opcode)
{
case P2PS_STM__NOTIFY_ENABLED_EVT:
P2P_Server_App_Context.Notification_Status = 1;
APP_DBG_MSG("-- P2P APPLICATION SERVER : NOTIFICATION ENABLED\n");
APP_DBG_MSG(" \n\r");
break;

```

```

case P2PS_STM_NOTIFY_DISABLED_EVT:
    P2P_Server_App_Context.Notification_Status = 0;
    APP_DBG_MSG("-- P2P APPLICATION SERVER : NOTIFICATION DISABLED\n");
    APP_DBG_MSG(" \n\r");
    break;

case P2PS_STM_WRITE_EVT:
    if(pNotification->DataTransferred.pPayload[0] == 0x00){
    . if(pNotification->DataTransferred.pPayload[1] == 0x01)
        {
            BSP_LED_On(LED_BLUE);
            APP_DBG_MSG("-- P2P APPLICATION SERVER : LED1 ON\n");
            APP_DBG_MSG(" \n\r");
            P2P_Server_App_Context.LedControl.Led1=0x01;
        }
        if(pNotification->DataTransferred.pPayload[1] == 0x00)
        {
            BSP_LED_Off(LED_BLUE);
            APP_DBG_MSG("-- P2P APPLICATION SERVER : LED1 OFF\n");
            APP_DBG_MSG(" \n\r");
            P2P_Server_App_Context.LedControl.Led1=0x00;
        }
    }
}

```

Calls the service function to update the characteristic (notify).

```

P2PS_Send_Notification ()
void P2PS_Send_Notification(void)
{
    if(P2P_Server_App_Context.ButtonControl.ButtonStatus == 0x00){
        P2P_Server_App_Context.ButtonControl.ButtonStatus=0x01;
    } else {
        P2P_Server_App_Context.ButtonControl.ButtonStatus=0x00;
    }

    if(P2P_Server_App_Context.Notification_Status){
        APP_DBG_MSG("P2P APPLICATION SERVER : INFORM CLIENT BUTTON 1 PUSHED \n");
        APP_DBG_MSG(" \n\r");
        P2PS_STM_App_Update_Char(P2P_NOTIFY_CHAR_UUID, (uint8_t *)
        &P2P_Server_App_Context.ButtonControl);
    } else {
        APP_DBG_MSG("P2P APPLICATION SERVER : CAN'T INFORM CLIENT - NOTIFICATION
        DISABLED\n ");
    }
}

```

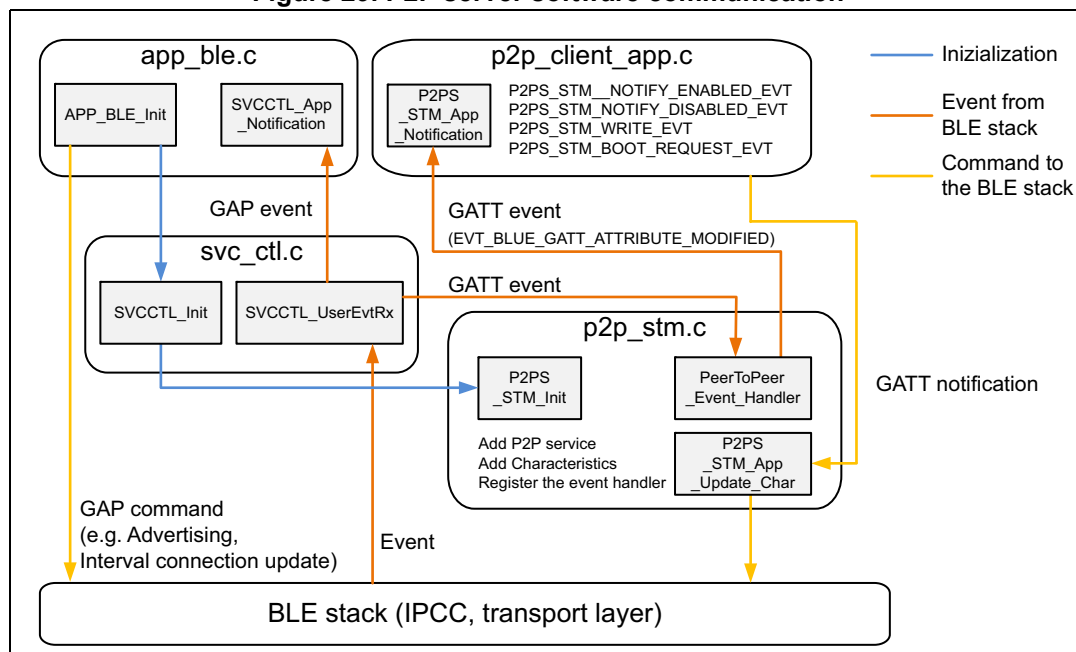
```

return;
}

```

7.4.4 P2P client application - Middleware application

Figure 29. P2P server software communication



There is no service created for the P2P client. It is only necessary to register the GATT client Handler `SVCCTL_RegisterClhHandler()` to be notified of any GATT events at application level.

In the application, the subfolder to create specific code is "User"

- `app_entry.c`: initializes the BLE transport layer and the BSP (e.g. LEDs, buttons)
- `app_ble.c`: initializes the GAP and manages the connection (scan and connect)
- `p2p_client_app.c`: initializes the GATT and manages the GATT client application.

P2P client - Scan and connect

The `app_ble.c` file

- Executes a scan to search for any P2P server advertising IDs:

```

static void Scan_Request( void )
{
    tBleStatus result;
    if (BleApplicationContext.Device_Connection_Status !=
        APP_BLE_CONNECTED_CLIENT)
    {
        BSP_LED_On(LED_BLUE);
        result = aci_gap_start_general_discovery_proc(SCAN_P, SCAN_L,
            PUBLIC_ADDR, 1);
    }
}

```



```

    if (result == BLE_STATUS_SUCCESS)
    {
        APP_DBG_MSG("\r\n\r** START GENERAL DISCOVERY (SCAN) ** \r\n\r");
    } else {
        APP_DBG_MSG("-- BLE_App_Start_Limited_Disc_Req, Failed \r\n\r");
        BSP_LED_On(LED_RED);
    }
}
return;
}

```

- Receives the ADV events report to be filtered to save the P2P server BD address:J'rric

```

case AD_TYPE_MANUFACTURER_SPECIFIC_DATA: // Manufactureur Specific
    if (adlength >= 7 && le_advertising_event->Advertising_Report[0].Data[k +
2] == 0x01) {
        APP_DBG_MSG("--- ST MANUFACTURER ID --- \n");
        switch (le_advertising_event->Advertising_Report[0].Data[k + 3]) {
            case CFG_DEV_ID_P2P_SERVER1:
                APP_DBG_MSG("-- SERVER DETECTED -- VIA MAN ID\n");
                BleApplicationContext.DeviceServerFound = 0x01;
                SERVER_REMOTE_BDADDR[0] = le_advertising_event-
>Advertising_Report[0].Address[0];
                SERVER_REMOTE_BDADDR[1] = le_advertising_event-
>Advertising_Report[0].Address[1];
                SERVER_REMOTE_BDADDR[2] = le_advertising_event-
>Advertising_Report[0].Address[2];
                SERVER_REMOTE_BDADDR[3] = le_advertising_event-
>Advertising_Report[0].Address[3];
                SERVER_REMOTE_BDADDR[4] = le_advertising_event-
>Advertising_Report[0].Address[4];
                SERVER_REMOTE_BDADDR[5] = le_advertising_event-
>Advertising_Report[0].Address[5];
                break;

```

- Initiates the connection to any detected P2P servers:

```

static void Connect_Request( void )
{
    tBleStatus result;
    APP_DBG_MSG("\r\n\r** CREATE CONNECTION TO SERVER ** \r\n\r");
    if (BleApplicationContext.Device_Connection_Status !=
APP_BLE_CONNECTED_CLIENT) {
        result = aci_gap_create_connection(
SCAN_P,
SCAN_L,
PUBLIC_ADDR, SERVER_REMOTE_BDADDR,
PUBLIC_ADDR,
CONN_P1,

```

```

CONN_P2,
0,
SUPERV_TIMEOUT,
CONN_L1,
CONN_L2);
• Starts "Services Discovery Procedure" once connection is established:
case EVT_LE_CONN_COMPLETE:
/**
 * The connection is established
 */
connection_complete_event = (hci_le_connection_complete_event_rp0 *)
meta_evt->data;
BleApplicationContext.BleApplicationContext_legacy.connectionHandle =
connection_complete_event->Connection_Handle;
BleApplicationContext.Device_Connection_Status = APP_BLE_CONNECTED_CLIENT;

APP_DBG_MSG("\r\n\r** CONNECTION EVENT WITH SERVER \n");
handleNotification.P2P_Evt_Opcode = PEER_CONN_HANDLE_EVT;
handleNotification.ConnectionHandle =
    BleApplicationContext.BleApplicationContext_legacy.connectionHandle;
P2PC_APP_Notification(&handleNotification);
result = aci_gatt_disc_all_primary_services(
    BleApplicationContext.BleApplicationContext_legacy.connectionHandle);
if (result == BLE_STATUS_SUCCESS) {
    APP_DBG_MSG("\r\n\r** GATT SERVICES & CHARACTERISTICS DISCOVERY \n");
    APP_DBG_MSG("* GATT : Start Searching Primary Services \r\n\r");
}

```

At this step, all the GATT events is transferred to the GATT client events handler managed in the p2p_client_app.c.

P2P client - Application control - GATT client communication

The p2p_client_app.c file:

- Initializes the P2P client application and registers the Client Event Handler
 - P2PC_APP_Init()
 - SVCCTL_RegisterClhHandler()
- Starts discovery procedures and manages the remote P2P server characteristics
 - aci_gatt_disc_all_char_of_service()
 - aci_gatt_disc_all_char_desc()
 - aci_gatt_write_char_desc()

```

case APP_BLE_DISCOVER_SERVICES:
APP_DBG_MSG("P2P_DISCOVER_SERVICES\n");
break;
case APP_BLE_DISCOVER_CHARACS:

```

```

APP_DBG_MSG("* GATT : Discover P2P Characteristics\n");
aci_gatt_disc_all_char_of_service(aP2PClientContext[index].connHandle,
aP2PClientContext[index].P2PServiceHandle,
aP2PClientContext[index].P2PServiceEndHandle);
break;
case APP_BLE_DISCOVER_WRITE_DESC:
APP_DBG_MSG("* GATT : Discover Descriptor of TX - Write Characteritic\n");
aci_gatt_disc_all_char_desc(aP2PClientContext[index].connHandle,
aP2PClientContext[index].P2PWriteToServerCharHdle,
aP2PClientContext[index].P2PWriteToServerCharHdle+2);
break;
case APP_BLE_DISCOVER_NOTIFICATION_CHAR_DESC:
APP_DBG_MSG("* GATT : Discover Descriptor of Rx - Notification
Characteritic\n");
aci_gatt_disc_all_char_desc(aP2PClientContext[index].connHandle,
aP2PClientContext[index].P2PNotificationCharHdle,
aP2PClientContext[index].P2PNotificationCharHdle+2);
break;
case APP_BLE_ENABLE_NOTIFICATION_DESC:
APP_DBG_MSG("* GATT : Enable Server Notification\n");
aci_gatt_write_char_desc(aP2PClientContext[index].connHandle,
aP2PClientContext[index].P2PNotificationDescHandle,
2,
(uint8_t *)&enable);
aP2PClientContext[index].state = APP_BLE_CONNECTED_CLIENT;
break;
case APP_BLE_DISABLE_NOTIFICATION_DESC :
APP_DBG_MSG("* GATT : Disable Server Notification\n");
aci_gatt_write_char_desc(aP2PClientContext[index].connHandle,
aP2PClientContext[index].P2PNotificationDescHandle,
2,
(uint8_t *)&enable);
aP2PClientContext[index].state = APP_BLE_CONNECTED_CLIENT;
break;

```

- **Manages GATT Events to find and to register the remote device characteristics handles**

– SVCCTL_EvtAckStatus_t Event_Handler()

```

uuid = UNPACK_2_BYTE_PARAMETER(&pr->Attribute_Data_List[idx]);
if(uuid == P2P_SERVICE_UUID){
APP_DBG_MSG("-- GATT : P2P_SERVICE_UUID FOUND - connection handle 0x%x \n",
aP2PClientContext[index].connHandle);
aP2PClientContext[index].P2PServiceHandle = UNPACK_2_BYTE_PARAMETER(&pr-
>Attribute_Data_List[idx-16]);
aP2PClientContext[index].P2PServiceEndHandle = UNPACK_2_BYTE_PARAMETER
(&pr->Attribute_Data_List[idx-14]);
aP2PClientContext[index].state = APP_BLE_DISCOVER_CHARACS ;

```

```

}
uuid = UNPACK_2_BYTE_PARAMETER(&pr->Handle_Value_Pair_Data[idx]);
/* store the characteristic handle not the attribute handle */
handle = UNPACK_2_BYTE_PARAMETER(&pr->Handle_Value_Pair_Data[idx-14]);
if(uuid == P2P_WRITE_CHAR_UUID) {
APP_DBG_MSG("-- GATT : WRITE_UUID FOUND - connection handle 0x%x\n",
aP2PClientContext[index].connHandle);
aP2PClientContext[index].state = APP_BLE_DISCOVER_WRITE_DESC;
aP2PClientContext[index].P2PWriteToServerCharHdle = handle;
}
else if(uuid == P2P_NOTIFY_CHAR_UUID) {
APP_DBG_MSG("-- GATT : NOTIFICATION_CHAR_UUID FOUND - connection handle
0x%x\n", aP2PClientContext[index].connHandle);
aP2PClientContext[index].state = APP_BLE_DISCOVER_NOTIFICATION_CHAR_DESC;
aP2PClientContext[index].P2PNotificationCharHdle = handle;
}

```

Once the P2P server services and characteristics handle are discovered, the application is able to:

- Control the remote device using the “Write” characteristic

```

tBleStatus Write_Char(uint16_t UUID, uint8_t Service_Instance, uint8_t
*pPayload) {
tBleStatus ret = BLE_STATUS_INVALID_PARAMS;
uint8_t index;
index = 0;
while((index < BLE_CFG_CLT_MAX_NBR_CB) && (aP2PClientContext[index].state
!= APP_BLE_IDLE)) {
switch(UUID) {
case P2P_WRITE_CHAR_UUID:
ret =aci_gatt_write_without_resp(aP2PClientContext[index].connHandle,
aP2PClientContext[index].P2PWriteToServerCharHdle,
2, /* charValueLen */
(uint8_t *) pPayload);
break;

```

- Receive notifications via the “Notify” characteristics

```

void Gatt_Notification(P2P_Client_App_Notification_evt_t *pNotification) {
switch(pNotification->P2P_Client_Evt_Opcode) {
case P2P_NOTIFICATION_INFO_RECEIVED_EVT: {
P2P_Client_App_Context.LedControl.Device_Led_Selection=pNotification-
>DataTransferred.pPayload[0];
switch(P2P_Client_App_Context.LedControl.Device_Led_Selection) {
case 0x01 : {
P2P_Client_App_Context.LedControl.Led1=pNotification-
>DataTransferred.pPayload[1];
if(P2P_Client_App_Context.LedControl.Led1==0x00) {
BSP_LED_Off(LED_BLUE);
APP_DBG_MSG(" -- P2P CLIENT : NOTIFICATION RECEIVED - LED OFF \n\r");

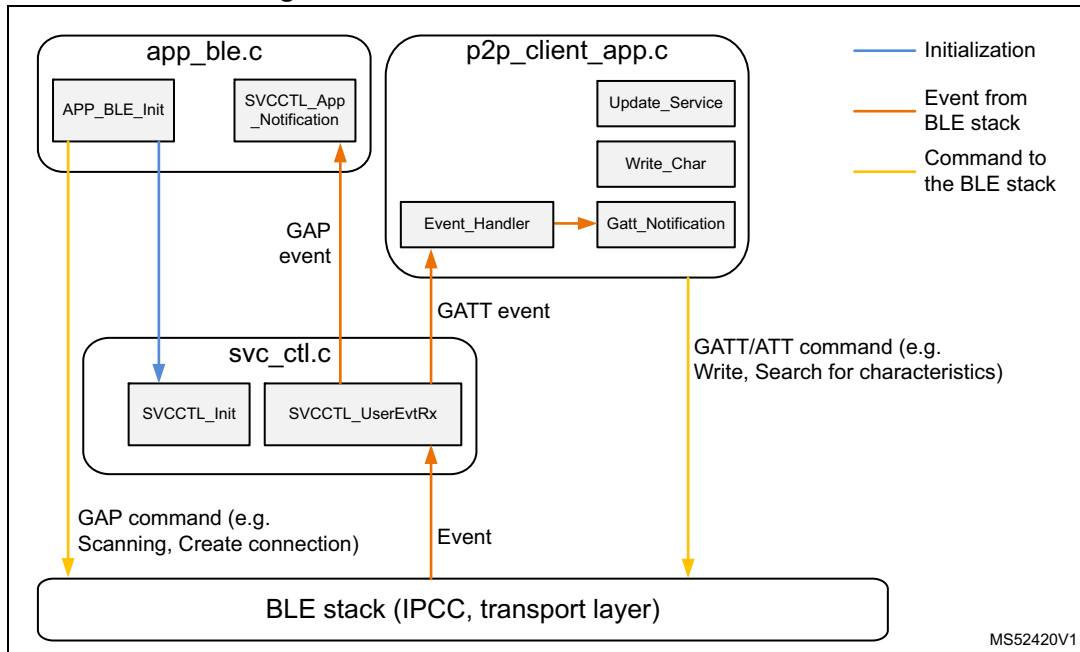
```

```

} else {
    BSP_LED_On(LED_BLUE);
    APP_DBG_MSG(" -- P2P CLIENT : NOTIFICATION RECEIVED - LED ON\n\r");
}
break;
}

```

Figure 30. P2P client software communication



7.5 FUOTA application

FUOTA is a standalone application able to install a BLE service to download the new CPU2 wireless stack, CPU1 application or configuration binaries:

- It requires that the first six Flash memory sectors of the application (where the FUOTA application is written) are never deleted.
- The FUOTA application enables:
 - The update of the whole CPU1 application
 - To download CPU2 wireless firmware to be applied by the FUS
 - To download user data at any address in CPU1 user Flash memory.

7.5.1 CPU1 user Flash memory mapping

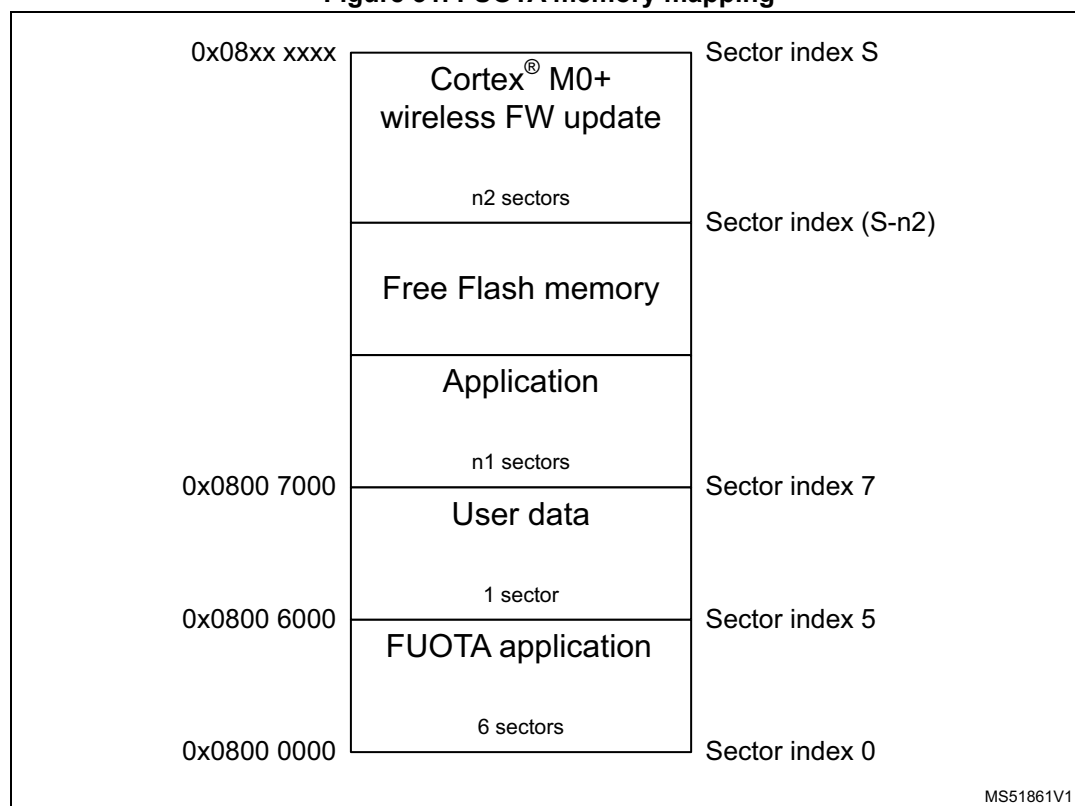
The FUOTA BLE application cannot update itself but is able to:

- Jump on an existing application (Sector index 7)
- Run and install the STMicroelectronics proprietary FUOTA GATT service and characteristics to upload any data in specified area of a remote device.

The User data section may be used to update parts of the configuration for the application.

The application area contains the application standalone binary. It can be fully updated with FUOTA application.

Figure 31. FUOTA memory mapping



7.5.2 BLE FUOTA application startup

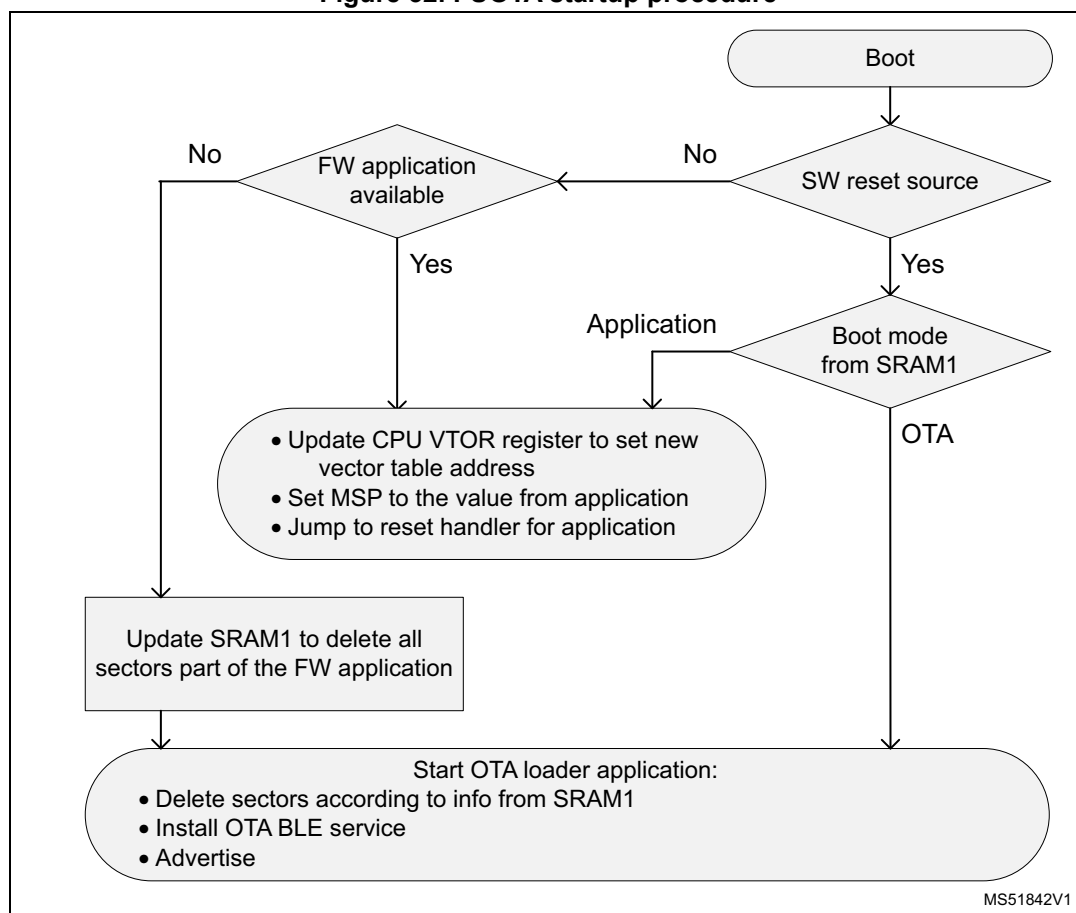
Once the project BLE_Ota is compiled and loaded, the application may:

- Either jump to the available application if binary code is present on application sectors (sector index 7)
 - no more activity related to BLE_Ota application
- Or start STMicroelectronics proprietary FUOTA GATT service and characteristics advertising:
 - the local name Advertising Data (AD) elements with “STM_OTA”
 - the manufacturer AD elements with Device ID “STM32WB FW Update OTA application”

The second possibility allows a remote device to upload a new binary (CPU2 wireless stack, CPU1 application or user data firmware update).

Note: *If only STMicroelectronics proprietary FUOTA GATT service and characteristics are used it is important to erase application sectors (from 7 onwards).*

Figure 32. FUOTA startup procedure



7.5.3 BLE FUOTA services and characteristics specification

The BLE FUOTA application (BLE_Ota project) is exported as a GATT service with the following characteristics:

- Base address to provide information where to store the new binary
- File upload reboot confirmation to confirm the reboot of the application after new binary file uploaded
- OTA raw data to transfer the data (binary file divided into packets).

Table 23. FUOTA service and characteristics UUID

Group	Service	Characteristic	Size	Mode	UUID
LED button control	OTA FW update	-	-	-	0000FE20-cc7a-482a-984a-7f2ed5b3e58f
	-	Base address	4 bytes	Write	0000FE22-8e22-4541-9d4c-21edae82ed19
	-	File upload reboot confirmation	1 byte	Indicate	0000FE23-8e22-4541-9d4c-21edae82ed19
	-	OTA raw data	20 bytes	Write without response	0000FE24-8e22-4541-9d4c-21edae82ed19

Table 24. Base address characteristics specification

Bit LSB	[0:7]	[8:31]
Name	Action	Address
Value	<ul style="list-style-type: none"> – 0x00: STOP all upload – 0x01: START M0+ file upload – 0x02: START M0+ file upload – 0x07: File upload finished – 0x08: Cancel upload 	0x007000

Table 25. File upload confirmation reboot Request characteristics specification

Octets LSB	0
Name	Indication
Value	0x01 Reboot

Table 26. Raw data characteristics specification

Octets LSB	0	1	...	19
Name	Raw data			
Value	File data			

7.5.4 Flow description example to upload new CPU1 application binary

There are two types of procedures to upload a new binary:

- Only STMicroelectronics proprietary FUOTA GATT service and characteristics application is loaded. (no application binary present on sector 7)
- Application is already running with the support of the Reboot request characteristic.

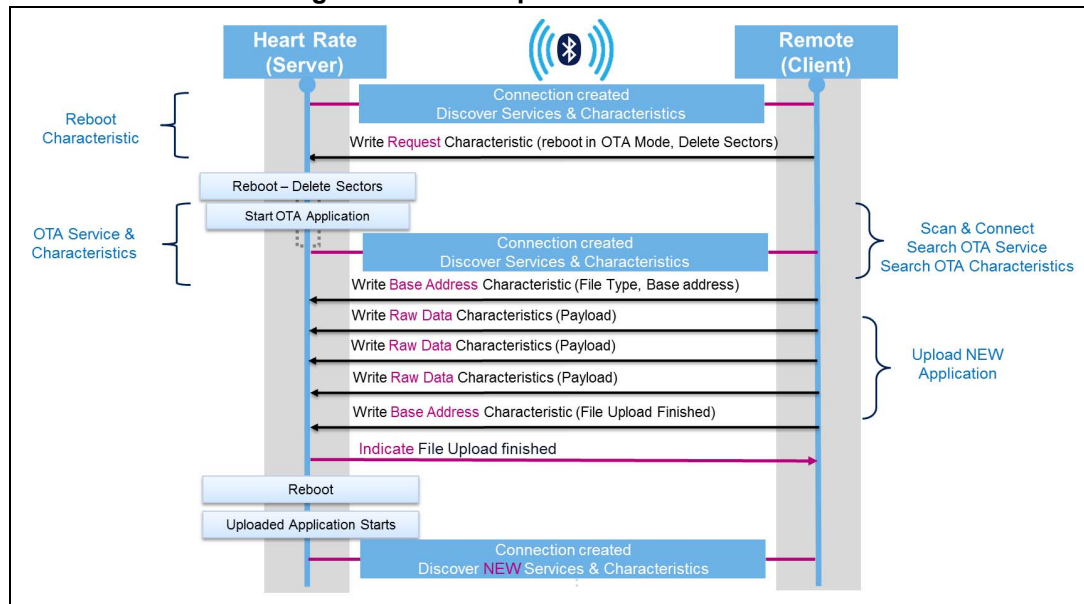
Table 27. Reboot request characteristics specification

Octets LSB	0	1	2
Name	Boot mode	Sector index	Number of sectors to erase
Value	<ul style="list-style-type: none"> – 0x00 Application – 0x01 FUOTA application 	07 → 0x0800 7000	0x00 ... 0xFF

Starting from application including the reboot request characteristic, this is the flow to update CPU1 application:

1. BLE application includes the reboot characteristics.
2. Once the GAP connection is established, the remote GATT client device researches services and characteristics (reboot request characteristics detected).
3. Next, in order to switch to the FUOTA application, the remote device writes the Reboot request characteristics with information for boot mode option and sectors to erase.
4. At this stage the BLE Link is disconnected to reboot on STMicroelectronics proprietary FUOTA GATT service and characteristics application.
5. Application sectors are erased with the information provided by the reboot characteristics and STMicroelectronics proprietary FUOTA GATT service and characteristics application starts advertising.
6. New connection has to be established by the remote device to discover the FUOTA service and characteristics.
7. The base address characteristic is used to initiate the new binary upload.
8. All the data is transferred via the raw data characteristic and programmed directly to the Flash memory once received.
9. The end of file transfer is confirmed by the base address characteristic.
10. Confirmation of the received file is indicate by the file upload confirmation characteristic.
11. At this stage, the FUOTA application checks the integrity of the new binary and reboots to start the new uploaded application.
12. If the application integrity is not ensured, the application sectors are erased to reboot on the FUOTA application.

Figure 33. FUOTA process with heart rate



7.5.5 Application example with smart phone

The reboot request characteristic is implemented in the projects

- BLE_HeartRate_ota
- BLE_P2pServer_ota

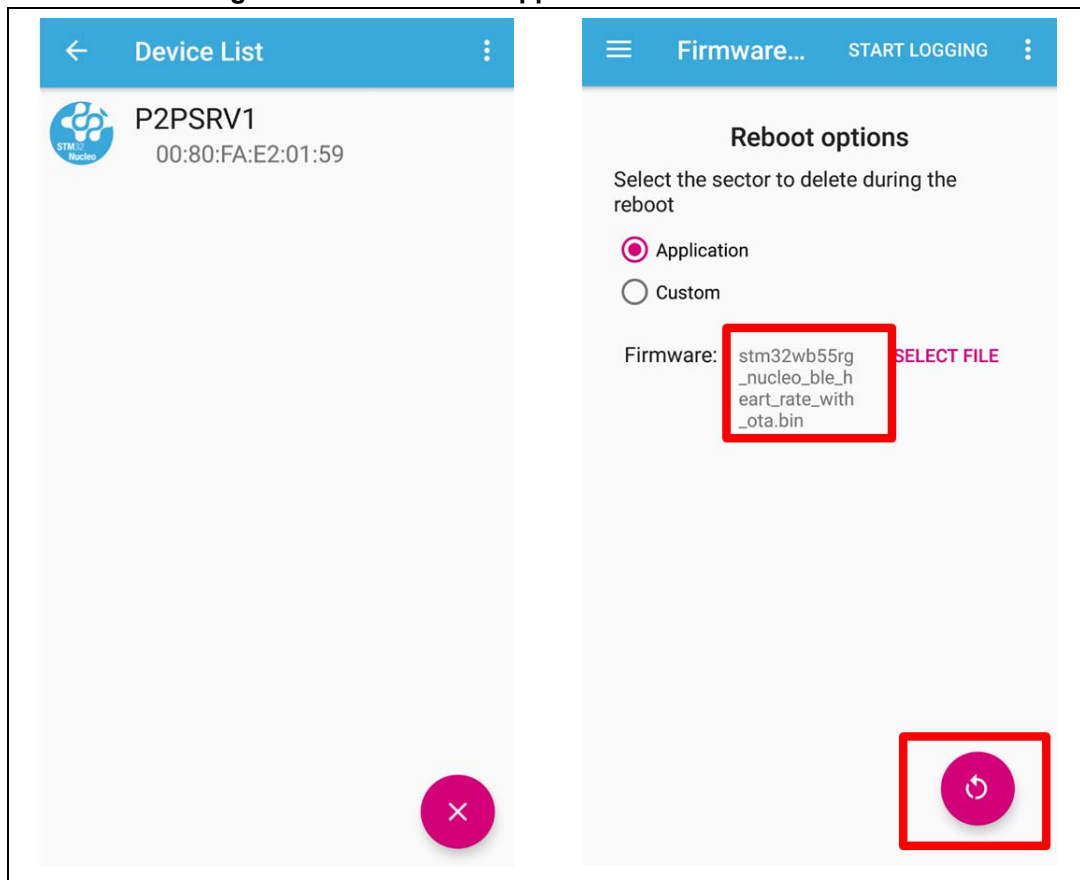
Both projects include the OTA reboot request bit mask in their advertising element. It is a way for the remote (scanner) to quickly acquire the information on the presence of the reboot request characteristic.

The ST BLE sensor mobile application supports the detection of this reboot request characteristic.

For example, moving from a P2P server application to heart rate application.

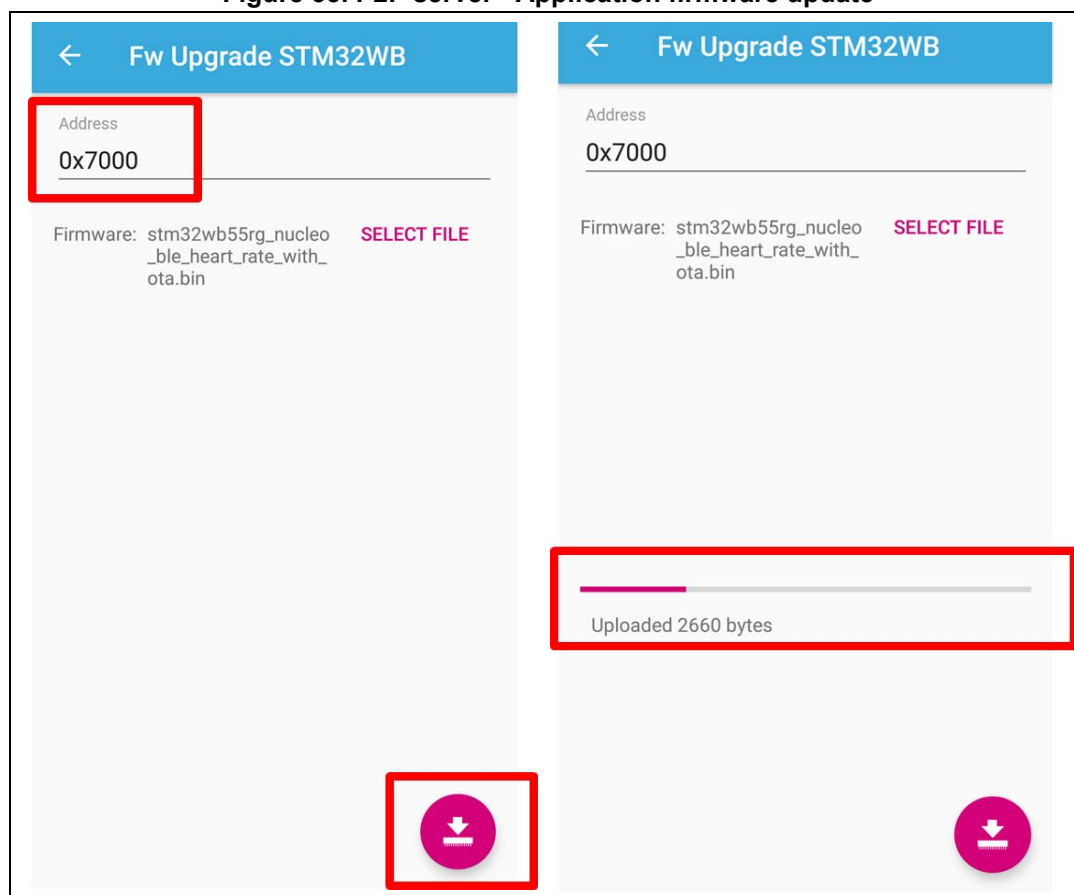
- Compile and load the BLE_Ota project to address 0x0800 0000
- Compile and load the BLE_p2pServer_ota project to address 0x0800 7000
- Reboot the device
 - At this stage, the P2P server advertises its presence.
- Discover and connect to the P2P server with ST BLE sensor mobile application
- Move to the reboot panel
- Select binary “BLE_HeartRate_ota” (copied before the demonstration to the smart phone memory)
- Click on upload
 - At this stage the reboot request characteristic is used to provide information about sectors to erase and the next reboot phase (FUOTA application).

Figure 34. P2P server - Application firmware selection



Once rebooted, the address to upload the application binary file is selected. The default address is 0x7000 (sector 7 - application). Changing the binary file to upload is still possible at this stage if it is needed.

Figure 35. P2P server - Application firmware update

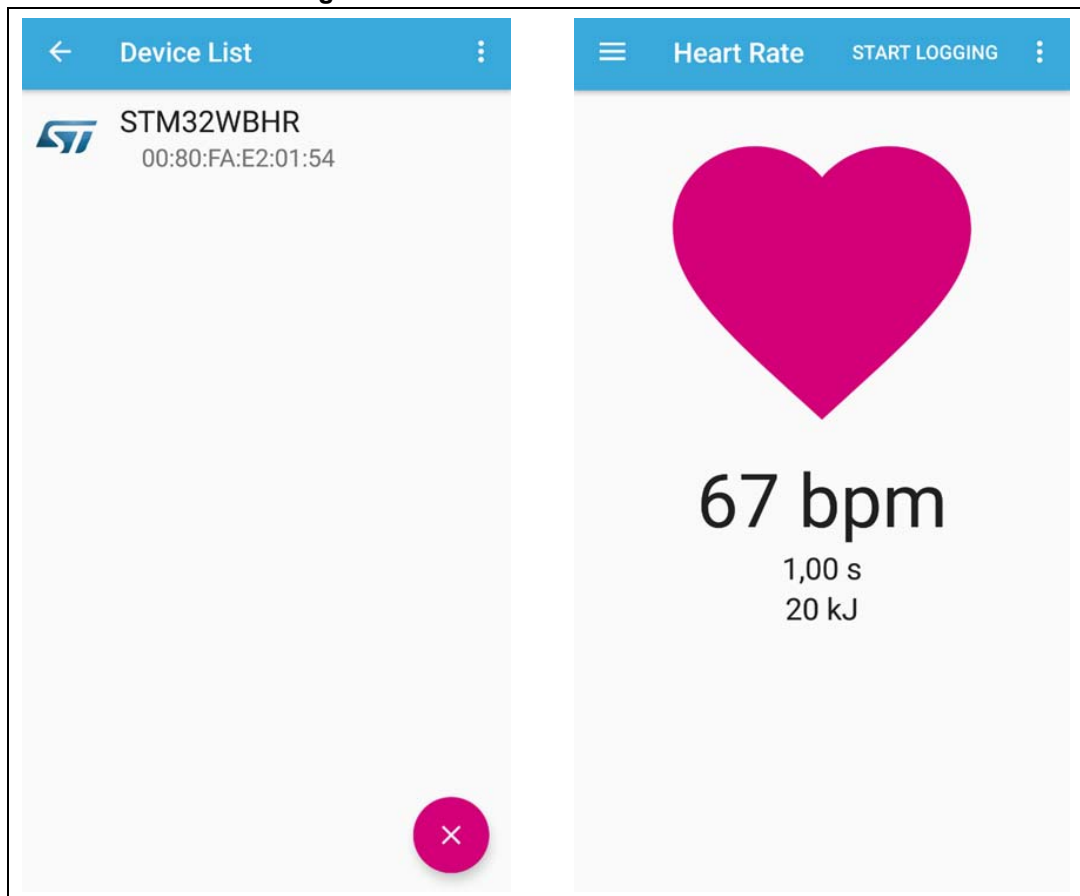


Once the upload is finished, the reboot procedure is executed to start the new application. Next, run a new scan procedure to discover the heart rate sensor advertising packets and connect to it.

After connecting to the device, the heart rate measurement values are notified by the sensor.

Note: The smart phone application associates the GATT database with remote Bluetooth address. To solve this issue the FUOTA application advertising address is increased by 1.

Figure 36. Heart rate sensor notification



7.5.6 How to use the reboot request characteristics

Whatever application is used, the reboot request characteristics may be integrated into a service to reboot the application in FUOTA application mode.

The application must be loaded at the address 0x0800 0700 with “BLE_HeartRate_ota” and “BLE_p2pServer_ota” examples, the configuration is done as follows:

- ble_conf.h to define the OTA Reboot characteristics

```

/*****
****

```

```

* Over The Air Feature (OTA) - STM Proprietary

```

```

****/

```

```

#define BLE_CFG_OTA_REBOOT_CHAR          1 /**< REBOOT OTA MODE
CHARACTERISTIC */

```

- app_ble.c

```

/**

```

```

* Initialization of ADV - Ad Manufacturer Element - Support OTA Bit Mask
*/

```

```

#if(BLE_CFG_OTA_REBOOT_CHAR != 0)

```

```
manuf_data[sizeof(manuf_data)-8] = CFG_FEATURE_OTA_REBOOT;
#endif
```

- **p2p_stm.c to add the characteristics (middleware)**

```
#if (BLE_CFG_OTA_REBOOT_CHAR != 0)
/**
 * Add Boot Request Characteristic
 */
aci_gatt_add_char(aPeerToPeerContext.PeerToPeerSvcHdle,
                  BM_UUID_LENGTH,
                  (Char_UUID_t *)BM_REQ_CHAR_UUID,
                  BM_REQ_CHAR_SIZE,
                  CHAR_PROP_WRITE_WITHOUT_RESP,
                  ATTR_PERMISSION_NONE,
                  GATT_NOTIFY_ATTRIBUTE_WRITE,
                  10,
                  0,
                  &(aPeerToPeerContext.RebootReqCharHdle));
#endif
```

- **p2p_stm.c to receive the request at GATT level and inform the application (middleware)**

```
else if (attribute_modified->Attr_Handle ==
(aPeerToPeerContext.RebootReqCharHdle + 1))
{
BLE_DBG_P2P_STM_MSG("-- GATT : REBOOT REQUEST RECEIVED\n");
Notification.P2P_Evt_Opcode = P2PS_STM_BOOT_REQUEST_EVT;
Notification.DataTransferred.Length=attribute_modified->Attr_Data_Length;
Notification.DataTransferred.pPayload=attribute_modified->Attr_Data;
P2PS_STM_App_Notification(&Notification);
}
```

- **p2p_server_app.c to manage the reboot request (application)**

```
void P2PS_STM_App_Notification(P2PS_STM_App_Notification_evt_t
*pNotification)
{
switch(pNotification->P2P_Evt_Opcode)
{
#if (BLE_CFG_OTA_REBOOT_CHAR != 0)

case P2PS_STM_BOOT_REQUEST_EVT:
APP_DBG_MSG("-- P2P APPLICATION SERVER : BOOT REQUESTED\n");
APP_DBG_MSG(" \n\r");

*(uint32_t*)SRAM1_BASE = *(uint32_t*)pNotification-
>DataTransferred.pPayload;
NVIC_SystemReset();
break;
#endif
#endif
```

7.5.7 Power failure recovery mechanism for CPU1 application

The BLE_ota application provides a power failure recovery mechanism while updating CPU1 application.

The two tags used to manage a power failure during CPU1 application firmware update are:

1. MagicKeywordAddress: must be mapped at 0x140 from start of the binary image to be loaded
2. MagicKeywordvalue: checked by the BLE_ota application at MagicKeywordAddress.

While flashing the new application, if the link is dropped, the BLE_ota application detects the failure and automatically erases the programmed sectors. This mechanism prevents a reboot on a wrong application.

```
/**
 * These are the two tags used to manage a power failure during CM4 Application OTA FW Update
 * The MagicKeywordAddress shall be mapped @0x140 from start of the binary image
 * The MagicKeywordvalue is checked in the ble_ota application
 */
PLACE_IN_SECTION("TAG_OTA_END") const uint32_t MagicKeywordValue = 0x94448A29 ;
PLACE_IN_SECTION("TAG_OTA_START") const uint32_t MagicKeywordAddress = (uint32_t)&MagicKeywordValue;

define region OTA_TAG_region = mem:(from (__ICFEDIT_region_ROM_start__ + 0x140) to (__ICFEDIT_region_ROM_start__ + 0x140 + 4));

define block CSTACK with alignment = 8, size = __ICFEDIT_size_cstack__ { };
define block HEAP with alignment = 8, size = __ICFEDIT_size_heap__ { };

initialize by copy { readwrite };
do not initialize { section .noinit,
                    section MAPPING_TABLE,
                    section MB_MEM1 };

place at address mem: __ICFEDIT_intvec_start__ { readonly section .intvec };

keep { section TAG_OTA_START };
keep { section TAG_OTA_END };
place in OTA_TAG_region { section TAG_OTA_START };
place in ROM_region { readonly, last section TAG_OTA_END };
```

7.6 Application tips

7.6.1 How to set Bluetooth device address

All Bluetooth devices must have an address that uniquely identifies them.

The following addresses types are supported by the STM32WB devices:

- public address
- random address (may be either a static or private address).

Device addresses may be either public or random. Public and random device addresses are both 48-bits long, and denoted as colon-delimited hex values (e.g. AA:BB:CC:DD:EE:FF).

The public device address must be created to conform with the IEEE 802-2001 standard, using a valid organization unique identifier (OUI) obtained from the IEEE registration authority. Public device addresses are known as MAC addresses.

For the details on how a BLE device can generate a random address the reader can refer to the Core Specification v5.0.

The STM32WB provides a 64-bit unique device Identification

- 24-bit company ID (0x00 80 E1 for STMicroelectronics)
- 8-bit device ID (0x05 for STM32WB)
- 32-bit unique device number to differentiate each individual device.

If the application needs to use a different public address, it has to be obtained from the right organization and then stored in a persistent memory location of the final product (either within the microcontroller Flash memory or OTP, or in an external storage area).

During the STM32WB initialization phase, the application must configure this address.

The ACI command to set the public address is:

```
tBleStatus aci_hal_write_config_data(uint8_t offset, uint8_t len, const
uint8_t *val).
```

The parameters must be set as follows:

- Offset: 0x00
- Length: 0x06
- Value: pointer to the public address value, e.g. 0xaabbccddeeff (6-byte array).

The application microprocessor must send the command `aci_hal_write_config_data` to the wireless microprocessor before starting any BLE operations and after every power-up or reset, since the command `aci_hal_write_config_data` does not systematically save the data in the Flash memory.

The following pseudo-code example illustrates how to set a MAC address from the application:

```
uint8_t bdaddr[] = {0xFF, 0xEE, 0xDD, 0xCC, 0xBB, 0xAA};
ret=aci_hal_write_config_data(0x00, 0x06, bdaddr);
if(ret) { PRINTF("Setting address failed.\n") }
```

BLE devices can also use random addresses. The address value can be read from the application using the `tBleStatus aci_hal_read_config_data(uint8_t offset, uint16_t data_len, uint8_t *data_len_out_p, uint8_t *data);` command with the parameter `offset` set to 0x80.

Alternatively, the application can set a random address from the external host processor using the `int hci_le_set_random_address(tBdAddr bdaddr)` command after each reset. If the random address is not set through the `hci_le_set_random_address` command, then the address generation is handled independently by the stack as described above.

The 64-bit UID of the STM32WB device can be used to derive the unique BLE 48-bit device address. It is also possible to get the BLE-48-bit device address from the OTP register.

```
const uint8_t* BleGetBdAddress( void ) {
    uint8_t *otp_addr;
    const uint8_t *bd_addr;
    uint32_t udn;
    uint32_t company_id;
    uint32_t device_id;
    udn = LL_FLASH_GetUDN();

    if(udn != 0xFFFFFFFF) {
        company_id = LL_FLASH_GetSTCompanyID();
        device_id = LL_FLASH_GetDeviceID();
```



```

    bd_addr_udn[0] = (uint8_t)(udn & 0x000000FF);
    bd_addr_udn[1] = (uint8_t)((udn & 0x0000FF00) >> 8);
    bd_addr_udn[2] = (uint8_t)((udn & 0x00FF0000) >> 16);
    bd_addr_udn[3] = (uint8_t)device_id;
    bd_addr_udn[4] = (uint8_t)(company_id & 0x000000FF);
    bd_addr_udn[5] = (uint8_t)((company_id & 0x0000FF00) >> 8);

    bd_addr = (const uint8_t *)bd_addr_udn;
}
else {
    otp_addr = OTP_Read(0);
    if(otp_addr) {
        bd_addr = ((OTP_ID0_t*)otp_addr)->bd_address;
    }
    else {
        bd_addr = M_bd_addr;
    }
}
return bd_addr;
}

```

7.6.2 How to add a task to the sequencer

- Declare task ID - app_conf.h -

```

/**< Add in that list all tasks that may send a ACI/HCI command */
typedef enum
{
    CFG_TASK_ADV_CANCEL_ID,
    CFG_TASK_SW1_BUTTON_PUSHED_ID,
    CFG_TASK_HCI_ASYNCH_EVT_ID,
    CFG_LAST_TASK_ID_WITH_HCICMD, /**< Shall be LAST in the list */
} CFG_Task_Id_With_HCI_Cmd_t;

/**< Add in that list all tasks that never send a ACI/HCI command */
typedef enum
{
    CFG_FIRST_TASK_ID_WITH_NO_HCICMD = CFG_LAST_TASK_ID_WITH_HCICMD - 1,
    /**< Shall be FIRST in the list */
    CFG_TASK_SYSTEM_HCI_ASYNCH_EVT_ID,
    CFG_LAST_TASK_ID_WITHO_NO_HCICMD
    /**< Shall be LAST in the list */
} CFG_Task_Id_With_NO_HCI_Cmd_t;
#define UTIL_SEQ_CONF_TASK_NBR    CFG_LAST_TASK_ID_WITHO_NO_HCICMD

```

- Register task with callback function- “Cancel Advertising” - app_ble.c

```
SCH_RegTask(CFG_TASK_ADV_CANCEL_ID, Adv_Cancel);
```

- Start the Task with priority - app_ble.c

```
SCH_SetTask(1 << CFG_TASK_ADV_CANCEL_ID, CFG_SCH_PRIO_0);
```

7.6.3 How to use the timer server

- Create the timer with callback function

```
/**
 * Create timer to handle the Led Switch OFF
 */
HW_TS_Create(CFG_TIM_PROC_ID_ISR,
&(BleApplicationContext.SwitchOffGPIO_timer_Id), hw_ts_SingleShot,
Switch_OFF_GPIO);
```

- Start the timer with timeout

```
HW_TS_Start(BleApplicationContext.SwitchOffGPIO_timer_Id,
(uint32_t)LED_ON_TIMEOUT);
```

- Stop the timer

```
HW_TS_Stop(BleApplicationContext.SwitchOffGPIO_timer_Id);
```

- Callback function example

```
static void Switch_OFF_GPIO() {
    BSP_LED_Off(LED_GREEN);
}
```

7.6.4 How to start the BLE stack - SHCI_C2_BLE_Init()

```
SHCI_C2_Ble_Init_Cmd_Packet_t ble_init_cmd_packet =
{
    0, 0, 0,                                /**< Header unused */
    0,                                       /** pBleBufferAddress not used */
    0,                                       /** BleBufferSize not used */
    CFG_BLE_NUM_GATT_ATTRIBUTES,
    CFG_BLE_NUM_GATT_SERVICES,
    CFG_BLE_ATT_VALUE_ARRAY_SIZE,
    CFG_BLE_NUM_LINK,
    CFG_BLE_DATA_LENGTH_EXTENSION,
    CFG_BLE_PREPARE_WRITE_LIST_SIZE,
    CFG_BLE_MBLOCK_COUNT,
    CFG_BLE_MAX_ATT_MTU,
    CFG_BLE_SLAVE_SCA,
    CFG_BLE_MASTER_SCA,
    CFG_BLE_LSE_SOURCE,
    CFG_BLE_MAX_CONN_EVENT_LENGTH,
    CFG_BLE_HSE_STARTUP_TIME,
    CFG_BLE_VITERBI_MODE,
    CFG_BLE_LL_ONLY,
    0                                         /** TODO Should be read from HW */
}
```

```
};
```

CFG_BLE_NUM_GATT_ATTRIBUTES

Maximum number of attribute records related to all the required characteristics (excluding the services) that can be stored in the GATT database, for the specific BLE user application.

For each characteristic, the number of attribute records goes from two to five depending on the characteristic properties:

- minimum of two (one for declaration and one for the value)
- add one more record for each additional property: notify or indicate, broadcast, extended property.

The total calculated value must be increased by 9, due to the records related to the standard attribute profile and GAP service characteristics, and automatically added when initializing GATT and GAP layers

- Min value: <number of user attributes> + 9
- Max value: depending on the GATT database defined by user application

CFG_BLE_NUM_GATT_SERVICES

Defines the maximum number of services that can be stored in the GATT database. Note that the GAP and GATT services are automatically added at initialization so this parameter must be the number of user services increased by two.

- Min value: <number of user service> + 2
- Max value: depending GATT database defined by user application

CFG_BLE_ATT_VALUE_ARRAY_SIZE

Size of the storage area for the attribute values.

Each characteristic contributes to the attrValueArrSize value as follows:

- Characteristic value length plus:
 - 5 bytes if characteristic UUID is 16 bits
 - 19 bytes if characteristic UUID is 128 bits
 - 2 bytes if characteristic has a server configuration descriptor
 - 2 bytes * CFG_BLE_NUM_LINK if the characteristic has a client configuration descriptor
 - 2 bytes if the characteristic has extended properties

Each descriptor contributes to the attrValueArrSize value as follows:

- Descriptor length

CFG_BLE_NUM_LINK

Maximum number of BLE links supported

- Min value: 1
- Max value: 8

CFG_BLE_DATA_LENGTH_EXTENSION

Disable/enable the extended packet length BLE 5.0 feature

- Disable: 0
- Enable: 1

CFG_BLE_PREPARE_WRITE_LIST_SIZE

Maximum number of supported “prepare write request”. The minimum required value can be calculated using the following DEFAULT_PREP_WRITE_LIST_SIZE macro:

```
#define DIV_CEIL(x, y)      (((x) + (y) - 1) / (y))

/**
 * DEFAULT_ATT_MTU: minimum mtu value that GATT must support.
 * 5.2.1 ATT_MTU, BLUETOOTH SPECIFICATION Version 4.2 [Vol 3, Part G]
 */
#define DEFAULT_ATT_MTU      (23)
/**
 * DEFAULT_MAX_ATT_SIZE: maximum attribute size.
 */
#define DEFAULT_MAX_ATT_SIZE      (512)

/**
 * PREP_WRITE_X_ATT(max_att): compute how many Prepare Write Request are
needed
 * to write a characteristic with size max_att when the used ATT_MTU value
is
 * equal to DEFAULT_ATT_MTU (23).
 */
#define PREP_WRITE_X_ATT(max_att)      (DIV_CEIL(max_att, DEFAULT_ATT_MTU
- 5U) * 2)
/**
 * DEFAULT_PREP_WRITE_LIST_SIZE: default minimum Prepare Write List size.
 */
#define DEFAULT_PREP_WRITE_LIST_SIZE
PREP_WRITE_X_ATT(DEFAULT_MAX_ATT_SIZE)
```

- Min value: see macros above
- Max value: a value higher than the minimum required can be specified, but it is not recommended

CFG_BLE_MBLOCK_COUNT

Number of allocated memory blocks for the BLE stack. The minimum required value can be calculated using the following MBLOCKS_CALC macros:

```
#define MEM_BLOCK_SIZE      (32)
/**
 * MEM_BLOCK_X_MTU (mtu): compute how many memory blocks are needed to
compose an ATT
```

```

* Packet with ATT_MTU = mtu.
* 7.2 FRAGMENTATION AND RECOMBINATION, BLUETOOTH SPECIFICATION Version 4.2
* [Vol 3, Part A]
*/

#define MEM_BLOCK_X_TX (mtu)                (DIV_CEIL((mtu) + 4U,
MEM_BLOCK_SIZE) + 1U)
#define MEM_BLOCK_X_RX (mtu, n_link)        ((DIV_CEIL((mtu) + 4U,
MEM_BLOCK_SIZE) + 2U) * (n_link) + 1)
#define MEM_BLOCK_X_MTU (mtu, n_link)       (MEM_BLOCK_X_TX(mtu) +
MEM_BLOCK_X_RX(mtu, (n_link)))

/**
* Minimum number of blocks required for secure connections
*/
#define MBLOCKS_SECURE_CONNECTIONS          (4)

/**
* MBLOCKS_CALC(pw, mtu, n_link): minimum number of buffers needed by the
stack.
* This is the minimum recommended value and depends on:
* - pw: size of Prepare Write List
* - mtu: ATT_MTU size
* - n_link: maximum number of simultaneous connections
*/
#define MBLOCKS_CALC(pw, mtu, n_link)        ((pw) + MAX(MEM_BLOCK_X_MTU(mtu,
n_link), (MBLOCKS_SECURE_CONNECTIONS)))

```

- Min value: see macro above
- Max value: a higher value can improve data throughput performance, but uses more memory.

CFG_BLE_MAX_ATT_MTU

Maximum ATT MTU size supported.

- Min value: 23
- Max value: 512

CFG_BLE_SLAVE_SCA

The sleep clock accuracy (ppm value) that used in BLE connected slave mode to calculate the window widening (in combination with the sleep clock accuracy sent by master in CONNECT_REQ PDU), refer to BLE 5.0 specifications - Vol 6 - Part B - chap 4.5.7 and 4.2.2.

- Min value: 0
- Max value: 500 (worst possible admitted by specification)

CFG_BLE_MASTER_SCA

The sleep clock accuracy handled in master mode. It is used to determine the connection and advertising events timing. It is transmitted to the slave in CONNEC_REQ PDU used by the slave to calculate the window widening, see [CFG_BLE_SLAVE_SCA](#) and [7], v5.0 Vol 6 - Part B - chap 4.5.7 and 4.2.2.

Possible values:

- 251 ppm to 500 ppm: 0
- 151 ppm to 250 ppm: 1
- 101 ppm to 150 ppm: 2
- 76 ppm to 100 ppm: 3
- 51 ppm to 75 ppm: 4
- 31 ppm to 50 ppm: 5
- 21 ppm to 30 ppm: 6
- 0 ppm to 20 ppm: 7

CFG_BLE_LSE_SOURCE

Source for the 32 kHz slow speed clock.

- External crystal LSE: 0 - No calibration
- Internal RO (LSI): 1 - As the accuracy of this oscillator can vary depending upon external conditions (temperature), it is calibrated every second to ensure correct behavior of timing sensitive BLE operations.

CFG_BLE_MAX_CONN_EVENT_LENGTH

This parameter determines the maximum duration of a slave connection event. When this duration is reached the slave closes the current connections event (whatever is the CE_length parameter specified by the master in HCI_CREATE_CONNECTION HCI command), expressed in units of 625/256 μ s (~2.44 μ s).

- Min value: 0 (if 0 is specified, the master and slave perform only a single TX-RX exchange per connection event).
- Max value: 1638400 (4000 ms). A higher value can be specified (max 0xFFFFFFFF) but results in a maximum connection time of 4000 ms as specified. In this case the parameter is not applied, and the predicted CE length calculated on slave is not shortened.

CFG_BLE_HSE_STARTUP_TIME

Startup time of the high speed (16 or 32 MHz) crystal oscillator in units of 625/256 μ s (~2.44 μ s).

- Min value: 0
- Max value: 820 (~2 ms). A higher value can be specified, but the value that implemented in stack is forced to ~2 ms.

CFG_BLE_VITERBI_MODE

Viterbi implementation in BLE LL reception

- 0: Enable
- 1: Disable

CFG_BLE_LL_ONLY

Enable/disable the BLE link layer only mode. In this mode the host stack (GAP/GATT/SMP and so on) code is not present; only the Link layer is implemented and can be handled through HCI command.

- “LL Only” mode disable: 0
- “LL Only” mode enable: 1

7.6.5 How to maximize data throughput

The maximum data throughput is achieved when GATT server notification is used with following link layer parameters:

- Connection interval: 50 ms
- Min_CE_Length and Max_CE_Length: 0x50 (50 ms)

Once the connection is established, the master device sends `aci_gatt_exchange_config` to get the `MAX_ATT_MTU` value.

Data exchange is limited to $(MAX_ATT_MTU - 3)$, which corresponds to the maximum notification length.

- If supported, set the link at 2M

To avoid fragmenting the LE data have, at maximum `PDU_length = 247` ($251 - 4$):

- Use `hci_le_set_data_length` command `hci_le_set_data_length(conn_handle, 251, 2120)`

To avoid fragmentation:

- If `MAX_ATT_MTU = 250` and `le_data_length = 251`, max data to transfer = 244 ($251 - 4 - 3$)
- If `MAX_ATT_MTU = 156` and `le_data_length = 251`, max data to transfer = 153 ($156 - 3$)

7.6.6 How to add a custom BLE service

In all BLE applications, it is possible to add a custom service in parallel to existing ones provided either in source code or library. All GAP/GATT events received by the CPU1 are going to the service controller (`svc_ctl.c` from `\Middlewares\ST\STM32_WPAN\ble\svc\Src`) responsible to initialize all BLE services and to forward GATT events to registered BLE services. An example of the flow is shown in [Figure 24: Heart rate project - Interaction between middleware and user application](#).

Each service must have a `custom_xxx.c` and `custom_xxx.h`.

There must be only three public interfaces to provide to the user:

```
void Custom_xxx_Init( void )
```

This is implemented in `custom_xxx.c` and does the following:

- creates the services and add characteristics
- registers the callback to the service controller with the API `SVCCTL_RegisterSvcHandler()`

The function `SVCCTL_InitCustomSvc()` must be implemented in the application to call `Custom_xxx_Init()`.

The callback registered with `SVCCTL_RegisterSvcHandler()` is used to receive GATT events from the service controller. The type of the callback must be `SVCCTL_EvtAckStatus_t (*SVC_CTL_p_EvtHandler_t)(void *p_evt)`.

Depending upon the BLE service definition, the received GATT event may be either processed only in the `custom_xxx.c` module or, most of the times, it must be forwarded to the application with the notification `Custom_xxx_Notification()`. Each GATT event is relevant for only one BLE service. To avoid the service controller to call all registered BLE services to report the received event, the callback returns to the service controller whereas the GATT has been processed or ignored.

There are three values that can be returned:

1. `SVCCTL_EvtNotAck`: means the GATT event was not relevant for that BLE service. The service controller keeps reporting this GATT event to other registered BLE services until it gets an ack. When a GATT event is not acknowledged by all registered BLE services, it is reported to the application with the notification `SVCCTL_App_Notification()`.
2. `SVCCTL_EvtAckFlowEnable`: means the GATT event has been processed and the service controller does not report it to either other registered BLE services or to the application.
3. `SVCCTL_EvtAckFlowDisable`: means the GATT event has been acknowledged and the service controller does not report it to either other registered BLE services or to the application. However, the GATT event has not been processed. The service controller notifies the transport layer that this event shall not be discarded. In that case, the transport layer will not report any more event until the command `hci_resume_flow()` has been called. As soon as the flow is resumed, the not acknowledged event is reported one more time. Note that these are all BLE user hci events not reported anymore and not only those to the BLE service that not acknowledged the GATT event.

```
tBleStatus Custom_xxx_UpdateChar( Custom_xxx_ChardId_t ChardId, uint8_t *  
p_payload )
```

This API is used by the application to update the characteristic of the server. The mapping between the `ChardId` of the interface and the UUID to be sent to the BLE stack must be implemented in the BLE service.

```
void Custom_xxx_Notification( Custom_xxx_Notification_t *p_notification )
```

This API is used to report, when relevant, to the application a GATT event received by the BLE service.

8 Building a BLE application on top of the HCI layer interface

CPU2 may be used as a BLE HCI layer co-processor. In that case, the user has to either implement its own HCI application, or use an existing open source BLE host stack.

Most BLE host stacks use a UART interface to communicate with a BLE HCI co-processor. The equivalent physical layer on the STM32WB device is the mailbox, as described in [Section 13.2: Mailbox interface](#).

The mailbox provides an interface for both the BLE and the System channel. The BLE host stack builds the command buffer to be sent over the BLE channel on the mailbox and has to provide an interface to report the events received through the mailbox. In addition to the mailbox BLE host stack adaptation, the user must notify the mailbox driver when an asynchronous packet is released.

The system channel is not handled by a BLE host stack. The user must implement its own transport layer to build the System command buffer to be sent to the mailbox driver and to manage the event received from the mailbox (including the notification to release an asynchronous buffer to the mailbox driver), or use the mailbox extended driver (as described in [Section 13.3: Mailbox interface - Extended](#)), which provides an interface on top of the provided transport layer which builds the System command buffer and to manage the system asynchronous event.

The BLE_TransparentMode project can be used as an example to build an application on top of a BLE HCI layer co-processor using the mailbox as described in [Section 13.2: Mailbox interface](#).

9 Thread

9.1 Overview

The Thread stack embarked in CPU2 core is provided by OpenThread, an open-source implementation of the Thread networking protocol, and is released by Nest.

OpenThread provides several APIs that address different services at different levels inside the stack. All these APIs (documented in the STM32WB firmware package) are exported on CPU1 core and can be used directly by the application.

The STM32WB firmware package is provided with several examples demonstrating how to run simple Thread applications. To run these applications, the appropriate CPU2 firmware binary need to be downloaded.

There are three major MO firmwares available, as detailed in [Table 28](#).

Table 28. MO firmwares available for Thread

CPU2 firmware library	Features	Comment
stm32wb5x_Thread_FTD_fw.bin	FTD: Full Thread device	The device can support all Thread roles except border router (leader, router, end device, sleepy end device). Thread roles are described in Section 13.10.5 .
stm32wb5x_Thread_MTD_fw.bin	MTD: Minimal Thread device	The device can act only as 'end device' or 'sleepy end device'. The benefit of the MTD configuration versus the FTD configuration is to require less memory.
stm32wb5x_BLE_Thread_fw.bin	Static concurrent mode	The device embarks the two stacks (BLE and Thread) in a single binary.

9.2 How to start

The easiest way to start with Thread is to use the two following applications:

- Thread_Cli_Cmd: shows how to control the Thread stack via CLI commands. The CLI (command line interface) commands are sent via an UART from a HyperTerminal (PC) to the board and can be used to create simple use-cases. This is the application used for running certification tests (Thread GRL test harness)
- Thread_Coap_Generic: requires two P-NUCLEO-WBxx boards. It shows a board exchanging CoAP messages with the other one. In this application, one device is acting as leader and the other one is acting as end device or router.

These two applications are provided in the STM32WB firmware package with an associated readme.txt file.

9.3 Thread configuration

Before starting any Thread application, the user has to:

- Download the appropriate firmware: Thread MTD, Thread FTD or Thread Static mode
- Use the correct option bytes.

Figure 37. User option bytes setting

User configuration option byte

<input checked="" type="checkbox"/> nBOOT0	<input checked="" type="checkbox"/> nRSTSHDW	<input checked="" type="checkbox"/> WWDGSW
<input checked="" type="checkbox"/> nBOOT1	<input checked="" type="checkbox"/> nRSTSTDBY	<input checked="" type="checkbox"/> IWDGSW
<input checked="" type="checkbox"/> nSWBOOT0	<input checked="" type="checkbox"/> nRSTSTOP	<input checked="" type="checkbox"/> IWDGSTDBY
<input checked="" type="checkbox"/> SRAM2RST	<input type="checkbox"/> PCROP_RDP	<input checked="" type="checkbox"/> IWDGSTOP
<input checked="" type="checkbox"/> SRAM2PE		

IPCCDBA 0x0000

Caution: The OpenThread stack provides several compilation flags to set different configurations. Nevertheless, since the stack inside the STM32WB is delivered as a binary, those flags are fixed and cannot be modified by the user. The selected flags can be seen in the files listed in [Table 29](#).

Table 29. Files for Thread configuration

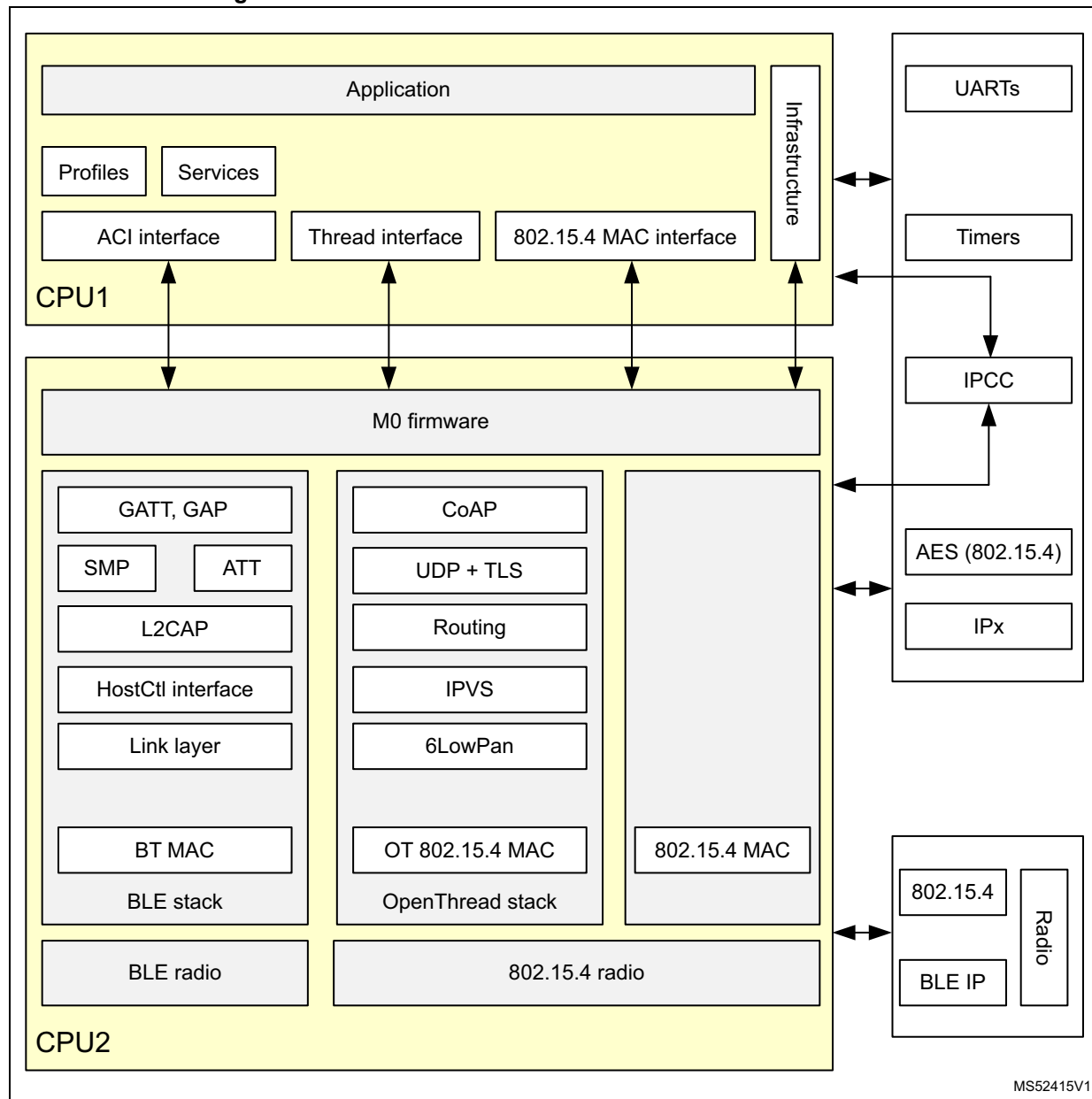
File name	Configuration
openthread_api_config_ftd.h	To be used with the Thread FTD CPU2 firmware
openthread_api_config_mtd.h	To be used with the Thread MTD CPU2 firmware
openthread_api_config_concurrent.h	To be used with Static concurrent mode CPU2 firmware

When building a Thread application, the appropriate configuration file must be used depending on the downloaded CPU2 firmware. The flags inside this configuration file are used to define which APIs are exported and available for CPU1 application. As mentioned before, these flags must not be modified by the user.

9.4 Architecture overview

[Figure 38](#) shows the overall software architecture with the two BLE and Thread stacks. All the code running on CPU2 is delivered as a binary library. The customer has only got access to CPU1 core and sees the firmware running on CPU2 as a black box. Both the ACI and the Thread interfaces allow the user to access, respectively, the BLE and the Thread task.

Figure 38. Software architecture with BLE and Thread stacks



9.5 Inter core communication

All OpenThread APIs are exposed to CPU1 and can be used to control the stack running on CPU2. The STM32WB middleware manages the communication between the two cores.

When the application calls an OpenThread function, a synchronous message is sent to CPU2 via IPCC. The parameters associated with this function are stored in shared memory.

OpenThread functions calls are put on hold until the command is completed to ensure that the overall system stays synchronized (see [Figure 39](#)). The application can register callbacks to be notified on specific events. These notifications are also put on hold, as shown in [Figure 40](#).

Figure 39. OpenThread functions calls

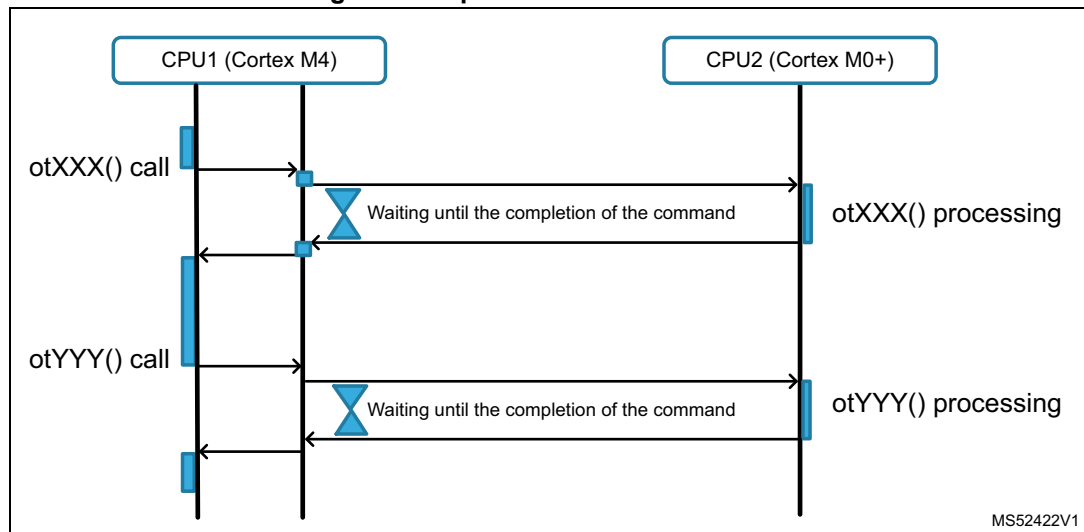
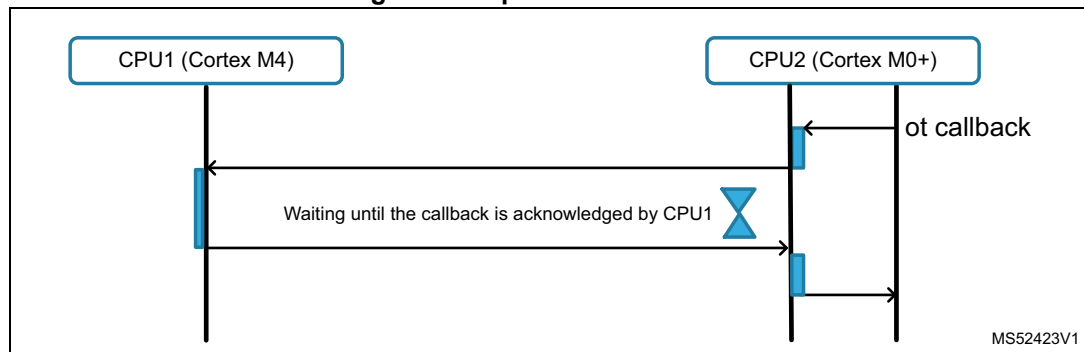


Figure 40. OpenThread callback



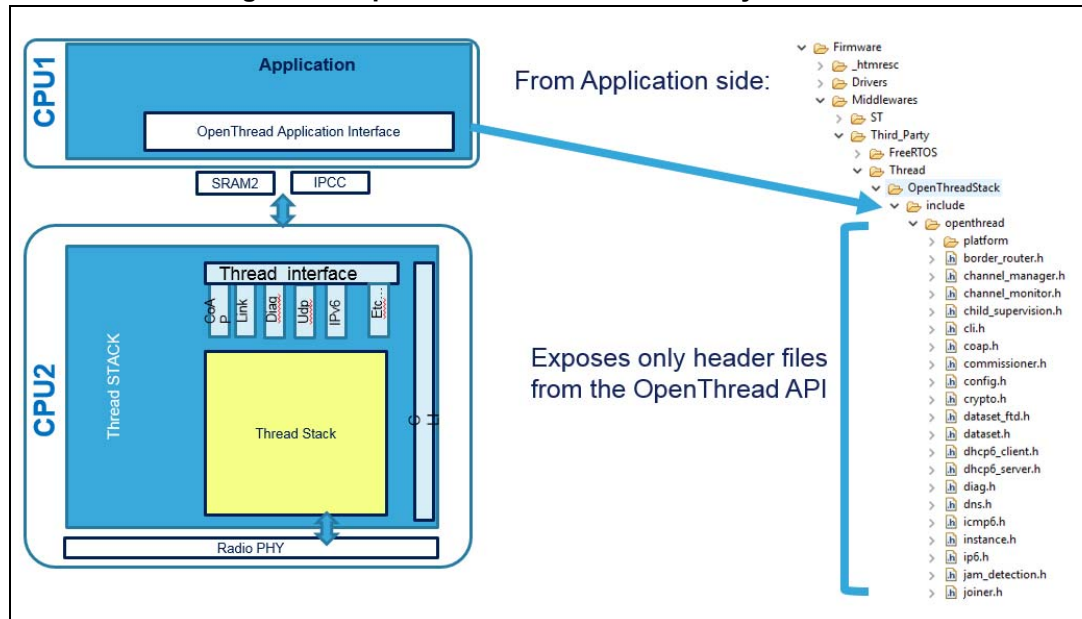
9.6 OpenThread API

OpenThread defines several APIs addressing different services at different level inside the stack:

- Functions used to manage CoAP services: `otCoapStart()`, `otCoapSendRequest()`
- Functions used to manage UDP datagrams: `otUdpOpen()` `otUdpConnect()`
- Functions that manage the radio configuration: `otLinkSetChannel()`
- Functions that manage the IPV6 addresses: `otIp6AddUnicastAddress()`

In total, there are more than 300 functions available. These APIs are described in the `STM32WBxx_OpenThread_API_User_Manual.chm` available in the STM32WB firmware package.

Figure 41. OpenThread stack API directory structure



9.7 Usage of the OpenThread APIs

The OpenThread APIs can be used as if the system is running on a single processor. The Thread interface hides all the multicore mechanisms (IPCC, shared memory), allowing the CPU1 to access to the OpenThread stack running on CPU2.

There are nevertheless two specificities linked to the way the STM32WB implements the OpenThread interface, described in the next subsections.

9.7.1 OpenThread instance

A lot of OpenThread APIs use the parameter **ainstance** as input, which defines the OpenThread instance, in bold in the example of the function `otThreadSetEnabled()` below:

```
otThreadSetEnabled(otInstance *ainstance, bool aEnabled)
```

In the STWM32WB Thread implementation, the OpenThread instance is directly allocated at the start of CPU2 firmware. CPU1 does not need to take care of this parameter, is always set to **NULL** (see the bold type in the code fragment below).

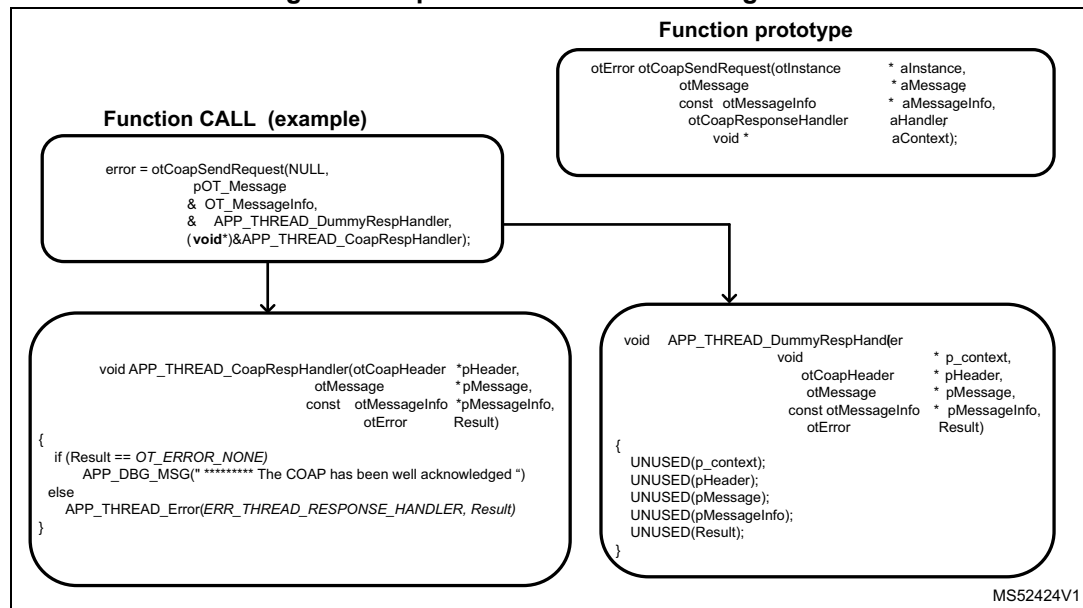
```
error = otThreadSetEnabled(NULL, true);
if (error != OT_ERROR_NONE)
{
    APP_THREAD_Error(ERR_THREAD_START,error);
}
```

9.7.2 OpenThread call back management

In the STWM32WB thread implementation, the callbacks passed as parameters inside OpenThread functions do not follow the exact prototype of the standard OpenThread

function. This is due to the dual core architecture constraints. The application callback must be passed in the context parameter as shown in [Figure 42](#).

Figure 42. OpenThread callback management



Note: The easiest way to see how OpenThread callbacks are managed is to refer to the different applications provided in the STM32WB firmware delivery.

9.8 System commands for Thread applications

Some commands can be called from the Thread applications:

- **SHCI_C2_THREAD_Init():** starts the Thread stack. Called at the end of initialization phase.
- **SHCI_C2_FLASH_StoreData():** stores the nonvolatile Thread data in the Flash memory. It is the application that decides when data must be stored in the Flash memory (e.g. after the commission phase, or after network configuration).

Note: This operation can take several seconds and must be called only when there is no Thread activity.

- **SHCI_C2_FLASH_EraseData():** Erases the nonvolatile Thread data from the Flash memory.

Note: This operation can take several seconds and must be called only when there is no Thread activity.

- **SHCI_C2_CONCURRENT_SetMode():** enables or disables Thread activity on CPU2 for Concurrent mode.
- **SHCI_C2_RADIO_AllowLowPower():** allows or forbids the 802_15_4 radio IP from entering in Low-power mode.
- **SHCI_GetWirelessFwInfo():** reads the informations relative to the loaded wireless binary.

9.8.1 Non-volatile Thread data

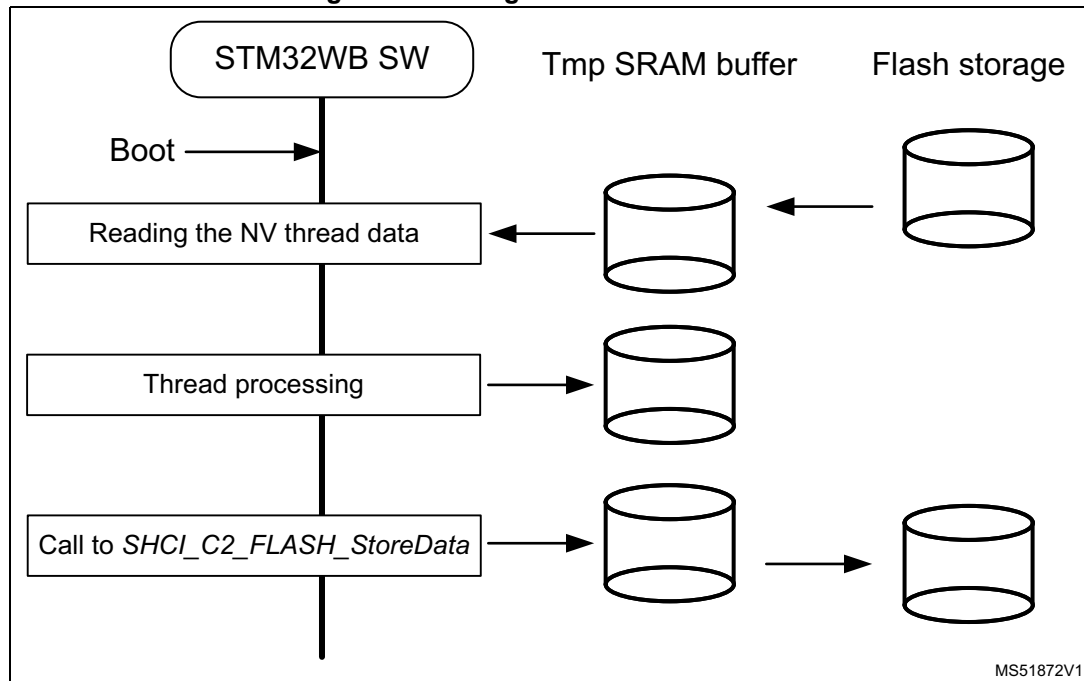
According to the Thread specification, several values must be stored in the Flash memory to reuse them later on. These values concern the following entities:

1. Active operational dataset:
Written whenever a new active operational dataset is received. This only occurs when the commissioner or other external entity updates the active operational dataset.
2. Pending operational dataset:
Written whenever a new pending operational dataset is received. This only occurs when the commissioner or other external entity updates the pending operational dataset.
3. Network info:
Written whenever the device role changes (i.e. detached, child, router, leader). Written whenever the MAC and/or MLE frame counter increments beyond a specific threshold.
4. Parent info:
Written whenever a child attaches to a parent.
5. Child info:
Written whenever a child is added/removed from the child table.

After reset, the nonvolatile Thread dataset is automatically read from the Flash memory. During run time, OpenThread regularly stores and updates this nonvolatile data in an internal SRAM buffer (see [Figure 43](#)). It is up to the application to force the copy of this nonvolatile data to the Flash memory using the function `SHCI_C2_FLASH_StoreData()`. As this operation blocks the access to the Flash memory (and so to the CPU), it must be done when there are no real time constraints (for instance after a Thread stop).

Note: The function `SHCI_C2_FLASH_StoreData()` is automatically triggered after a call to `otInstanceReset()` or `otInstanceFactoryReset()`.

Figure 43. Storage on non-volatile data



9.8.2 Low-power support

To reach the minimal power consumption, the device must be put in SED (sleepy end device) mode, waking up to poll for messages from its parent or to send data. For most of the time the device sleeps and enters automatically in Low-power mode. Low-power Thread devices can sleep and operate on battery power for years.

When the system is in Low-power mode, as soon as the application sends an otCmd, the system wakes up, executes the command and goes back in Low-power mode. If an application sends multiple otCmd sequentially, the system wakes up and goes back to sleep at high frequency. To avoid the risk of having multiple unneeded short wakeup/sleep cycles, the application allows or forbids the radio to enter Low-power mode via the function `SHCI_C2_RADIO_AllowLowPower()`. An example of this function is provided in the application named `Thread_SED_Coap_Multicast`.

10 Step by step design of an OpenThread application

This section provides information and code examples on how to design and implement an OpenThread application on a STM32WB device.

10.1 Initialization phase

Several steps are mandatory to initialize the STM32WB Thread application:

- Initialize device (HAL, reset device, clock and power configuration)
- Configure platform (e.g. button, LED)
- Configure hardware (e.g. UART, debug)
- Start CPU2, then have it send System notification to the application (on CPU1 side)
- On receiving the notification, the application starts the Thread configuration.

10.2 Set-up the Thread network

In the Thread applications provided in the firmware package, the setup of the Thread network is always done with the same function: `APP_THREAD_DeviceConfig()`

This function processes the following steps:

- Erase persistent Thread parameters to perform a clean start: `otInstanceErasePersistentInfo()`
- Register application callbacks that are called by the OpenThread stack when the role of the node is changed. (e.g. when the node becomes router). Operation performed using `otSetStateChangedCallback()`
- Set the Channel : `otLinkSetChannel()`
- Set the PANID: `otLinkSetPanId()`
- Enable IPv6 communication: `otIp6SetEnabled()`
- Start the CoAP server: `otCoapStart()`
- Add a CoAP resource to the CoAP Server: `otCoapAddResource()`
- Start the Thread protocol operation: `otThreadSetEnabled()`

After these steps

- If the board is first one on this Thread network, the node becomes a leader (green LED on in Thread for example).
- If a leader is already present on the network, the node joins as a router or child (red LED on in Thread for example).

10.3 CoAP request

The constrained application protocol (CoAP) is a specialized web transfer protocol for use with constrained nodes and networks (such as low-power, lossy).

CoAP provides a request/response interaction model between application endpoints, supports built-in discovery of services and resources, and includes key concepts of the web such as URIs and Internet media types.

Note: *This section does not detail all the OpenThread APIs related to CoAP, but gives an overview of the main functions and abstractions available as part of STM32WB Thread examples.*

10.3.1 Creating an otCoapResource

```
typedef struct otCoapResource
{
    const char *          mUriPath; ///< The URI Path string
    otCoapRequestHandler mHandler; ///< The callback for handling a
    received request
    void *                mContext; ///< Application-specific context
    struct otCoapResource *mNext;   ///< The next CoAP resource in the list
} otCoapResource;
```

The declaration is as follows:

```
static otCoapResource OT_Ressource = {C_RESSOURCE,
APP_THREAD_DummyReqHandler, (void*)APP_THREAD_CoapRequestHandler, NULL};
```

with:

mUriPath = C_RESSOURCE : name of the resource (eg: "light")

mHandler = APP_THREAD_DummyReqHandler() : Dummy Request Handler. See Note below.

mContext = APP_THREAD_CoapRequestHandler() : Handler called when the server receives a COAP request.

mNext = NULL : Not used

Note: *Due to the STM32WB implementation (dual core CPU1/CPU2 with wrapper for OpenThread interface), the parameter mHandler must be filled with a dummy Request handler function (doing nothing) and the effective request handler has to be passed to mContext parameter.*

10.3.2 Sending a CoAP request

The application Thread_Coap_Generic proposes an abstraction layer to facilitatesending CoAP requests. This is done using following function:

```
static void APP_THREAD_CoapSendRequest(otCoapResource* pCoapRessource,
    otCoapType CoapType,
    otCoapCode CoapCode,
    const char *Address,
    uint8_t* Payload,
    uint16_t Size)
```

10.3.3 Receiving a CoAP request

It is called when the server receives a CoAP request.

The prototype of a CoAP request handler is as follows:

```
static void APP_THREAD_CoapRequestHandler(otCoapHeader * pHeader,
    otMessage * pMessage,
    const otMessageInfo * pMessageInfo)
```

In this function, the user can read the received message by calling the following function:

```
otMessageRead()
```

If the type of the message is confirmable (using `otCoapHeaderGetType()`), a CoAP response has to be sent (see [Section 11.3: Thread_Coap_Generic](#) for examples).

10.4 Commissioning

Commissioning requires a device with the commissioner role, and another with the joiner role. The commissioner is either a Thread device in an existing network, or a device external to the Thread network (such as a mobile phone) that performs the role.

The joiner is the device wishing to join the Thread network.

A Thread commissioner is used to authenticate a device on the network. It does not transfer, nor have possession of Thread network credentials such as the master key.

This document covers basic, on-mesh commissioning without an external commissioner or border router.

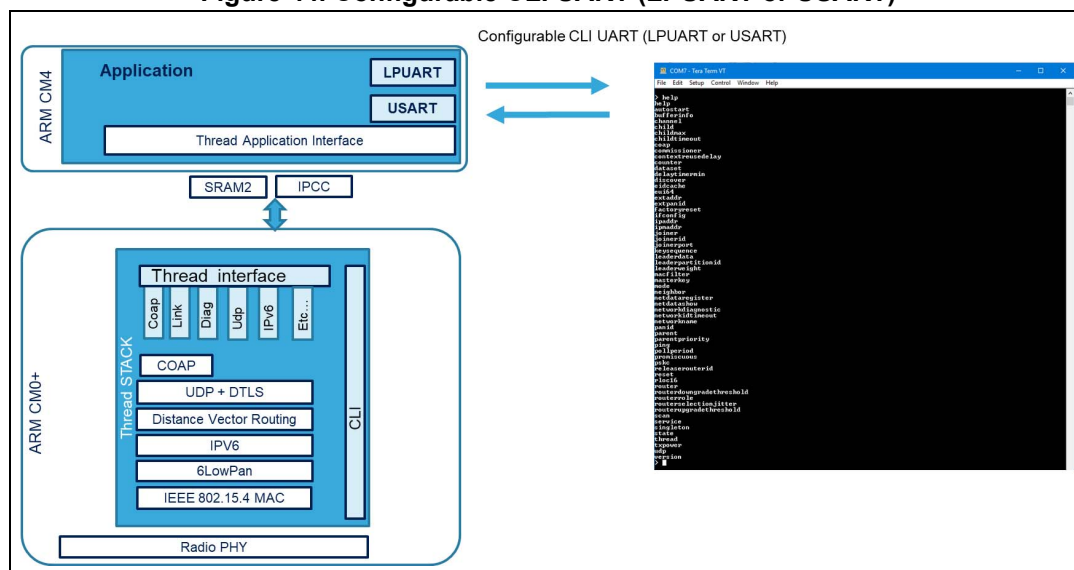
Thread_Commissioning application demonstrates a simple commissioning example.

10.5 CLI

The OpenThread stack exposes configuration and management APIs via a command line interface.

The certification environment (GRL test harness) uses the CLI to execute test cases.

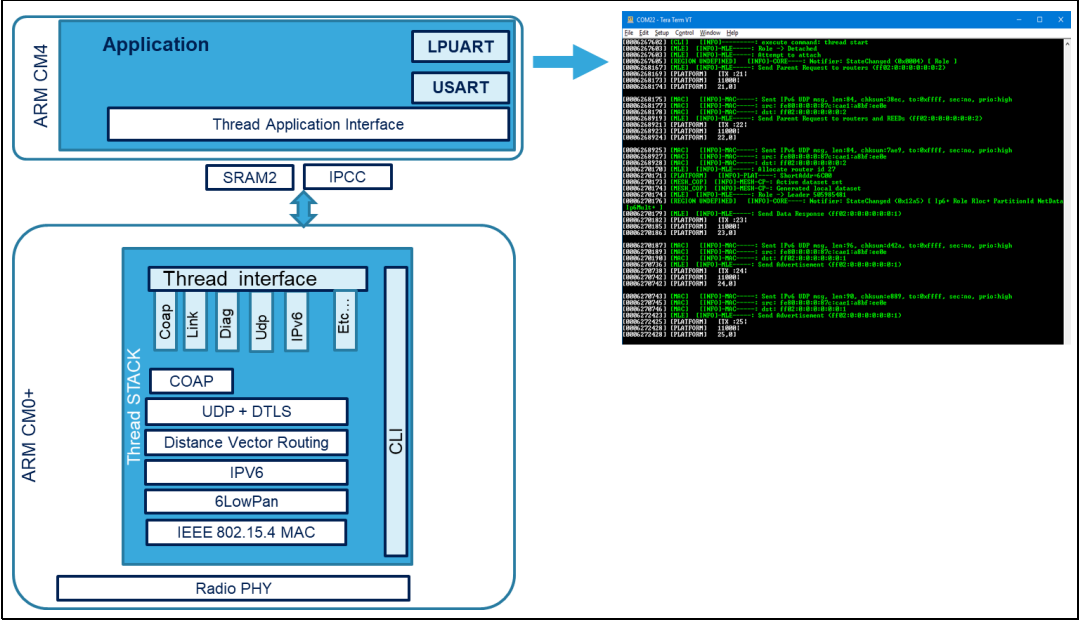
Figure 44. Configurable CLI UART (LPUART or USART)



10.6 Traces

Traces from CPU1 and CPU2 applications are routed to the UART (configured at compilation time using app_conf.h file).

Figure 45. Traces for Thread applications



OpenThread stack trace levels are dynamically configurable via OpenThread APIs using otSetDynamicLogLevel().

11 STM32WB OpenThread application

11.1 Thread_Cli_Cmd

This application shows how to control the OpenThread stack via Command lines.

CLI commands are sent via a UART from an HyperTerminal (PC) to the STM32WBxx_NUCLEO board.

This is the application used for certification process.

11.2 Thread_Coap_DataTransfer

This application demonstrates how to transfer large blocks of data using CoAP messaging protocol.

In this application the mesh-local scope and multicast addressing types are used to probe the mesh-local IP addresses of the child devices to which the file is transferred.

Nodes are split into two forwarding roles: router or end device.

In this application, which uses two devices, one acting as a leader (router) and the other one as an end device (child mode).

After the reset of the two boards, one of them is in leader mode (green LED2 on) and the other one in child mode (red LED3 on).

Once the child mode is established for one of the devices, it starts the provisioning procedure in multicast mode to probe the IP address of the leader device.

Then this is used to start the file transfer procedure in unicast mode, the successful operation is signaled by the lightening of the blue LED.

11.3 Thread_Coap_Generic

This application demonstrates the use of CoAP messages. It provides the abstraction level to send CoAP multicast request.

This application requires two STM32WB boards. The objective is to demonstrate both boards exchanging CoAP messages with each other. In this application, one board is acting as leader and the other one is acting as end device or router.

11.4 Thread_Coap_Multiboard

This application shows how to use CoAP to send messages to multiple boards in a unicast way. It is designed to use from two to five STM32WBxx_NUCLEO boards.

The purpose of this application is to create a small Thread mesh network.

When the setup is correctly configured, a CoAP request is automatically and continuously transferred from one board to next in the following order:

- Board 1 → Board 2 → (...) → Board n → Board 1 → ...

To each board is associated a specific IPv6 address:

- fdde:ad00:beef:0:442f:ade1:3fc:1f3a for board number 1
- fdde:ad00:beef:0:442f:ade1:3fc:1f3b for board number 2
- fdde:ad00:beef:0:442f:ade1:3fc:1f3c for board number 3 if present
- fdde:ad00:beef:0:442f:ade1:3fc:1f3d for board number 4 if present
- fdde:ad00:beef:0:442f:ade1:3fc:1f3e for board number 5 if present

11.5 Thread_Commissioning

This application demonstrates the commissioning process between a commissioner and a joiner.

It shows a device distributing its Thread parameters (channel, panid, masterkey) to another device using to the commissioning process.

This application requires two STM32WBxx_NUCLEO boards.

One device acts as commissioner and the other one as joiner.

In this application, the commissioner accepts a newcomer in its Thread network.

11.6 Thread_FTD_Coap_Multicast

This application demonstrates the use of CoAP multicast message for Full Thread devices.

Note: To be used with Thread FTD CPU2 binary.

This application uses two devices, one device acts as a leader (router) and the other one as end device (child mode).

After the reset of the two boards (named respectively A and B), one board is in leader mode (green LED2 on), the other one in child mode (red LED3 on).

To send a CoAP command from board A to board B, press the SW1 pushbutton on board A. Board B receives the CoAP command to turn on its blue LED1. Pressing again the same push-button turns the blue LED1 off.

Same CoAP commands can be sent from board B to board A.

11.7 Thread_SED_Coap_Multicast

This application demonstrates the use of CoAP multicast message sent from a sleepy end device.

Note: To be used with Thread MTD CPU2 binary.

Two boards are needed for the proposed use case:

- One board acts as a leader (router) in FTD mode (board A)
- The other one acts as a SED in MTD mode (board B).

The board acting as a leader must be flashed with the FTD application: use the application "Thread_FTD_Coap_Multicast" + Thread FTD binary on CPU2.

The board acting as a SED must be flashed with the MTD application “Thread_SED_Coap_Multicast” + Thread MTD binary on CPU2.

After the two boards are reset, one board (A) automatically reaches the leader mode (green LED2 on) and the other one (B) the SED mode (red LED3 on) a few seconds later.

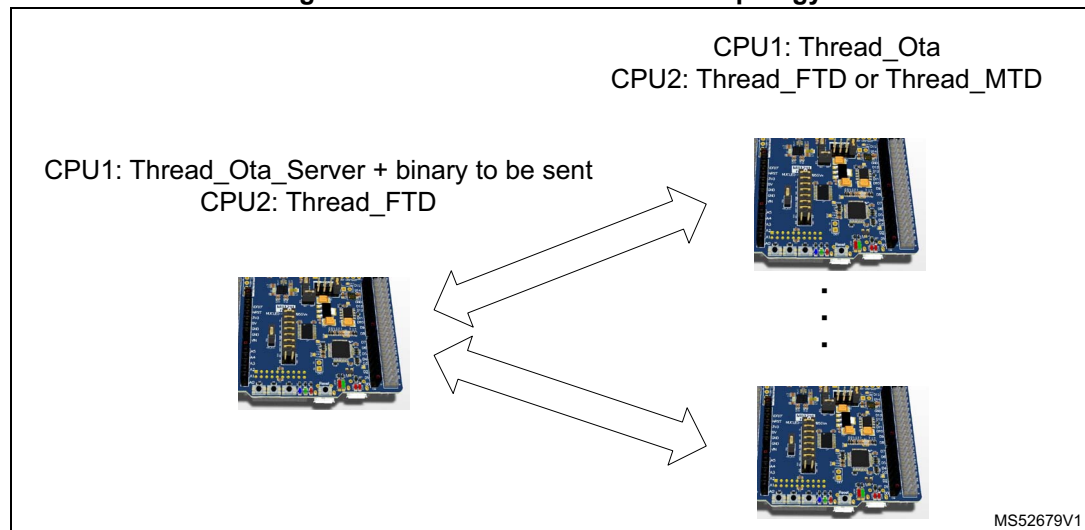
At this stage, these two boards belong to the same Thread network and device 2 sends a CoAP multicast request every second to device 1 to turn on/off its blue LED.

11.8 Thread FUOTA

11.8.1 Principle

The goal is to use Thread protocol to update CPU1 application binary or CPU2 wireless coprocessor binary on a remote device.

Figure 46. Thread FUOTA network topology



This thread requires at least two STM32WBxx boards (see [Figure 46](#)) running Thread protocol with specific applications:

- one board running Thread_Ota_Server application
- one or more boards running Thread_Ota application

FUOTA process can take place only on one device at a time.

The server initiates a FUOTA provisioning process and one client must respond to it. Multiple clients are updated one at the time.

11.8.2 Memory mapping

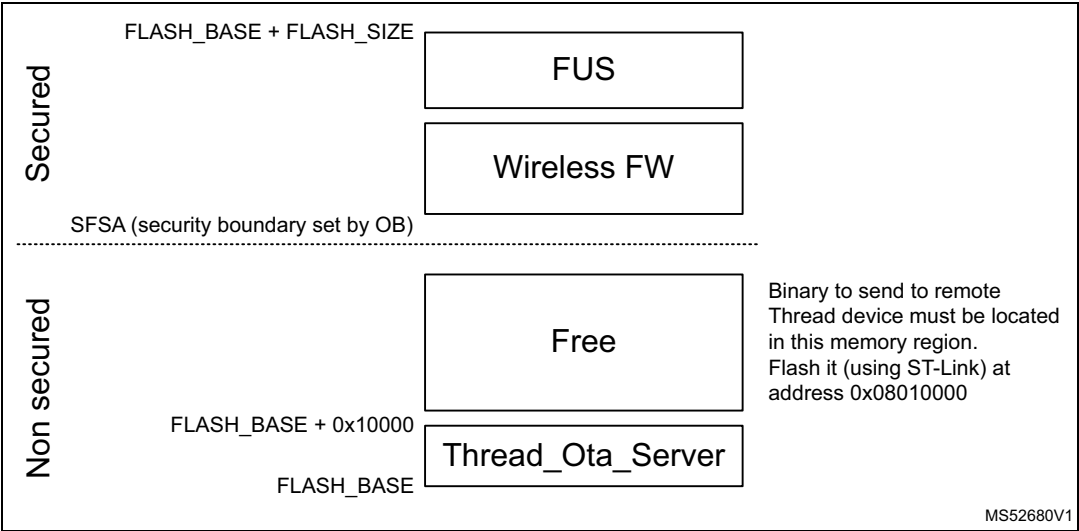
Server side

The binary file to be installed (either for CPU1 or for CPU2 update) on remote device has to be flashed first on the “FREE” memory region on the Server side (see [Figure 47](#)).

Maximum size of the binary to be transferred is equal to:

FREE region size = SFSAAddress - (FLASH_BASE - 0x8010000)

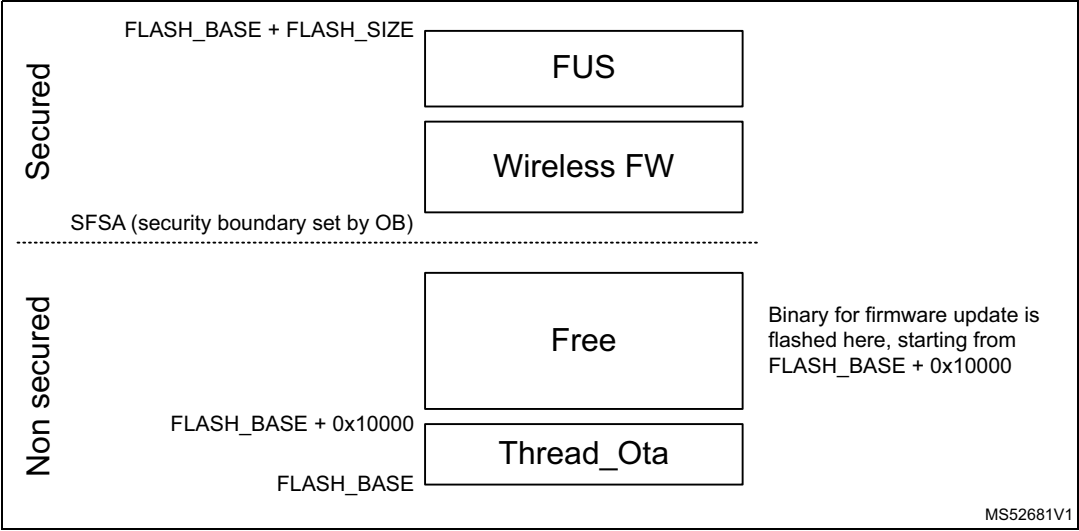
Figure 47. OTA server (Thread_Ota_Server) Flash memory mapping



Client side

On the client side, before receiving the binary from the server, the Flash memory is as shown in [Figure 48](#).

Figure 48. FUOTA client Flash memory mapping initial state



After receiving the binary data from server side, the Flash memory is updated as shown in [Figure 49](#) and [Figure 50](#), respectively, for CPU1 binary transfer and CPU2 binary transfer.

Figure 49. FUOTA server Flash memory mapping after CPU1 binary transfer

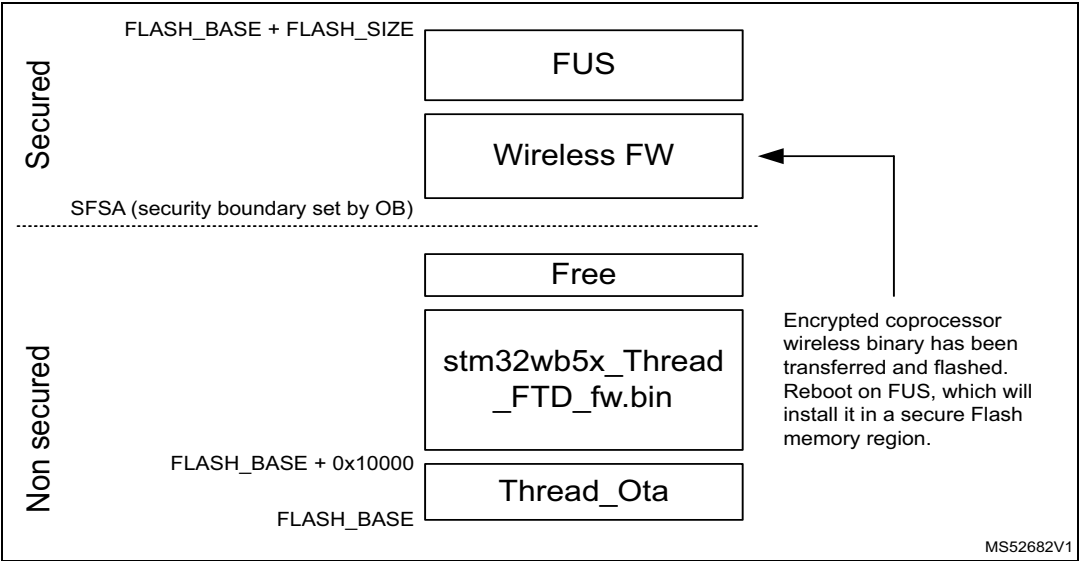
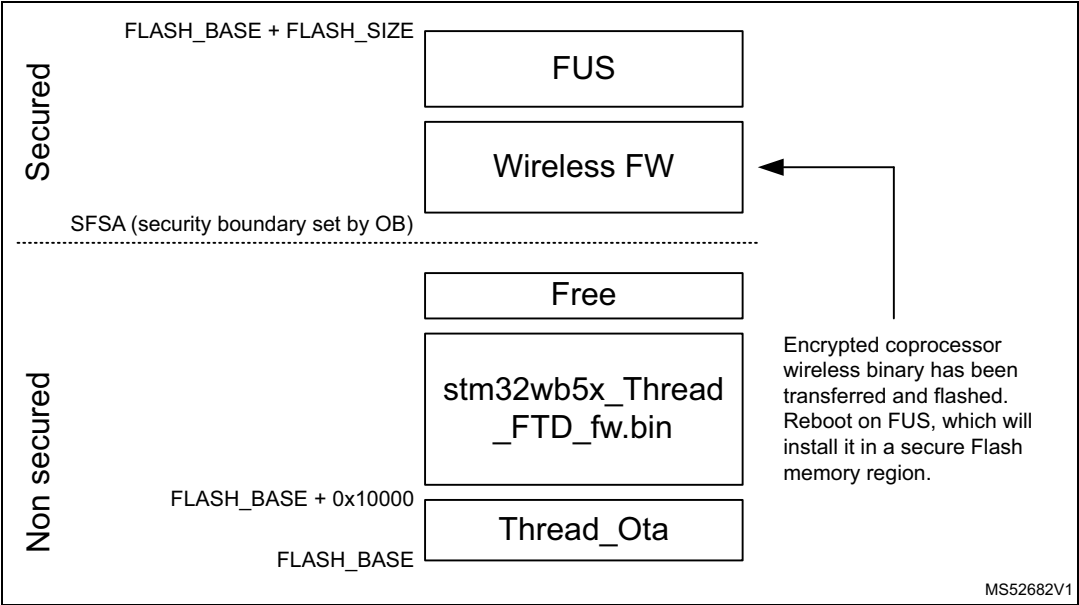


Figure 50. FUOTA server Flash memory mapping after CPU2 binary transfer

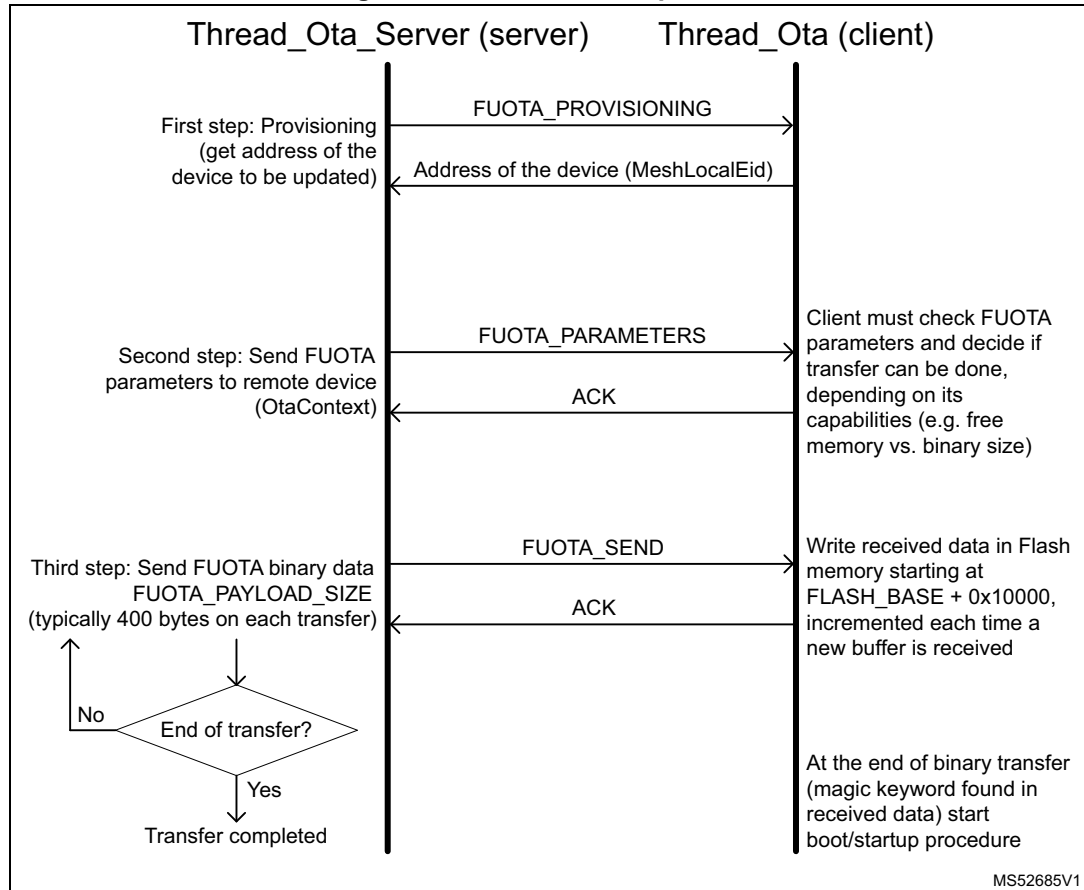


11.8.3 Thread FUOTA protocol

This is a STMicroelectronics proprietary protocol to update CPU2 wireless coprocessor binary or CPU1 FW application using Thread, based on CoAP request.

[Figure 51](#) details the steps to perform the firmware update transfer.

Figure 51. Thread FUOTA protocol



MS52685V1

1. Server sends a message to record the address of the remote device on which FUOTA is processed.
Server sends a multicast, Non-Confirmable, Get CoAP request on resource: "FUOTA_PROVISIONING"
The remote device answers with the Mesh Local Eid (Endpoint Identifier), which identifies a Thread interface, independent from the network topology.
2. `OtaContext` data structure is sent to the remote device. It contains:
 - File type: `FW_APP` update or `FW_COPRO_WIRELESS` update
 - Binary size: size in bytes of the binary to be transferred
 - Base address: start address in Flash memory for remote device to copy binary data to
 - Magic keyword: keyword specifying end of the binary
3. Transfer binary to remote device.
The transfer is performed by buffers of `FUOTA_PAYLOAD_SIZE` (default 400 bytes). This is configurable on Server side.

For each transfer, Thread_Ota_Server waits for acknowledgment from the remote device before continuing the next buffer transfer.

On the remote side, each data buffer received is written to Flash memory.

When magic keyword is found, it means that this is the last buffer to transmit.

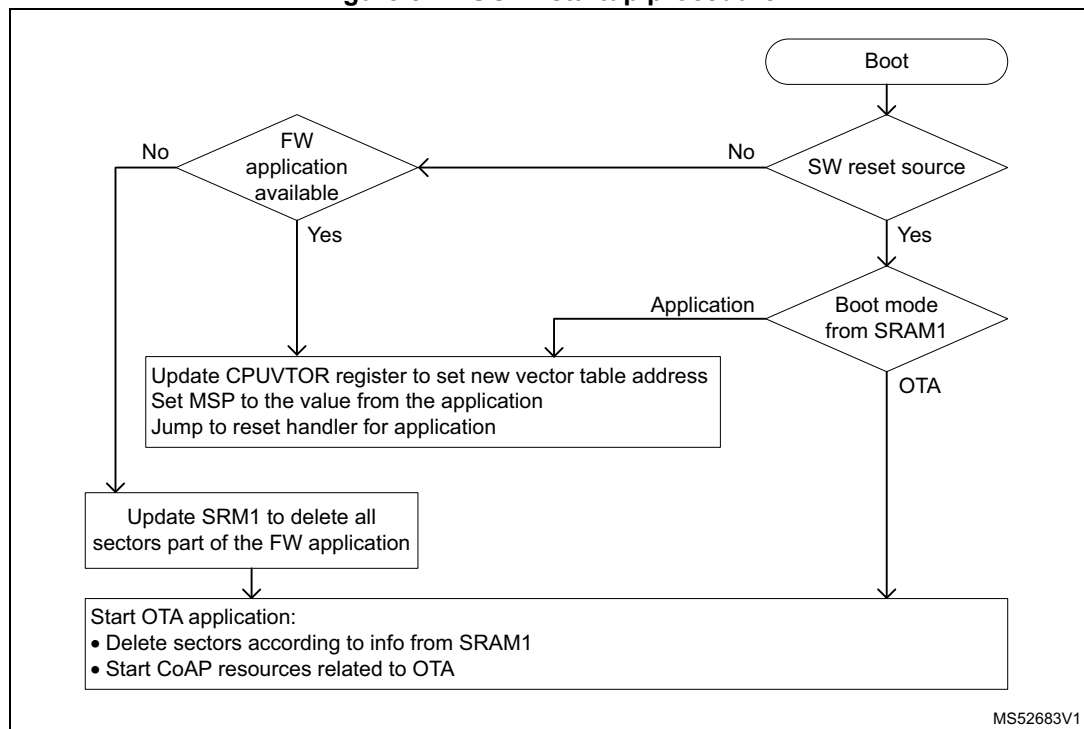
11.8.4 FUOTA application startup procedure

Once binary data has been transferred to the remote device (Thread FUOTA client), the startup procedure is different for the update of a CPU1 application or of CPU2 coprocessor wireless binary.

FUOTA for CPU1

On the client side after the binary transfer is completed, the process shown in [Figure 52](#) takes place to jump on OTA specific application (example: Thread_Coap_Generic_Ota):

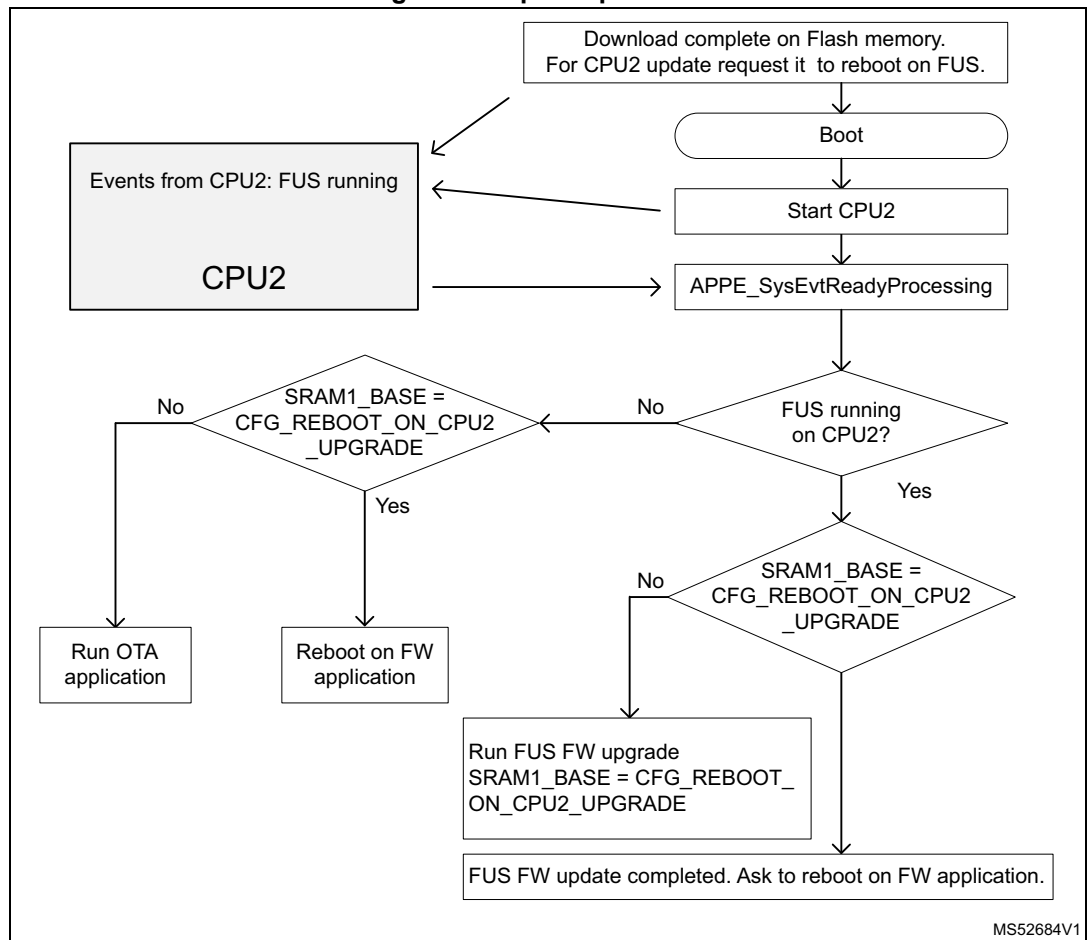
Figure 52. FUOTA startup procedure



FUOTA for CPU2

CPU2 update involves FUS (firmware upgrade service) software component, which is responsible to decrypt and install secure binary.

Figure 53. Update procedure



11.8.5 Applications

Thread_Ota_Server

This application must be loaded on STM32WB 1Nucleo board acting as FUOTA server.

Thread_Ota

This application must be loaded on STM32WB Nucleo board acting as FUOTA client.

Thread_Coap_Generic_Ota

This application is almost identical to Thread_Coap_Generic, the differences are:

- Use special tags (to manage end data transfer and data consistency):
 - TAG_OTA_END : The Magic Keyword value is checked in the thread_ota application
 - TAG_OTA_START : The Magic Keyword address shall be mapped at 0x140 from start of the binary image

Therefore, by reading memory content at 0x140 it must be equal to Magic keyword value.

- Scatter file must be updated to place the sections above

Example for IAR:

```
Vector table and ROM start @ moved to 0x08010000:
define symbol __ICFEDIT_intvec_start__ = 0x08010000;
define symbol __ICFEDIT_region_ROM_start__ = 0x08010000;
define region OTA_TAG_region = mem:[from
(__ICFEDIT_region_ROM_start__ + 0x140) to
(__ICFEDIT_region_ROM_start__ + 0x140 + 4)];
keep { section TAG_OTA_START};
keep { section TAG_OTA_END };
place in OTA_TAG_region { section TAG_OTA_START };
place in ROM_region { readonly, last section TAG_OTA_END };
```

12 MAC IEEE Std 802.15.4-2011

12.1 Overview

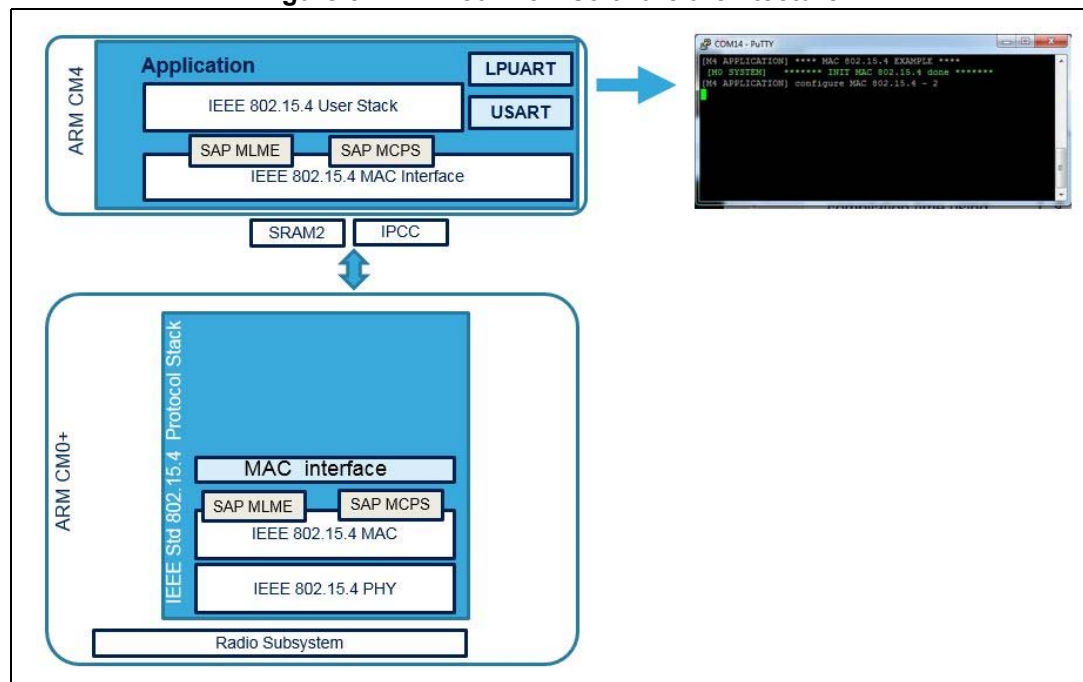
MAC IEEE Std 802.15.4-2011 layer is embedded by the MAC dedicated firmware running on CPU2 core (Radio protocol processor). The MAC layer relies on the PHY layer, which addresses the RF subsystem component.

As this implementation is provided in binary format and running on CPU2, the MAC API is exposed to CPU1 core to let user address MAC service access points. The user may then set up its own STM32WB device as an FFD (full feature device, i.e. coordinator), or as an RFD (reduced feature devices, i.e. node) as described in IEEE Std 802.15.4-2011 specification document.

12.2 Architecture

Figure 54 shows the MAC software architecture used when the customer expects to implement an in house 802.15.4 network by integrating a custom solution or a third party solution on the application processor.

Figure 54. MAC 802.15.4 software architecture

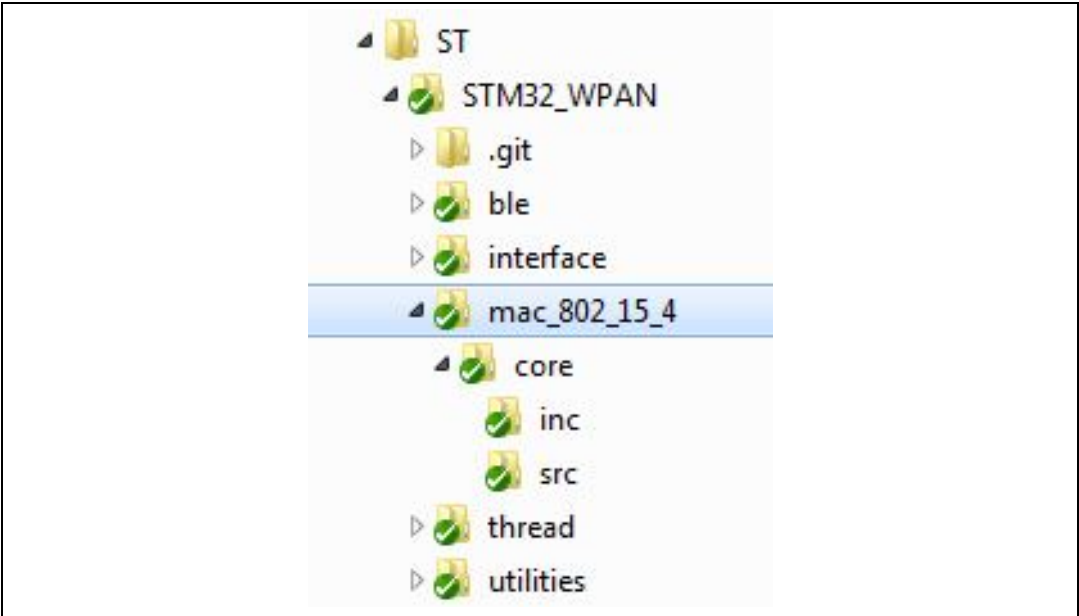


12.3 API

The MAC IEEE Std 802.15.4-2011 specification document defines an interface between 802.15.4 network layers and the medium access control layer. This API allows the user to address the MAC management entity service called MLME (MAC sub - Layer management entity) as the MAC data service called MCPS (MAC common part sub layer entity).

A MAC API dedicated to the application core with its associated implementation is available from the middleware provided under \Middlewares\ST\STM32_WPAN\mac_802_15_4 (see [Figure 55](#)).

Figure 55. MAC API dedicated to application core



This implementation is documented in STM32WBxx_MAC_802_15_4_User_Manual.chm available under Firmware\Middlewares\ST\STM32_WPAN\mac_802_15_4 directory of the STM32WB FW package. Detailed primitive descriptions are accessible through the IEEE Std 802.15.4-2011 document.

12.4 **How to start**

12.4.1 **Board configuration**

Ensure that the option bytes are set as in [Figure 56](#).

Figure 56. Option bytes configuration for MAC 802.15.4



12.4.2 MAC radio protocol processor CPU2 firmware

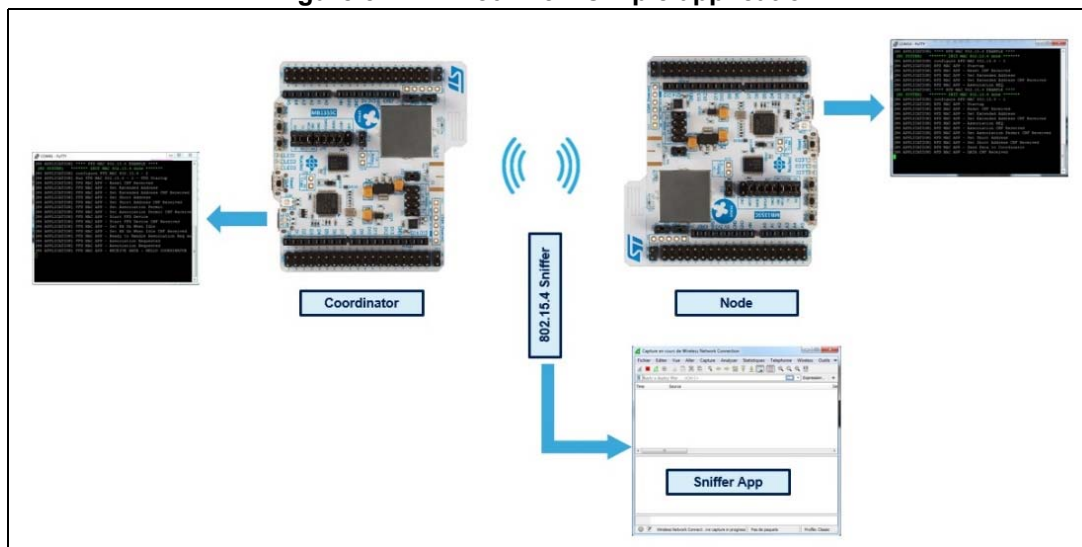
The user first needs to download the appropriate dedicated MAC firmware binary for CPU2 radio protocol core, see [Release_Notes.html](#) located in `Firmware\Projects\STM32WB_Copro_Wireless_Binaries` directory of the STM32WB FW package.

12.4.3 MAC application processor firmware

Before implementing a custom stack solution or integrating a third party stack provided for CPU1 application core MAC API, the user may ramp-up with the MAC application example referring to the two following applications that have to run simultaneously on two STM32WB boards:

- `Mac_802_15_4_FFD`: shows how to implement a simple 802.15.4 coordinator. This device manages the network as association request and gets or provides data on node demand.
- `Mac_802_15_4_RFD`: shows how to implement a simple 802.15.4 node. This device emits an association request to the coordinator. Once the addressed coordinator positively responds to the request, the node receives its new short address and then emits data to the coordinator.

Figure 57. MAC 802.15.4 simple application



Both applications, dedicated to Nucleo STM32WB boards, are available from `NUCLEO-WBxx.Nucleo application Mac_802_15_4` directories (see [Figure 58](#)).

Figure 58. MAC 802.15.4 applications - Directory structure

A readme.txt file describes the MAC sequence handled by each 802.15.4 devices. The files are available from each root projects.

12.4.4 Output

The user may use an OTA sniffer, on the right channel, to listen to the negotiation between the two boards during the association phase and to watch the data exchange once the node is registered in network managed by the coordinator.

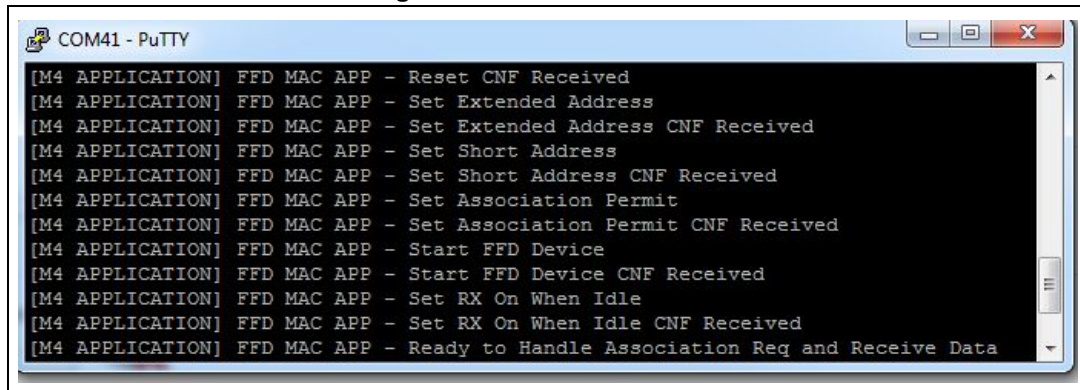
Application traces are routes to the UART. User can then start a HyperTerminal session, using a preferred terminal emulator, on each of the implemented Virtual COM port to check every MAC step.

The TTY Session configuration to connect console:

- Baud: 115200
- Data bits: 8
- Stop bits: 1
- Parity: None
- Flow control: XON/XOFF.

Running the two applications leads to the Hyper terminal shown in figures [59](#) to [61](#).

Figure 59. Coordinator start

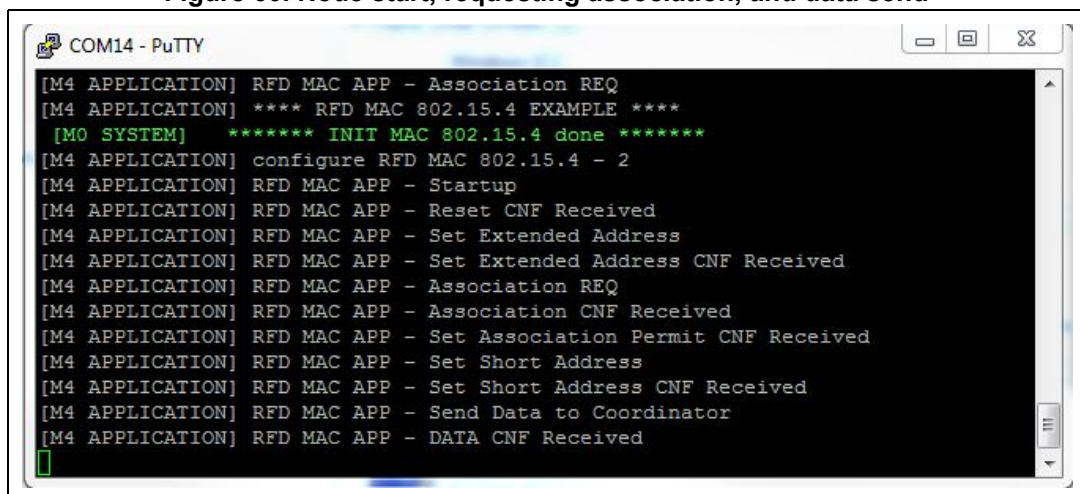


```

[M4 APPLICATION] FFD MAC APP - Reset CNF Received
[M4 APPLICATION] FFD MAC APP - Set Extended Address
[M4 APPLICATION] FFD MAC APP - Set Extended Address CNF Received
[M4 APPLICATION] FFD MAC APP - Set Short Address
[M4 APPLICATION] FFD MAC APP - Set Short Address CNF Received
[M4 APPLICATION] FFD MAC APP - Set Association Permit
[M4 APPLICATION] FFD MAC APP - Set Association Permit CNF Received
[M4 APPLICATION] FFD MAC APP - Start FFD Device
[M4 APPLICATION] FFD MAC APP - Start FFD Device CNF Received
[M4 APPLICATION] FFD MAC APP - Set RX On When Idle
[M4 APPLICATION] FFD MAC APP - Set RX On When Idle CNF Received
[M4 APPLICATION] FFD MAC APP - Ready to Handle Association Req and Receive Data

```

Figure 60. Node start, requesting association, and data send

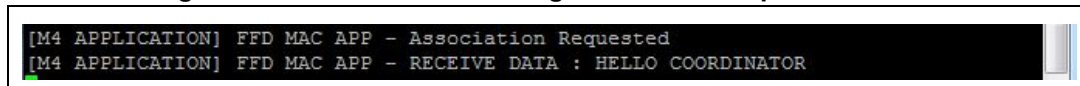


```

[M4 APPLICATION] RFD MAC APP - Association REQ
[M4 APPLICATION] **** RFD MAC 802.15.4 EXAMPLE ****
[M0 SYSTEM] ***** INIT MAC 802.15.4 done *****
[M4 APPLICATION] configure RFD MAC 802.15.4 - 2
[M4 APPLICATION] RFD MAC APP - Startup
[M4 APPLICATION] RFD MAC APP - Reset CNF Received
[M4 APPLICATION] RFD MAC APP - Set Extended Address
[M4 APPLICATION] RFD MAC APP - Set Extended Address CNF Received
[M4 APPLICATION] RFD MAC APP - Association REQ
[M4 APPLICATION] RFD MAC APP - Association CNF Received
[M4 APPLICATION] RFD MAC APP - Set Association Permit CNF Received
[M4 APPLICATION] RFD MAC APP - Set Short Address
[M4 APPLICATION] RFD MAC APP - Set Short Address CNF Received
[M4 APPLICATION] RFD MAC APP - Send Data to Coordinator
[M4 APPLICATION] RFD MAC APP - DATA CNF Received

```

Figure 61. Coordinator receiving association request and data



```

[M4 APPLICATION] FFD MAC APP - Association Requested
[M4 APPLICATION] FFD MAC APP - RECEIVE DATA : HELLO COORDINATOR

```

12.4.5 MAC IEEE Std 802.15.4-2011 system

This is currently the implemented MAC system command.

SHCI_C2_MAC_802_15_4_Init() starts the MAC layer and RF subsystem on radio processor (CPU2).

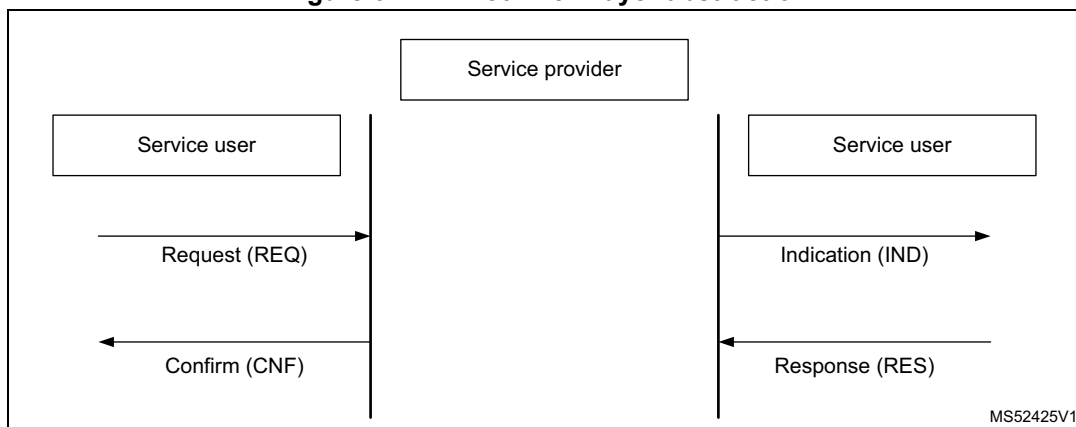
Non-volatile data are not guaranteed by the MAC layer. It is up to the application upper layer to ensure that these data are kept in the Flash memory, and to restore those to be used later on.

Low power feature is not supported.

12.4.6 Integration recommendations

The MAC layer offers service primitives by implementing an abstraction layer. This abstraction layer, described in MAC IEEE Std 802.15.4-2011 specification documentation, is illustrated in [Figure 62](#).

Figure 62. MAC 802.15.4 layer abstraction



The proposed API lets the user call REQ and RES primitives with associated defined structure initialized from the upper layer. To get notification from the MAC layer, custom call function have to be implemented called MAC indication (IND) or MAC confirmation (CNF).

Request and Response examples

- Set the short address of the current device
- Call MAC_MLMESetReq with initialized SetReq structure storing the short address to set.

```
// Set Device Short Address
uint16_t shortAddr = 0x1122;
SetReq.PIB_attribute = g_MAC_SHORT_ADDRESS_c;
SetReq.PIB_attribute_valuePtr = (uint8_t*) &shortAddr;
MacStatus = MAC_MLMESetReq( &SetReq );
```

- Respond to an association indication

When an association is requested, a coordinator may respond by providing the response with a short address to the requester:

- Call MAC_MLMEAssociateRes with initialized AssociateRes structure storing the attributed short address.

```
APP_DBG("Srv task : Response to Association Indication");
MAC_associateRes_t AssociateRes;
uint16_t shortAssociationAddr = 0x3344;

memcpy(AssociateRes.a_device_address, g_MAC_associateInd.a_device_address, 0x08);
memcpy(AssociateRes.a_assoc_short_address, &shortAssociationAddr, 0x08);
AssociateRes.security_level = 0x00;
AssociateRes.status = MAC_SUCCESS;

MacStatus = MAC_MLMEAssociateRes(&AssociateRes);
```

- Confirmation and indication examples

To be notified of confirmation or indication messages from lower MAC Layer, the user has to register custom callbacks in `MAC_callbacks_t macCbConfig` (example provided in `app_ffd_mac_802_15_4.c`):

```
/* Mac Call Back Initialization */
macCbConfig.mlmeResetCnfCb = APP_MAC_mlmeResetCnfCb;
macCbConfig.mlmeScanCnfCb = APP_MAC_mlmeScanCnfCb;
macCbConfig.mlmeAssociateCnfCb = APP_MAC_mlmeAssociateCnfCb;
macCbConfig.mlmeAssociateIndCb = APP_MAC_mlmeAssociateIndCb;
...
```

- Action on data indication

The user has to implement custom callbacks to retrieve data from MAC services:

On data indication message from MAC layer, the `macCbConfig.mcpsDataIndCb` is used to call `APP_MAC_mcpsDataIndCb` callback, which may be implemented as follows to retrieve the indication data carried by `MAC_dataInd_t` structure (`app_mac_802-15-4_process.c`):

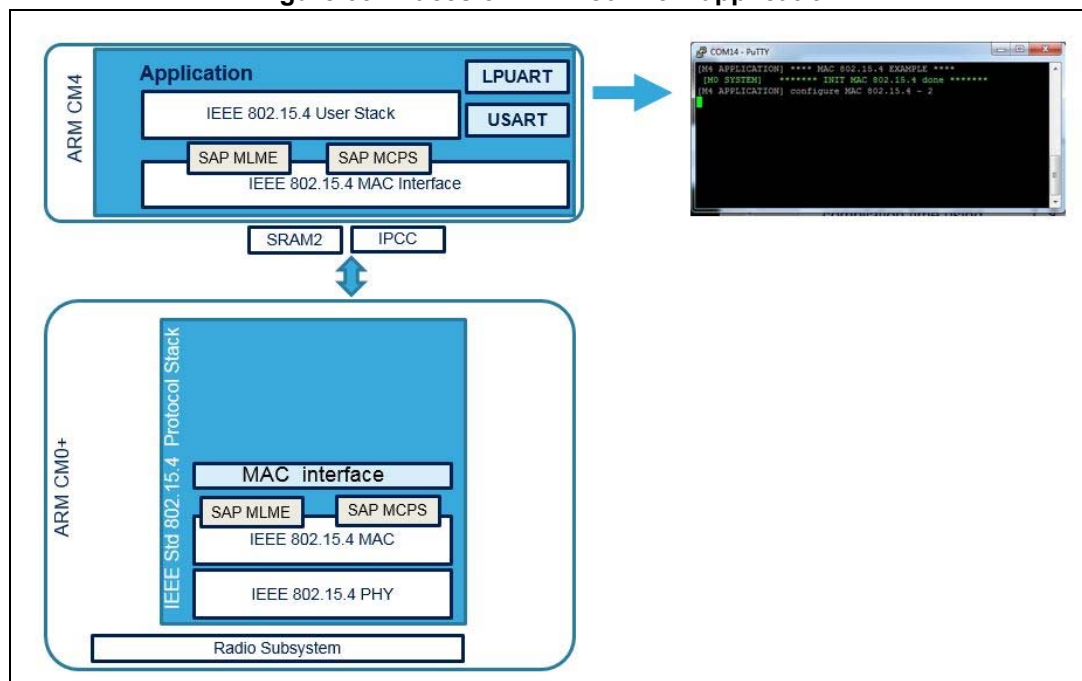
```
MAC_Status_t APP_MAC_mcpsDataIndCb( const MAC_dataInd_t * pDataInd )
{

    memcpy(&g_DataInd, pDataInd, sizeof(MAC_dataInd_t));

    return MAC_SUCCESS;

}
```

Figure 63. Traces on MAC 802.15.4 application

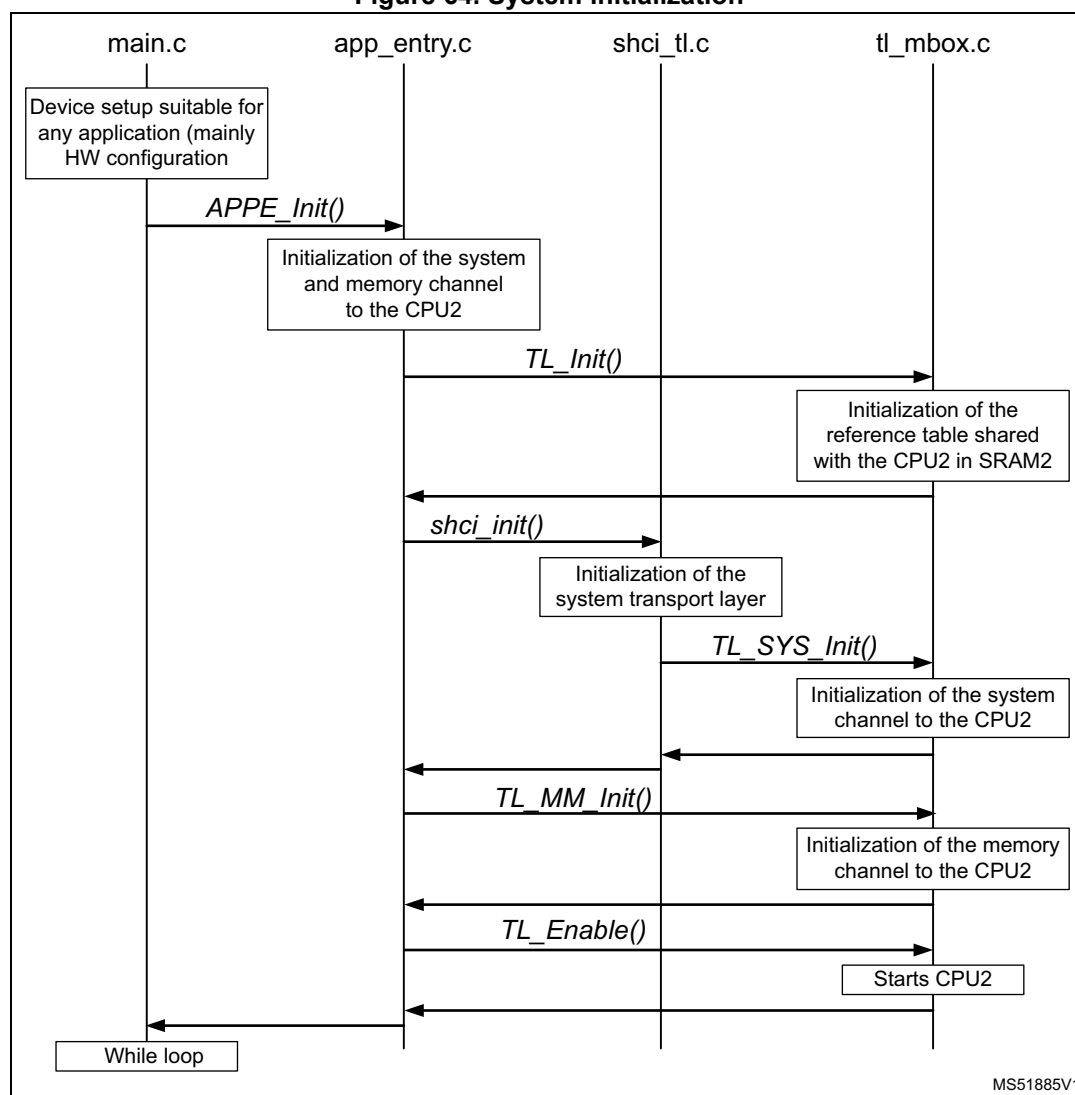


13 Annexes

13.1 Detailed flow of the device initialization

At startup, the device is first initialized and then the system channel to CPU2 is initialized. After this sequence is over, CPU1 returns to the background while loop and waits for the notification from CPU2 that it is ready to receive system command. CPU1 may run other application initializations that are not RF (CPU2) related. This startup is the same whether CPU2 is running a Full BLE host stack, HCI only interface or an OpenThread Stack.

Figure 64. System initialization



MS51885V1

When CPU2 is ready to receive system commands, it sends a notification to CPU1. Upon receiving the notification **shci_notify_async_evt()**, the user must call **shci_user_evt_proc()** to allow the system transport layer to process the event. The user application is notified with **APPE_SysUserEvtRx()** that a system event is received. As the

`shci_notify_async_evt()` is received in the IPCC interrupt handler context, the information is passed to the background so that the `shci_user_evt_proc()` is called from the background while loop (out of any interrupt context). This mechanism is the same whether CPU2 is running a Full BLE host stack, HCI only interface or an OpenThread Stack.

Figure 65. System ready event notification

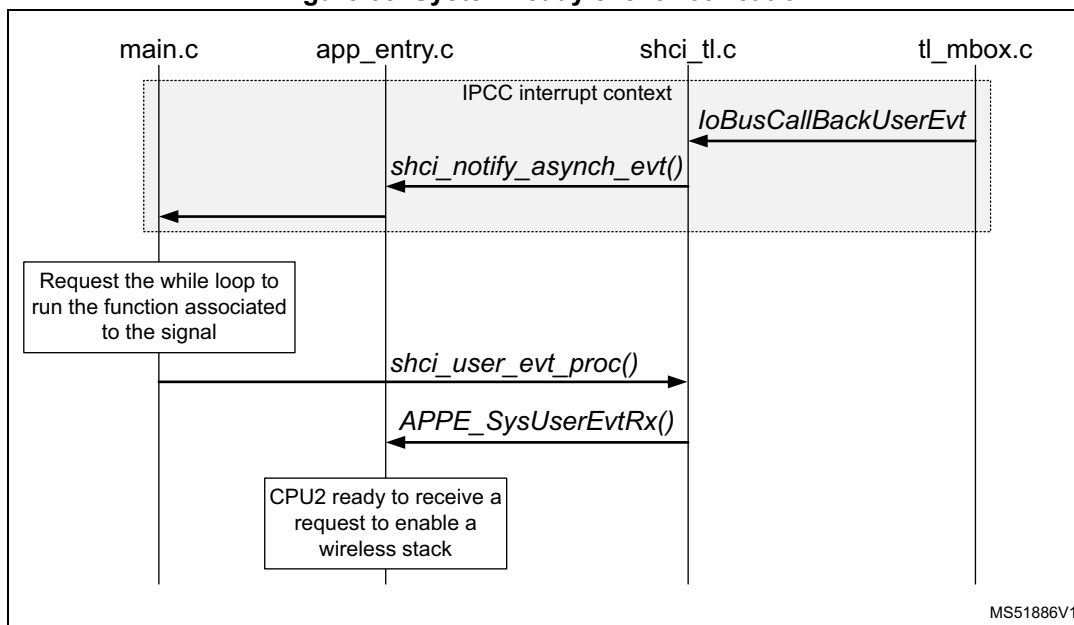
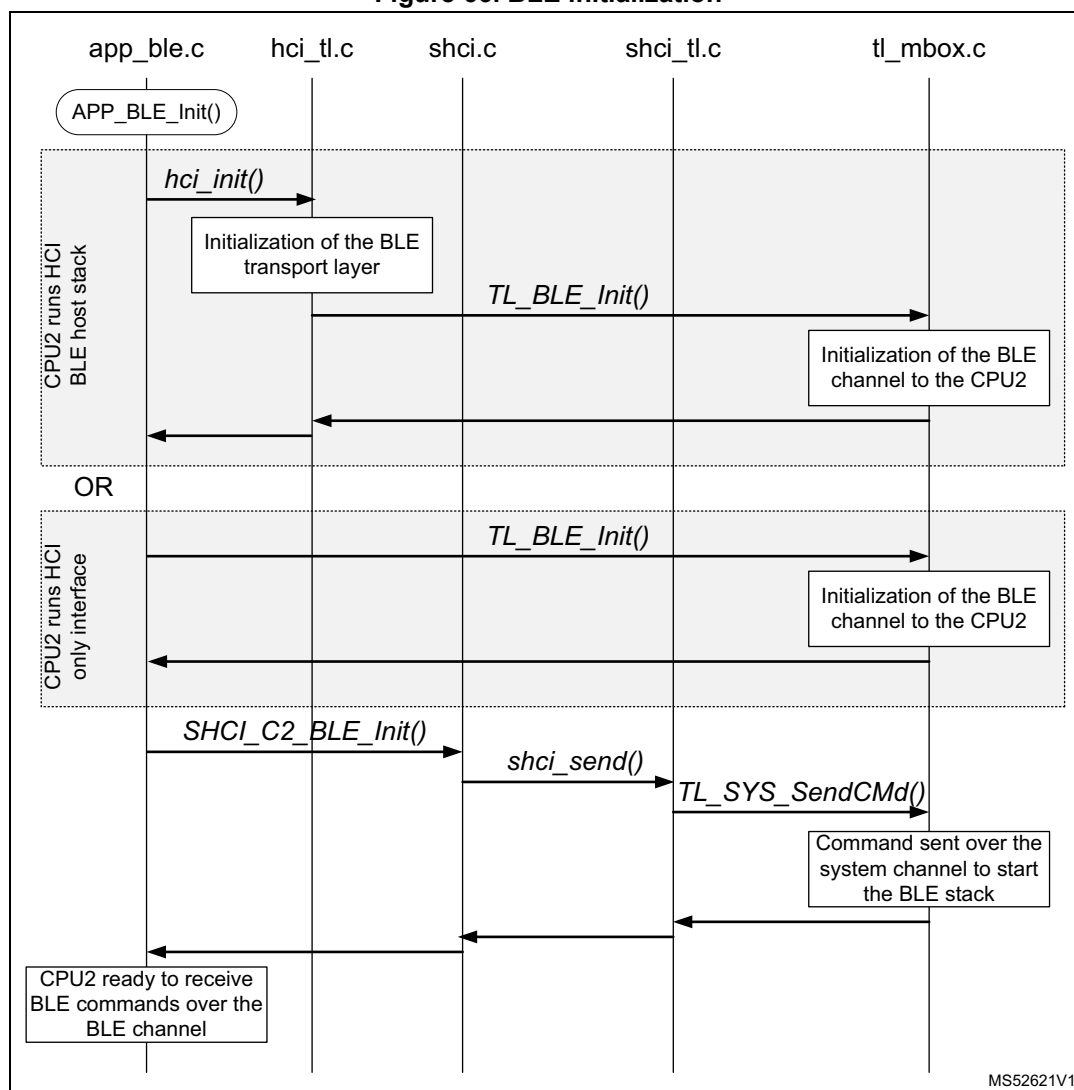


Figure 66. BLE initialization



On receiving a system event, the BLE transport layer is initialized and a system command is sent to CPU2 to start the BLE stack. As soon as the SHCI_C2_BLE_Init() system command has been sent to CPU2, CPUit is ready to receive BLE commands.

When CPU2 runs an HCI only interface, the BLE transport layer starts running in the Host BLE stack on CPU1. Therefore, the BLE transport layer provided must not be used and initialized.

13.2 Mailbox interface

This interface is the lowest level that must be used to send a command to the BLE controller. It is used in the transparent mode application and must be used when a BLE stack open source is used on top of the BT SIG HCI interface.

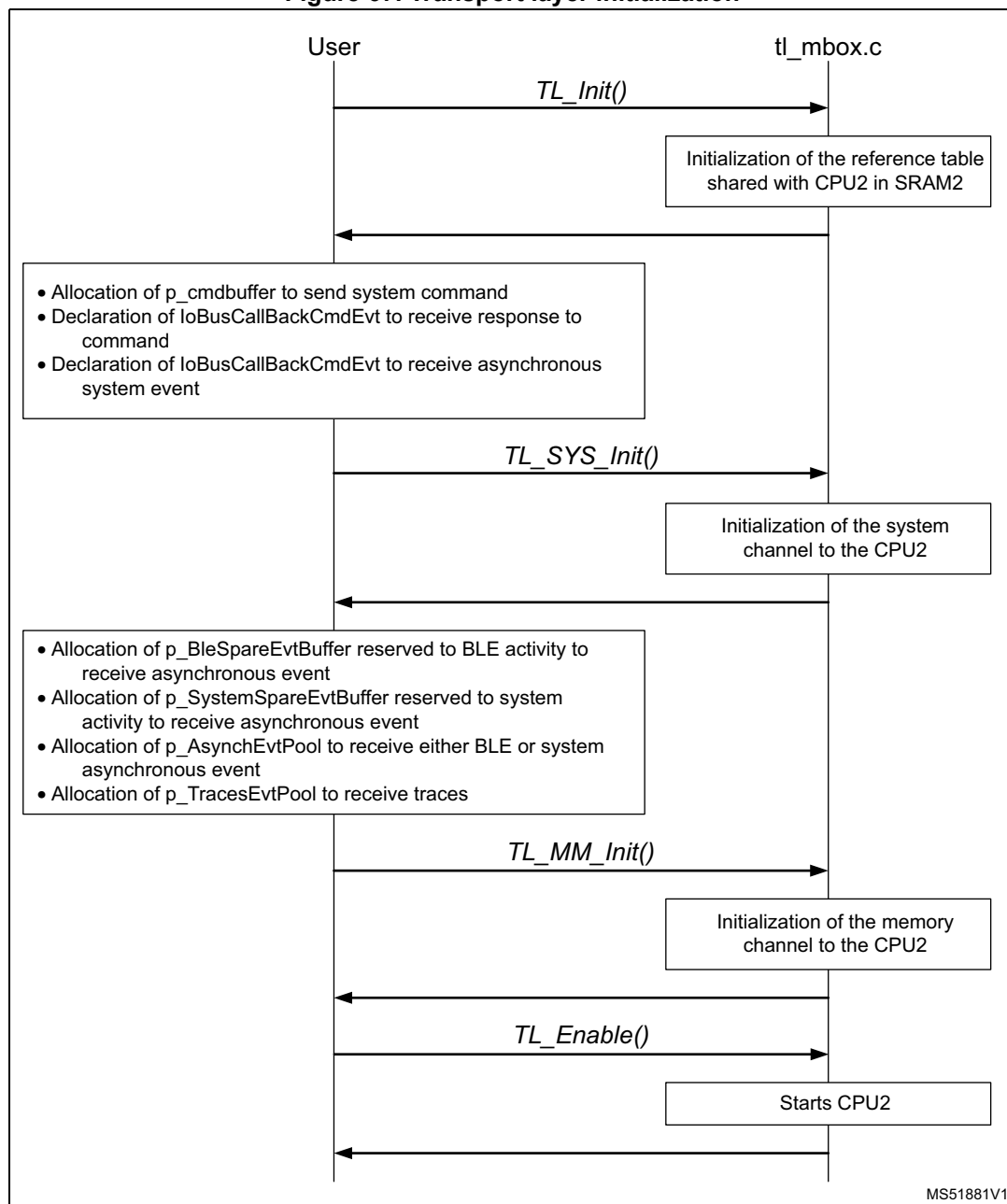
13.2.1 Interface API

Table 30. Interface APIs

Function	Description
void TL_Init(void)	Initializes the shared memory
void TL_Enable(void)	Enables the transport layer
int32_t TL_SYS_Init(void* pConf)	Initializes the system channel
int32_t TL_SYS_SendCmd(uint8_t* buffer, uint16_t size)	Send a system command
int32_t TL_BLE_Init(void* pConf)	Initializes the BLE channel
int32_t TL_BLE_SendCmd(uint8_t* buffer, uint16_t size)	Sends a BLE command
int32_t TL_BLE_SendAclData(uint8_t* buffer, uint16_t size)	Sends ACL data packet
void TL_MM_Init(TL_MM_Config_t *p_Config)	Initializes the Memory channel
void TL_MM_EvtDone(TL_EvtPacket_t * hcievt)	Releases a buffer to the Memory channel

13.2.2 Detailed interface behavior

Figure 67. Transport layer initialization



```
void TL_Init( void ):
```

This is the first command to be sent. It initializes the mailbox driver and shared memory.

```
int32_t TL_SYS_Init( void* pConf ):
```

The user must first allocate the buffer to be used by the mailbox driver to send system command (p_cmdbuffer), the two callbacks to be used to receive the system command

response (IoBusCallBackCmdEvt) and the system asynchronous event (IoBusCallBackUserEvt).

The IoBusCallBackCmdEvt implements the new requirement where a new system command is only sent when the response of the previous one has been received.

This commands initializes the System channel in the mailbox driver.

```
void TL_MM_Init( TL_MM_Config_t *p_Config ):
```

The user must first allocate the buffer to be used by the mailbox driver to only report a BLE Asynchronous event (p_BleSpareEvtBuffer), the buffer to be used by the mailbox driver to only report a System Asynchronous event (p_SystemSpareEvtBuffer), the pool of memory (p_AsynchEvtPool) to be used by the BLE Controller to report either a BLE or System Asynchronous event and the pool of memory (p_TracesEvtPool) to be used by CPU2 for report traces.

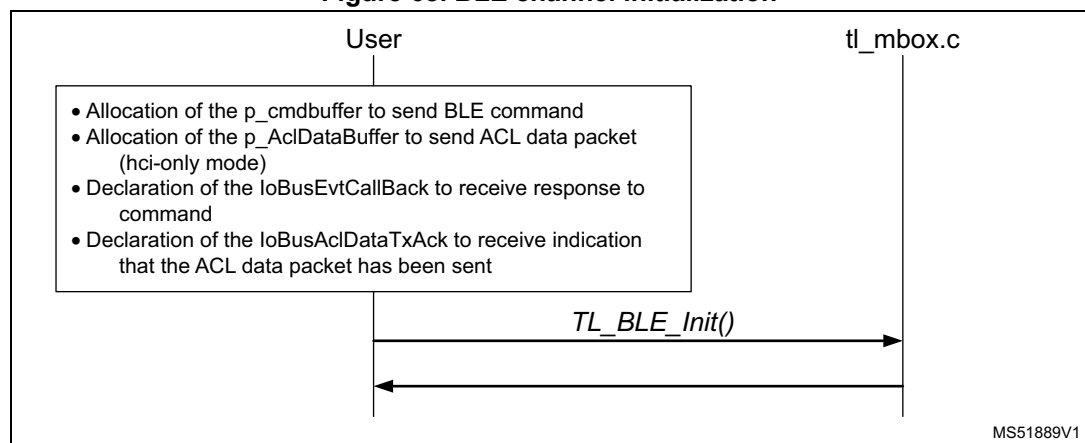
The p_BleSpareEvtBuffer and p_SystemSpareEvtBuffer buffers are used to guarantee that even if the memory pool p_AsynchEvtPool is empty, CPU2 is always able to report either BLE or System events.

This commands initializes the Memory channel in the mailbox driver.

```
void TL_Enable( void ):
```

When the mailbox driver is fully initialized, this command is sent to start CPU2.

Figure 68. BLE channel initialization



MS51889V1

```
int32_t TL_BLE_Init( void* pConf ):
```

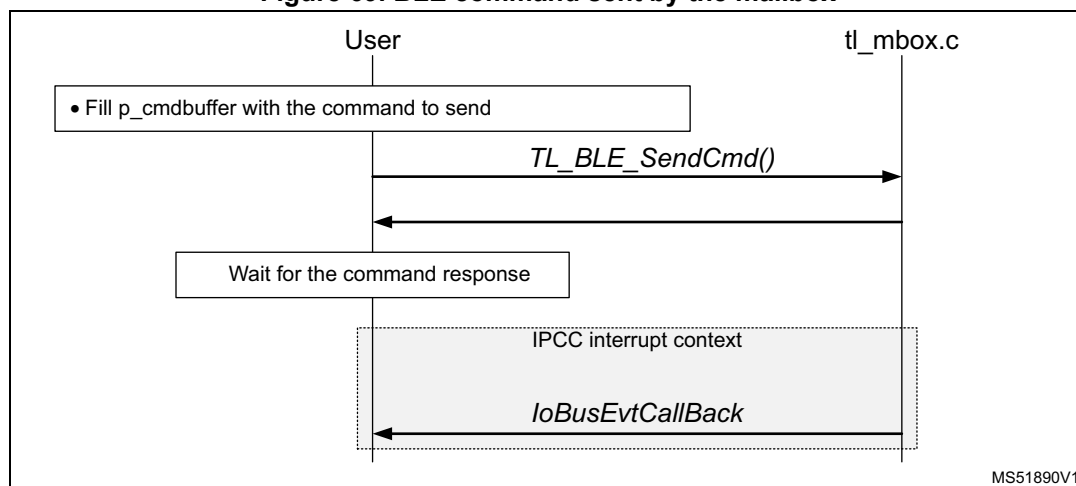
The user must first allocate the buffer to be used by the mailbox driver to send a BLE command (p_cmdbuffer), the buffer to be used by the mailbox driver to send ACL data packet (p_AclDataBuffer), and the two callbacks to be used to receive a BLE event (IoBusEvtCallBack) and the acknowledge of the ACL Data packet (IoBusAclDataTxAck).

The IoBusEvtCallBack must be used to comply to the requirement that a new BLE command can be sent only when the command flow (as specified by the BT SIG) allows it.

When not in HCI only mode, both p_AclDataBuffer and IoBusAclDataTxAck are not used and must be set to 0.

This commands initializes the BLE controller.

Figure 69. BLE command sent by the mailbox

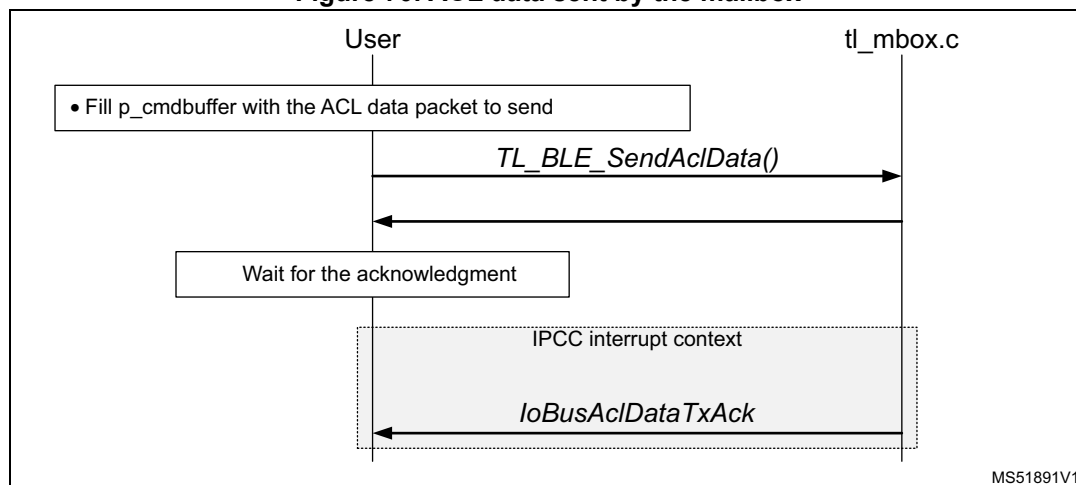


```
int32_t TL_BLE_SendCmd( uint8_t* buffer, uint16_t size ):
```

The user must first fill the buffer `p_cmdbuffer` with the command to be sent. The parameter `buffer` and `size` are not used.

The user must wait for the command response received with `IoBusEvtCallBack` to check the flow command control in the response packet to understand if a new command can be sent or not. The `IoBusEvtCallBack` is generated asynchronously in the IPCC interrupt context. It is recommended, depending on the processing load, to implement a background mechanism to decode the received packet (out of the IPCC interrupt context).

Figure 70. ACL data sent by the mailbox



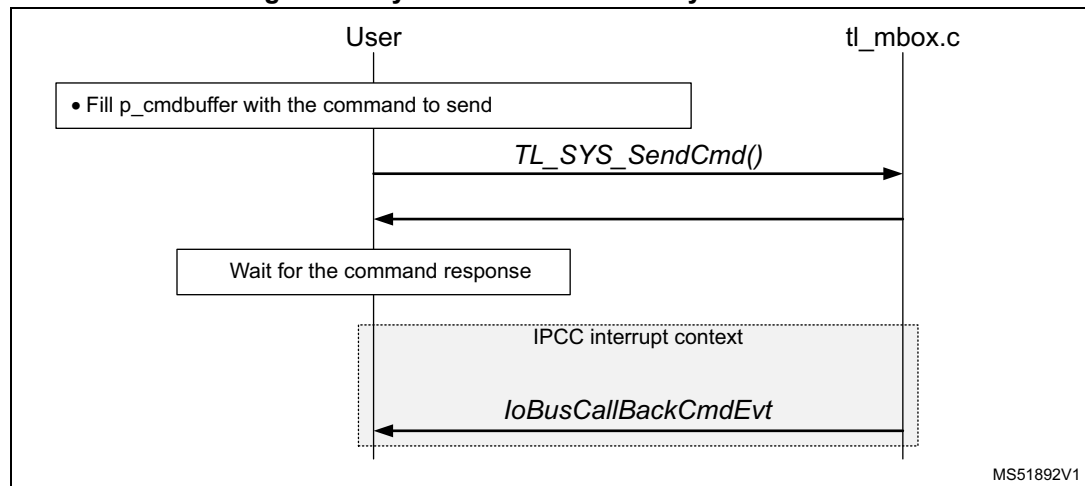
```
int32_t TL_BLE_SendAclData( uint8_t* buffer, uint16_t size ):
```

The user must first fill the `p_AclDataBuffer` buffer with the ACL data packet to be sent. The parameter `buffer` and `size` are not used.

The user must wait for the acknowledge received with `IoBusAclDataTxAck` before sending a new ACL data packet. The `IoBusAclDataTxAck` is generated asynchronously in the IPCC interrupt context. It is recommended, depending on the processing load, to implement a background mechanism to handle the acknowledgment (out of the IPCC interrupt context).

The ACL data packet interface is supported only in HCI Mode. When supported, it is possible to send ACL data packets while a BLE command is pending. The BLE command and ACL data packets do not share resources.

Figure 71. System command sent by the mailbox

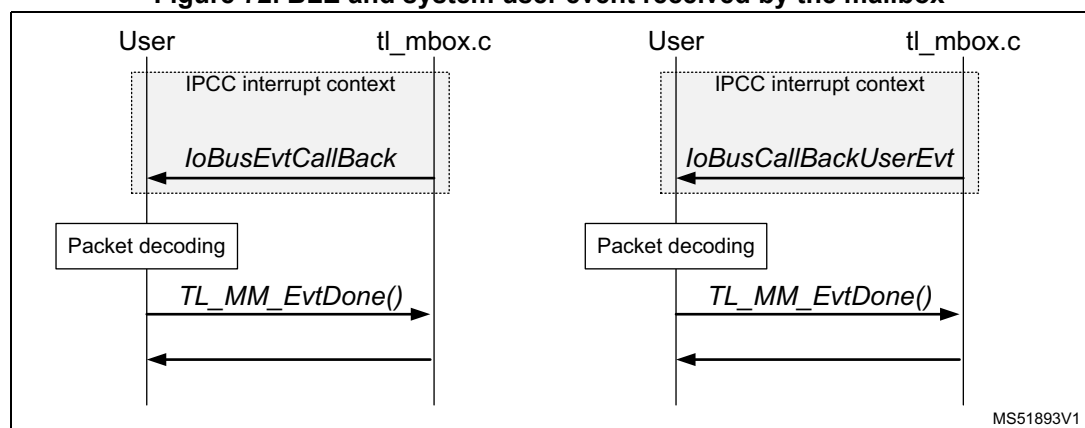


```
int32_t TL_SYS_SendCmd( uint8_t* buffer, uint16_t size )
```

The user must first fill the `p_cmdbuffer` buffer with the command to be sent. The parameter `buffer` and `size` are not used.

The user must wait for the command response received with `IoBusCallBackCmdEvt` before sending a new command. The `IoBusCallBackCmdEvt` is generated asynchronously in the IPCC interrupt context. It is recommended, depending on the processing load, to implement a background mechanism to decode the received packet (out of the IPCC interrupt context).

Figure 72. BLE and system user event received by the mailbox



```
void TL_MM_EvtDone( TL_EvtPacket_t * hcievt ):
```

This API must be called to return the packet to the Memory manager running on CPU2 in the following cases

- For each packet received with `IoBusEvtCallBack` (User BLE event callback) that is not a BLE Command response
- For each packet received with `IoBusCallBackUserEvt` (User System event callback).

13.3 Mailbox interface - Extended

The mailbox interface is suitable when the command to be sent is built by the user into a buffer to be sent by the mailbox. In the same way, the user must decode the event packet received and manage the command flow control to check if a new command can be sent.

This is the case when using a BLE host stack running on CPU1 on top of the HCI interface. In this case, CPU2 is used in HCI only mode.

However, the BLE host stack does not support the system channel required to initialize CPU2. Therefore, when using only the mailbox interface, the user must build the system command packet to be sent to CPU2 and must manage the event received from CPU2.

It is possible to mix a simple BLE mailbox interface with a higher level shci interface to encode/decode the system packet when connecting to the system mailbox interface. This is the purpose of the "Mailbox interface - Extended"

13.3.1 Interface API

The BLE and memory interface is identical to the simple mailbox interface.

To use the higher shci interface (from `shci.h`), the shci transport layer must be initialized and connected to the Mailbox driver.

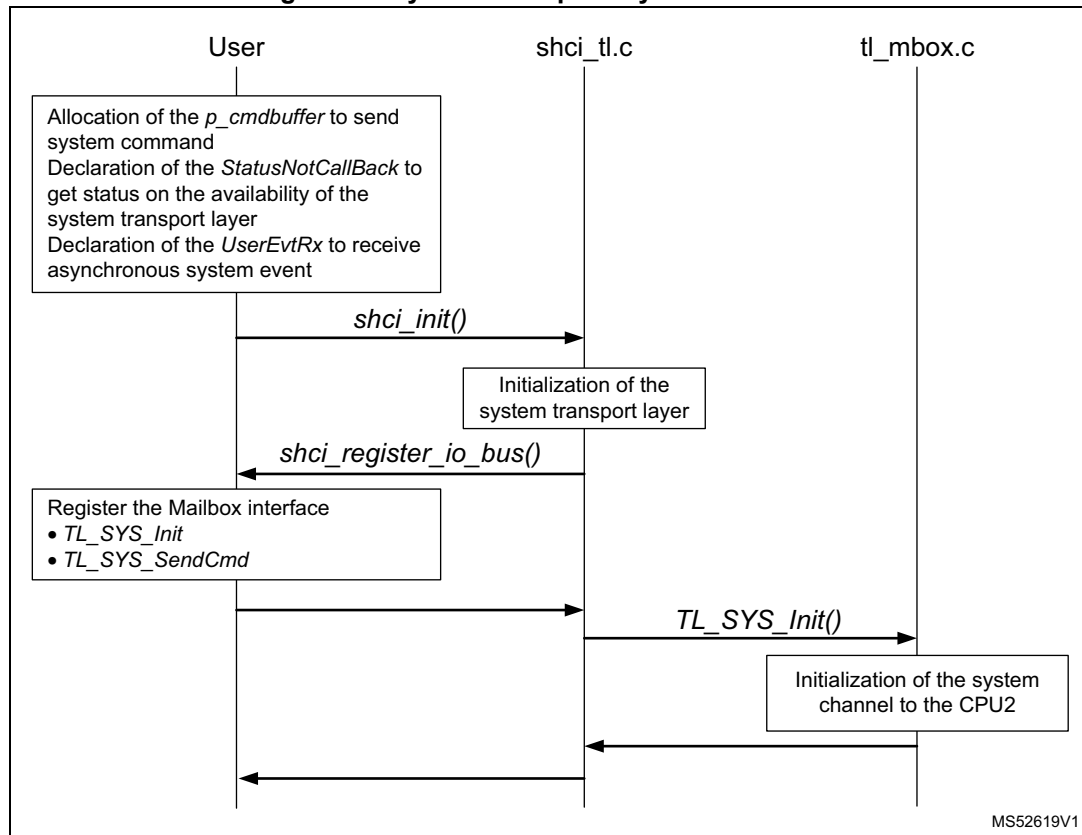
The two API `TL_SYS_Init()` and `TL_SYS_SendCmd()` along with the two callbacks `IoBusCallBackCmdEvt` and `IoBusCallBackUserEvt` are used and implemented in the transport layer and cannot be used individually any longer.

Table 31. Interface APIs

Function	Description
<code>void shci_init(void(* UserEvtRx)(void* pData), void* pConf)</code>	Initializes the system transport layer.
<code>void shci_register_io_bus(tSHciIO* fops)</code>	Registers the mailbox interface to the system transport layer.
<code>void shci_notify_asynch_evt(void* pdata)</code>	Requests the user to call <code>shci_user_evt_proc</code>
<code>void shci_resume_flow(void)</code>	Resumes the asynchronous user event reporting when stopped by the user.
<code>void shci_cmd_resp_wait(uint32_t timeout)</code>	Waits for a command response.
<code>void shci_cmd_resp_release(uint32_t flag)</code>	Notifies that a command response has been received.
<code>void shci_user_evt_proc(void)</code>	Processes the received asynchronous user event and calls <code>UserEvtRx</code> .

13.3.2 Detailed interface and behavior

Figure 73. System transport layer initialization



MS52619V1

```
void shci_init(void(* UserEvtRx)(void* pData), void* pConf):
```

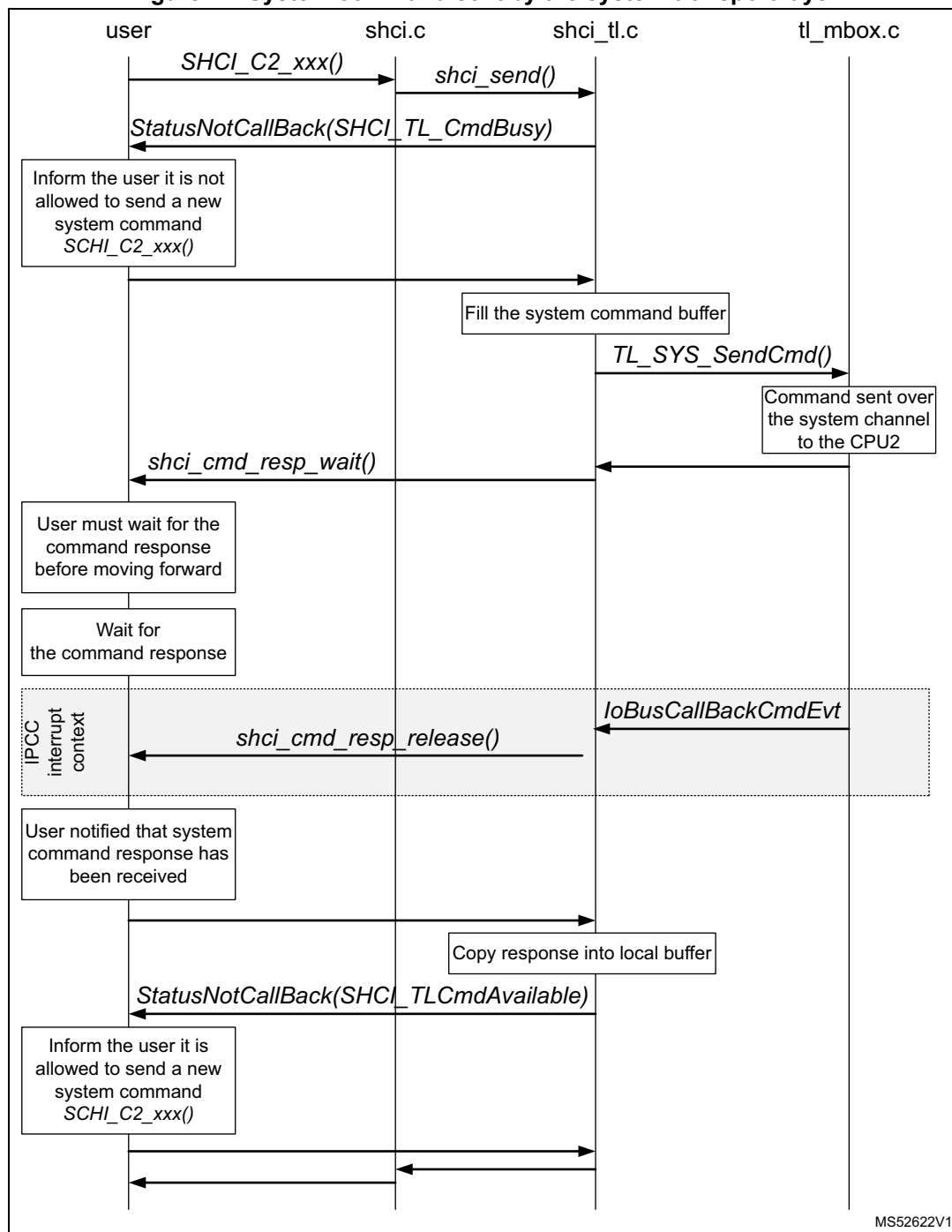
The user must first allocate the buffer to be used by the mailbox driver to send a system command (`p_cmdbuffer`), the two callbacks that will receive a user asynchronous system event (`UserEvtRx`) and the transport layer availability notification (`StatusNotCallBack`).

This command initializes the System channel in the Transport layer and the mailbox driver.

```
void shci_register_io_bus(tSHciIO* fops);:
```

This command registers the Mailbox driver to the system transport layer.

Figure 74. System command sent by the system transport layer

**SHCI_C2_xxx()**

The list of supported system commands that can be used by the application is in the file shci.h.

```
void StatusNotCallBack(SHCI_TL_CmdStatus_t status):
```


This is the registered callback in shci_init() to acknowledge if a system command can be sent. It must be used in a multi-thread application where system commands may be sent from different threads.

When status = SHCI_TL_CmdBusy, the system transport layer is busy and no new system command are be sent.

```
void shci_cmd_resp_wait(uint32_t timeout):
```

The application must only use this command in with the shci_cmd_resp_wait() to notify the response has been received

The parameter is meaningless.

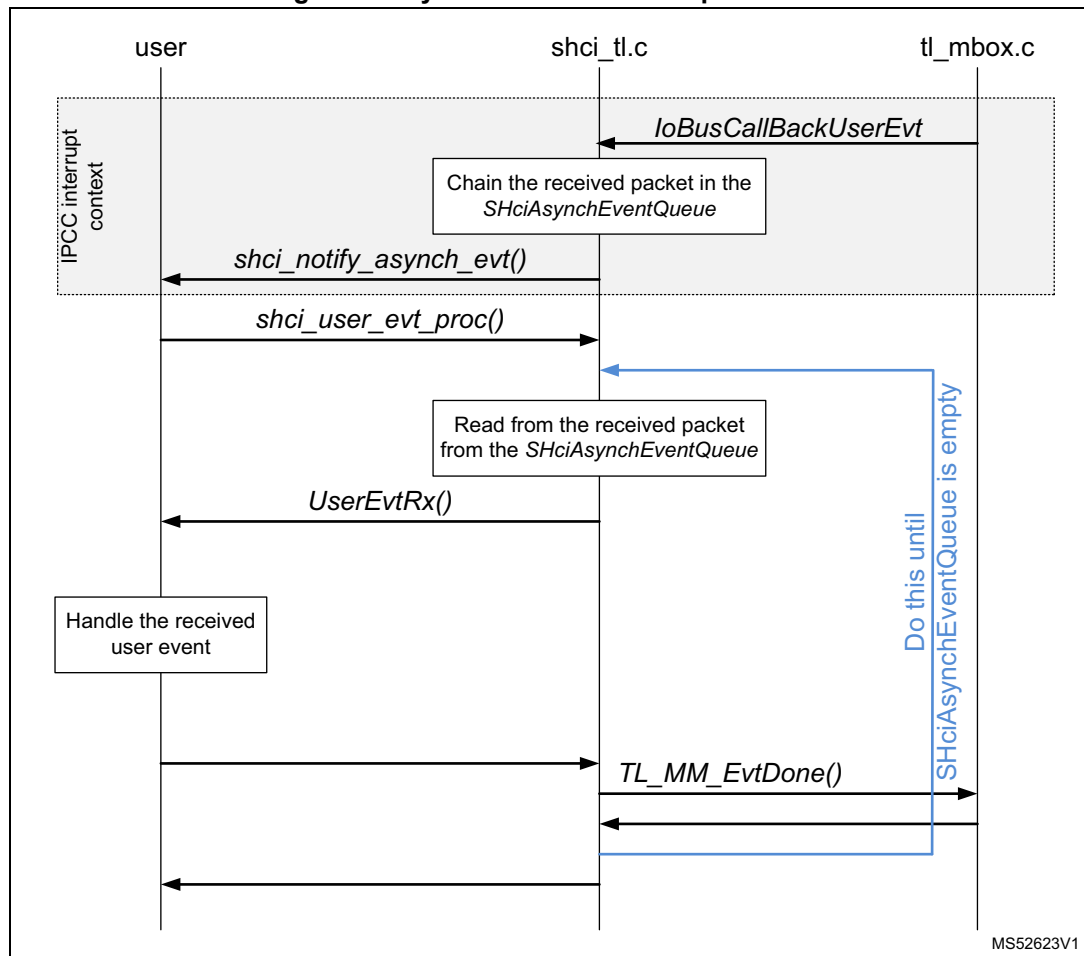
```
void shci_cmd_resp_wait(uint32_t timeout):
```

This function informs the user that the response of the pending system command has been received.

It is called in the IPCC interrupt context. When moving out from this API, the application may return from the API shci_cmd_resp_wait().

The parameter is meaningless.

Figure 75. System user event reception flow



```
void shci_notify_asynch_evt(void* pdata):
```

This API notifies the user that a system user event has been received. The user has to call the `shci_user_evt_proc()` to process the notification in the system transport layer. As the `shci_notify_asynch_evt()` notification is called from the IPCC interrupt context, it is strongly recommended to implement a background mechanism to call `shci_user_evt_proc()` (out of IPP Interrupt context).

`pdata` holds the address of the `SHciAsynchEventQueue`.

```
void shci_user_evt_proc(void):
```

This function reports the received event to the user with `UserEvtRx()`. As the received event queue `SHciAsynchEventQueue` is filled within the IPCC interrupt context, new events may be stored in the queue while the user is processing an event. `UserEvtRx()` is called for each event retrieved from the queue. The `shci_user_evt_proc()` process frees the buffer to CPU2 memory manager for each return of `UserEvtRx()`.

```
void UserEvtRx (void * pData):
```

This reports to the user the received system event. The buffer holding the received event is freed on return of this function.

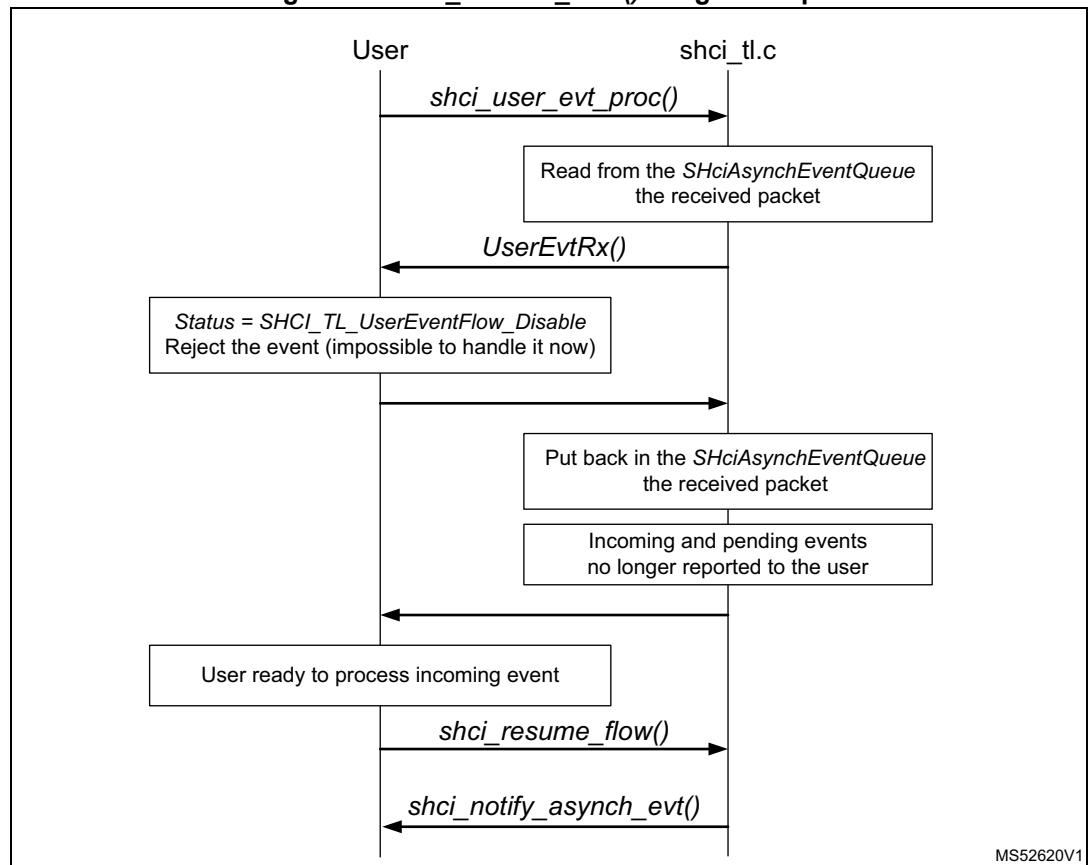
pData is the address of a structure holding the following parameters:

```
typedef struct
{
    SHCI_TL_UserEventFlowStatus_t status;
    TL_EvtPacket_t *pkt;
} tSHCI_UserEvtRxParam;
```

pkt: holds the address of the received event.

status: provides a way for user to notify the system transport layer that the received packet has not been processed and must not be thrown away. When not filled in by the user on return of UserEvtRx(), this parameter is set to SHCI_TL_UserEventFlow_Enable, which means the user has processed the received event.

Figure 76. shci_resume_flow() usage example



```
void shci_resume_flow( void ):
```

When the user is not able to process incoming event, it must set the status parameter to SHCI_TL_UserEventFlow_Disable before returning from UserEvtRx(). In that case, the

system transport layer does not release the system event and does not report any new incoming events.

When the user is ready to process a system event, it must send the `shci_resume_flow()` that informs the system transport layer to restart reporting of system event.

13.4 ACI interface

This is the interface to the BLE stack running on CPU2. It provides a full set of APIs to use all features in the BLE layers (GATT, GAP, HCI LE).

The ACI commands are sent over the HCI transport.

The interfaces to access all BLE layers (GATT, GAP) are located in the folder `\Middlewares\ST\STM32_WPAN\ble\core\Inc\core`.

When using the ACI interface, the BLE controller must be set in Full stack mode. The HCI transport layer must be implemented in the application to send and receive command from the ACI interface to the mailbox.

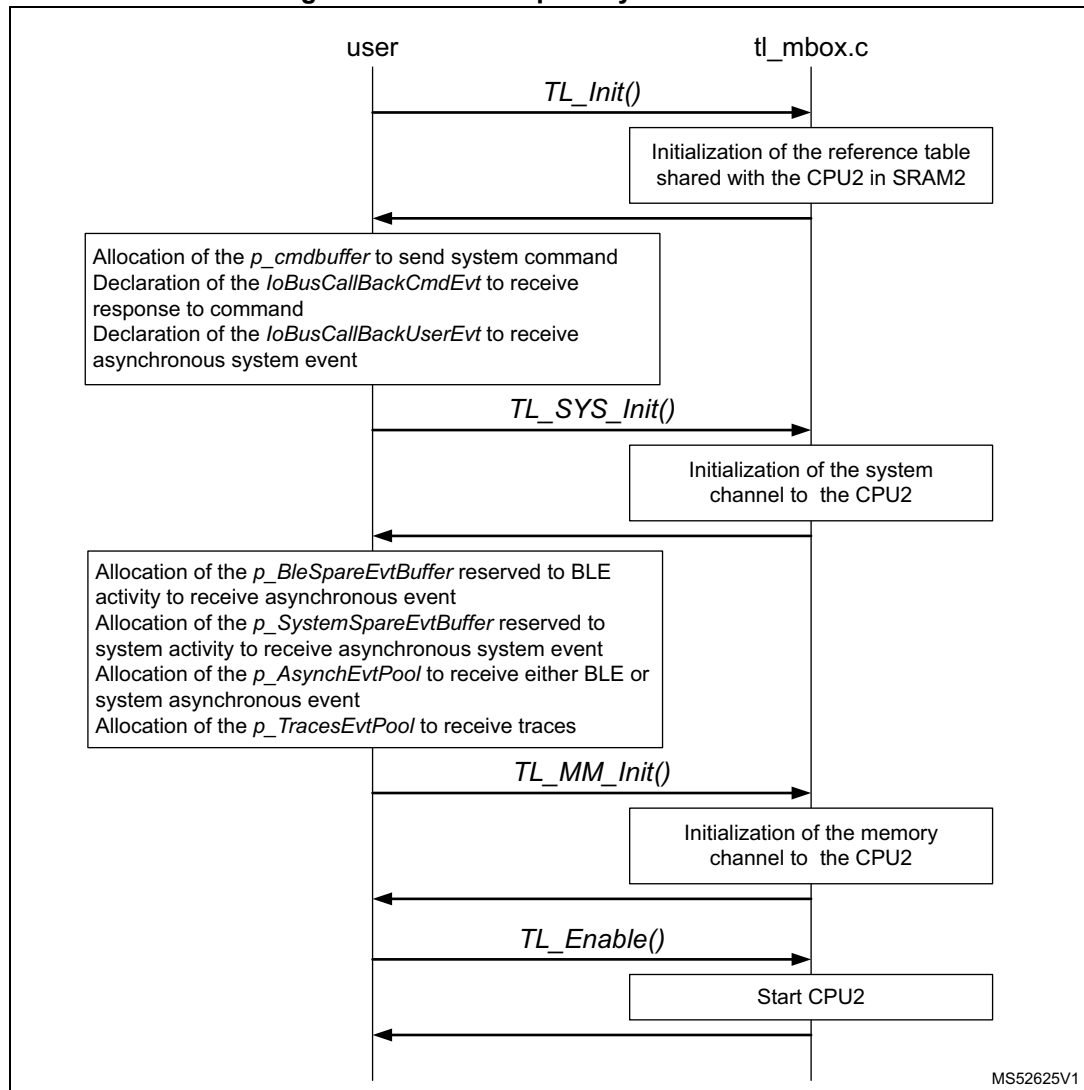
The new interface is basically the [Mailbox interface - Extended](#) where the HCI transport layer is implemented. When the ACI interface is used, the application no longer uses the low level mailbox interface.

Table 32. BLE transport layer interfaces

Function	Description
<code>void hci_init(void(* UserEvtRx)(void* pData), void* pConf);</code>	Initializes the BLE transport layer
<code>void hci_register_io_bus(tHciIO* fops);</code>	Registers the mailbox interface to the BLE transport layer
<code>void hci_notify_asynch_evt(void* pdata);</code>	Requests the user to call <code>hci_user_evt_proc</code>
<code>void hci_resume_flow(void)</code>	Resumes the asynchronous user event reporting when stopped by the user
<code>void hci_cmd_resp_wait(uint32_t timeout)</code>	Waits for a command response
<code>void hci_cmd_resp_release(uint32_t flag)</code>	Notifies that a command response has been received
<code>void hci_user_evt_proc(void</code>	Process the received asynchronous user event and call <code>UserEvtRx</code>

13.4.1 Detailed interface and behavior

Figure 77. BLE transport layer initialization



```
void hci_init(void(* UserEvtRx)(void* pData), void* pConf);:
```

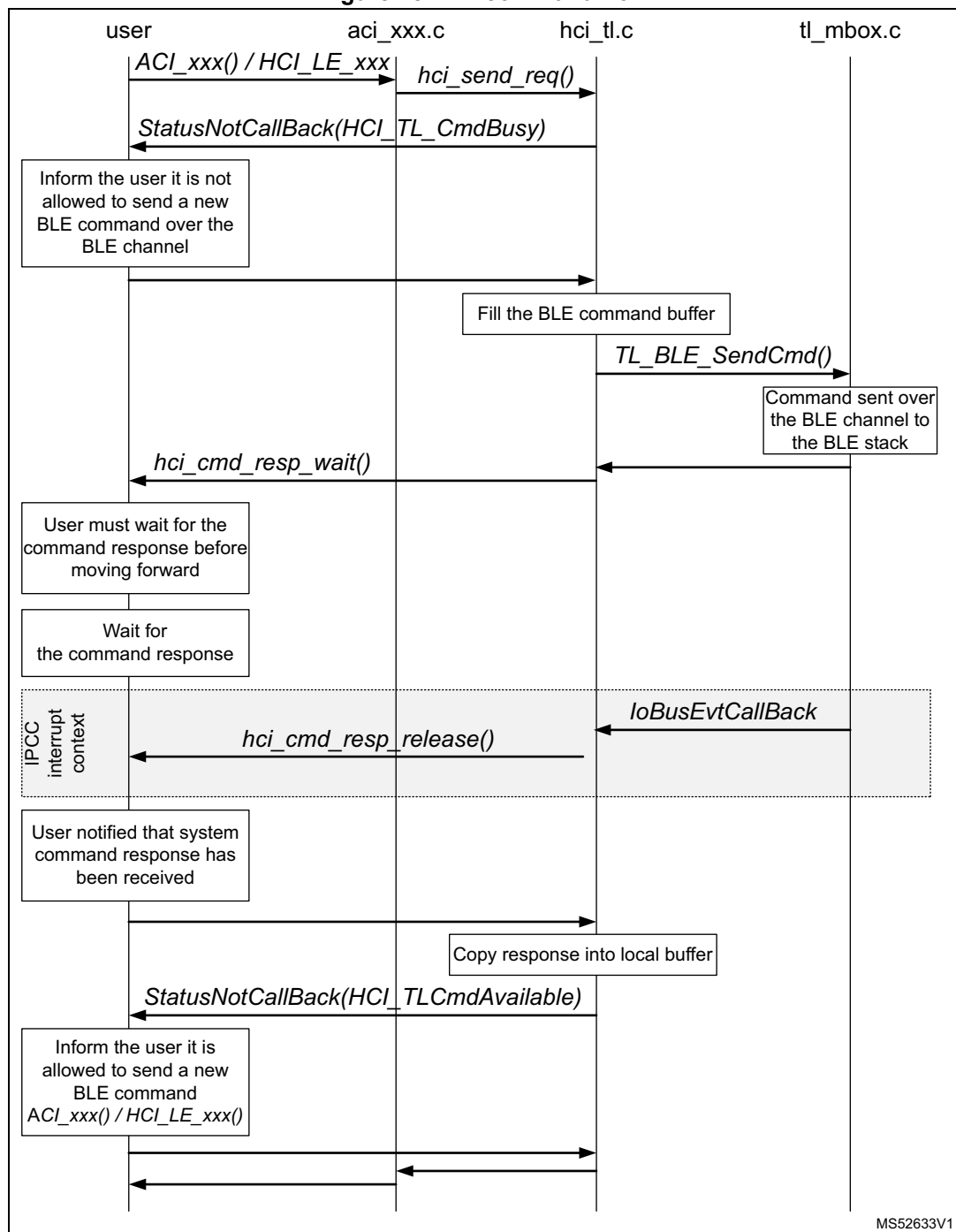
The user must first allocate the buffer to be used by the mailbox driver to send a BLE command (*p_cmdbuffer*), the two callbacks to be used to receive a user asynchronous system event (*UserEvtRx*) and the transport layer availability notification (*StatusNotCallBack*).

This commands initializes the BLE Channel in the HCI Transport layer and the mailbox driver.

```
void hci_register_io_bus(tSHciIO* fops);:
```

This commands registers the mailbox driver to the HCI transport layer.

Figure 78. ACI command flow



ACI_xxx() / HCI_LE_xxx()

The list of supported system commands that can be used by the application is in the folder `\Middlewares\ST\STM32_WPAN\ble\core\inc\core`.

```
void StatusNotCallBack(HCI_TL_CmdStatus_t status):
```

This is the registered callback in `hci_init()` to acknowledge if a BLE command can be sent. To be used in a multi-thread application where the BLE commands may be sent from different threads.

When `status = HCI_TL_CmdBusy`, the HCI transport layer is busy and no new BLE command can be sent.

```
void hci_cmd_resp_wait(uint32_t timeout):
```

The application must not return from this command until the `hci_cmd_resp_wait()` is called to notify the response has been received

The parameter is meaningless.

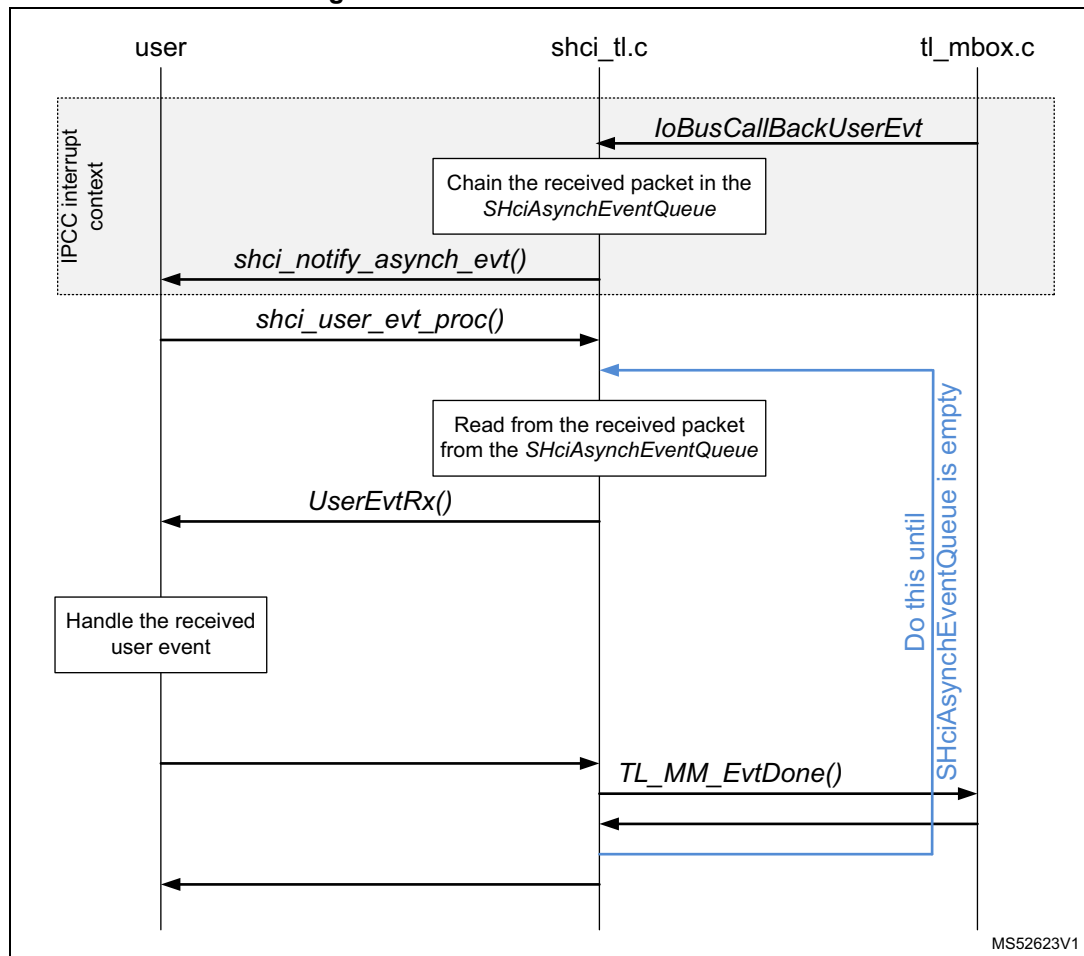
```
void hci_cmd_resp_wait(uint32_t timeout):
```

This function informs the user that the response of the BLE command pending has been received.

It is called in the IPCC interrupt context. When moving out from this API, the application may return from the API `hci_cmd_resp_wait()`.

The parameter is meaningless.

Figure 79. BLE user event receive flow



MS52623V1

```
void hci_notify_asynch_evt(void* pdata):
```

This API notifies the user a BLE user event has been received. The user must then call the `hci_user_evt_proc()` to process the notification in the HCI transport layer. As the `hci_notify_asynch_evt()` notification is called from the IPCC interrupt context, it is strongly recommended to implement a background mechanism to call `hci_user_evt_proc()` (out of IPP Interrupt context)

`pdata` holds the address of the `HciCmdEventQueue`.

```
void hci_user_evt_proc(void):
```

This function reports the received event to the user through `UserEvtRx()`. As the received event queue `HciCmdEventQueue` is filled within the IPCC interrupt context, new events may be stored in the queue while the user is processing an event. `UserEvtRx()` is called for each event retrieved from the queue. The `hci_user_evt_proc()` process is responsible for freeing the buffer to the CPU2 memory manager on each `UserEvtRx()` return.

```
void UserEvtRx (void * pData):
```


This reports the received BLE user event. The buffer holding the received event is freed on return of this function.

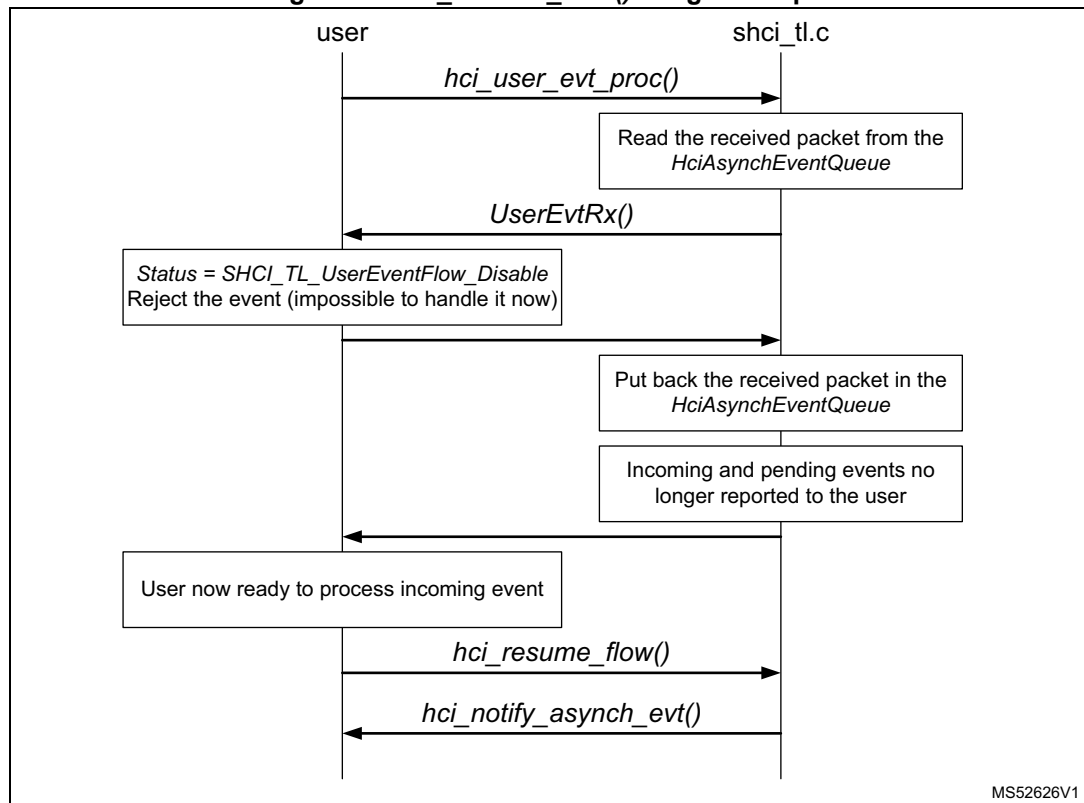
pData is the address of a structure holding the following parameters:

```
typedef struct
{
    HCI_TL_UserEventFlowStatus_t status;
    TL_EvtPacket_t *pkt;
} tHCI_UserEvtRxParam;
```

pckt: holds the address of the received event

status: provides a way for the user to notify the HCI transport layer that the received packet has not been processed and must not be thrown away. When not filled by the user on return of UserEvtRx(), this parameter is set to HCI_TL_UserEventFlow_Enable which means the user has processed the received event.

Figure 80. hci_resume_flow() usage example



MS52626V1

```
void hci_resume_flow( void ):
```

When the user is not able to process an incoming event, it must set the status parameter to `HCI_TL_UserEventFlow_Disable` before returning from `UserEvtRx()`. In that case, the HCI transport layer does not release the BLE user event and does not report any new incoming events.

When the user is ready to process BLE user event, it must send the `hci_resume_flow()` that informs the HCI transport layer to resume BLE user event reporting.

13.5 STM32WB system commands and events

13.5.1 Commands

Table 33. System interface commands

Command	Code	Description
SHCI_C2_FUS_GetState()	0xFC52	Refer to [5] .
SHCI_C2_FUS_FwUpgrade()	0xFC54	
SHCI_C2_FUS_FwDelete()	0xFC55	
SHCI_C2_FUS_UpdateAuthKey()	0xFC56	
SHCI_C2_FUS_LockAuthKey()	0xFC57	
SHCI_C2_FUS_StoreUsrKey()	0xFC58	
SHCI_C2_FUS_LoadUsrKey()	0xFC59	
SHCI_C2_FUS_StartWs()	0xFC5A	
SHCI_C2_FUS_LockUsrKey()	0xFC5D	
SHCI_C2_BLE_Init()	0xFC66	Sends the BLE Init parameters. Must be sent before any ACI command. Refer to Section 7.6.5: How to maximize data throughput for more details.
SHCI_C2_THREAD_Init()	0xFC67	Refer to Section 9.8: System commands for Thread applications .
SHCI_C2_DEBUG_Init	0xFC68	Enables the traces on both CPU1 and CPU2 and the GPIO debug configuration on CPU2.
SHCI_C2_FLASH_EraseActivity	0xFC69	Notifies CPU2 that Flash memory erase operation may be requested by CPU1. This allows CPU2 to enable timing protection versus the erase operation.
SHCI_C2_CONCURRENT_SetMode()	0xFC6A	Refer to Section 9.8: System commands for Thread applications .
SHCI_C2_FLASH_StoreData()	0xFC6B	
SHCI_C2_FLASH_EraseData()	0xFC6C	
SHCI_C2_RADIO_AllowLowPower()	0xFC6D	
SHCI_C2_MAC_802_15_4_Init()	0xFC6E	Refer to Section 12.4.5: MAC IEEE Std 802.15.4-2011 system .
SHCI_C2_Reinit()	0xFC6F	Requests CPU2 to restart its initialization phase on receiving an event generated by an SEV instruction on CPU1. This is expected to be used by the SBSFU when no RF activity has been started.
SHCI_GetWirelessFwInfo()		Returns the version and memory footprint of the wireless stack and FUS running on CPU2.
SHCI_C2_ZIGBEE_Init()	0xFC70	Initializes the ZigBee® protocol stack on CPU2.

Table 33. System interface commands

Command	Code	Description
SHCI_C2_ExtpaConfig()	0xFC72	Sends to CPU2 the GPIO to be used and its configuration to drive the enable/disable pin of an external PA.
SHCI_C2_SetFlashActivityControl()	0xFC73	Requests CPU2 to use either the PESD bit or Semaphore 7 to protect its timing versus Flash memory operation. When the command is not sent, CPU2 uses PESD.

13.5.2 Events

Table 34. User system events

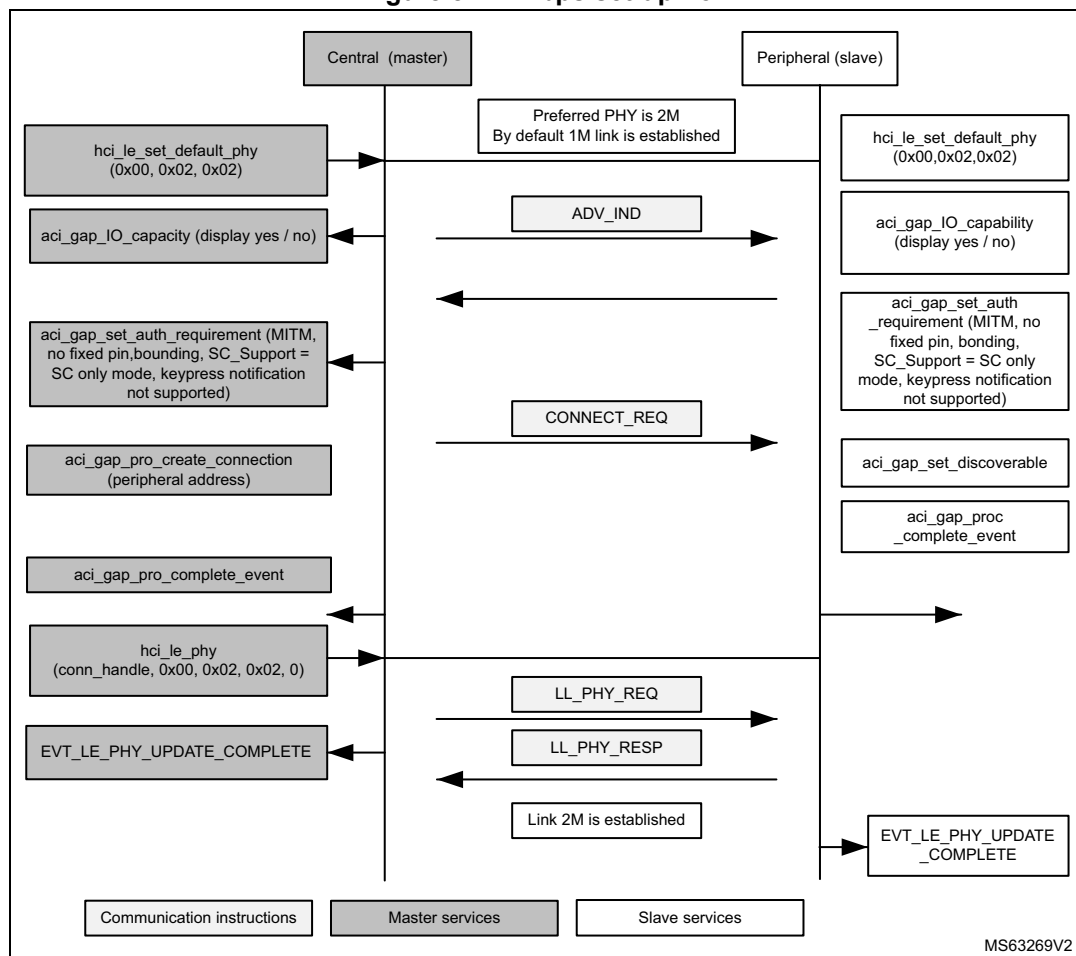
Event	Code	Description
SHCI_SUB_EVT_CODE_READY	0x9200	Returned as soon as CPU2 has been started and is ready to receive commands.
SHCI_SUB_EVT_ERROR_NOTIF	0x9201	Reports error(s) from CPU2.

13.6 BLE - Set 2 Mbps link

During the device initialization phase, the preferred TX_PHYS, RX_PHYS values can be initialized.

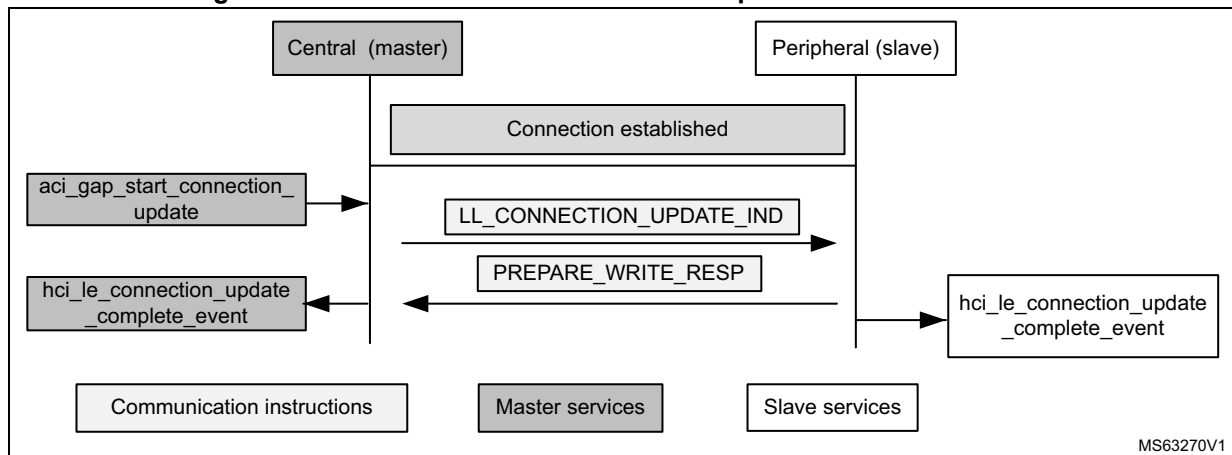
After the connection at 1 Mbps, it is possible to change the PHY to 2 Mbps for this link, as detailed in [Figure 81](#).

Figure 81. 2 Mbps set-up flow

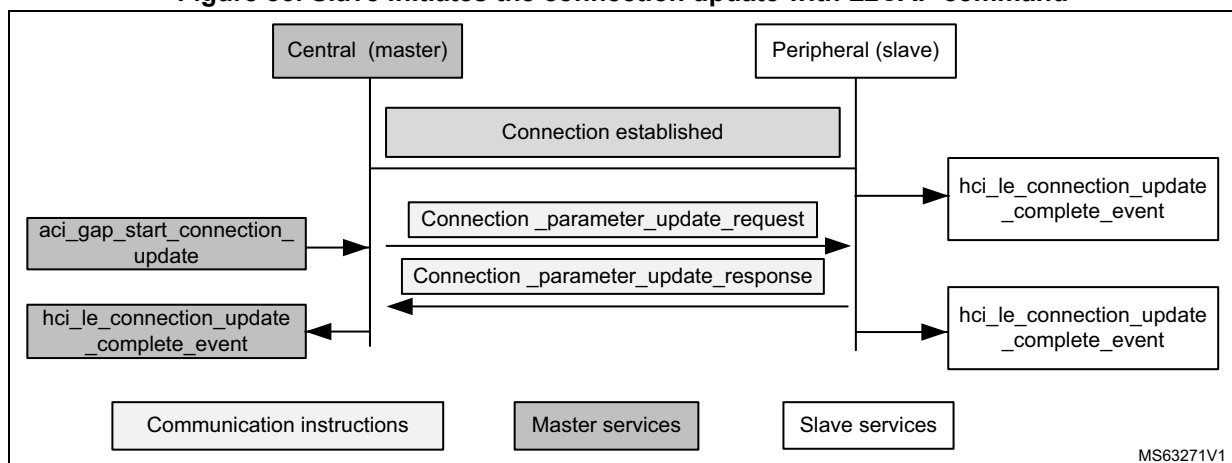


13.7 BLE - Connection update procedure

Once a connection is established, it is possible for the master to update the connection parameters with the `aci_gap_start_connection_update` command.

Figure 82. Master initiates the connection update with HCI command

Once a connection is established, it is possible for the slave to update the connection parameters with `aci_l2cap_connection_parameter_update_req` command.

Figure 83. Slave initiates the connection update with L2CAP command

13.8 BLE - Security procedure

13.8.1 LE security mode1 level 3

[Figure 84](#), [Figure 85](#) and [Figure 86](#) illustrate an example of an LE security mode 1 level 3 sequence, using the following initialization parameters.

- For the central:
 - aci_gap_set_IO_capability (keyboard/display)
 - aci_gap_set_auth_requirement (MITM, no fixed pin, SC_Support=0 SC not supported)
- For the peripheral:
 - aci_gap_set_IO_capability (display only)
 - aci_gap_set_auth_requirement (no MITM, fixed pin=0x1234, SC_Support=0 SC not supported)

Figure 84. LE security mode1 level 3 key distribution feature

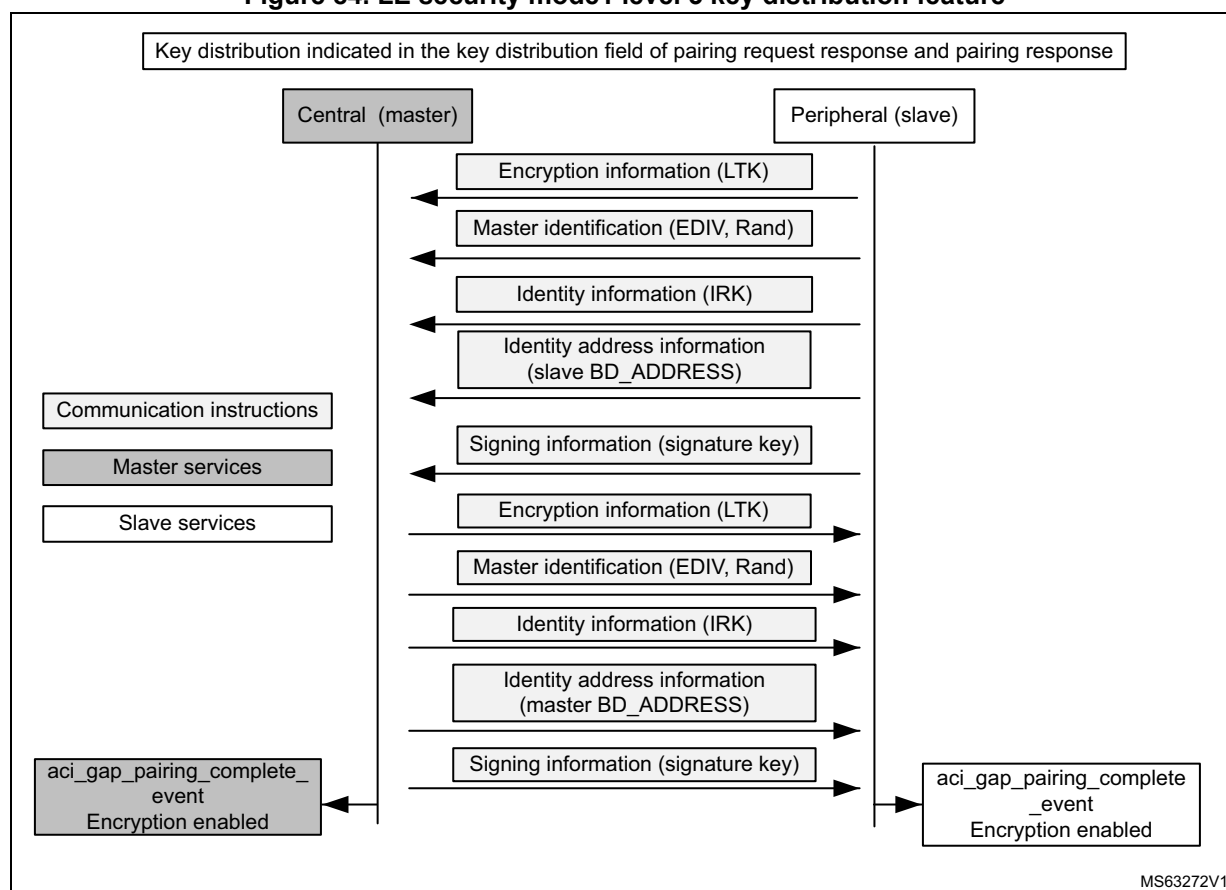


Figure 85. LE security mode1 level 3 pairing feature exchange

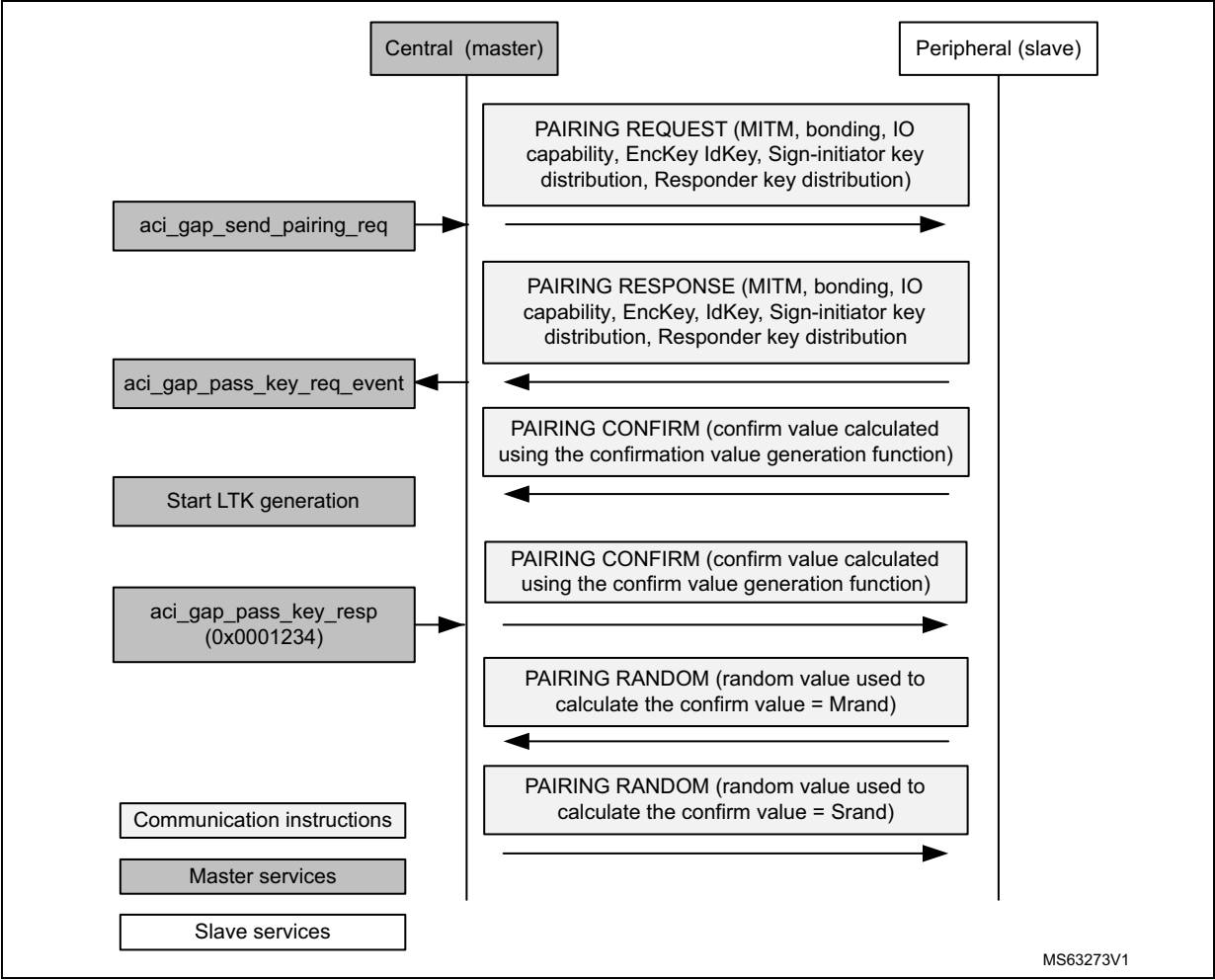
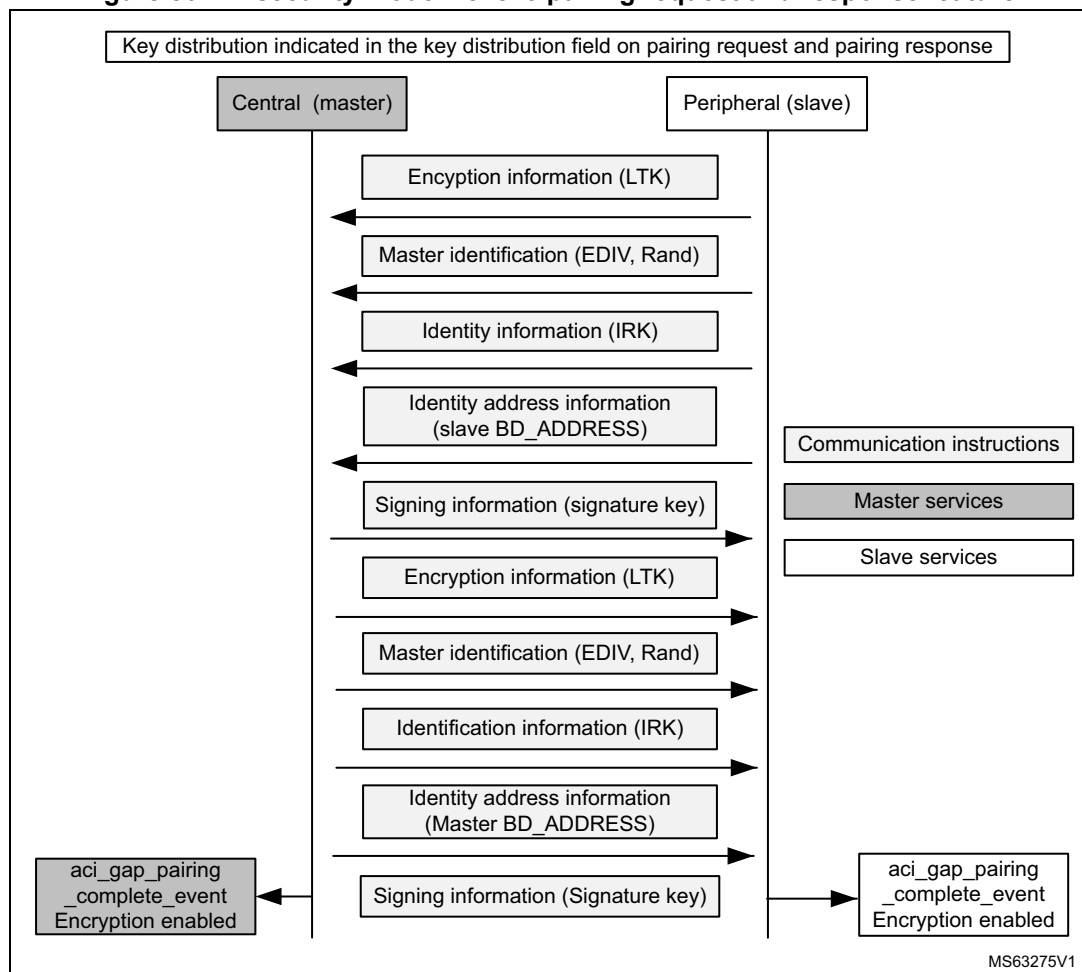


Figure 86. LE security mode1 level 3 pairing request and response feature

13.8.2 LE security mode1 level 4

Figure 87, *Figure 88* and *Figure 89* illustrate an example of security mode1 level 4 sequence, using the following initialization parameters:

- aci_gap_set_IO_capability (display_yesno)
- aci_gap_set_auth_requirement (MITM, no fixed pin, SC_Support=SC only mode)

Figure 87. LE security mode1 level 4

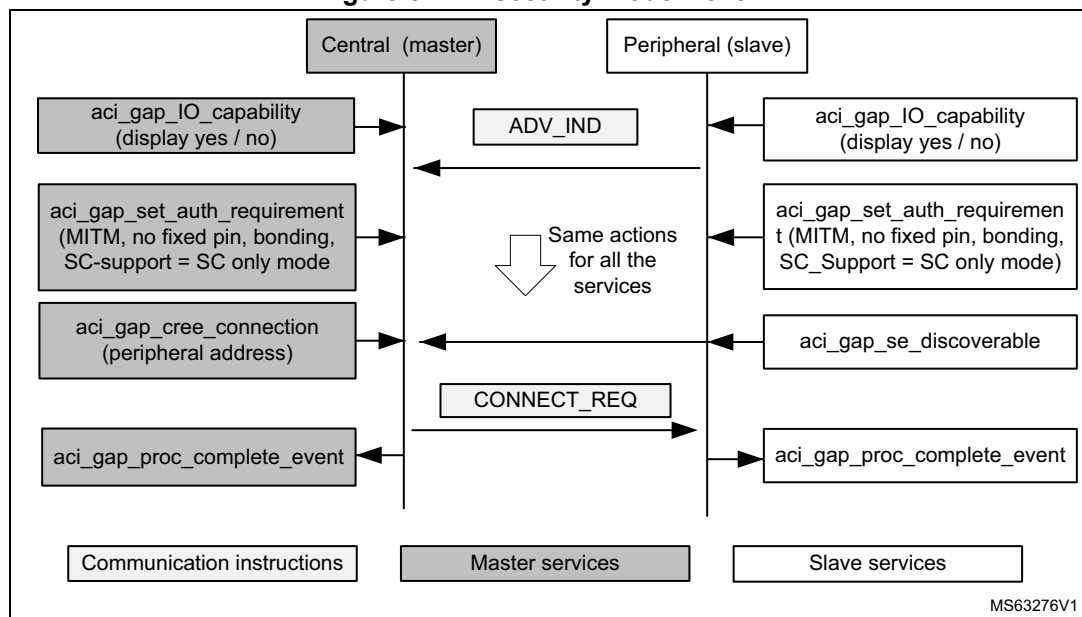


Figure 88. LE security mode1 level 4

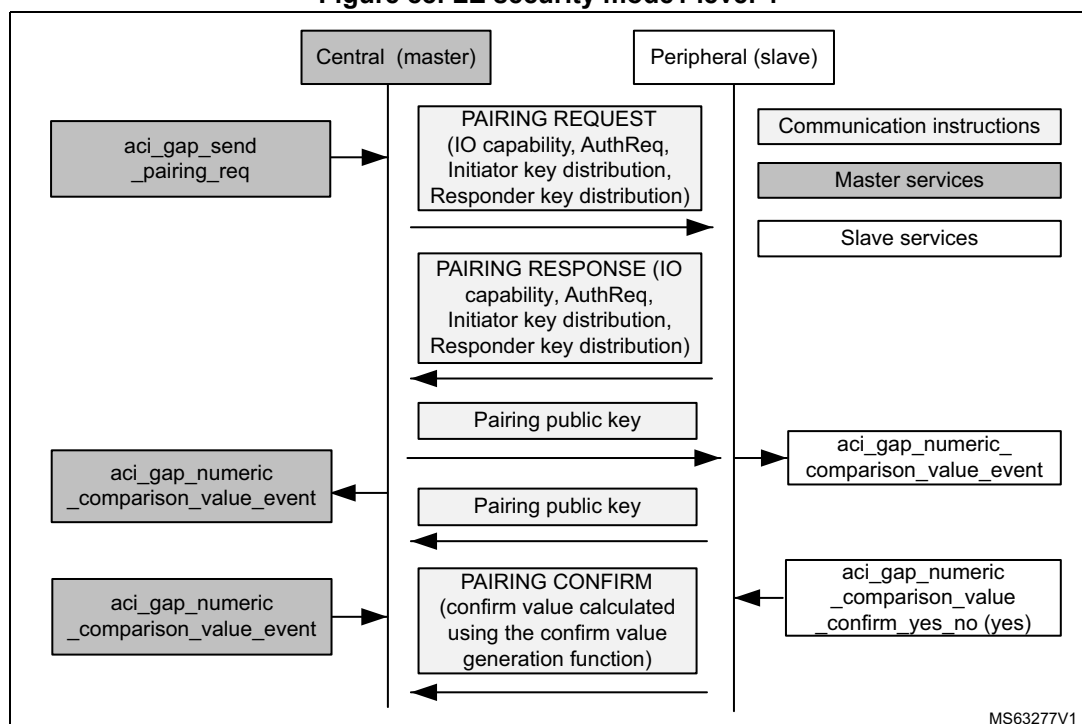
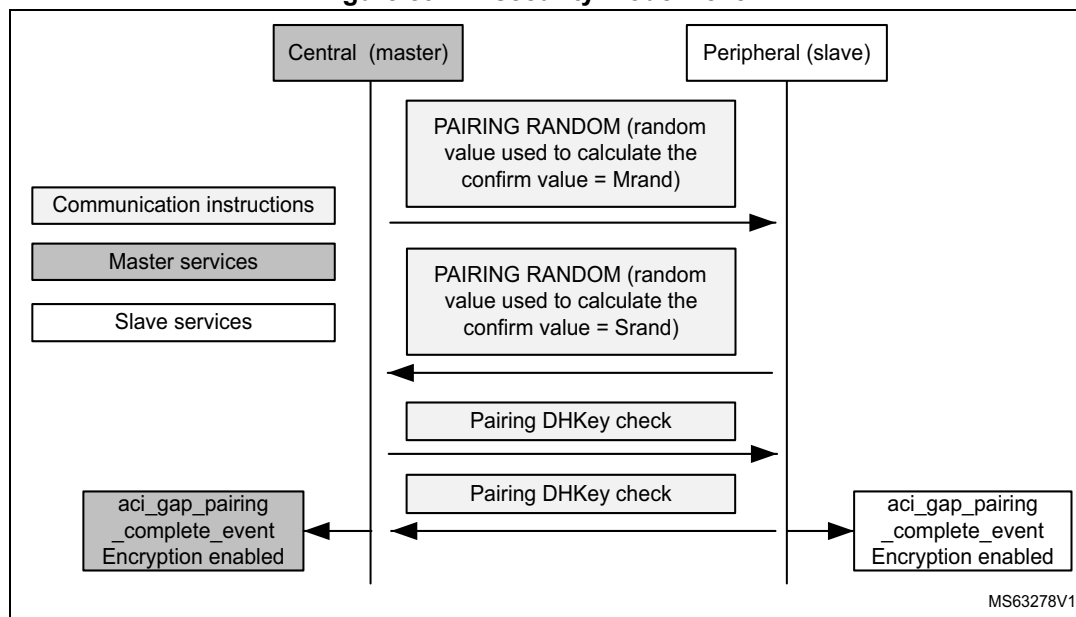


Figure 89. LE security mode1 level 4



13.8.3 LE security mode1 level 4 - Key-press notification

Figure 90 and Figure 91 illustrate an example of a security mode1 level 4 sequence, using the following initialization parameters:

- `aci_gap_set_IO_capability` (display_yesno)
- `aci_gap_set_auth_requirement` (MITM, no fixed pin, SC_Support=SC only mode, keypress notification supported)

Figure 90. LE security mode1 level 4 - Key-press notification (1/2)

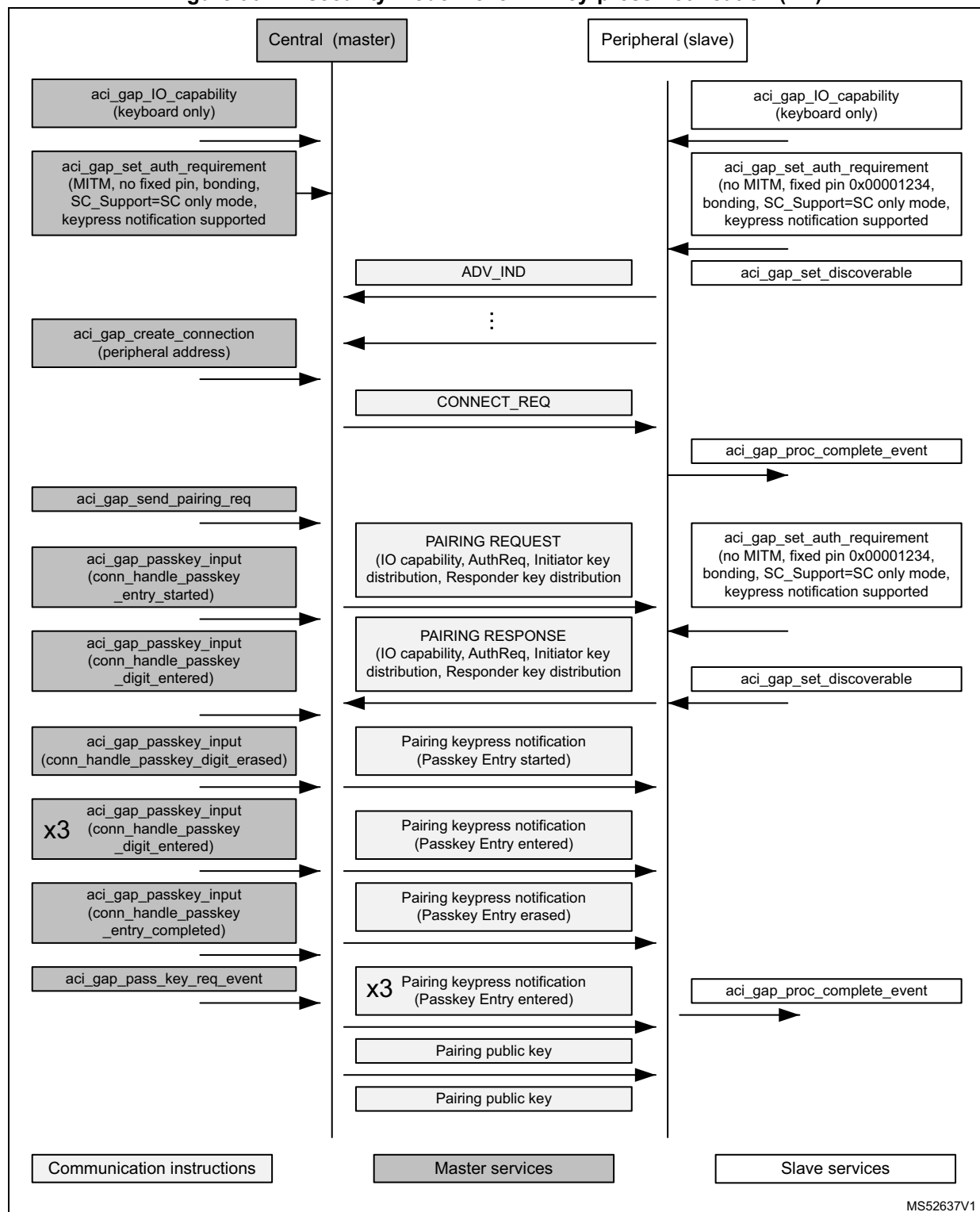
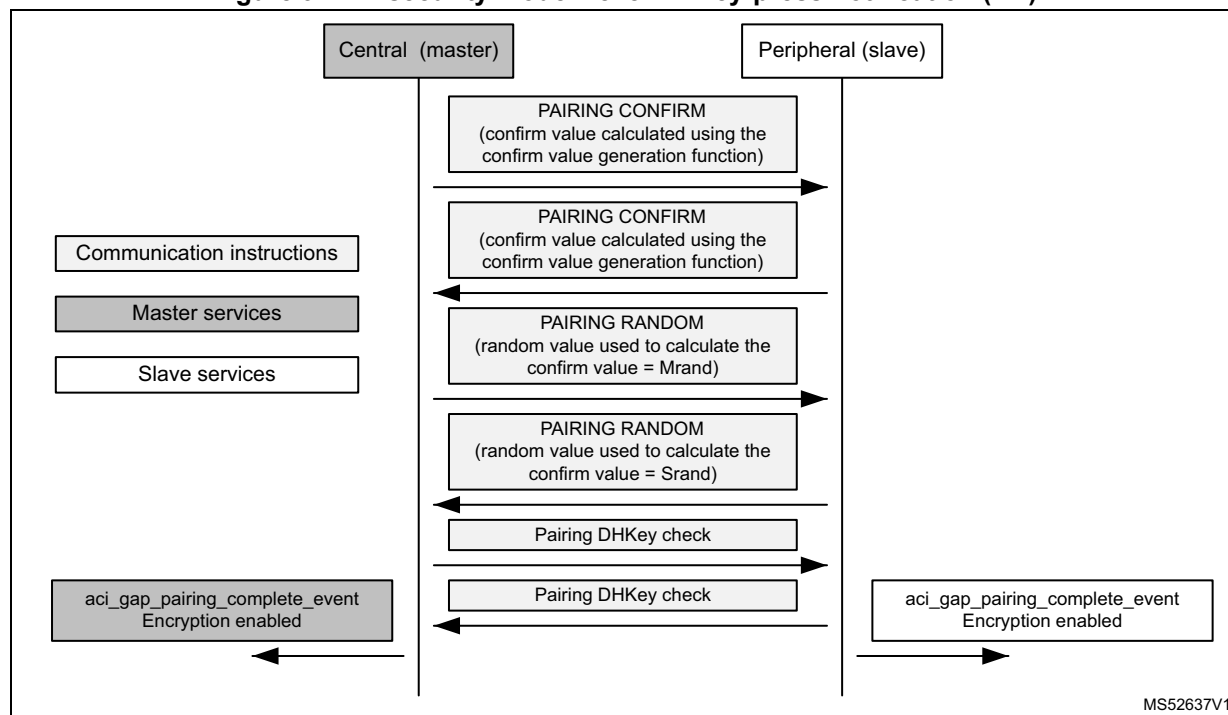


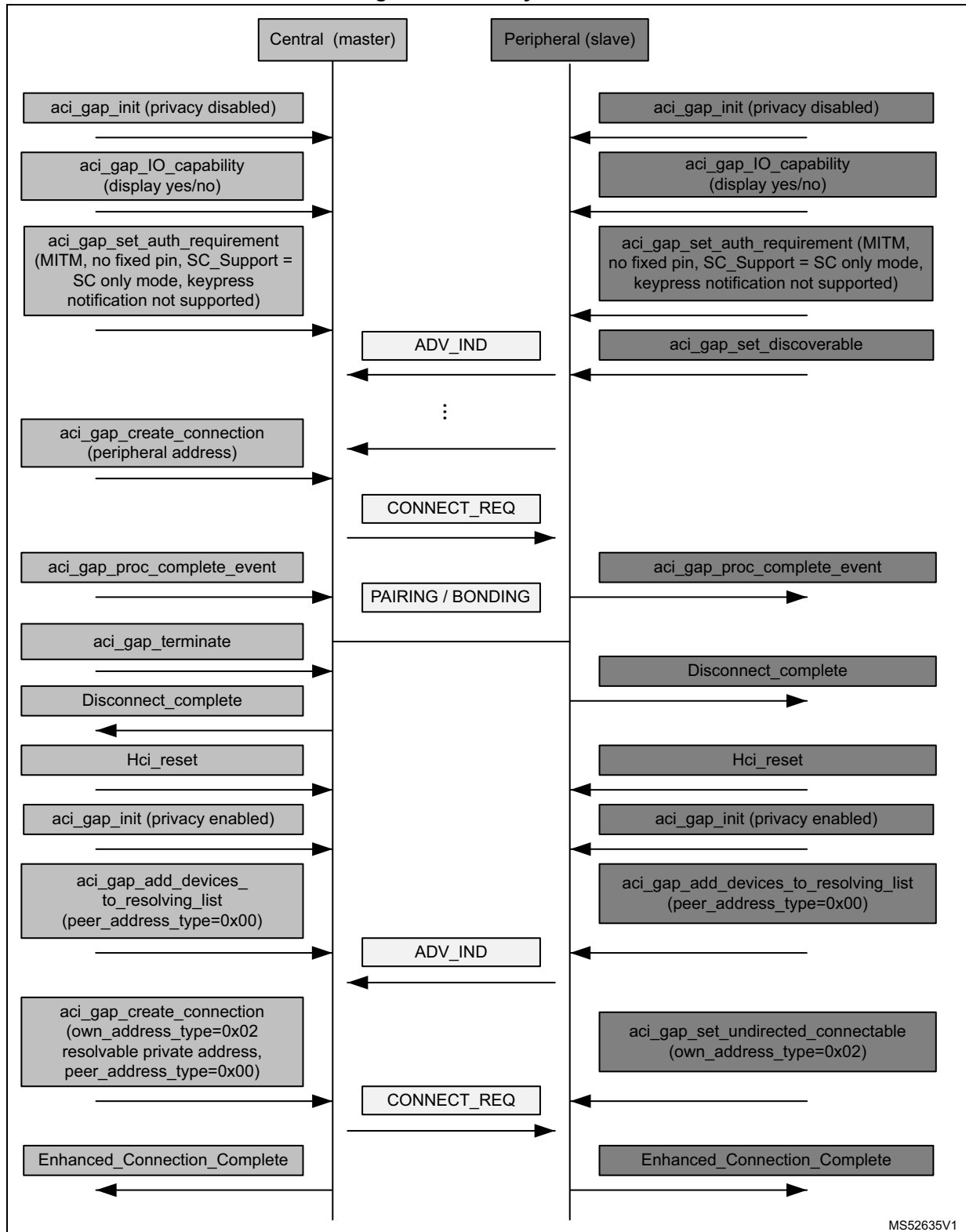
Figure 91. LE security mode1 level 4 - Key-press notification (2/2)



13.8.4 Privacy enabled

[Figure 92](#) illustrates a connection, pairing, bonding, disconnection, reset and reinitialization sequence example for devices with privacy enabled.

Figure 92. Privacy enabled



13.9 BLE - Link layer data packet

The BLE has a single packet format used for both the advertising and data channel packets.

Figure 93. Data packet breakdown

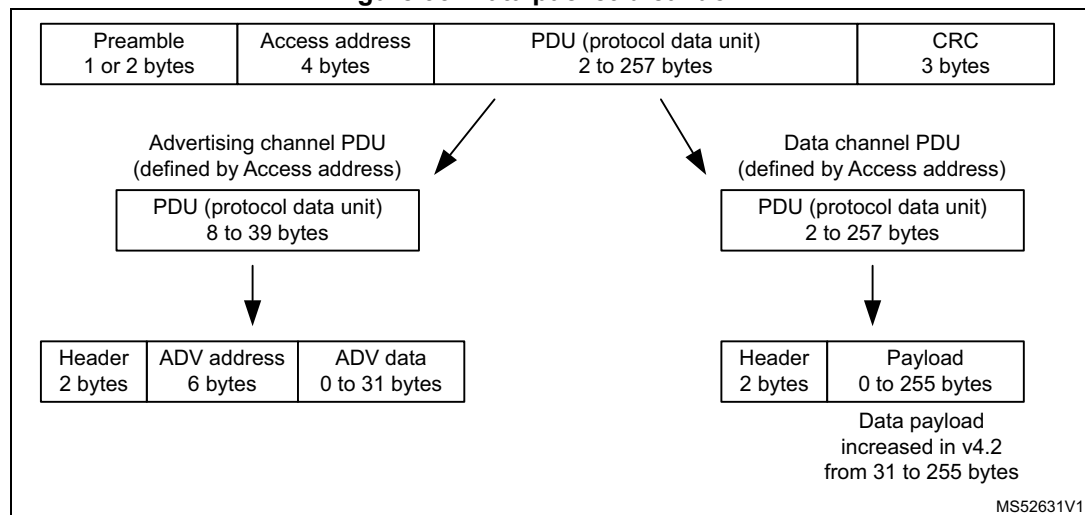
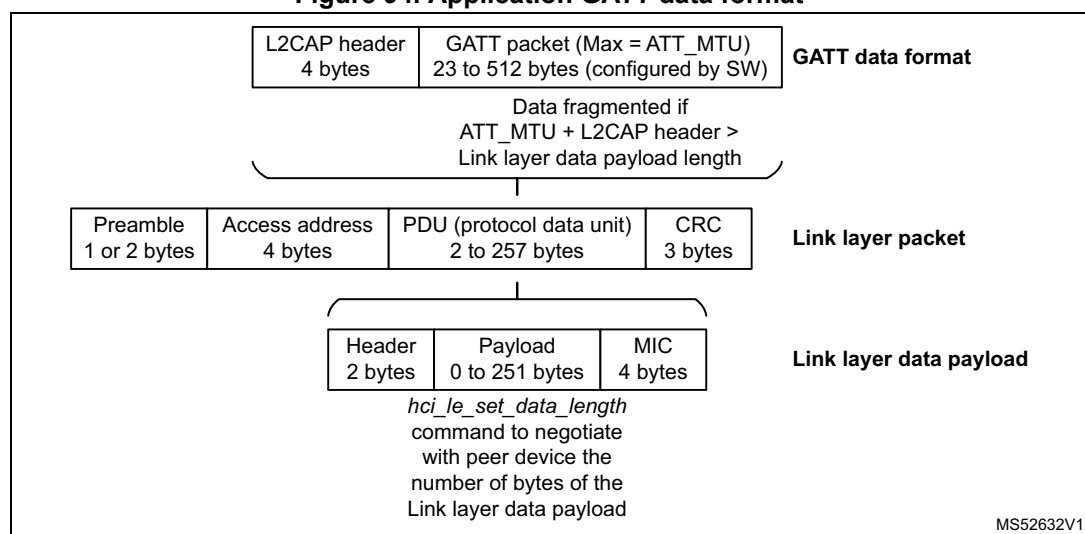


Figure 94. Application GATT data format



13.10 Thread overview

13.10.1 Introduction

The Thread stack is an open standard for reliable, cost-effective, low-power, wireless D2D communication. It is designed specifically for connected home applications where IP-based networking is desired and a variety of application layers can be used on the stack.

The full specification ([9]) is available on <http://threadgroup.org/>.

This standard is based on the IEEE 802.15.4 [IEEE802154] PHY (physical) and MAC (media access control) layers operating at 250 kbps in the 2.4 GHz band.

13.10.2 Main characteristics

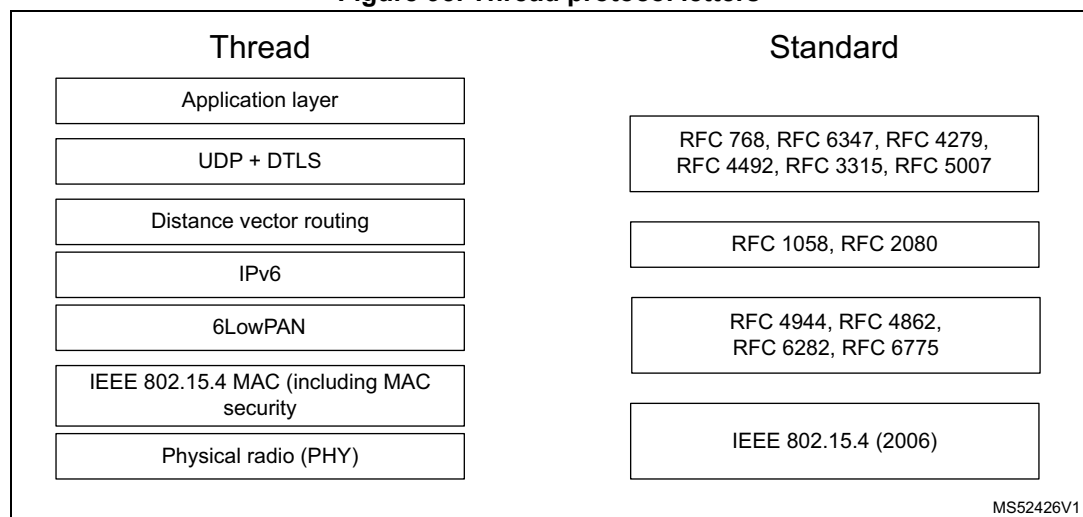
Thread targets smart home applications like environment control, thermostat, alarms, energy management, smart lockers and smart lighting devices. One of the main advantages of this standard is that it is based on IPv6, hence any Thread network can easily be connected to any other IPV6 application. Another big advantage is that it is based on a real mesh network. Once deployed, this network is supposed to be very robust and reliable. For instance, when a route fails, the system is able to auto-reconfigure itself by finding a new route to the destination. Through a mesh network, devices can communicate with each other across much longer distances.

Thread does not really define any application layer. Nevertheless, most of the Thread applications use CoAP to transfer data. CoAP is widely deployed and is already used natively inside Thread in address resolution management, for instance. On STM32WB devices the CoAP layer is exposed to the customer.

13.10.3 Layers

Thread is based on mature and well proven standards, as shown in [Figure 95](#).

Figure 95. Thread protocol letters



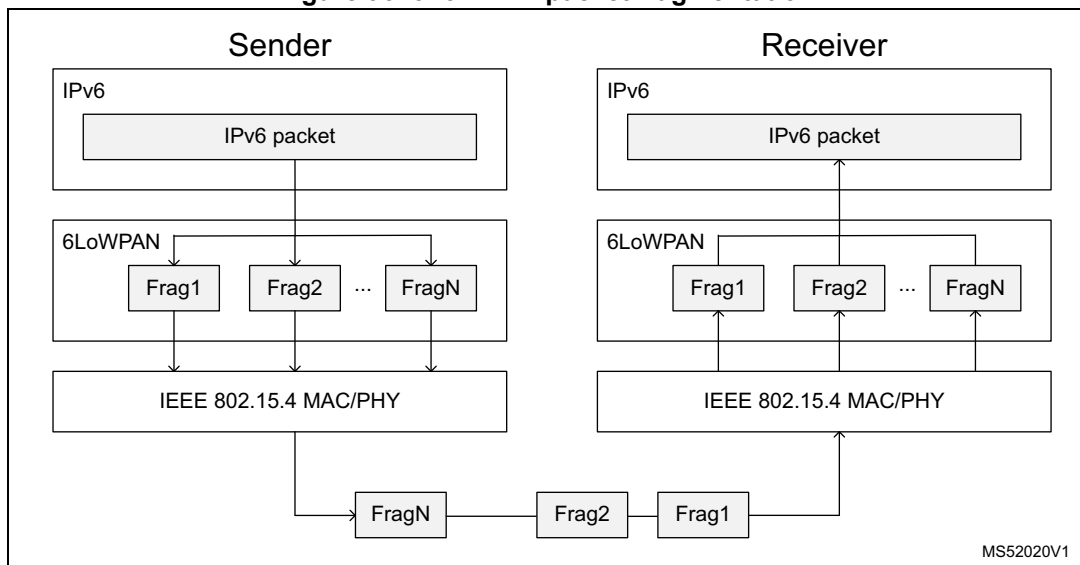
Starting from the lower layer:

- MAC layer, based only on a subset of IEEE 802.15.4 specification from 2006. It supports a rate of 250 kbps in the 2.4 GHz band. There are 16 channels available, ranging from channel 11 to channel 26. Inside a Thread network, only one single channel is used in real time. The MAC radio layer uses the CSMA mechanism to send frames. If the transmission medium is busy it is delayed by a random value. This mechanism reduces the probability of transmission collision between two nodes. On

the STM32WB, transmission delay by a random value is managed directly by the hardware.

- 6LoWPAN layer: 6LoWPAN stands for “IPv6 over low power wireless personal area networks”. On Ethernet, an IPV6 packet of 1280 bytes is easily sent as a single “monolithic” frame. On the MAC layer, this not possible because the maximum packet size is limited to 127 bytes. For this, Thread uses the 6LowPan layer. This layer implements two techniques:
 - Fragmentation (splitting the packets in small TX pieces, and reassembling them in RX)
 - Header compression (in some cases, a header of 48 bytes can be compressed into a header of only 6 bytes).

Figure 96. 6LoWPAN packet fragmentation



- IPv6 (Internet Protocol version 6), intended to replace IPv4.
 IPv4 uses 32-bit addressing, IPV6 uses 128-bit addressing, which gives billions of possibilities. In addition to a larger addressing space, IPv6 provides other technical benefits, in particular it facilitates the routing procedure.
 In Thread there are several addresses defined:
 - MeshLocal64: the address is “topology independent”, it means that it is stable and will never change, even if a device becomes router or end device. The MeshLocal64 address is usually the address used when pinging from one device to another.
 - MeshLocal16: even if the application uses the mMeshLocal64, at low level, the stack will use the mMeshLocal16 address to perform the routing. The Mesh local contains the RLOC field (routing locator). This address is topology dependent (depending upon the network and the link quality). A child may decide to select a

new parent, hence a new router, and gets a new address. A child can also become a router, depending on the use case.

- MeshLinkLocal64: the address starts with 0xFE80, and ends with the MAC extended address with the universal/local bit inverted. It is used for direct point to point link and for the MLE messages.
- Routing: All the mesh network management is based on MLE (mesh link establishment) messages. These messages are used to detect neighboring devices, to configure the system and to maintain routing cost all over the network. Thread claims to be very robust and is able to manage dynamic routing adaptation. Routers periodically send advertisement messages, which contain the following parameters:
 - Link quality between the sender and its neighbors
 - Route cost to access to all routers in the Thread network partition.

All routers contain a table with the link quality in UL and DL with all its neighboring routers and the routing cost for all the routers present inside the mesh network.

In this table, there are also the “next hops” defining how to travel all over the network and the so called “age” value, which represents the elapsed time since the latest advertisement reception.

The quality link is a value comprised between 0 and 3, 3 being the best quality (when the signal strength recorded is above 20 dB). Having only four possible link quality values minimizes the overhead of communicating the link quality with neighbors. Routers acting as leaders maintain an additional database for tracking router ID assignments and the extended address associated with each router.
- Application layer: Thread supports CoAP, and this protocol acts as the application layer in our design. CoAP can be considered as a very light version of http protocol. It requires far less resources than http and has a very low overhead. Like http, CoAP is based on the REST model: servers make resources available under a URL, and clients access these resources using requests such as Get, Put, Post, and Delete. The URL (uniform resource locator) specifies the resources and the way to access them. There are four types of messages:
 - Non confirmable message
 - Confirmable message
 - Acknowledgment message
 - Reset message.

13.10.4 Mesh topology

Thread supports Mesh network. As shown in [Figure 97](#), devices inside a Thread network can have two main roles:

- Router
 - Forwards packets for network devices
 - Provides secure commissioning services for devices trying to join the network
 - Keeps its transceiver enabled at all times
- End device
 - Communicates primarily with a single router
 - Does not forward packets for other network devices
 - Can disable its transceiver to reduce power

Amongst all routers, one is always promoted as 'leader'. The Thread leader is a router manages a the set of routers in a Thread network.

Among all end devices, there can be sleepy end devices, REEDs or standard end devices'.

- REED (router eligible end device) is an end device that can be promoted router if needed
- Sleepy end device is normally disabled, it wakes up occasionally to poll for messages from its parent or to send data.

The size of the Mesh network is configurable. There is a maximum of 32 active routers. Each router can be connected to different child devices. Each child ID is coded on 9 bits, resulting in a theoretical maximum number of 511 children per router. Because of memory constraints on STM32WB the number of child per router is limited to 10.

Figure 97. Thread network topology

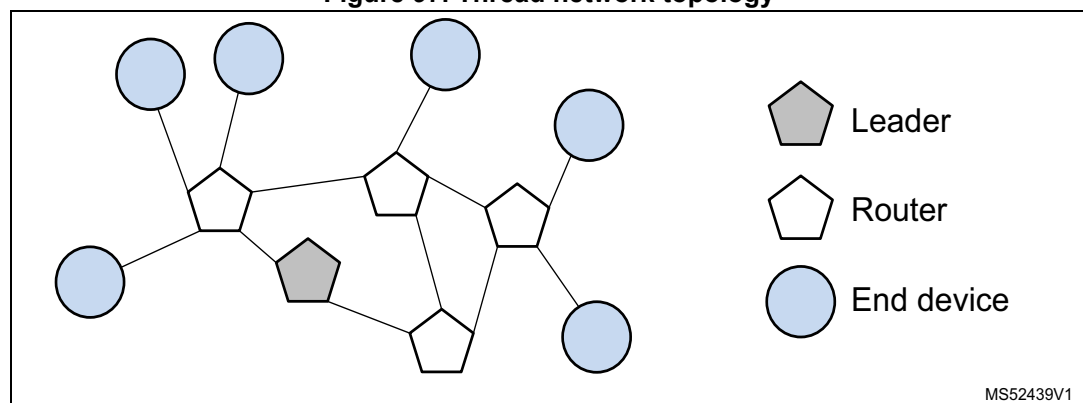
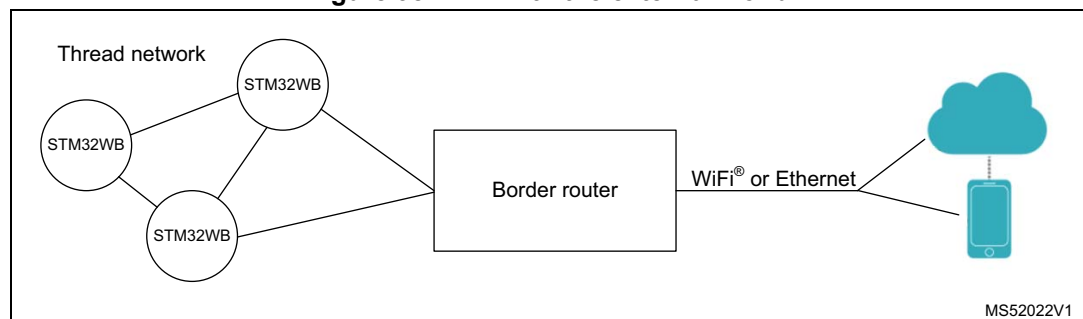


Figure 98. Link with the external world



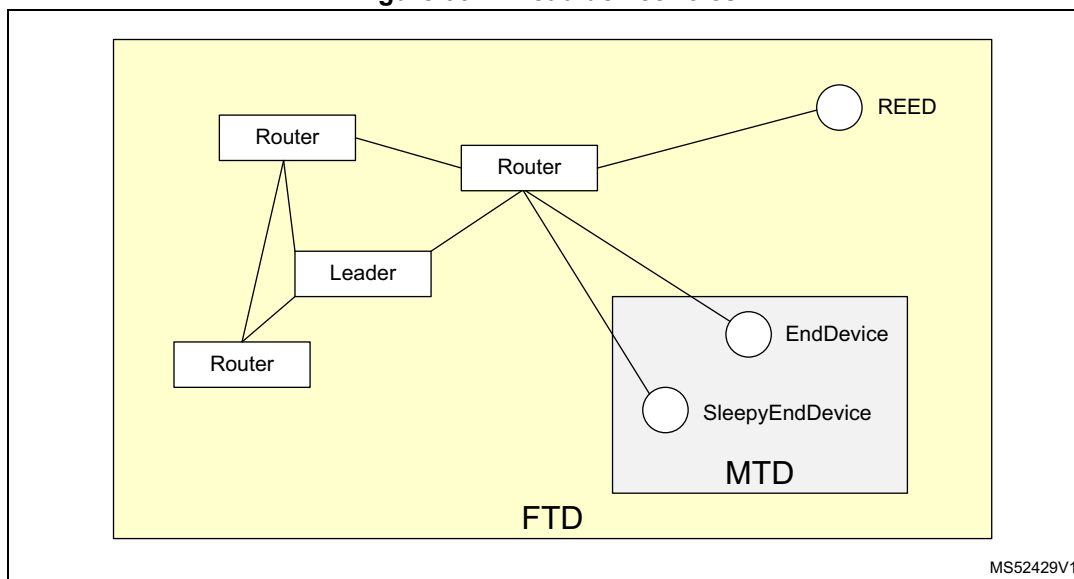
13.10.5 Thread configuration

When compiling OpenThread, several options can be set depending on the targeted use case. For STM32WB two cases are considered:

1. Full Thread device (FTD): the device can act as a simple sleepy end device but also as router and leader inside the Thread network.
2. Minimal Thread device (MTD): the device acts only as end device or sleepy end device

The MTD configuration needs less memory (both RAM and Flash) vs. the FTD configuration. On the other hand, an MTD only acts as end device or sleepy end device.

Figure 99. Thread device roles



14 Conclusion

Bluetooth Low Energy (BLE) or 802.15.4 applications based on for STM32WB Series microcontrollers require the understanding of dedicated software protocols and architectures.

This document details how the developer must create the embedded application software, a key element is to follow the correct procedure for the system initialization.

15 Revision history

Table 35. Document revision history

Date	Revision	Changes
18-Jun-2019	1	Initial release.
26-Sep-2019	2	Updated Introduction , Section 4.2: Memory mapping , Section 4.3: Shared peripherals , Section 9.2: How to start , Section 9.6: OpenThread API , Section 11.1: Thread_Cli_Cmd , Section 11.4: Thread_Coap_Multiboard , Section 11.5: Thread_Commissioning , Section 12.3: API and Section 12.4.3: MAC application processor firmware . Added Section 11.8: Thread FUOTA and its subsections. Updated Figure 4: Memory mapping . Updated Table 2: Semaphores .
23-Mar-2020	3	Updated Section 4.3: Shared peripherals and Section 7.6.1: How to set Bluetooth device address . Added Section 4.7: Flash memory management , Section 4.8: Debug information from CPU , Section 4.9: FreeRTOS low power and their subsections. Updated Table 2: Semaphores , Table 33: System interface commands and Table 34: User system events . Updated Figure 10: Algorithm to write/erase data in the Flash memory , Figure 24: Heart rate project - Interaction between middleware and user application and Figure 29: P2P server software communication . Minor text edits across the whole document.

IMPORTANT NOTICE – PLEASE READ CAREFULLY

STMicroelectronics NV and its subsidiaries ("ST") reserve the right to make changes, corrections, enhancements, modifications, and improvements to ST products and/or to this document at any time without notice. Purchasers should obtain the latest relevant information on ST products before placing orders. ST products are sold pursuant to ST's terms and conditions of sale in place at the time of order acknowledgement.

Purchasers are solely responsible for the choice, selection, and use of ST products and ST assumes no liability for application assistance or the design of Purchasers' products.

No license, express or implied, to any intellectual property right is granted by ST herein.

Resale of ST products with provisions different from the information set forth herein shall void any warranty granted by ST for such product.

ST and the ST logo are trademarks of ST. For additional information about ST trademarks, please refer to www.st.com/trademarks. All other product or service names are the property of their respective owners.

Information in this document supersedes and replaces information previously supplied in any prior versions of this document.

© 2020 STMicroelectronics – All rights reserved