AN4499
Application note

STM32 - nRF51822 Bluetooth Low Energy system solution

Introduction

The scope of this document is to describe the Bluetooth Low Energy (BLE) software (STSW-STM32149) implementation on the STM32L1 series and nRF51822 with the following features.

- Compatible with BLE profiles provided by Nordic
- Application integration ready
- Easy add-on of low power BLE solution on STM32L1 series
- Extremely low STM32L1 CPU load (HRS 1s update rate 0.065%)
- No latency requirements on STM32L1 series
- Small STM32L1 memory footprint

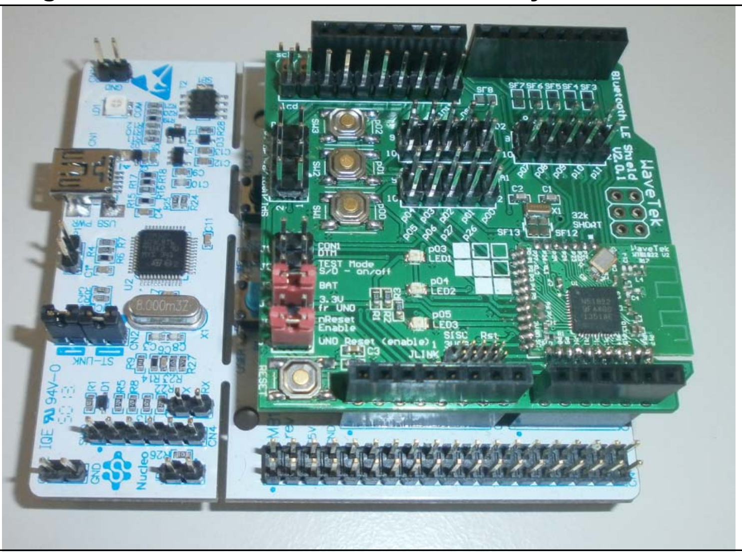
This document also describes how to interface to your own customer application and create your BLE services.

Customer application examples on STM32L1 using the Nordic BLE services are provided.

The reference hardware platform is based on the STM32Nucleo/64 and the Wavetek Bluetooth LE shield with Nordic BLE module nRF51822. The software supports the following list of products.

Note: It can be ported to other STM32 series.

Figure 1. STM32 Nordic nRF51822 BLE system solution



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1 References

[1] nRF51822 Soft Device specification, Nordic:

http://www.nordicsemi.com/

[2] nRF51822 Reference manual, Nordic:

http://www.nordicsemi.com/

[3] nRF51822 Product Specification, Nordic:

http://www.nordicsemi.com/

[4] Nordic Serializer project APIs

http://www.nordicsemi.com/

[5] STM32L151xx Reference Manual, ST:

http://www.st.com/

[6] STM32L15x Datasheet – Production data, ST:

http://www.st.com/

[7] STM32 Nucleo HW User Manual, ST

http://www.st.com/

[8] Wavetek Arduino Bluetooth LE shield UM, Wavetek

http://www.wavetek.com.hk

2 Product definition

The following firmware components are used:

- STM32 BLE application solution including the BLE SD FW Module
- nRF51822 S110 SoftDevice binary (see reference to Nordic documentation)
- nRF51822 connectivity serialized solution from Nordic (see reference to Nordic documentation)

Table 1. STM32 memory footprint

	ROM (Kbytes)	RAM (Kbytes)
Full BLE SD FW Module (When HRS application only)	31.3 (22.8)	2.3
NVM driver, Timer server, UART driver, low power Manager	3.3	0.7

The STM32 + nRF51822 application provides a 2 chip BLE solution, where the STM32 operates as a host device and nRF51822 is the connectivity part.

In the STM32 + nRF51822 system the whole BLE stack is situated on the nRF51822 device, which interfaces to the STM32 via a UART.

The BLE SD FW module, UART, timer, NVM and the customer application are built on the STM32 platform. The customer application may be either a dedicated simple BLE application or a wider application on which BLE connectivity is added:

The following modules are required to add a BLE connectivity to the STM32:

- **Profile service management** :

  The BLE services are running on the nRF51822 system and this module is providing an implementation proposal on the STM32 side to manage each supported BLE services. Although the implementation proposal is ready to be used, the user may implement its own services management.
- **BLE SD FW module**:

  This module is not expected to be modified by the user. It provides an interface to the application to send and receive messages with the nRF51822 system. It requires from the STM32 platform a timer, a UART and a NVM.
- **Timer server** :

  The Timer Server is an implementation proposal of a module that can provide multiple virtual timers all sharing the RTC Wakeup. The BLE Module gets a timer from that module to operate but the user may implement its own timer mechanism to be connected to the BLE Module.
- **NVM driver:**

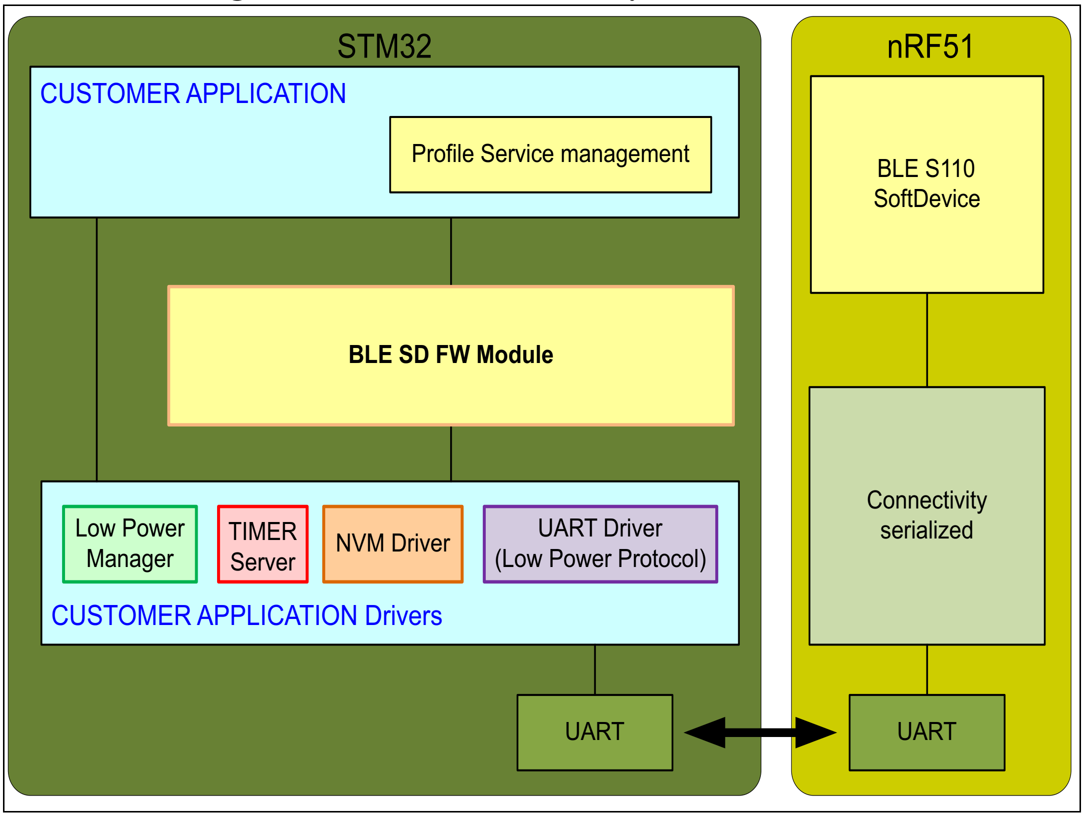
  The Non Volatile Memory driver is a very specific implementation proposal, using the EEPROM, suitable to be used by the BLE SD FW module. It provides an efficient mechanism to minimize the performance impact of the high latency required to write in the EEPROM. The user may implement its own NVM driver to be connected to the BLE SD FW Module.

- **UART driver**:
  The UART driver implements a proprietary low power protocol communication over UART between the STM32 and the nRF51822 system. Although the user may implement its own driver, it is strongly recommended to use the current implementation that has been pre integrated so that it is ready to be used.
- **Low power manager**:
  The UART and NVM drivers are making dynamically requests on the availability of the HS clock. On top of this, the application may have some modules that could require different low power mode over the time. The low power manager provides an implementation proposal of an easy interface to receive all requests regarding power management and compute the lowest power mode the system may enter. The user may implement its own low power manager.

A detailed description on the nRF51822 system is available on the Nordic's website.

The STM32 + nRF51822 BLE system architecture is given in the figure below.

Figure 2. STM32 + nRF51822 system architecture



3 Getting started

3.1 BLE system description

By default the UART communication between the target MCU and ST-LINK MCU is enabled in order to support Virtual Com Port for mbed (SB13 and SB14 ON, SB62 and SB63 OFF).

As the communication between the target MCU and shield or extension board is required, SB62 and SB63 should be ON, SB13 and SB14 should be OFF.

The solution is composed of the following software items:

- STMicroelectronics BLE FW package: three pre-compiled applications
  - stm_dtm_app.hex
  - stm_hrs_app.hex
  - stm_hts_app.hex
- nRF51822 SoftDevice binary (*www.nordicsemi.com*)
- s110_nrf51822_6.0.0_softdevice.hex
- nRF51822 serialized solution from Nordic (*www.nordicsemi.com*)
  - ble_app_connectivity.hex

As the reference platform to run the previous software the following hardware items are used:

- 1 x STM32Nucleo/64 board revC with STM32L152RE
  see Nucleo Rev C Hardware User manual [7] for more details

Note: By default the USART2 communication between the target MCU and ST-LINK MCU is enabled in order to support Virtual Com Port for mbed (SB13 and SB14 ON, SB62 and SB63 OFF). As the communication between the target MCU and shield or extension board is required, SB62 and SB63 should be ON, SB13 and SB14 should be OFF

- 1 x Wavetek Arduino shield with Nordic BLE module nRF51822
  see Wavetek shield User Manual [8] for more details

Android Phone running STM32 BLE Toolbox can be used as demonstration tool.

- STM32_BLE_Toolbox.apk delivered with the solution

3.2 Features

The followings BLE services are supported with the system solution:

- Heart Rate service with Battery monitoring
- Health Thermometer service
- Direct Test Mode entry
- Advertiser Only

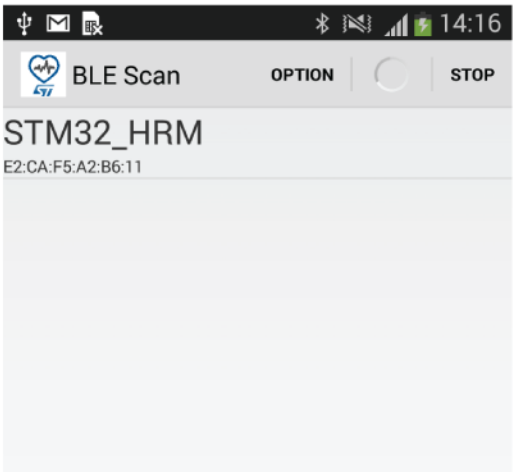
3.3 Hardware/software quick setup

- Plug Wavetek Bluetooth LE shield on STM32Nucleo/64 board via the Arduino connectors. (See Figure at the front page 1)
- Connect the STM32 Nucleo/64 board to the PC with an USB cable (USB cable not provided)
- The PWD LED2 shall light up
- As pre-condition, the nRF51822 S110 Soft Device binary must be programmed. Refer to Nordic Quick Starter Guide documentation. (This part can’t be programmed with the ST-LINK)
- The nRF51822 needs to be programmed with the “Connectivity serialized” application.
- To program the “Connectivity serialized” via ST-LINK
  - ST-LINK CN2 jumpers are OFF
  - Wavetek Bluetooth LE shield RST J5&J6 Jumpers OFF
  - Connect SWDCLK interface pin

    STM32Nucleo/64 ST-LINK SWD CN4 pin 2 to Wavetek Bluetooth LE shield P1/JLINK SWDCLK pin4
  - Connect SWDIO interface pin

    STM32Nucleo/64 ST-LINK SWD CN4 pin4 to Wavetek Bluetooth LE shield J6.1
  - Load “Connectivity” binary on nRF51822 with Keil™ or other tool
- Select BLE feature for STM32_ble_app” application
  - Open “STM32_ble_app” project with MDK-ARM Microcontroller Development Kit by Keil™ or other tool
  - Open stm32l1xx_conf.h to configure your project and compile.
- Program the STM32 with “STM32_ble_app” application
  - Remove SWD interface connections between STM32Nucleo/64 ST-LINK and Wavetek Bluetooth LE shield
  - ST-LINK CN2 jumpers are On
  - Load “STM32L1_App_ble” binary on STM32 with Keil™ or other tool (STM32 ST-LINK Utility)
- Reset the System with Button Reset B2 on Nucleo Board.
- BLE State is advertising
- Use Android or iPhone application to verify the advertiser packets

Figure 3. STM32 + nRF51822 HRM on Android



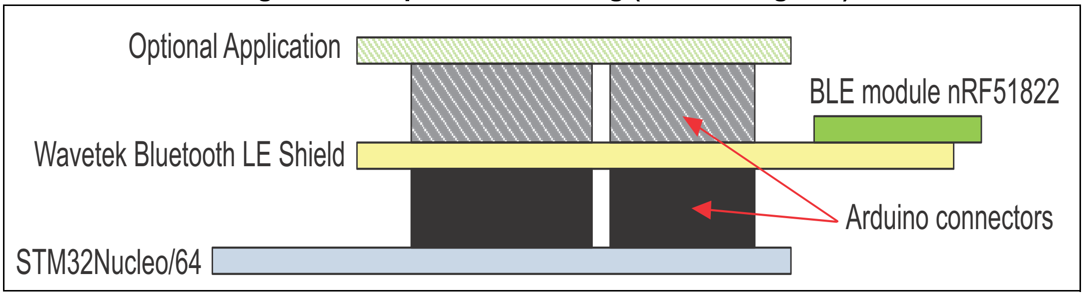
4 Reference platform

4.1 Interface description

The STM32 + nRF51822 system HW platform will consist of a STM32Nucleo/64 board from STMicroelectronics with a plugged nRF51822 Wavetek Arduino shield with BLE Module nRF51822 from Nordic.

In addition there is possibility to add an application module on top of the system via an extended Arduino shield.

Figure 4. HW platform stacking (Arduino signals)



The interface between the STM32 and nRF51822 consist of the following Arduino signals:

Table 2. Interface between the STM32 and nRF51822

nRF51822 Signal	IO	STM32 Signal	IO	Arduino	Comment
RXD	I	USART2_TX, PA2	O	D1	UART data STM32 to nRF51822
TXD	O	USART2_RX, PA3	I	D0	UART data nRF51822 to STM32
CTS	I	USART2_RTS, PA1	O	A1	UART STM32 RX Flow Control
RTS	O	USART2_CTS, PA0	I	A0	UART nRF51822 RX Flow Control
nRESET	I	PC7, GPIO	O	D9	BLE nReset nRF51822 device
VCC	-	-	-	3V3	Power provided by STM32Nucleo/64
GND	-	-	-	GND	Ground

The additional application interface between STM32 and Wavetek board consist of the following Arduino signals:

Table 3. Interface between the STM32 and Wavetek board

Application Signal	IO	Arduino	Comment
PA10, GPIO	IO	D2	GPIO (LED3 - D3)
PB3, GPIO	IO	D3	GPIO (LED2 - D2)
PB5, GPIO	IO	D4	GPIO (LED1 - D1)
PB4, GPIO	IO	D5	GPIO (Button3 - SW3)
PA8, GPIO	IO	D7	GPIO (Button2 - SW2)
PA9, GPIO	IO	D8	GPIO (Button1 - SW1)

4.2 UART 4-wire interface

The UART 4-wire interface is used to communicate between the 2 devices. The HW CTS/RTS flow control signals are also used for the low power control.

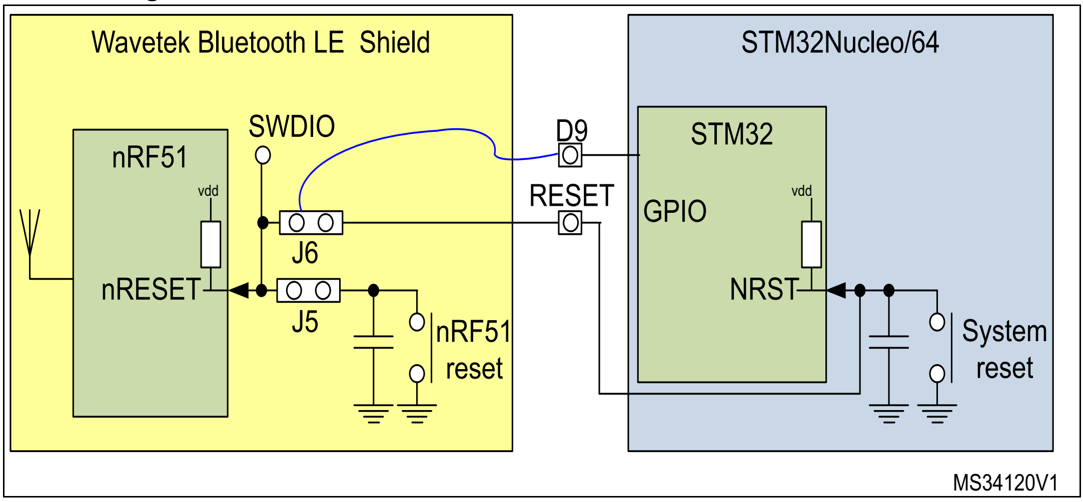
4.3 Reset system

The reset system can be divided into the following functions:

- Power on reset
- System reset

nRF51822 shield (Wavetek) jumper reset J1 shall be OFF.

Figure 5. nRF51822 - STM32 communication interface UART 4-wire



4.3.1 Power on reset

Both the STM32 and the nRF51822 have their own integrated power on reset detector these will guarantee that both the STM32 and the nRF51822 devices are reset correctly on application power on.

4.3.2 System reset

A system reset button is connected to the STM32. A system reset the STM32 which subsequently will generate a reset pulse on the GPIO to reset the nRF51822. This will guarantee that both the STM32 and the nRF51822 devices are reset on a system reset.

To allow STM32 to reset nRF51822 by GPIO, Wavetek Bluetooth LE shield jumpers reset J5 & J6 shall be OFF if D9 and nReset (J6.1) are connected by a cable.

Another option is to reset the system by STM32Nucleo/64 system reset, jumper J5 shall be OFF and jumper J6 shall be ON if the cable is not connected.

4.4 Device programming

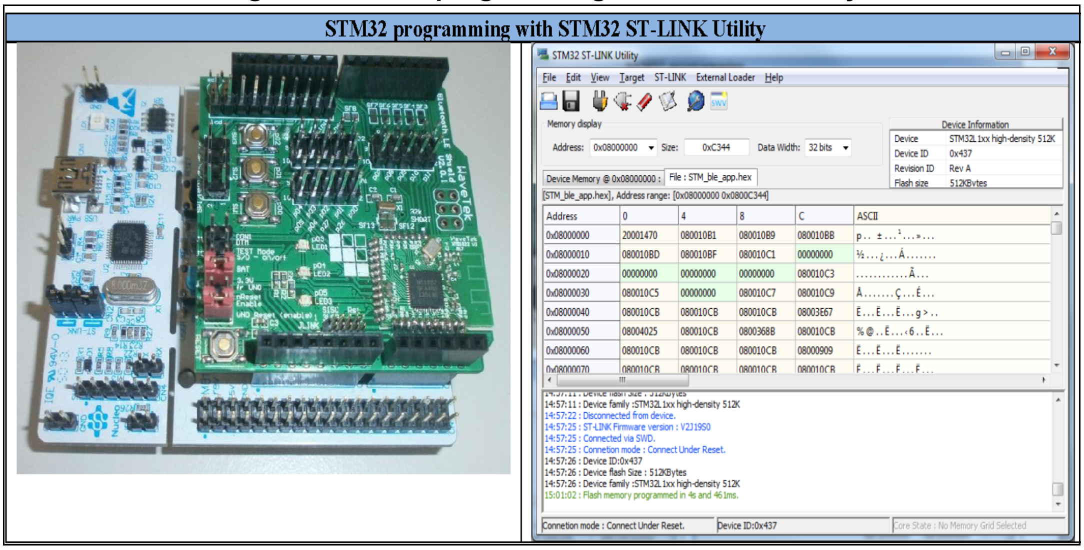
The system solution provides FW download possibility through ST-LINK for both the STM32 and the nRF51822 serialized application. (The nRF51822 “Soft Device” can’t be loaded with the ST-LINK.)

See the STM32Nucleo/64 HW User Manual on how to program the software.

To program the STM32 solution with the ST-LINK/V2, the following procedure has to be respected:

- Remove SWD cable connection
- STM32Nucleo/64 CN2 jumpers ON
- See the example done with the STM32 ST-LINK Utility to program the STM32 on STM32Nucleo/64 Board
  - Connect ST-LINK Utility Tool with option: connect under reset
  - Open “STM_ble_app.hex”
  - Program

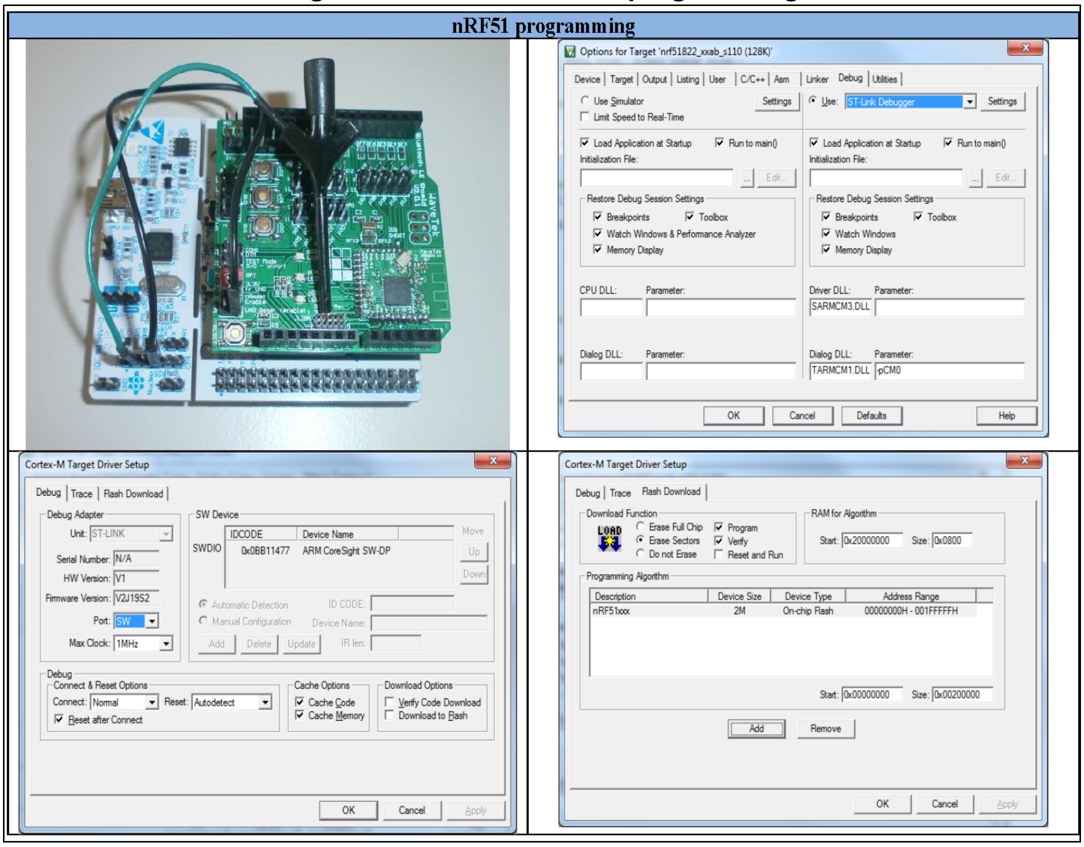
Figure 6. STM32 programming with ST-LINK Utility



To program the nRF51822 solution with the ST-LINK, the following procedure has to be respected:

- STM32Nucleo/64 CN2 jumpers OFF
- Wavetek Bluetooth LE shield RST J5 & J6 Jumpers OFF – nReset between STM32 & nRF51822 not connected
- Connect **JTCK**
  – STM32Nucleo/64 ST-link SWD CN4 pin2 to Wavetek Bluetooth LE shield JLINK SWDCLK pin4
- Connect **SWDI0**
  – STM32Nucleo/64 ST-link SWD CN4 pin4 to Wavetek Bmuetooth LE shield J6 pin1 or JLINK SWDIO pin2
- See the example done with Keil to program the nRF51822 on Wavetek Bluetooth LE shield
  – Use ST-Link Debugger
  – Select Debug port SW
  – Select Programming Algorithm nRF51xxx

Figure 7. nRF51822 device programming



5 Software description

This section provides a description of the interfaces of the different blocks shown in figure2 “STM32 + nRF51822 system architecture”:

- The interfaces between the BLE SD FW module and the STM32 peripherals (UART, Timer, NVM, Clocking)
- The interfaces between the BLE SD FW module and the application
- The project structure folder. It describes the split between the BLE SD FW module as such that does not require any modification by the application and the files that need to be adapted by the application.

Note: In the current delivery, the lowest low power mode supported when BLE is enabled is LP Stop. The application may enter Standby mode when BLE is not enabled.

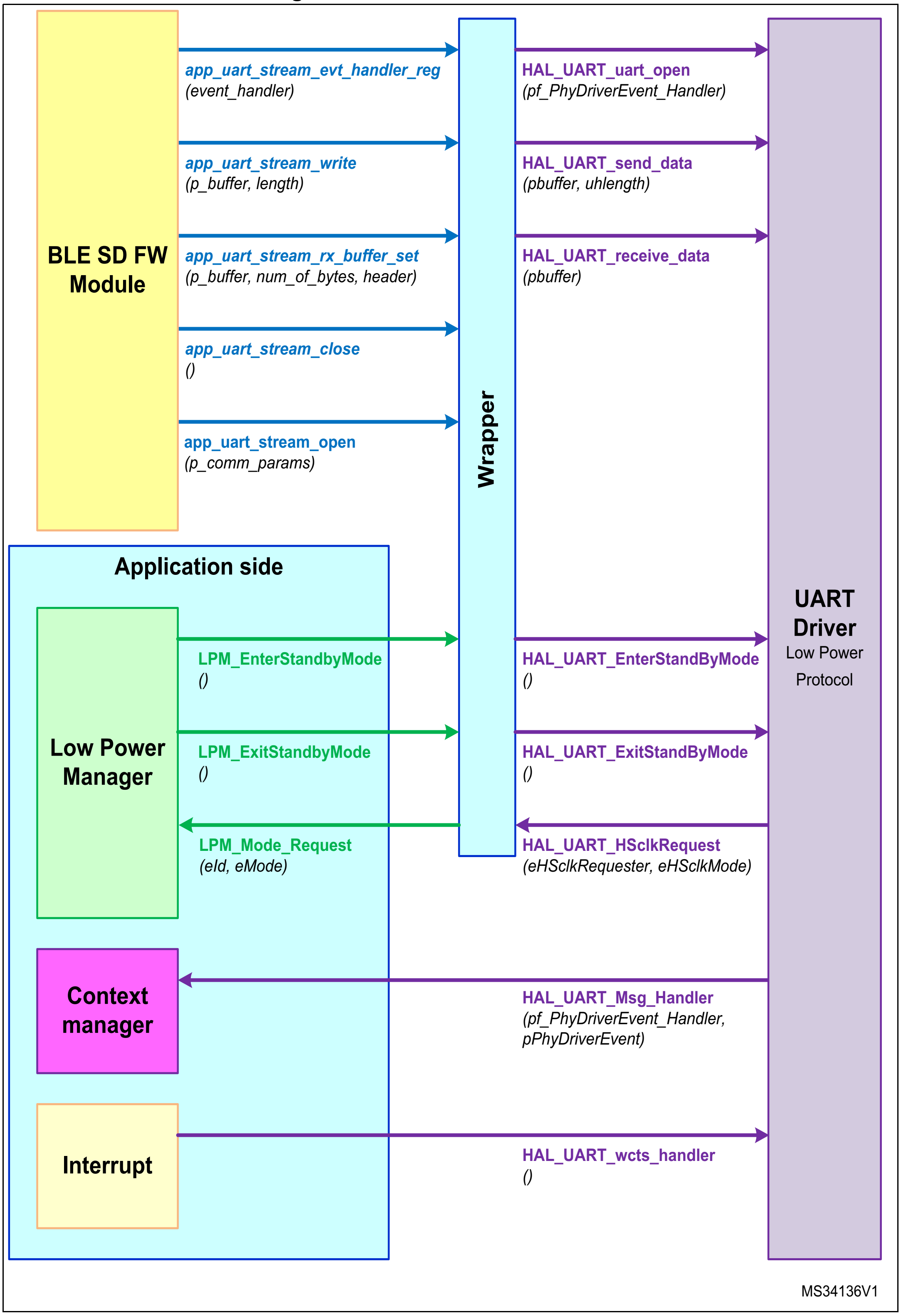
Although it is described below in that chapter, there is no need for the application in the current delivery to:

- Connect the UART CTS on the Wakeup pin
- Call the API HAL_UART_EnterStandByMode() when the device enters Standby mode
- Call the API HAL_UART_ExitStandByMode () when the device exits Standby mode

5.1 UART Interface

The BLE module sends and receives data over the UART interface. The UART driver provides a simple interface to send and receive messages and implements a proprietary protocol to notify the application when the UART may be disabled to enter low power mode.

Figure 8. UART interface overview



5.1.1 BLE SD FW module

The following interfaces shall be mapped to the BLE module. They are not used by the application:

- HAL_UART_uart_open()
- HAL_UART_send_data()
- HAL_UART_receive_data()

As the mapping is not depending on the application but only on the BLE SD FW module interface, a default implementation is done in the file **ble_uart.c**.

There is no need for the application to make any modification.

5.1.2 Low power manager

- HAL_UART_EnterStandByMode()
- This API shall be called by the application before entering Standby mode
- HAL_UART_ExitStandByMode()
- This API shall be called by the application after the system did not succeed entering Standby mode. This is recovering the configuration before the HAL_UART_EnterStandByMode() has been called
- HAL_UART_HSclkRequest()
- This API is notifying the application when the HS clock may be stopped and when it shall be kept enabled. In addition, the application may switch ON the AHB DMA1 clock when the HS clock is requested and switch OFF the AHB DMA1 clock when the HS clocked is not required. This would save additional power when entering SLEEP mode.

5.1.3 Interrupt

- HAL_UART_wcts_handler()

  This interrupt handler shall be called by the application in the EXTI15_10_IRQHandler() interrupt handler only when either USART1 or USART3 is used as interface with the connectivity device. When USART2 is selected, the UART driver is implementing the EXTI0_IRQHandler.

5.1.4 Context manager

- HAL_UART_Msg_Handler()

  This API is notifying the BLE SD FW module that an event occurred on the UART interface. By default, all messages are handled in the **UART interrupt context**. The application may implement an Operating System to change the context priority where the BLE messages may be handled. A signal to the BLE task may be sent from this API to notify a full message has been received over UART.

5.1.5 Configuration

The UART driver is fully configured in the file **hal_uart_driver_configuration.h**.

- The application may select to use USART1, USART2 or USART3 and chose the IO mapping. Default configuration is **UART2** on **PA0**, **PA1**, **PA2**, and **PA3**.
- The application may change the UART baudrate. However, it is recommended to keep the default setting **1Mbits** for power consumption optimization.
- The application may select which wakeup pin is used to get out of Standby mode on request from the nRF51822 connectivity device. Default is **WakeupPin1**. The wakeup pin selected shall be connected to the STM32 CTS line.
- The UART driver uses DMA, UART and EXTI interrupts. The priority set in the NVIC may be changed to allow the application to select the best priority with regard to already existing interrupts and timing requirement. The UART driver is able to run fine whatever priority is set. It is recommended to keep the same order as the default configuration which provides the best latency over UART. Default order is **DMA (the highest), UART and EXTI (the lowest).**

5.1.6 STM32 resource requirements when BLE feature is used

The UART driver requires some hardware resources that shall be made available before enabling the BLE feature. These hardware resources shall be kept enable as long as the BLE feature is enabled. The application should switch OFF all these hardware resources when BLE is disabled to save power.

The hardware resources concerned are:

- The GPIO AHB clock on which the UART is mapped from the file **hal_uart_driver_configuration.h** (GPIOxEN bit in the RCC_AHBENR register)
- The DMA1 AHB clock (DMA1EN bit in the RCC_AHBENR register)
- The DMA1 AHB clock in Sleep Mode (DMA1LPEN bit in the RCC_AHBLPENR register)
- The SRAM AHB clock in Sleep Mode (SRAMLPEN bit in the RCC_AHBLPENR register)
- The SYSCFG APB2 clock ((SYSCFGEN bit in the RCC_APB2ENR register)
- The PWR APB1 clock ((PWREN bit in the RCC_APB1ENR register)
- The APB clock of the USARTx selected in the file **hal_uart_driver_configuration.h** (USARTxEN bit in the RCC_APBxENR register)
- The APB clock in Sleep mode of the USARTx selected in the file **hal_uart_driver_configuration.h** (USARTxLPEN bit in the RCC_APBxLPENR register)

5.1.7 Integration

To include the UART low power driver in an existing application using BLE SD FW, the application shall:

1. Set the configuration required (USART, IOs, baudrate, wakeup pin and interrupt priority) in the file **hal_uart_driver_configuration.h**
2. Include the file **hal_uart.c** in the project
3. Map the UART BLE interface on the HAL UART driver (This step is already done in the wrapper implemented in the file **ble_uart.c.** The application may just include that file in the project)
4. Update the application low power manager to call the **HAL_UART_EnterStandByMode()** before entering standby mode (This step is done in the low power manager provided in the example). If standby mode is not supported in the application, there is nothing to do.
5. Update the application low power manager to call the **HAL_UART_ExitStandByMode()** when the CPU wakes up after failing entering standby mode (This step is done in the low power manager provided in the example). If standby mode is not supported in the application, there is nothing to do.
6. Implement the API **HAL_UART_HSclkRequest()** to handle the HS clock requirement and AHB DMA1 clock according to the low power UART driver activity.
7. When either USART1 or USART3 is selected, update the EXTI15_10_IRQHandler() to call the **HAL_UART_wcts_handler()** when the CTS line has triggered the interrupt. The . HAL_UART_wcts_handler() shall not be called if the CTS line is not the source that triggers the EXTI15_10_IRQHandler(). When USART2 is selected, there is nothing to do and the low power UART driver is taking care of it.
8. When an Operating System is used, the **HAL_UART_Msg_Handler()** may be used to send a signal with the associated parameter to handle the message in a different context than the UART interrupt. This API is executed within the UART interrupt handler context.

5.2 Timer interface

The BLE SD FW module uses a timer to timeout the connection parameters negotiations with the remote device. In order to save power consumption, this timer should be running on either the LSI or LSE LPO clock.

The timer server provides the following features:

- Up to 255 virtual timers (or less due to RAM limitation)
- Single shot and Repeated mode
- Stop a virtual timer and restart it with a different timeout value
- Delete a timer
- Timeout up from 1 to 65535 ticks

The timer server provides multiple virtual timers sharing the Wakeup TIMER. Each virtual timer may be defined to be a single shot timer or a repeated timer. When a repeated timer elapses, the user is notified and the virtual timer is restarted automatically with the same timeout. When a single shot timer elapses, the user is notified and the virtual timer is set to the pending state. The user may stop a virtual timer and restart it with a different timeout value. When a virtual timer is not needed anymore, the user should delete it to free the slot in the timer server.

Figure 9. Timer interfaces overview

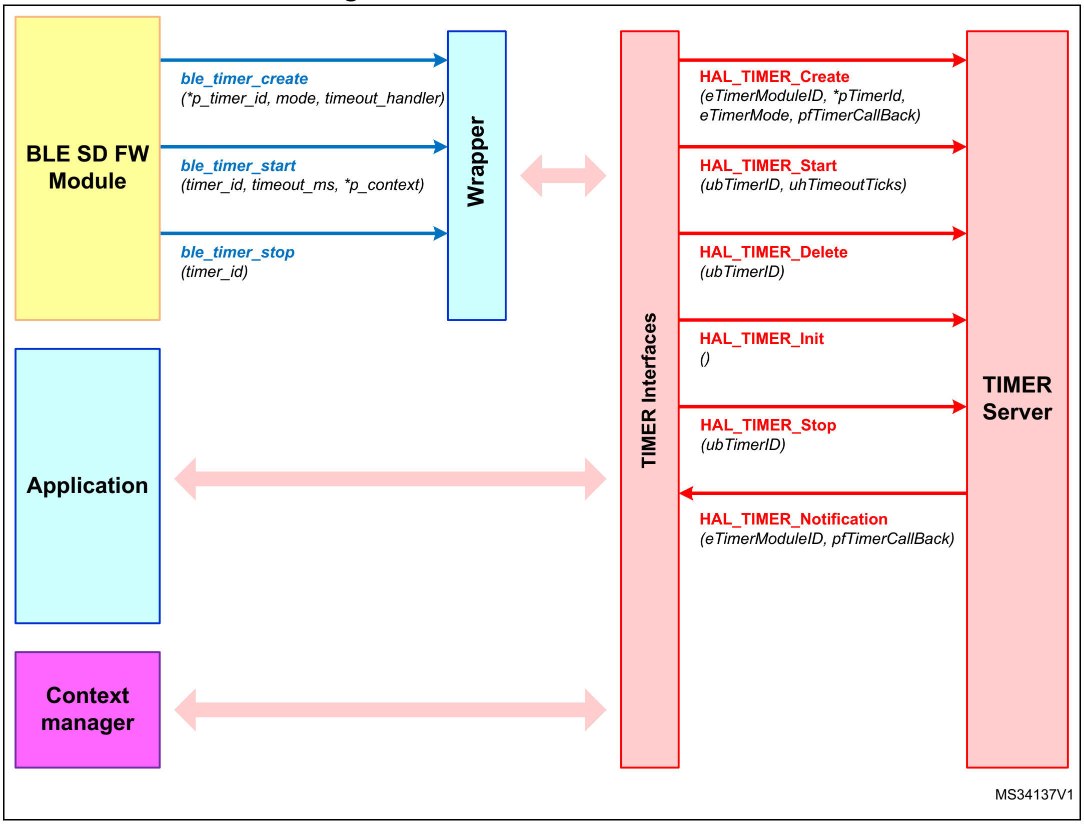
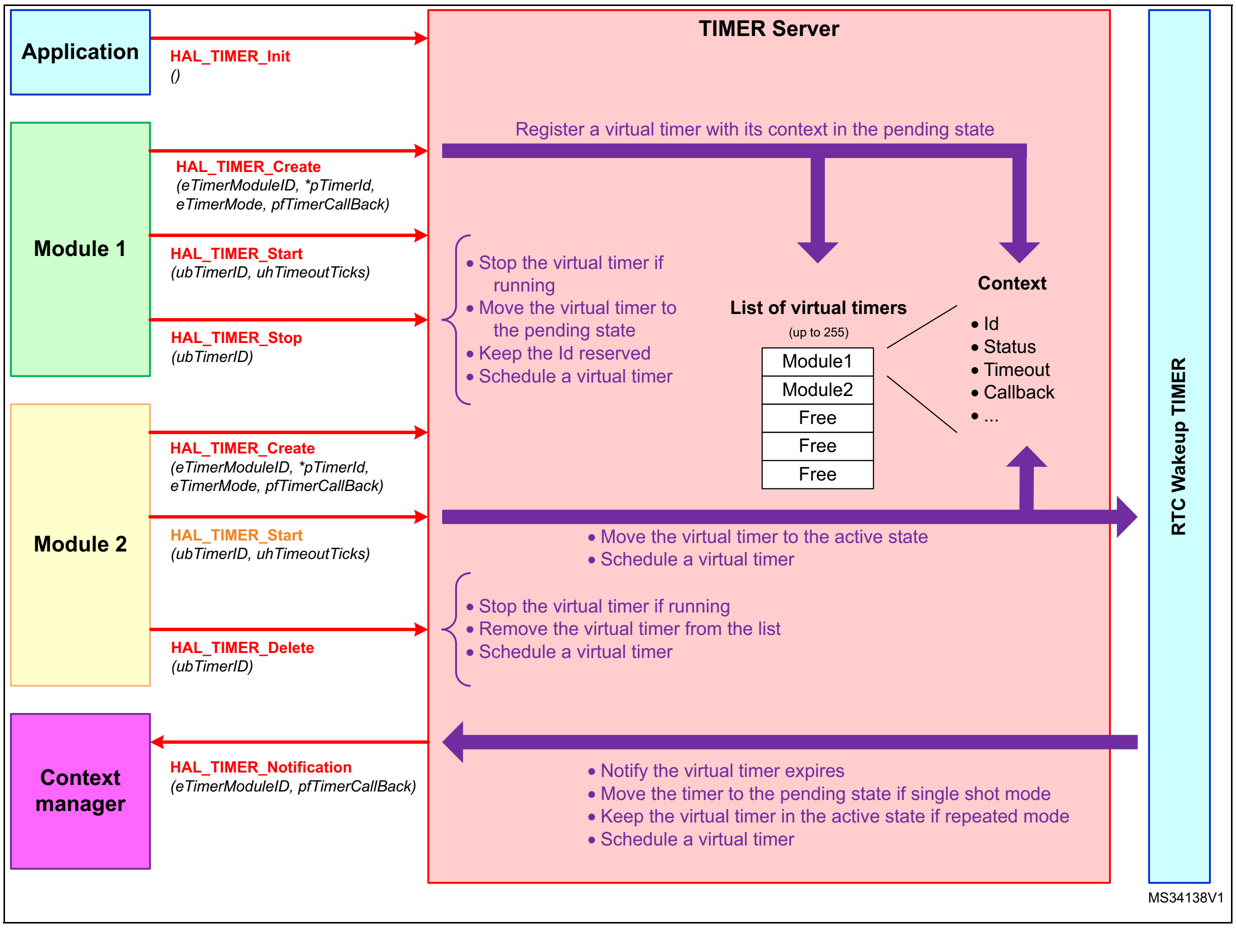


Figure 10. Timer design overview



5.2.1 BLE SD FW module

The following interfaces from the BLE SD FW module shall be mapped to the timer server:

- ble_timer_create()
- ble_timer_start()
- ble_timer_stop()

A default mapping to the timer server is done in the file **ble_timer.c**.

There is no need for the application to make any modification.

5.2.2 Initialization

- HAL_TIMER_Init() :
  This API shall be called by the application before any timer is requested to the timer server. It configures the RTC module to be connected to the LSI input clock.

5.2.3 User module

- HAL_TIMER_Create()

  The user shall call this API to create a timer. Once created, the timer is reserved to the module until it has been deleted. When creating a timer, the user shall specify the mode (Single shot or Repeated), the Callback to be notified when the timer expires and a Module ID to identify in the timer interrupt handler which module is concerned.

  In return, the User gets a timer ID to handle it.
- HAL_TIMER_Start()

  This API shall be used to start a timer. The timeout value is specified and may be different each time.

  When the timer is in the Single shot mode, it will move to the pending state when it expires. The user may restart it at any time with a different timeout value

  When the timer is in the Repeated mode, it always stay in the running state. When the timer expires, it will be restarted with the same timeout value.

  This API shall not be called on a running timer.
- HAL_TIMER_Stop()

  This API may be used to stop a running timer. A timer which is stopped is move to the pending state.

  A pending timer may be restarted at any time with a different timeout value but the mode cannot be changed.
- HAL_TIMER_Delete()

  This API should be used when a timer is not needed anymore by the user. A deleted timer is removed from the timer list managed by the timer server. It cannot be restarted again. The user has to go with the creation of a new timer if required and may get a different timer id.

5.2.4 Context manager

- HAL_TIMER_Notification ()

  This API notifies the application that a timer expires. This API is running in the **RTC Wakeup interrupt context**. The application may implement an Operating System to change the context priority where the timer Callback may be handled. This API provides the module ID to identify which module is concerned and to allow sending the information to the correct task.

5.2.5 Configuration

Some parameters of the Timer server may be configured in the file **hal_timer.h**.

- **MAX_NBR_CONCURRENT_TIMER**: The user may define the maximum number of virtual timer supported. It shall not exceed 255. Default configuration is **8**
- **NVIC_UART_RTC_WAKEUP_IT_PRIORITY**: The user may define the priority in the NVIC of the RTC_WKUP interrupt handler that is used to manage the wakeup timer. Default configuration is **3**.
- **eHAL_TIMER_ModuleID_t**: The user shall define the list of Module Id that the timer server shall support.

Before running the Timer server, the application shall:

- Configure the input clock of the RTC and the clock prescaler. This is defining the timer tick. In the current implementation, the timer tick is equal to the LSI input clock divided by 16 (**432us**). It may provide a timeout value up to **28s.**
- Keep the access always available in the RTC register while the Timer server is running
- Keep disable the write protection in the RTC block while the Timer server is running

5.2.6 Integration

To include the TIMER server in an existing application, the application shall:

1. Include the file **hal_timer.c** in the project
2. Map the Timer BLE interface on the HAL Timer server (This step is already done in the wrapper implemented in the file **ble_timer.c.** The application may just include that file in the project)
3. When an Operating System is used, the **HAL_TIMER_Notification()** may be used to send a signal with the associated parameter to handle the Callback in a different context than the RTC Wakeup interrupt. This API is executed within the RTC Wakeup interrupt handler context. This API shall be implemented by the application.

The timer created by the BLE SD FW module is deleted on a disconnect event. The application shall first disconnect the link before switching OFF the nRF device to make sure the reserved timer for BLE is deleted.

5.3 NVM interface

The BLE SD FW module requires storing some parameters in a non-volatile memory. While the firmware is running, the BLE SD FW module keeps a copy in the RAM memory. This copy in RAM is uploaded at BLE initialization with the data from the NVM. When a parameter is updated, a store to NVM is requested. There is no read access to the NVM from the BLE SD FW module except at initialization. The BLE SD FW module always reads the parameters from the RAM copy.

The NVM driver has been designed to especially fit the BLE behavior. Due to the high latency on writing data in the NVM, the driver stores in a queue the operation (write or erase) requested and releases the CPU to keep on running code. The NVM driver writes the data in the NVM and waits for the completion interrupt. On each interrupt, the NVM driver writes new data until there is no more data to be written.

As the NVM drivers stores only the operation to execute and the reference of the data, these data shall be kept available in the RAM memory.

There is no feedback to the application of the completion of an operation.

During the programming of the NVM, the HS clock shall be kept available. The NVM driver notifies the application at the start end the end of the programming the lowest power mode supported.

Figure 11. NVM interfaces overview

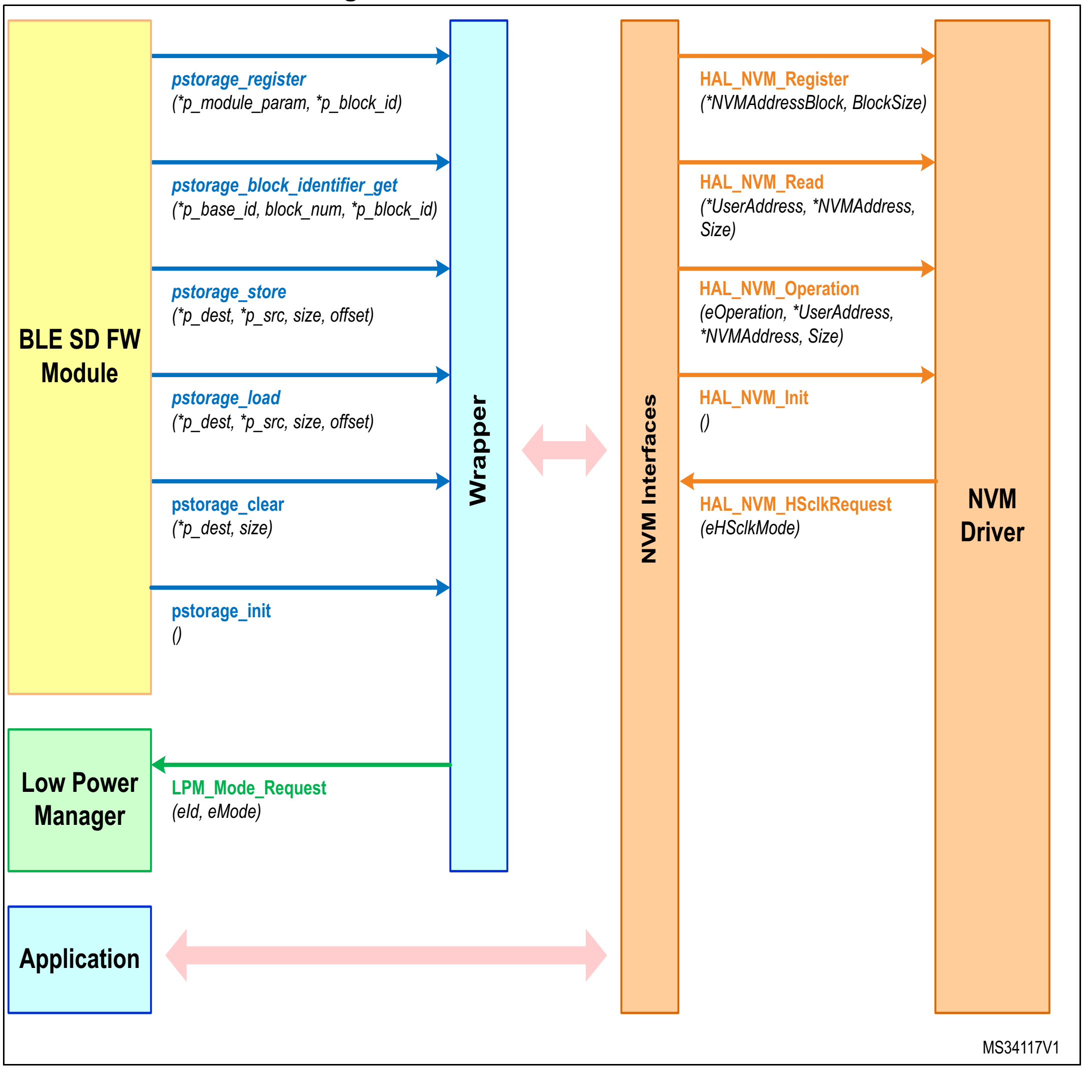
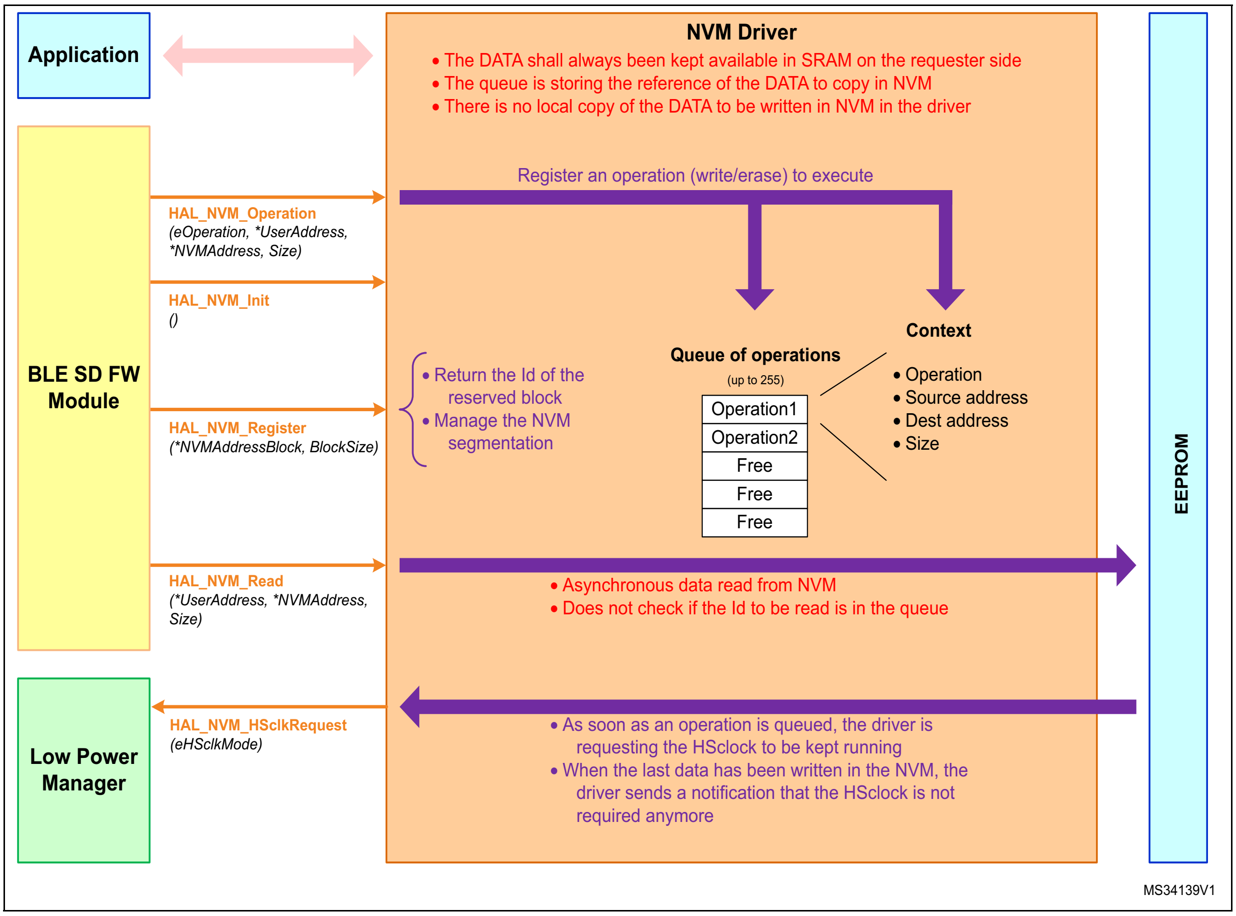


Figure 12. NVM design overview



5.3.1 BLE SD FW module

The following interfaces from the BLE SD FW module shall be mapped to the NVM driver:

- pstorage_register()
- pstorage_block_identifier_get()
- pstorage_store()
- pstorage_load()
- pstorage_clear()
- pstorage_init()

A default mapping to the timer server is done in the file ble.nvm**.c**.

There is no need for the application to make any modification.

5.3.2 Initialization

- HAL_NVM_Init()
  This API shall be called before any request is done to the NVM driver.

5.3.3 Operations

- HAL_NVM_Register()

  This API reserves a block of the required size in the NVM and returns the base address to the user.
- HAL_NVM_Operation()

  This API is used to either write or erase data in the NVM.

  When a “write” operation is requested, the user shall provide the address of the data to be copied, the NVM destination address and the amount of data to be written. The data shall be kept available at any time from the source address as the NVM driver does not make temporary copy.

  When an “erase” operation is requested, the user shall provide the base address in NVM of the data to be erased and the amount of data to erase. The source address parameter when an “erase” operation is requested is not considered by the NVM driver and can be set to any value.
- HAL_NVM_Read()

  This API is used to read an amount of data from the NVM.

  The user shall provide the NVM start address, the destination address where to copy the data and the amount of data to copy.

  The NVM driver does not check whether the section to be read from the NVM may be in the operation queue to be written or not. It is the responsibility of the application to not read a section if it may be on the way to be written.

5.3.4 Low power manager

- HAL_NVM_HSclkRequest()

  This API notifies the application when the HS clock may be stopped and when it shall be kept enabled. The NVM driver sends the notification when the operation queue gets a command and when the operation queue is empty.

  There is no notification to the application for each command completed but this API may be used as well to make sure ALL commands (Write/Erase) that have been sent to the NVM driver have been completed.

5.3.5 Configuration

Some parameters of the NVM driver may be configured in the file **hal_nvm.h**.

- **NVM_OPERATION_QUEUE_SIZE**: The user may define the maximum number of operations to be queued. It shall not exceed 255. Default configuration is **30**
- **NVM_BASE_ADDRESS**: The user may define the base address in the NVM from where the NVM driver may allocate blocks to the user. There is no block size limitation checking in the NVM driver. Default configuration is **0x08082000** (This is the start address of the EEPROM in bank2 as the code is by default running in bank1. This prevents latencies when the NVM is written while the code is running from FLASH).
- **NVM_IT_PRIORITY**: The user may define the priority in the NVIC of the FLASH interrupt handler that is used to notify the NVM driver the end of programming. Default configuration is **3**.

5.3.6 Integration

To include the NVM driver, the application shall:

1. Set the configuration required in the file **hal_timer.h**
2. Include the file **hal_nvm.c** in the project
3. Map the pstorage BLE interface on the HAL NVM driver (This step is already done in the wrapper implemented in the file ble.nvm**.c.** The application may just include that file in the project)
4. Implement the API **HAL_NVM_HSclkRequest()** to handle the HS clock requirement according to the NVM driver activity.

5.4 Low power manager interface

When the BLE feature is used, it requires the UART and NVM driver to be supported. Both drivers have some requirements on the availability of the HS clock. The request comes asynchronously to the application. In addition, the application may have some requirements on the availability of the HS clock that would come as well asynchronously to both the UART and NVM driver requests. There is a need for the application to implement a module that would take care of all these requirements and to compute the lowest power mode the system may enter at any time.

The low power manager provides a simple interface to receive the input of different users (up to 32) and computes the lowest power mode the system may enter. It provides as well hooks to the application before entering or on exit of low power mode.

Figure 13. Low power manager interfaces overview

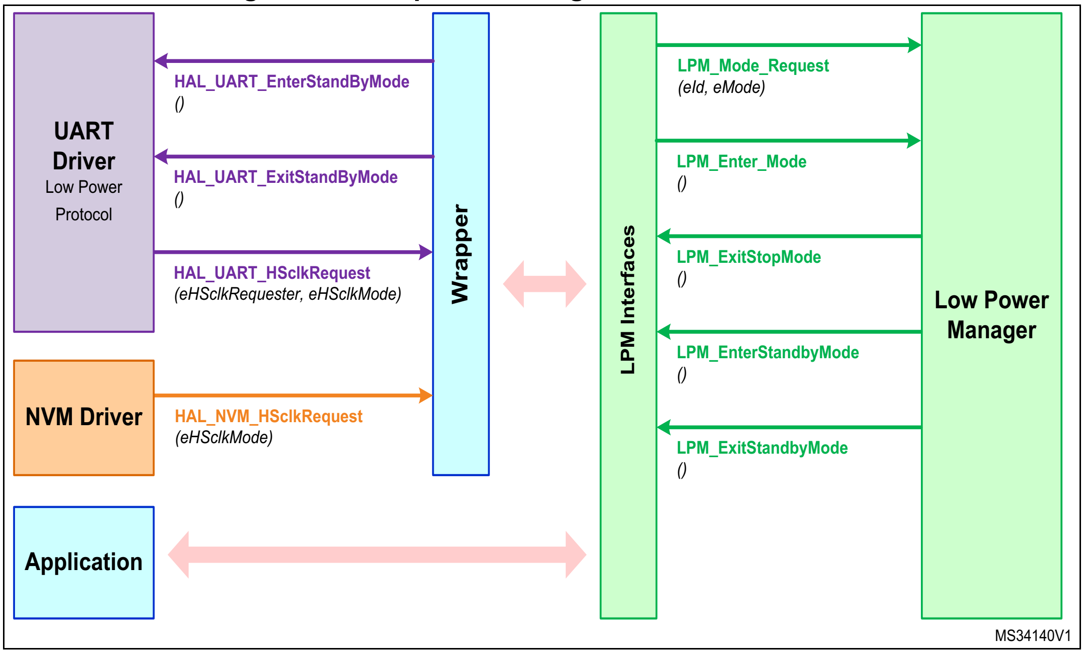
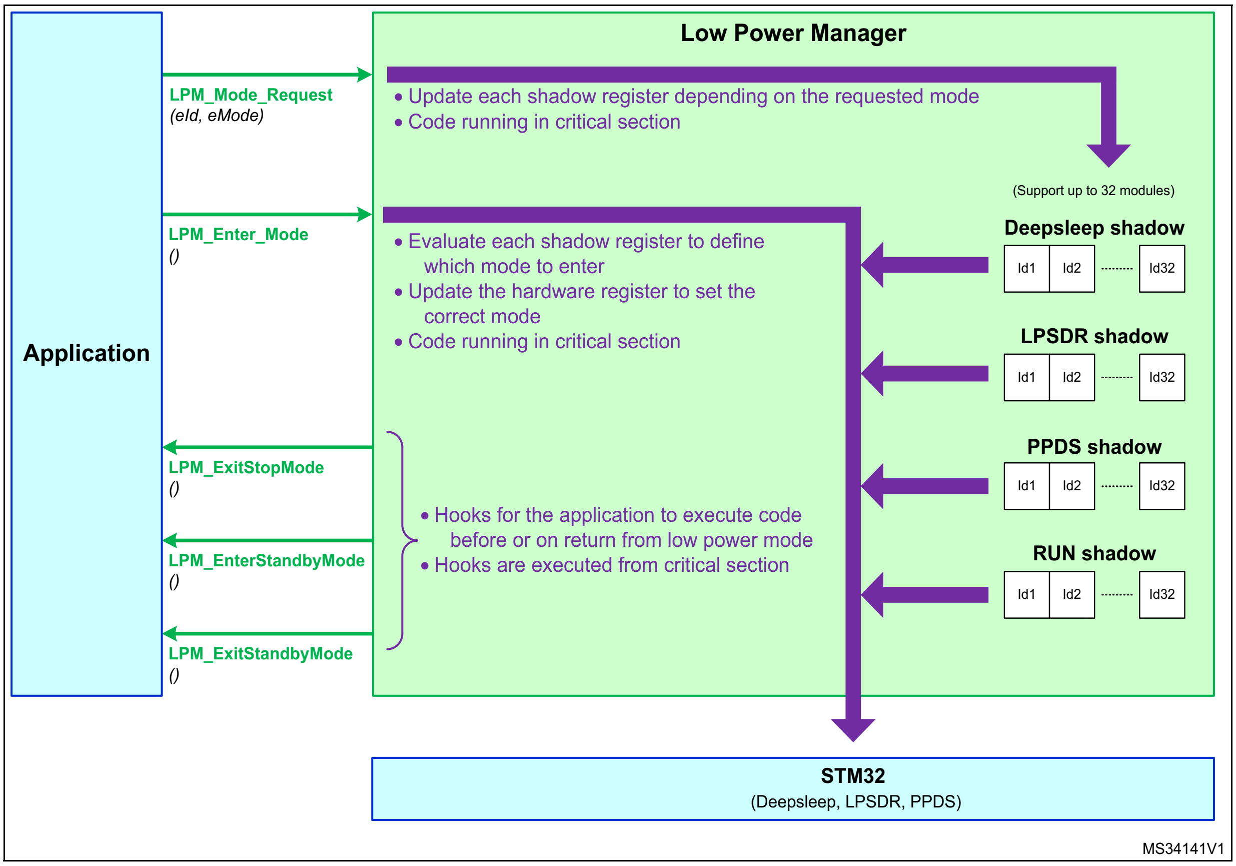


Figure 14. Low power manager design overview



5.4.1 API

- LPM_Mode_Request()

  This API shall be used by all users to specify the lowest low power mode it supports.
- LPM_Enter_Mode()

  This API shall be used by the application when there is no more code to execute so that the system may enter low power mode.
- LPM_ExitStopMode()

  This API is called by the low power manager in a critical section (PRIMASK bit set) to allow the application to implement dedicated code before getting out from the critical section.

  This is the location where the application should reconfigure the clock tree as the system gets out from Stop mode with the MSI clock selected as source clock.
- LPM_EnterStandbyMode()

  This API is called by the low power manager in a critical section (PRIMASK bit set) to allow the application to implement dedicated code before entering standby mode.

  This is the location where the application could save data in the retention memory as the RAM memory content will be lost.
- LPM_ExitStandbyMode()

  This API is called by the low power manager in a critical section (PRIMASK bit set) to allow the application to implement dedicated code before getting out from Standby mode.

  This can only happen when the Standby mode is finally not entered. In that case, the application may reverse some configurations done before entering Standby mode. When Standby mode is successful, the system is reset when getting out from this low power mode.

5.4.2 Configuration

The application shall configure in the file **stm32l1xx_lpm.h** the Id for each user supported and the list of low power mode supported.

The default lowest power mode supported for all users is **Standby mode**.

5.4.3 Integration

To include the low power manager driver, the application shall:

1. Set the configuration required in the file **stm32l1xx_lpm.h**
2. Include the file **stm32l1xx_lpm.c** in the project.

5.5 Exit from standby mode

The user may select in the UART configuration which Wakeup pin to use to exit standby mode on request of the nRF51822 system. When several Wakeup pins are configured on the STM32 system, the application shall manage the other wakeup pins. The wakeup pin selected for the BLE feature is fully managed by the UART driver and the application does not need to implement dedicated code for this.

5.6 BLE SD FW module firmware integration in application

The **STM32_ble_app** project provides an application using the BLE SD FW module based on a scheduler. It comes with a Timer server, NVM driver and low power protocol UART driver to interface with the STM32 platform. Whenever the BLE function is enabled, the STM32 shall not enter standby mode, the application shall take care that STOP mode is the lowest low power mode used.

The user may either implement its own services or integrate those which are provided in the project.

5.6.1 BLE startup

When the nRF device is in OFF mode, the application shall execute following steps to get BLE ready to be used:

1. **Enable the TIMER and NVM services.**

   The NVM driver is enabled at the same time the BLE SD FW module is initialized. There is no additional implementation required in the application

   To enable the timer server, the application shall called the API HAL_TIMER_Init().
2. **Enable hardware resources required for the BLE low power protocol UART driver**

   All resources as described in “6.1.6 STM32 resource requirements when BLE feature is used” are enabled in the API UART_BLE_Init(). The user may update the content of this API depending on its own implementation.
3. **Reset and initialize the nRF device**

   The nRF device shall be first reset before running any initialization. The reset is applied when the API connectivity_chip_reset() is called. The firmware drives low the IO connected to the nRF nRESET pin for a minimum amount of time. After that time, the firmware configures the IO to analog mode to release the nRF nRESET pin. The nRF nRESET pin should not be driven high to release the reset. The reset timing requirement may be found on the Nordic website.

   After the nRF device has been reset, the firmware runs the nRF initialization with the API ble_app_main_init_Reset(). All details on the nRF initialization may be found on the Nordic website.

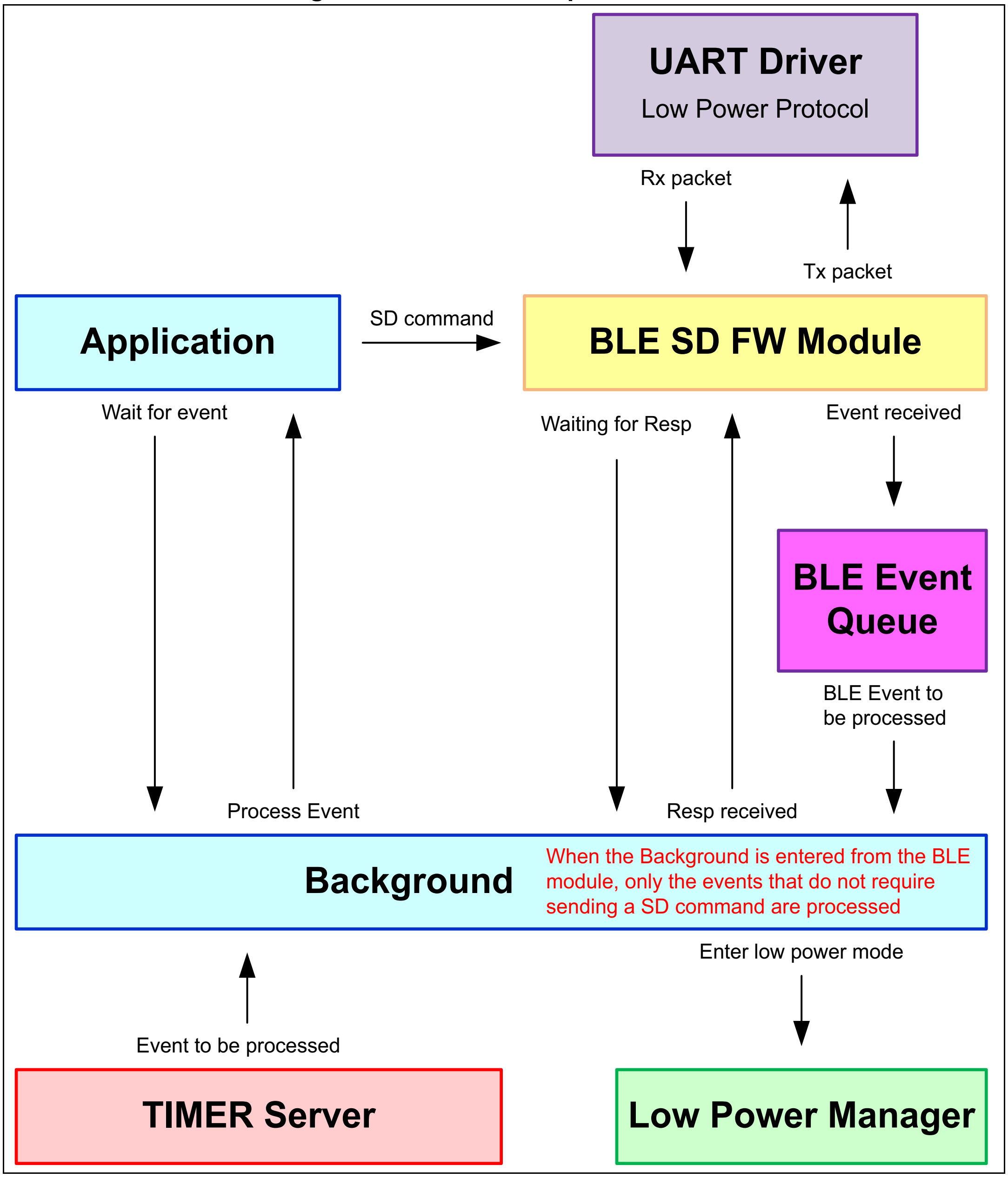
5.6.2 Communication with the BLE SD FW module

The application sends requests or data to the BLE SD FW module with a SD command.

When a SD command is sent, the application shall wait for the response before sending another SD command. On each SD command, the BLE SD FW module calls the API blocking_resp_wait() to pause the BLE processing until the response is received. The application may enter low power mode until the response is received. In addition, all events that do not require sending a SD command may be processed as well over that time.

As described below, the current project provides a scheduler where the API blocking_resp_wait() is implemented in the file blocking.c to enter the background task when waiting for a response. When the firmware enters the background task from the BLE SD FW module, all events that do not require sending a SD command are processed.

Figure 15. Scheduler implementation

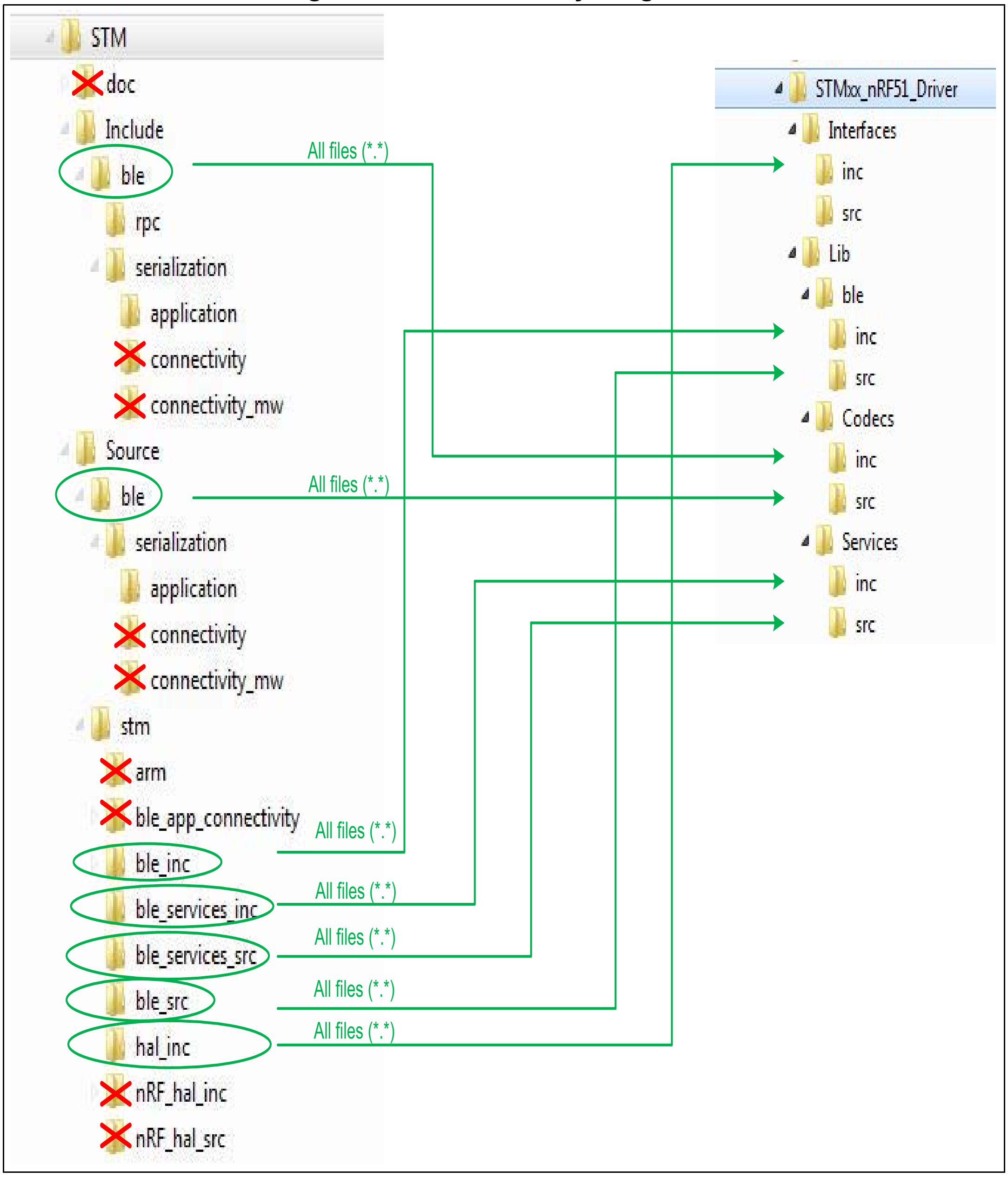


5.7 Nordic delivery integration

To integrate the BLE Nordic delivery in the STM32 project, the steps are:

1. Delete all folders from the Nordic delivery with a red cross in the figure below
2. Copy all files from the source delivery to the STM project as described below

Figure 16. Nordic delivery integration



- The “Interfaces” folder contains the header interfaces between the BLE and the STM32 drivers in the “inc” folder and the implementation in the “src” folder. As long as the interfaces in the “inc” did not change, there is no reason to change the existing implementation in the “src” folder
- The “Lib” folder contains all internal BLE files that are not required to be changed by the application. The user shall include the relevant headers in the project depending on which command and services are used in the application

As long as the interfaces with the BLE SD FW module are not changed, the integration of a new Nordic delivery has no impact on the application.

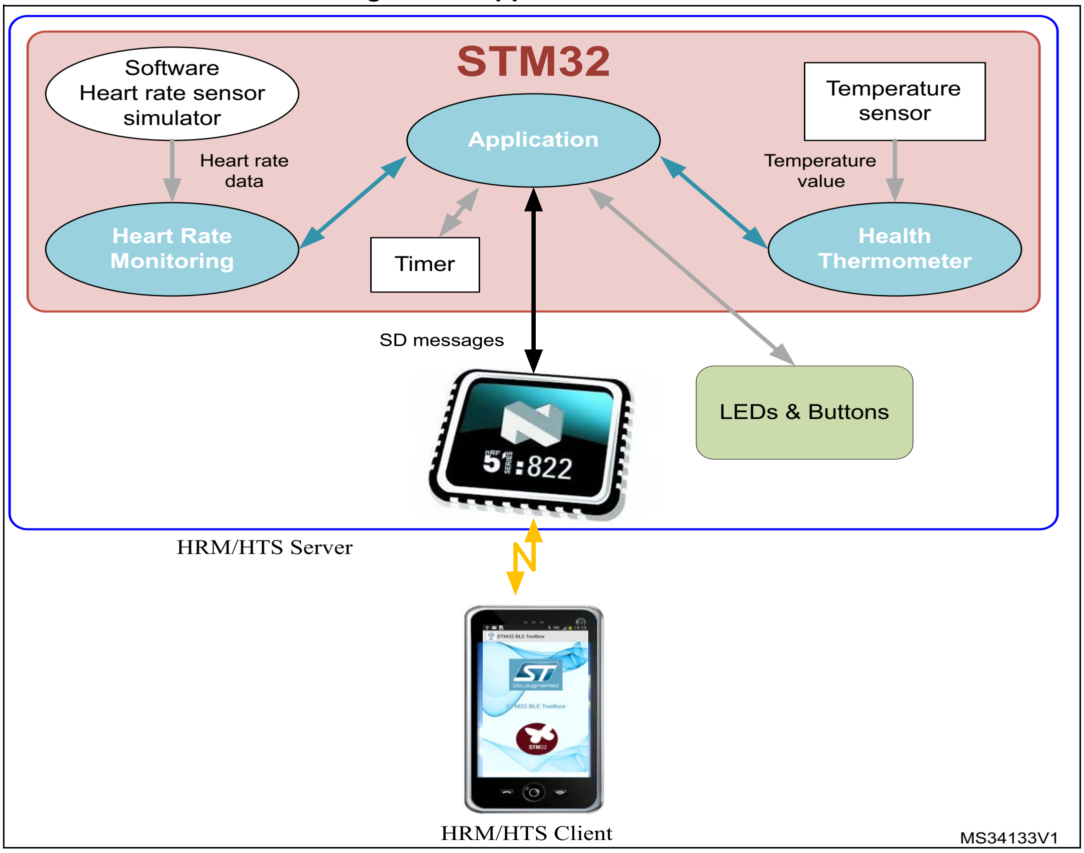
6 BLE application configuration

The Nordic nRF51822 SDK provides examples how to manage the different profiles and Services.

To allow customers to verify BLE profiles and services, two applications are available in the STM32 “Project” directory:

- Direct Test Mode application
  – “STM_dtm_app” project
- Heart Rate Monitoring/Health Thermometer application
  – “STM_ble_app” project

Figure 17. Application overview



6.1 Architecture

The application part contains the code source to manage the different BLE services. To use a BLE profile, several services are initialized. Next, the service manages the values characteristics, the notifications and BLE events by using the Soft Device functions and events.

The files “ble_services”.c are reused from the Nordic SDK.

6.2 Direct test mode application

The Direct Test Mode application is a firmware example that manages to initialize the nRF51822 to enter Direct Test Mode and redirect the nRF51822 UART to the tester.

- Project : **STM_dtm_app**

  To initialize the DTM on nRF51822 side, the following function sends information to the nRF51822:
- ble_dtm_init (&uart_params)

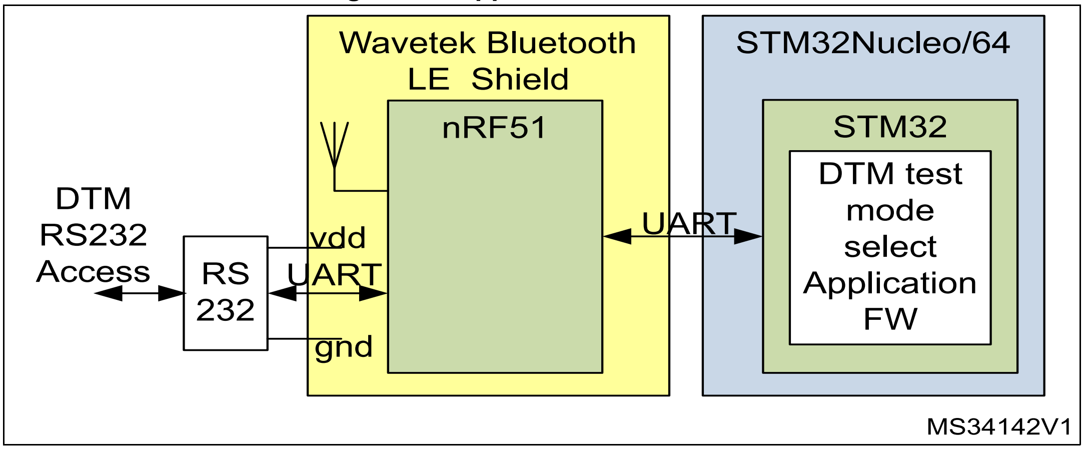
  The DTM uart parameters are configured by the following defines:
- #defineDTM_RX_PIN_NUMBER 10
- #defineDTM_TX_PIN_NUMBER 11
- 57600 is the default Uart Baud rate

Next, the STM32 after having sent the DTM command goes to Standby.

When in DTM test mode the UART between the STM32 and nRF51822 does no longer operate. The nRF51822 communicates directly to the BLE tester via the UART on the configured set of IO's.

If needed the conversion from 3.3V to RS232 is done outside the Wavetek Bluetooth LE shield by a RS232 to 3.3V TTL Converter. (i.e. SerialComm TTL-232-33P).

Figure 18. Application DTM access



6.3 Heart rate monitoring / Health thermometer application

The "**STM_ble_app**" project allows the customers to enable both the Heart Rate service or/and the Health Thermometer service.

In case both "compilation switches" are not used, the firmware just initializes and starts the advertiser parameters.

The configuration is done with **stm32l1xx_conf.h** file.

- #define APP_HRS
- #define APP_HTS

The application supports the bond manager. The identification information exchanged between central device and peripheral device are store in memory to be used for identity verification when they reconnect in the future.

After the startup of the application, pushing the button “B1” erases all the stored bonding information. It is also recommended to delete the bonding information on the remote device.

Once a BLE connection is done, the button “B1” is used to update and provide the Heart value to the connectivity device.

Table 4. configuration of the BLE application

	ADV only	HRS Only	HTS only	HRS & HTS
Device name	STM32_ADV	STM32_HRM	STM32_HRS	STM32_HRM_HTS
Manufacturer Name	STM32			
Advertising Interval	40ms			
Connection Interval(1)	NA	1s		
Conn Sup Timeout	NA	4s		
BLE Services	NA	Heart rate Battery device Information	Health Thermometer	Heart Rate Battery Device Information Health Thermometer

1. The connection Interval is proposed by the server once service notification is requested by the Client.

6.3.1 Advertising application

In case, both “APP_HRS” and “APP_HTS” are not defined, the application manages the advertising interval, the device name, the GAP configuration, and connection establishment according to the following parameters. The application also manages the connection, disconnection and timeout events.

6.3.2 Heart Rate application

Once the “APP_HRS” is defined, the application includes:

- Heart Rate Service
- Device Information Service
- Battery Service

The application reuses the Nordic Services code example.

- ble_hrs.c
- ble_dis.c
- ble_bas.c

The module ble_hrs.c implements the Heart Rate Service with the Heart Rate Measurement, Body Sensor Location and Heart Rate Control Point characteristics. During initialization it adds the Heart Rate Service and Heart Rate Measurement characteristic to the BLE stack database. It also adds the Body Sensor Location and Heart Rate Control Point characteristics.

The module ble_dis.c implements the Device Information Service. During initialization it adds the Device Information Service to the BLE stack database. It then encodes the supplied information, and adds the corresponding characteristics.

The module ble_bas.c implements the Battery Service with the Battery Level characteristic. During initialization it adds the Battery Service and Battery Level characteristic to the BLE stack database. It also adds a Report Reference descriptor to the Battery Level characteristic (used when including the Battery Service in the HID service).

By calling the previous modules, the application initializes the services.

- Initialize Heart Rate Service
  – Sensor Location : Finger (can be changed easily by a define)
  – Security Level for heart rate service measurement attribute
  – Security Level for body sensor location attribute
- Initialize Battery Service
  – Security Level for battery characteristics attribute
  – Security Level for battery report read attribute
- Initialize Device information Service
  – Manufacturer Name : “STM32”

The application manages the GAP configuration, and connection establishment according to the Bluetooth Specification Heart Rate Profile.

The Heart Rate values are provided by an application sensor module (**ble_sensorsim.c**”), there is no external sensor.

Different timers are started to simulate:

- Battery measurement
- Heart Rate measurement
- RR interval
- Sensor contact detection

At the first connection, the parameters are provided by the client side.

The connection interval is requested by the application once the heart rate notification is enabled by the server. (ble_conn_param.c)

6.3.3 Health thermomether application

Once the “APP_HTS” is defined, the application includes:

- Health Thermomether Service

  The application reuses the Nordic Services code example.
- ble_hts.c

  The module ble_hts.c implements the Health Thermometer Service to provide to the Client the temperature in Degree Celsius, the Temperature Type and the Time Stamp.

  The temperature value is measured by the internal STM32 temperature sensor. There is no external sensor.

  At each indication enabled by the remote, the temperature is measured, provided to the nRF51822 and finally transferred to the remote.

  The connection parameters are provided by the client side and may be changed by the application.

7 Performances results

This chapter relates system performance measured for power consumption & data throughput. It describes efficiency of the overall system in term of low power consumption along with maximum data throughput achievable.

7.1 Static power consumption

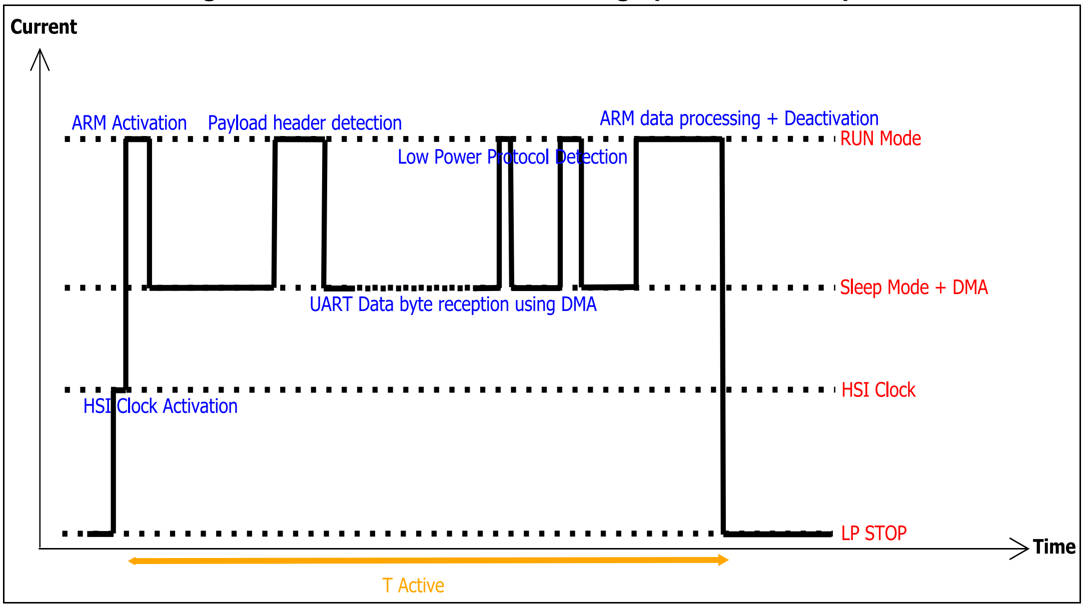
The referenced STM32 Static power consumption numbers such as Standby mode, Low Power Stop Mode, are to be taken from the STM32 Datasheet reference [6].

7.2 SD command exchange power consumption profile

Next graph shows in detail power values diagram of Power Consumption on STM32 devices for UART message processing through the BLE SD FW MODULE while:

In UART Receiving Mode by Current vs Time using #APP_HRS only:

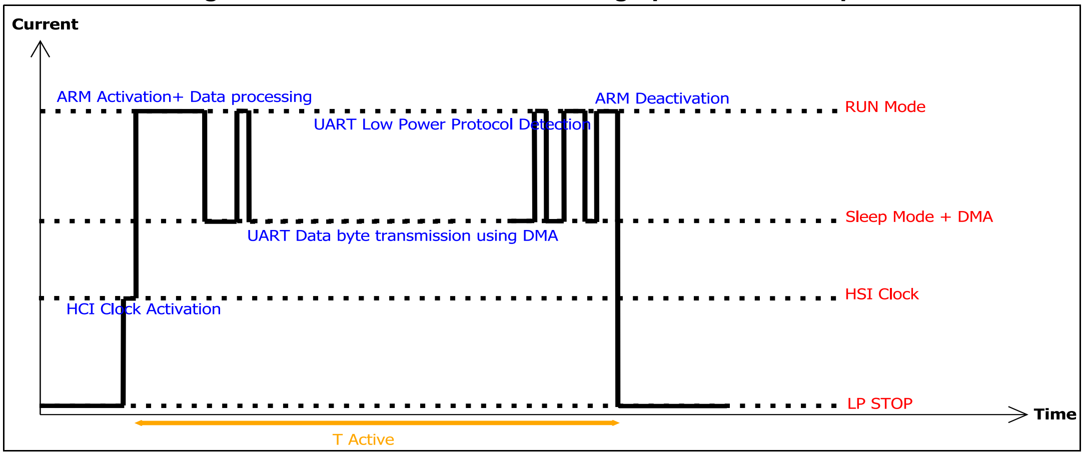
Figure 19. RxSD command exchange power consumption



As example: Start Advertising Command, with Tactive - 800 us (typ)

- RUN mode: 40% (typ)

Figure 20. TxSD command exchange power consumption



As example: Start Advertising Command, with Tactive - 458 us (typ)

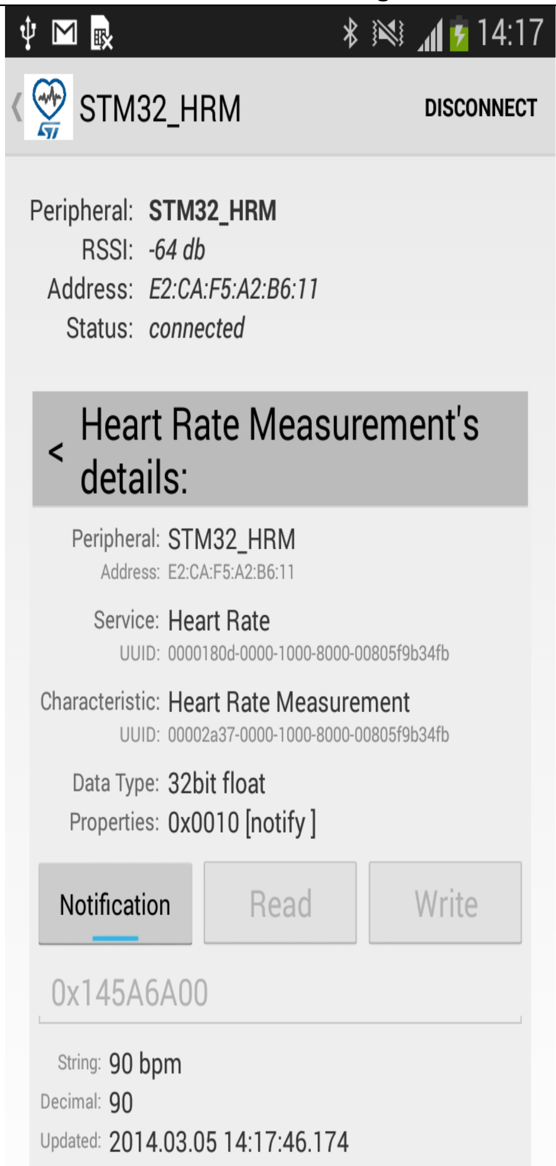
- RUN mode: 48% (typ)

7.3 Connection average power consumption

To predict power consumption in dynamic approach, typical profile scenarios are selected, on which the device is connected to Mobile phone running Android or iOS BLE application (as shown in Figure 12).

The Heart Rate Monitoring Application is used to measure the system power consumption.

Figure 21. STM32 heart rate monitoring mobile notification



The Table below indicate average power consumption for HRM/HTS profile providing data to mobile phone at different connection interval.

System configuration is set as follow:

- 1 x STM32Nucleo/64 board revC with STM32L152RE
- 1 x Wavetek Arduino shield with BLE module nRF51822v1.0
- Voltage: 3.3V
- STM32 CPU HCLK Clock: 8MHz
- UART: 1MegaBaud
- Ambient Temperature: 25°C
- Firmware: STM_ble_app (#define APP_HRS)

Table 5. HRS profile average power consumption

STM32L152#APP_HRS						
(Connection Interval & Heart rate update)		250ms	500ms	1s	2.5s	4s
nRF51822 Power consumption (uA)		80	47.95	32.19	22.87	19.96
LP_STOP Mode	STM32 Power consumption (uA)	9.7	5.76	3.77	2.57	2.34
	Total Power consumption STM32+nRF51822 (uA)	89.7	53.71	35.96	25.44	22.3
	CPU load	0.250%	0.125%	0.062%	0.025%	0.015%

NB : Numbers are typical, measured on a single STM32 + nRF51822 solution for reference only.

7.4 Data throughput

The following data throughput is measured using the same system configuration as describe previously.

To reach maximum data throughput over the air between The STM32 + nRF51822 BLE system and BLE remote device, the connection interval is fixed to 7.5ms and data packet are sent via L2CAP Layer.

Table 6. Maximum data throughput L2CAP average power consumption

STM32L152 #APP_L2CAP_TX_TEST (L2CAP throughput Test)		
Connection Interval		7.5 ms
Average Payload Throughput		89 kbit/s
nRF51822 Power consumption(uA)		6.596 mA
LP STOP Mode	STM32 Power Consumption (uA)	1.014mA
	Total power consumption STM32 nRF51822 (uA)	7.61mA
	CPU Load	22%

Frontline BLE air sniffer is used to capture in real time all data transmit over the air.

8 System limitations

- The STM32 shall not enter standby mode when BLE is enabled.

9 Revision history

Table 7. Document revision history

Date	Revision	Changes
25-June-2014	1	initial release