Getting started with the X-CUBE-BLEMESH1 software expansion for STM32Cube

Introduction

The X-CUBE-BLEMESH1 expansion software package for STM32Cube runs on the STM32 and provides easy-to-use networking APIs based on a Mesh profile library and a BLE stack.

The expansion is built on STM32Cube software technology to ease portability across different STM32 microcontrollers.

The software lets you easily create your own application for extending BLE Mesh networks (by offering a ready-to-use Mesh core library), a complete set of compatible APIs, and a lighting reference design demo application running on the X-NUCLEO-IDB05A2 and X-NUCLEO-BNRG2A1 expansion boards connected to a NUCLEO-L152RE or NUCLEO-L476RG development board.

RELATED LINKS

Visit the STM32Cube ecosystem web page on www.st.com for further information

1 Acronyms and abbreviations

Table 1. List of acronyms

Acronym	Description
BLE	Bluetooth® Low Energy
BSP	Board support package
CMSIS	Cortex® microcontroller software interface standard
GATT	Generic attribute profile
HAL	Hardware abstraction layer
SPI	Serial peripheral interface

2 X-CUBE-BLEMESH1 software expansion for STM32Cube

2.1 Overview

The X-CUBE-BLEMESH1 software package extends STM32Cube functionality and features:

- Complete software to build Mesh network with Bluetooth® Low Energy (BLE) nodes, extending network coverage to large areas up to 32767 nodes and 126 hops
- Bluetooth SIG Mesh Profile 1.0.1 Certification
- Use of BLE enabled smartphones to monitor and control multiple BLE nodes via proxy protocol and legacy BLE GATT connectivity
- Two-layer security, thanks to 128-bit AES CCM encryption and 256-bit ECDH protocol, ensuring protection against multiple attacks, including Replay, Bit-Flipping, Eavesdropping, Man-in-the-Middle, and Trashcan
- Generic Model, Lighting Model and Vendor Model examples included
- Sample implementation available on the X-NUCLEO-IDB05A2 and X-NUCLEO-BNRG2A1 expansion boards connected to a NUCLEO-L152RE or NUCLEO-L476RG development board
- Easy portability across different MCU families, thanks to STM32Cube
- Free, user-friendly license terms

It integrates BlueNRG-M0 and BlueNRG-M2 products in a powerful, range-extending the Bluetooth Mesh network with true full-duplex communication. The solution contains the core functionality for secure communication and provides the flexibility you need to build applications.

2.2 Architecture

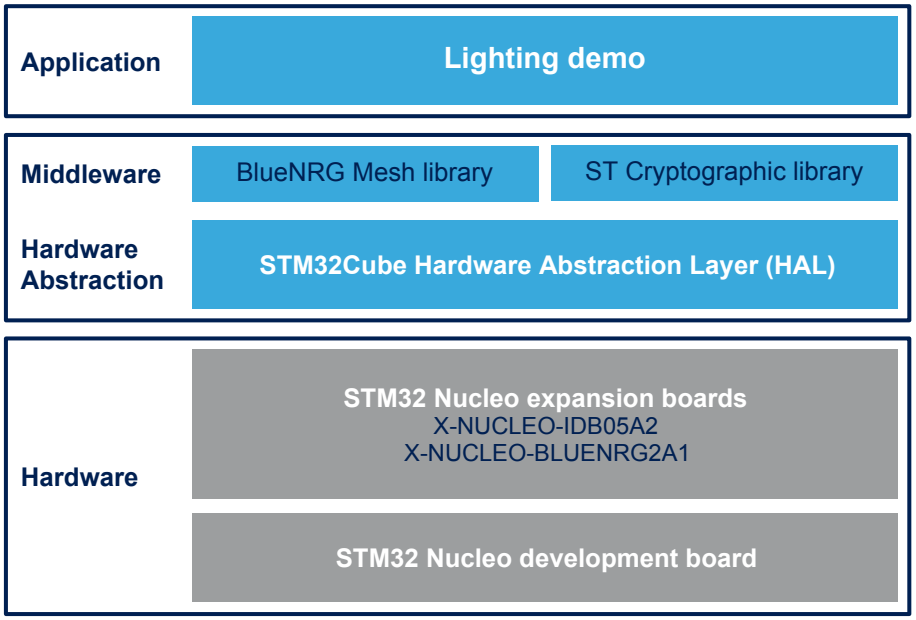
This fully compliant STM32Cube software expansion enables development of BLE-Mesh applications using the BlueNRG-M0 and BlueNRG-M2 devices.

The software is based on the STM32CubeHAL hardware abstraction layer for the STM32 microcontroller and extends STM32Cube by providing the middleware library for the BLE-Mesh application using the Bluetooth low energy expansion board.

The software layers used by the application software to access and use the Bluetooth low energy expansion board are:

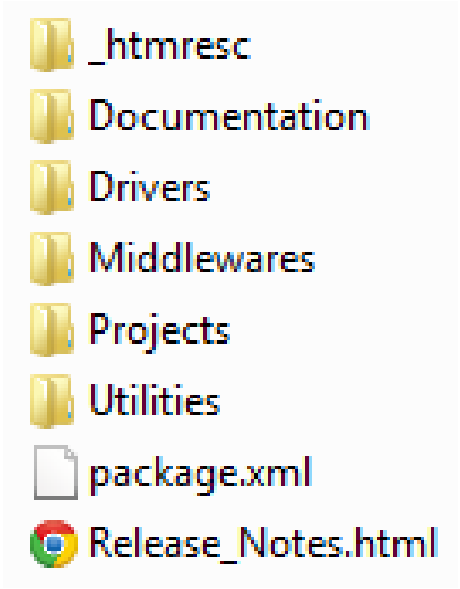
- **STM32Cube HAL layer**: provides a generic, multi-instance set of simple APIs (application programming interfaces) to interact with the upper layers (application, libraries and stacks). These generic and extension APIs are based on a common architecture and the layers above them, like the middleware layer, can function without requiring specific hardware configuration data for a given microcontroller unit (MCU). This structure improves the library code reusability and guarantees easy portability across other devices.
- **Board support package (BSP) layer**: supports the peripherals on the STM32 Nucleo board, except for the MCU. This limited set of APIs provides a programming interface for certain board specific peripherals (like the user button, the reset button, etc.) and helps in identifying the specific board version.
- **Middleware**: includes the Mesh model implementation as source code and Mesh profile implementation as library. The Mesh models include generic model, lighting model and vendor model implementation examples. The crypto library is also used for encryption and decryption.

Figure 1. **X-CUBE-BLEMESH1 architecture**



2.3 Folder structure

Figure 2. **X-CUBE-BLEMESH1 package folder structure**



The software is packaged in the following main folders:

- **Documentation**: with a compiled HTML file generated from the source code that details the software components and APIs.
- **Drivers**: contains the HAL drivers, the board specific drivers for each supported board or hardware platform, including the on-board components ones and the CMSIS layer which is a vendor-independent hardware abstraction layer for the Cortex-M processor series.
- **Middlewares**: the Mesh model implementation as source code and Mesh profile implementation as library. The Mesh models include generic model, lightness model and vendor model implementation examples. The crypto library is also used for encryption and decryption.
- **Projects**: a sample application used for a lighting application demo on BLE-Mesh. The projects are provided for the NUCLEO-L152RE and NUCLEO-L476RG and platforms with three development environments (IAR Embedded Workbench for ARM, RealView Microcontroller Development Kit (MDK-ARM), and STM32CubeIDE.
- **Utilities**: contains the “STM32L4_MAC” and “STM32L1_MAC” folders, which provide some examples of the external MAC address.

2.4 APIs

Detailed function and parameter descriptions for the user-APIs are compiled in an HTML file in the software package Documentation folder.

2.5 Sample application description

The function APIs available for application development based on Mesh network over Bluetooth Low Energy devices are described below.

The Mesh over BLE library features:

- Mesh network creation between nodes
- unicast, multicast (group), broadcast addressing
- relay feature management: all the packets whose destination address is for another node are re-transmitted
- communication with devices for advanced features, such as provisioning and proxy service

The user application handles:

- Mesh stack initialization
- user callbacks required for the application
- application handling

2.5.1 Initialization of application callbacks

An example application using the X-NUCLEO-IDB05A2 and X-NUCLEO-BNRG2A1 expansion board with either a NUCLEO-L152RE or a NUCLEO-L476RG board is provided in the “Projects” directory. Ready-to-build projects are available for multiple IDEs. The application starts by initializing the callbacks required for the different events and functionalities.

These callbacks are used in the BlueNRG-Mesh library to call the functions based on specific events or the library state machine.

```
const MODEL_Vendor_cb_t Model_Vendor_cb[] =
{
#ifdef ENABLE_VENDOR_MODEL_SERVER
  {
    VendorModel_PID1_GetOpcodeTableCb,
    VendorModel_PID1_GetStatusRequestCb,
    VendorModel_PID1_ProcessMessageCb
  },
#endif
  { 0, 0,0 }
};

const Appli_Vendor_cb_t VendorAppli_cb =
{
    /*Vendor Commads*/
  Appli_Vendor_LEDControl,
  Appli_Vendor_DeviceInfo,
  Appli_Vendor_Test,
  Appli_LedCtrl,
  Appli_GetTestValue,
  Appli_Vendor_Data_write
};

void GetApplicationVendorModels(const MODEL_Vendor_cb_t** pModelsTable, MOBLEUINT32*
VendorModelscount)
{
  *pModelsTable = Model_Vendor_cb       ;
  *VendorModelscount = MODEL_VENDOR_COUNT;

   TRACE_M(TF_VENDOR_M, "GetApplicationVendorModels \r\n");
}
```

The structure MODEL_Vendor_cb_t is used to initialize the vendor model for the application implementation. The function `GetApplicationVendorModels` is used to initialize the vendor callbacks in the library.

2.5.2 Initialization and main application loop

To develop an application for Mesh over BLE on the BlueNRG-M0 and BlueNRG-M2 platform follow the procedure below.

Step 1. Call the `InitDevice()` API.

It automatically calls the `SystemInit()` API to initialize the device vector table, interrupt priorities and clock.

Step 2. Call the `Appli_CheckBdMacAddr()` API to check the validity of the MAC address.

If the MAC address is not valid, the firmware is stuck in while (1) loop with the LED blinking continuously.

Step 3. Initialize the hardware callback functions for the BLE hardware by updating `MESH_USER_CB_MAP and MESH_BLE_CB_MAP const MESH_USER_CB_MAP user_cb =`.

```
{
  Appli_BleUnprovisionedIdentifyCb,
  Appli_BleSetUUIDCb,
  Appli_BleSetProductInfoCB,
  Appli_BleSetNumberOfElementsCb,
  Appli_BleDisableFilterCb
};

const MESH_BLE_CB_MAP ble_cb =
{
  Appli_BleStackInitCb,
  Appli_BleSetTxPowerCb,
  Appli_BleGattConnectionCompleteCb,
  Appli_BleGattDisconnectionCompleteCb,
};
```

Step 4. To create an application interface for BLE radio initialization and TxPower configuration:

Step 4a. initialize GATT connection and disconnection callbacks for the application interface

Step 4b. call `BluenrgMesh_BleHardwareInitCallBack(&user_cb, &ble_cb);` to complete the initialization of hardware callbacks

Step 5. Initialize the Mesh library by calling `BluenrgMesh_Init(&BLEMeshlib_Init_params).`

If an error occurs, the demo firmware shows the message *Could not initialize BlueNRG-Mesh library!* on the terminal window, making the LED blink continuously. The terminal interface can be opened using the VCOM port created by the USB connection available on the boards.

Step 6. Check whether the device has been provisioned with the `BluenrgMesh_IsUnprovisioned()` API. A provisioned device has network keys and other parameters configured in the internal flash memory.

If the node is unprovisioned, the `BluenrgMesh_InitUnprovisionedNode()` API initializes it, otherwise it helps to initialize the device.

Step 7. Print the messages to the terminal window for the nodes that are being initialised.

The message also prints the MAC address assigned to the node.

Step 8. Initialize the BlueNRG-Mesh models using the `BluenrgMesh_ModelsInit()` API.

Step 9. To initialize the node to the unprovisioned state, hold down the user button for at least 5 seconds.

It erases all the network parameters configured in the device internal memory. Once unprovisioning is complete, you have to reset the board.

Step 10. Call the `BluenrgMesh_Process()` in while(1) loop as frequently as possible, so that it calls `BLE_StackTick()` internally to process BLE communication.

Other APIs called in while(1) loop are `BluenrgMesh_ModelsProcess()` and `Appli_Process().`

Any application implementation is performed in the state-machine by non-blocking functions with frequent calls to `BluenrgMesh_Process().`

Step 11. Check for user inputs or buttons regularly for any action to take.

2.5.3 Node transmit power setup

The `Appli_BleSetTxPowerCb()` calls the aci function to set the power `aci_hal_set_tx_power_level(uint8_t En_High_Power, uint8_t PA_Level).`

By default, +4 dbm is configured, but it can be changed by the user.

The following different settings are available in the firmware:

```
 /* MACROS for Power Level definitions */
#define POWER_LEVEL_LOW            0
#define TX_POWER_LEVEL_MINUS_18DBM 0 // = -18 dBm,
#define TX_POWER_LEVEL_MINUS_15DBM 1 // = -15 dBm,
#define TX_POWER_LEVEL_MINUS_12DBM 2 // = -12 dBm,
#define TX_POWER_LEVEL_MINUS_9DBM  3 // = -9 dBm,
#define TX_POWER_LEVEL_MINUS_6DBM  4 // = -6 dBm,
#define TX_POWER_LEVEL_MINUS_2DBM  5 // = -2 dBm,
#define TX_POWER_LEVEL_0DBM        6 // =  0 dBm,
#define TX_POWER_LEVEL_PLUS_5DBM   7 // =  5 dBm.
#define POWER_LEVEL_HIGH           1
#define TX_POWER_LEVEL_MINUS_14DBM 0 // = -14 dBm,
#define TX_POWER_LEVEL_MINUS_11DBM 1 // = -11 dBm,
#define TX_POWER_LEVEL_MINUS_8DBM  2 // = -8 dBm,
#define TX_POWER_LEVEL_MINUS_5DBM  3 // = -5 dBm,
//#define TX_POWER_LEVEL_MINUS_2DBM  4 // = -2 dBm,
#define TX_POWER_LEVEL_PLUS_2DBM   5 // =  2 dBm,
#define TX_POWER_LEVEL_PLUS_4DBM   6 // =  4 dBm,
#define TX_POWER_LEVEL_PLUS_8DBM   7 // =  8 dBm
```

2.5.4 Firmware UART interface

The boards can be connected to a PC via USB. Any terminal software (Hercules, Putty, etc.) can be used to open the serial communication port on the PC to check the messages from the board.

The UART of the controller on the board is connected to the PC via a VCOM (virtual communication) port that can be opened with the following settings:

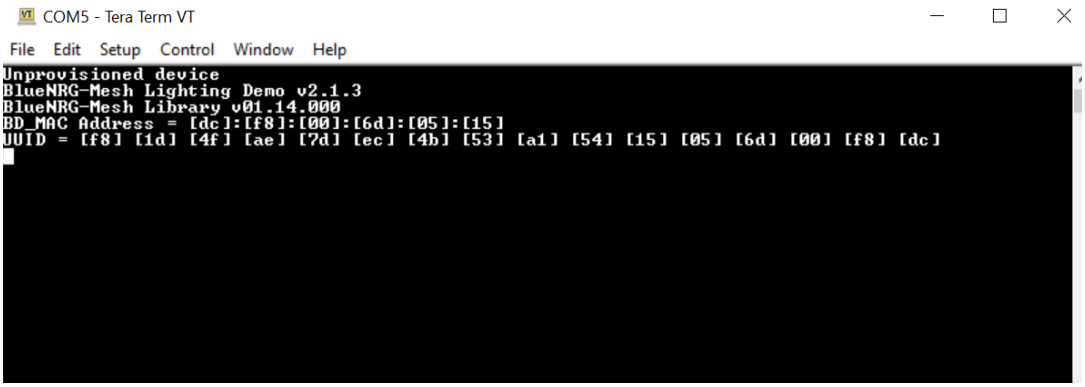
- Baud: 115200
- data size: 8
- parity: none
- stop bits: 1
- no hardware control

From the firmware main.c file, you can see certain messages are printed to the VCOM by the following code:

```
#if !defined(DISABLE_TRACES)
/* Prints the MAC Address of the board */
printf("BlueNRG-Mesh Lighting Demo v%s\n\r", BLUENRG_MESH_APPLICATION_VERSION);
printf("BlueNRG-Mesh Library v%s\n\r", BluenrgMesh_GetLibraryVersion());
printf("BD_MAC Address = [%02x]:[%02x]:[%02x]:[%02x]:[%02x]:[%02x] \n\r",
bdaddr[5],bdaddr[4],bdaddr[3],bdaddr[2],bdaddr[1],bdaddr[0] );
#endif
```

After the board is connected and the terminal window is opened, press the reset button. If the firmware starts successfully, the following messages appear in the virtual com window.

Figure 3. Virtual com window after startup



2.5.5 GATT connection/disconnection

Each node in the network can estabilsh a connection with the smartphone through GATT interface. When connected, the node becomes a proxy to bridge the messages and responses between the Mesh network and the smartphone.

The detection of connection and disconnection with the smartphone is managed by the following callbacks, initialized during the main loop:

- `Appli_BleGattConnectionCompleteCb;`
- `Appli_BleGattDisconnectionCompleteCb;`

During provisioning, the GATT connection is established with the node which needs to be provisioned. If the smartphone moves out of the range of the proxy node, it establishes a new connection with another available node.

2.6 External MAC address utilities

By default, a static random address is generated internally in each node. For specific usage or testing, you can program the nodes with a known unique MAC address. This external address is stored at a specific location in the flash memory of the MCU. Some examples of such MAC addresses are available in the folders (Utilities/STM32L4_MAC and Utilities/STM32L1_MAC) depending on the MCU.

To use an external MAC address, it is necessary to uncomment the EXTERNAL_MAC_ADDR_MGMT macro.

Demo application firmware and MAC address are flashed independently, that is, you don't have to update a MAC address if another firmware has been flashed.

The MAC address has to be unique in each node for the Mesh network.

When using an external MAC address, it is recommended to do full erase and then program:

1. STM32L1_BNRG_MS_Lighting_Demo_Ext_MAC.bin file in Binary/STM32L152RE-Nucleo folder, and then program the MAC addresses from Utilities/STM32L1_MAC (for NUCLEO-L152RE)
2. STM32L4_BNRG_MS_Lighting_Demo_Ext_MAC.bin file in Binary/STM32L476RG-Nucleo folder and then program the MAC addresses from Utilities/STM32L4_MAC (for NUCLEO-L476RG)

3 System setup guide

3.1 Hardware description

3.1.1 STM32 Nucleo

STM32 Nucleo development boards provide an affordable and flexible way for users to test solutions and build prototypes with any STM32 microcontroller line.

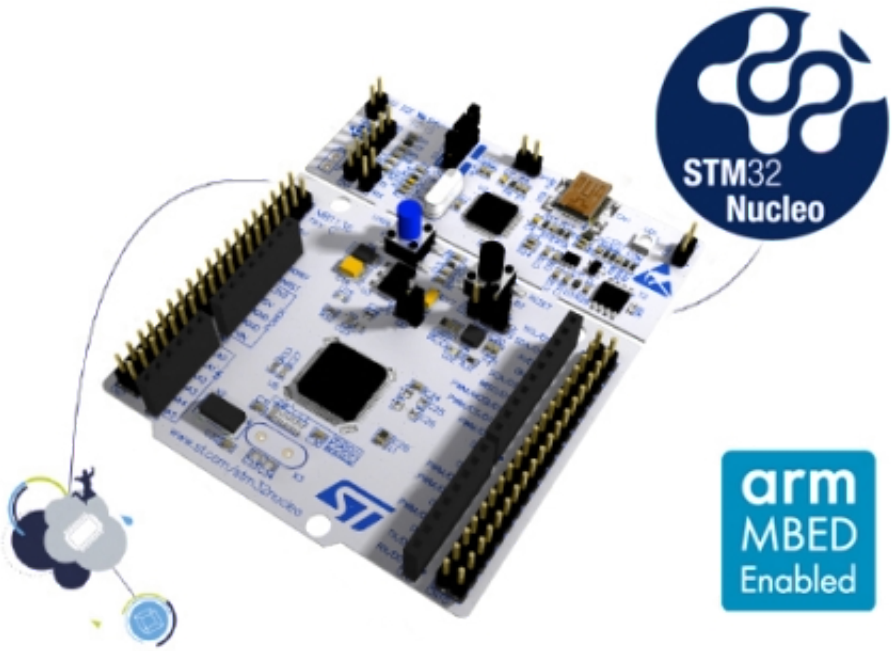
The Arduino connectivity support and ST morpho connectors make it easy to expand the functionality of the STM32 Nucleo open development platform with a wide range of specialized expansion boards to choose from.

The STM32 Nucleo board does not require separate probes as it integrates the ST-LINK/V2-1 debugger/ programmer.

The STM32 Nucleo board comes with the comprehensive STM32 software HAL library together with various packaged software examples for different IDEs (IAR EWARM, Keil MDK-ARM, STM32CubeIDE, mbed and GCC/ LLVM).

All STM32 Nucleo users have free access to the mbed online resources (compiler, C/C++ SDK and developer community) at www.mbed.org to easily build complete applications.

Figure 4. STM32 Nucleo board



3.1.2 X-NUCLEO-IDB05A2 expansion board

The X-NUCLEO-IDB05A2 Bluetooth low energy expansion board is based on the BlueNRG-M0 BLE network processor module.

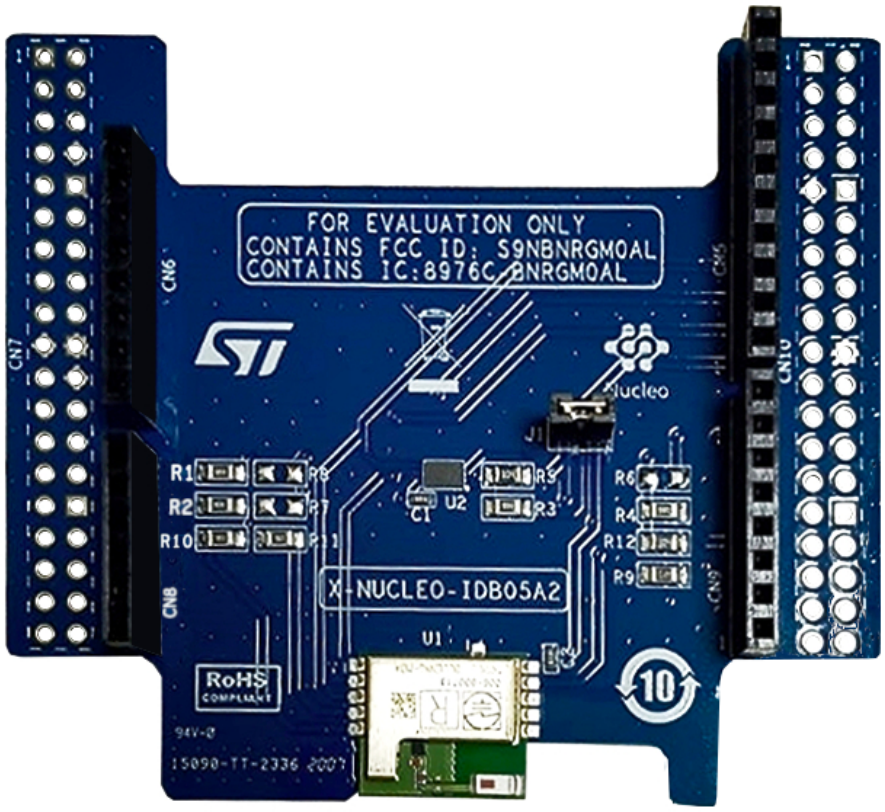
The BlueNRG-M0 is Bluetooth v4.2 compliant, FCC and IC certified (FCC ID: S9NBNRGM0AL; IC: 8976C-BNRGM0AL). It supports simultaneous master/slave roles and can behave as a Bluetooth low energy sensor and hub device at the same time.

The BlueNRG-M0 provides a complete RF platform in a tiny form factor, with integrated radio, antenna, high frequency and LPO oscillators.

The X-NUCLEO-IDB05A2 is compatible with the ST morpho (not mounted) and Arduino UNO R3 connector layout.

The X-NUCLEO-IDB05A2 interfaces with the STM32 microcontroller via the SPI pin and allows changing the default SPI clock, SPI chip select and SPI IRQ by replacing a resistor on the expansion board.

Figure 5. X-NUCLEO-IDB05A2 expansion board



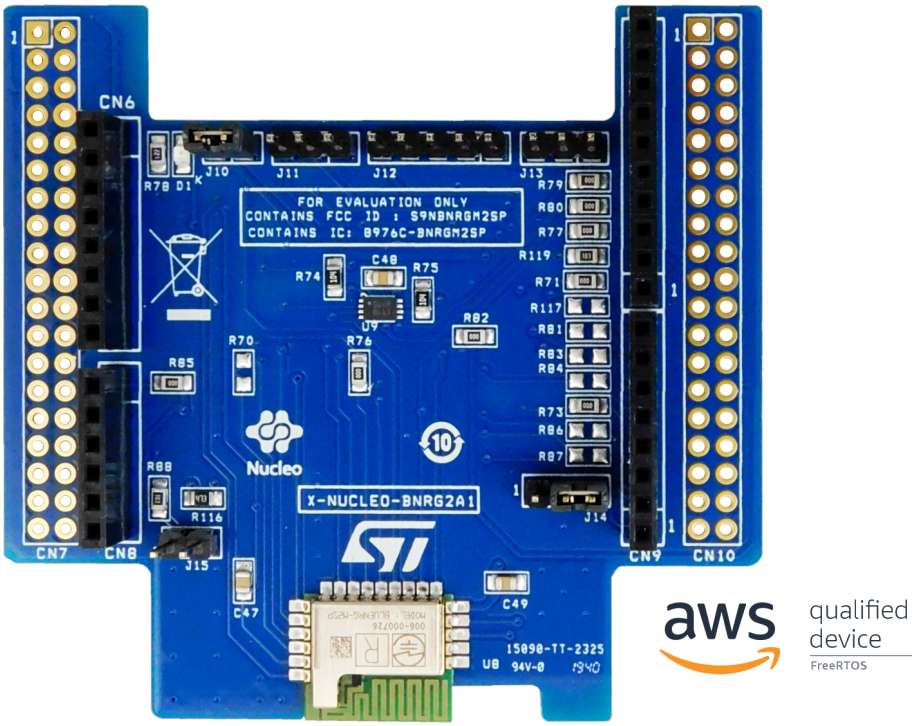
3.1.3 X-NUCLEO-BNRG2A1 expansion board

The X-NUCLEO-BNRG2A1 expansion board provides Bluetooth low energy connectivity for developer applications and can be plugged onto an STM32 Nucleo development board (e.g., NUCLEO-L476RG with ultra-low power STM32 microcontroller) through its Arduino UNO R3 connectors.

The expansion board features the Bluetooth® v5.2 compliant and FCC certified BlueNRG-M2SP application processor module based on the ST BlueNRG-2 System-on-Chip. This SoC manages the complete Bluetooth low energy stack and protocols on its Cortex-M0 core and programmable Flash, which can accommodate custom applications developed using the SDK. The BlueNRG-M2SP module supports master and slave modes, increased transfer rates with data length extension (DLE), and AES-128 security encryption.

The X-NUCLEO-BNRG2A1 interfaces with the STM32 Nucleo microcontroller via SPI connections and GPIO pins, some of which can be configured by the hardware.

Figure 6. X-NUCLEO-BNRG2A1 BLE expansion board



3.2 Hardware setup

The following hardware components are needed:

1. One STM32 Nucleo development platform (suggested order code: either NUCLEO-L476RG or NUCLEO-L152RE)
2. One BLE expansion board (order code: X-NUCLEO-IDB05A2 or X-NUCLEO-BNRG2A1)
3. One USB type A to Mini-B USB cable to connect the STM32 Nucleo to the PC

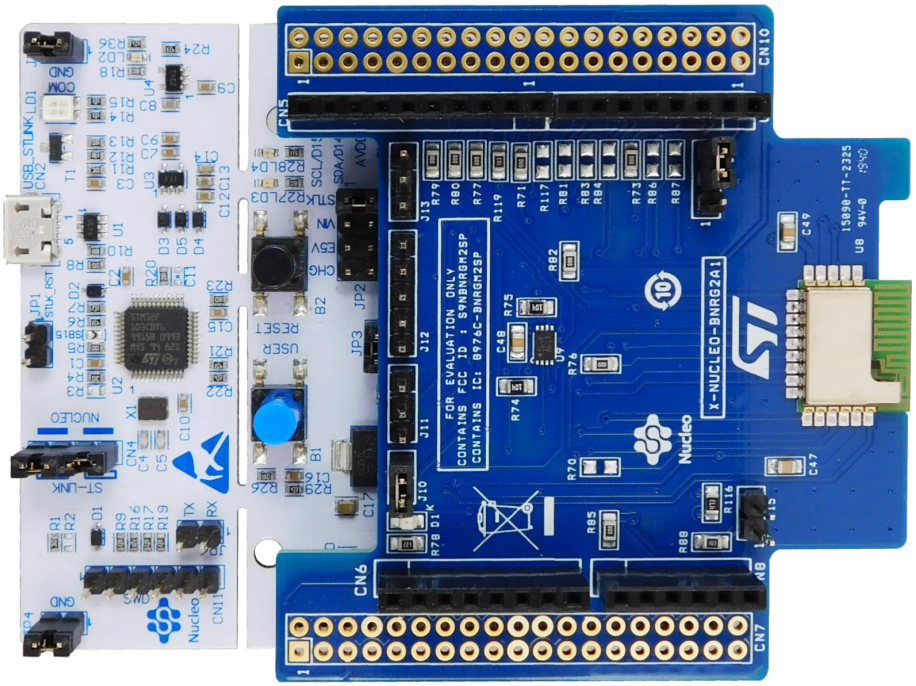
3.2.1 STM32 Nucleo and BLE expansion board setup

The STM32 Nucleo board integrates the ST-LINK/V2-1 debugger/programmer.

The developer can download the ST-LINK/V2-1 USB driver by looking for the STSW-LINK009 software on www.st.com.

The X-NUCLEO-IDB05A2 and the X-NUCLEO-BNRG2A1 BLE expansion board interface with the external STM32 microcontroller on STM32 Nucleo via SPI. It can be easily connected to the STM32 Nucleo through the Arduino UNO R3 extension connector as shown below.

Figure 7. X-NUCLEO-BNRG2A1 expansion board plus STM32 Nucleo



3.3 Software setup

The following software components are needed for a suitable development environment for creating applications for the STM32 Nucleo equipped with the BLE expansion board:

- X-CUBE-BLEMESH1 expansion for STM32Cube dedicated to Bluetooth Mesh application development. The X-CUBE-BLEMESH1 firmware and related documentation is available on www.st.com.
- One of the following development tool-chain and compilers:
  - Keil RealView Microcontroller Development Kit (MDK-ARM-STM32) + ST-LINK
  - IAR Embedded Workbench for ARM (IAR-EWARM) + ST-LINK
  - STM32CubeIDE based on GCC + ST-LINK

Appendix A References

1. Mesh over Bluetooth Low Energy
   https:www.st.com/en/embedded-software/stsw-bnrg-mesh.html
2. Bluetooth Mesh Networking Specifications
   https://www.bluetooth.com/specifications/mesh-specifications
3. Bluetooth Mesh Model Specification
   www.bluetooth.com/specifications/adopted-specifications

Revision history

Table 2. **Document revision history**

Date	Version	Changes
24-Aug-2018	1	Initial release.
10-Dec-2021	2	Updated Introduction, Section 1 Acronyms and abbreviations, Section 2.1 Overview, Section 2.2 Architecture, Section 2.3 Folder structure, Section 2.5.1 Initialization of application callbacks, Section 2.5.2 Initialization and main application loop, Figure 3. Virtual com window after startup, Section 2.6 External MAC address utilities, Section 3.1.1 STM32 Nucleo, Section 3.2 Hardware setup, Section 3.2.1 STM32 Nucleo and BLE expansion board setup, and Section 3.3 Software setup. Added Section 3.1.2 X-NUCLEO-IDB05A2 expansion board and Section 3.1.3 X-NUCLEO-BNRG2A1 expansion board. Removed Section 2 What is STM32Cube? and Section 2.1 STM32Cube architecture, and replaced them with a link in the Introduction. Removed Section 4.1.2 X-NUCLEO-IDB05A1 expansion board.

Contents

List of tables

List of figures