UM2080

User manual

Getting started with the FP-NET-6LPWIFI1 software package connecting 6LoWPAN IoT nodes to the Internet via Wi-Fi networks

Introduction

FP-NET-6LPWIFI1 is an STM32Cube function pack which lets you connect your IoT node in a 6LoWPAN wireless sensor network to the Internet via a Wi-Fi network.

The software, together with the suggested combination of STM32 and ST devices, can be used, for example, to develop smart home, building, ligthting or remote monitoring applications.

The package contains sample applications to manage the 6LoWPAN devices through the OMA Lightweight M2M (LwM2M) protocol and to connect the devices to the IBM Watson IoT cloud services via the MQTT protocol.

The software runs on the STM32 microcontroller and includes drivers for the S2-LP sub-1GHz RF transceiver; the software also comes with ready-to-use binary firmware for wireless sensor nodes.

The software is based on STM32Cube technology and expands STM32Cube-based packages.

1 Acronyms and abbreviations

Table 1. List of acronyms

Acronym	Description
IDE	Integrated development environment
BSP	Board support package
HAL	hardware abstraction layer
UDP	User datagram protocol
6LoWPAN	IPv6 over low power wireless personal area networks
RPL	Routing protocol for low power and lossy networks
MCU	Microcontroller unit
MQTT	Message queuing telemetry transport
RF	Radio frequency
OS	Operating system
CoAP	Constrained application protocol
LWM2M	Lightweight machine to machine
IoT	Internet of things
MEMS	Micro electro-mechanical systems
Wi-Fi	Wireless LAN based on IEEE 802.11
GUI	Graphical user interface

2 FP-NET-6LPWIFI1 software expansion for STM32Cube

2.1 Overview

The FP-NET-6LPWIFI1 software package expands STM32Cube functionality.

The key features of the package are:

- Complete firmware to connect 6LoWPAN and Wi-Fi networks
- Middleware libraries to support Contiki OS and Contiki 6LoWPAN protocol stack 3.x, MQTT protocol and Wi-Fi connectivity
- Support for mesh networking technology via the standard RPL protocol
- Sample applications to connect a 6LoWPAN network node to a remote server with the OMA Lightweight M2M (LWM2M) protocol or to Watson IoT cloud services provided by IBM
- Sample implementation available for the X-NUCLEO-S2868A1 expansion board connected to a B-L475E-IOT01A Discovery board
- Easy portability across different MCU families, thanks to STM32Cube
- Free, user-friendly license terms

This software uses the Contiki OS to develop two sample applications:

- Wi-Fi bridge: to connect 6LoWPAN network nodes to the Internet with network level bridging (i.e. it carries the same protocol end-to-end);
- LWM2M to IBM: to connect an OMA Lightweight M2M network to the Watson IoT services provided by IBM.

6LoWPAN network communication is carried out by the sub-1GHz radio (X-NUCLEO-S2868A1, X-NUCLEO-IDS01A4 or X-NUCLEO-IDS01A5 expansion board). The Wi-Fi bridge forwards all packets destined to the Internet pass via Wi-Fi radio (X-NUCLEO-IDW01M1 expansion board).

Contiki OS technical details can be found at https://github.com/contiki-os/contiki/wiki in the **Internals** section. For information regarding Contiki APIs, refer to the documentation in the FP-NET-6LPWIFI1 package.

An open source implementation of the MQTT protocol (http://www.eclipse.org/paho/) ported to STM32 Nucleo is integrated in the package middleware; thus, the STM32 Nucleo-based microsystem can connect to the IBM Watson IoT cloud services.

MQTT is a lightweight messaging protocol with a small code footprint and low power and bandwidth use. It is particularly suitable for sensor data telemetry and implementation in embedded systems. Futher information regarding the MQTT protocol is available at www.mqtt.org.

2.2 Architecture

This software is based on the STM32CubeHAL hardware abstraction layer for the STM32 microcontroller. The package extends STM32Cube by providing a board support package (BSP) for the Wi-Fi and the sub-1GHz RF communication expansion boards.

The drivers abstract low-level details of the hardware and allow the middleware components and applications to access sensor data in a hardware-independent manner to access and control the S2-LP sub-1GHz RF transceiver.

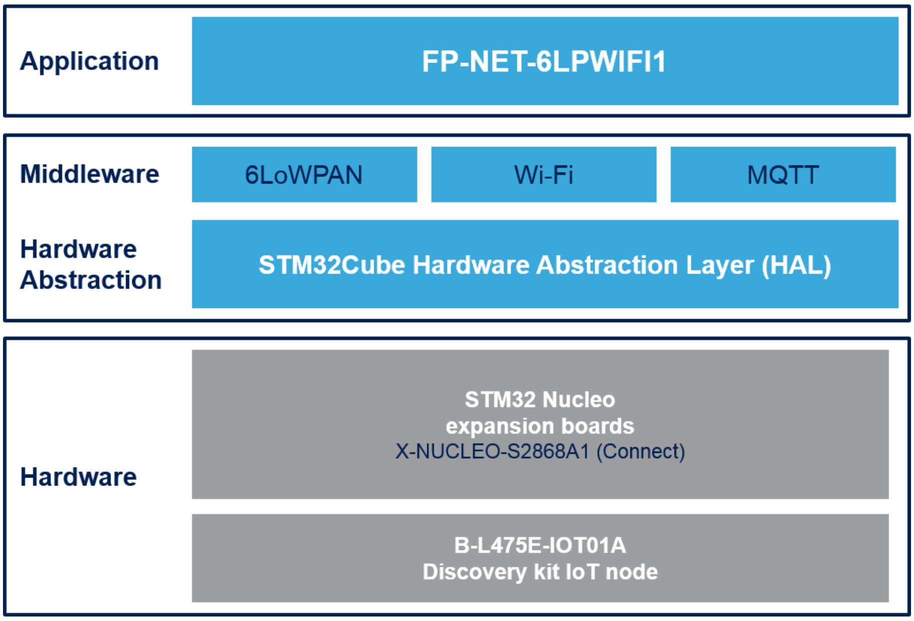
The package includes some middleware libraries to support Wi-Fi and 6LoWPAN stacks, along with a sample application accessing sensors and actuators on the 6LoWPAN nodes using standard protocols such as LWM2M and CoAP over UDP, and another sample application to connect the LWM2M devices to the Watson IoT cloud. Developers can use it to prototype end-to-end IoT applications.

The application software accesses the X-NUCLEO-S2868A1, X-NUCLEO-IDS01A4 or X-NUCLEO-IDS01A5 and X-NUCLEO-IDW01M1 expansion boards via:

- The **STM32Cube HAL** driver layer, which provides a simple, generic, multi-instance set of application programming interfaces (APIs) to interact with the upper application, library and stack layers. It has generic and extension APIs and is directly built around a generic architecture and allows successive layers like the middleware layer to implement functions without requiring specific hardware configurations for a given microcontroller unit (MCU). This structure improves library code reusability and facilitates portability to other devices.

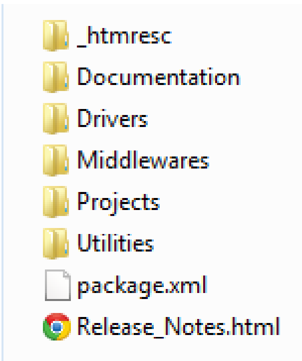
- The **board support package** (BSP) layer supports all the peripherals on the STM32 Nucleo except the MCU. This limited set of APIs provides a programming interface for certain board-specific peripherals like the LED, the user button, etc. This interface also helps in identifying the specific board version.

Figure 1. **FP-NET-6LPWIFI1 software architecture**



2.3 Folder structure

Figure 2. **FP-NET-6LPWIFI1 package folder structure**



The following folders are included in the software package:

- Documentation: contains a compiled HTML file generated from the source code which details the software components and APIs.
- Drivers: contains the HAL drivers and the board-specific drivers for each supported board or hardware platform, including the on-board components and the CMSIS vendor-independent hardware abstraction layer for ARM Cortex-M processor series.
- Middlewares: contains libraries for the Contiki OS, for the MQTT protocol, and the interface for the Wi-Fi expansion software.
- Projects: contains a sample application using application-level functions to bridge a 6LoWPAN network with a Wi-Fi network (UDP protocol support only), and a sample application for connecting a network of LwM2M client nodes to the IBM Watson IoT cloud. The projects are built for B-L475E-IOT01A Discovery board, and for NUCLEO-F401RE boards and the following development environments:

1. IAR Embedded Workbench for ARM
2. RealView Microcontroller Development Kit (MDK-ARM)
3. System Workbench for STM32 (SW4STM32)

- Utilities: contains ready-to-use firmware binaries that allow a node in the 6LoWPAN network to connect to the Internet and share its resources (e.g., sensors or actuators) with the OMA lightweight M2M protocol.

2.4 APIs

Detailed technical information with full user API function and parameter description are in a compiled HTML file in the “Documentation” folder.

2.5 Sample application description

2.5.1 Wi-Fi bridge

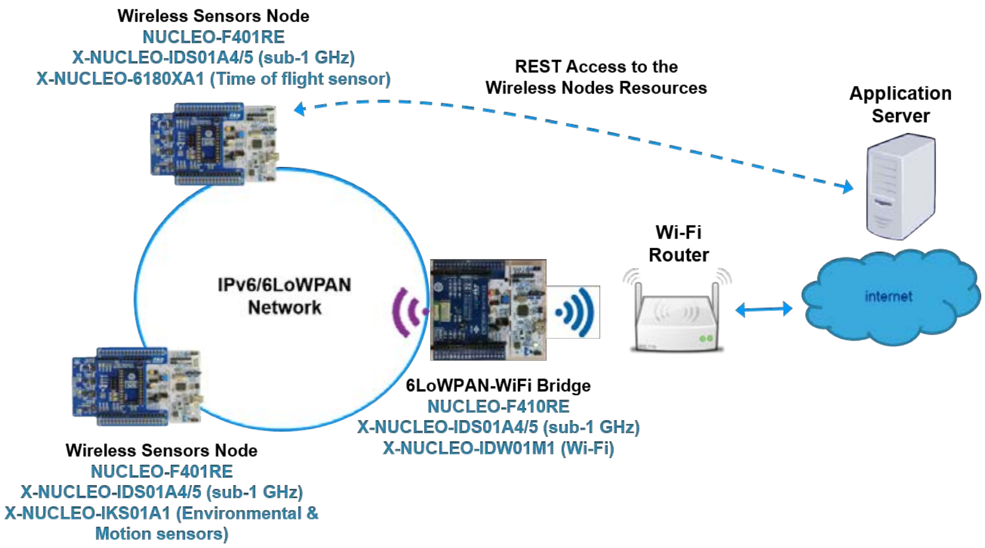
This sample application with ready-to-build projects for multiple IDEs is located in the ‘Projects’ directory.

Use it to create a bridge between a 6LoWPAN network and the Internet using Contiki OS and the Wi-Fi module. This application supports the UDP protocol and uses NAT64 technology to translate IPv6 packets to IPv4 packets.

While the nodes connected to the Wi-Fi bridge issue direct requests to a specific server, it is actually the Wi-Fi bridge which connects the nodes to the requested server by transparently forwarding every packet from the 6LoWPAN network to the IPv4 network.

Note: For bidirectional communication, the application can support up to 4/8 sensor nodes simultaneously (the actual number depends on the Wi-Fi module in use as this limit is related to the max. number of connections that can be opened in parallel); for unidirectional node-to-server communication (e.g., sensor data transmission), this limit does not apply.

Figure 3. Overall system architecture (example with bridge based on NUCLEO-F401RE)



To run the application:

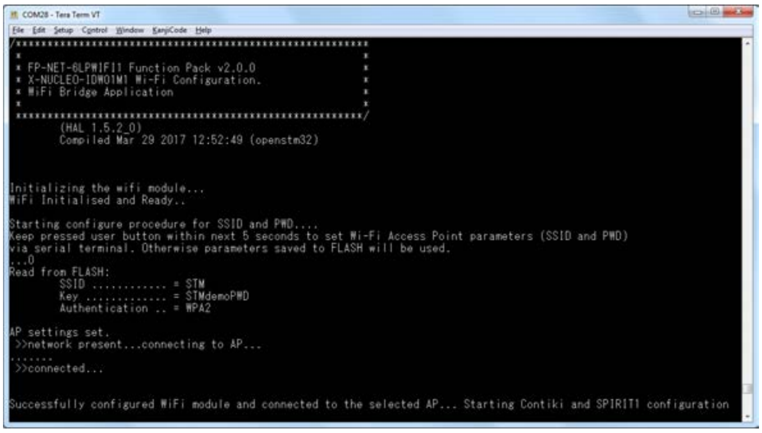
Step 1. Compile the project using one of the supported IDEs, see Section 3.2 Software requirements

Step 2. Program the firmware on the STM32 Nucleo board: you can copy (or drag and drop) the binary file to the USB mass storage location created when you plug the STM32 Nucleo board to your PC. If the host is a Linux PC, the STM32 Nucleo F4 device can be found in the /media folder with the name “NUCLEO_F401RE”. For example, if the created mass storage location is “/media/NUCLEO_F401RE”, then the command to program the board with a binary file named “my_firmware.bin” is simply: `cp my_firmware.bin /media/NUCLEO_F401RE`. Alternatively, you can program the STM32 Nucleo board directly through one of the supported development toolchains (please refer to the corresponding toolchain user manual for further information).

Step 3. Open a serial line monitor utility, select the serial port name to which the board is connected and configure it thus:
- Baud Rate = 115200
- Parity = None
- Bits = 8
- Stopbits = 1

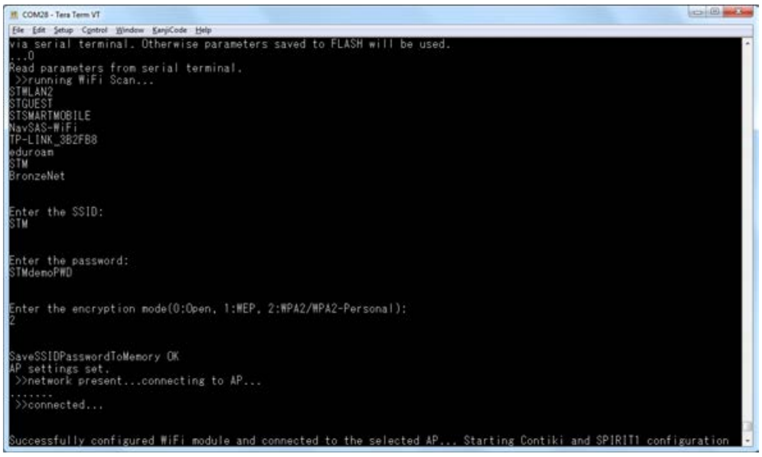
Step 4. Press the RESET (black) button on the STM32 Nucleo board. The following configuration prompt should appear.

Figure 4. Wi-Fi bridge configuration



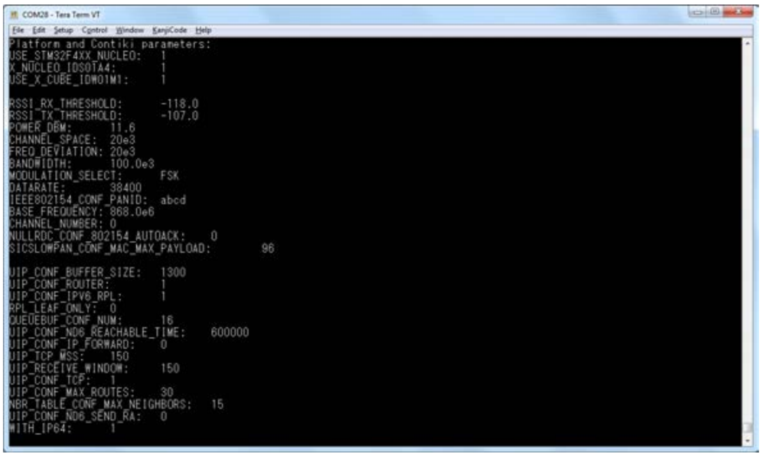
Step 5. When asked, press the User Button to enter your own credentials (see Figure 5. Wi-Fi bridge custom credentials) or just wait five seconds to retrieve from FLASH the credentials (if any) you used the previous time (see Figure 4. Wi-Fi bridge configuration)

Figure 5. Wi-Fi bridge custom credentials



Step 6. After successfully joining the selected Wi-Fi network, a list of the main system and Contiki parameters is printed, for user information and debugging purposes.

Figure 6. **Wi-Fi bridge Contiki parameters**



2.5.2 Wireless sensor node for Wi-Fi bridge application

To enable user deployment and testing of end-to-end solutions between wireless sensor nodes and internet servers, sample node applications are available in the form of source code and of pre-compiled and ready-to-use binaries for STM32 Nucleo platforms equipped with expansion boards.

These applications demonstrate how a node can connect to a remote server with the OMA lightweight M2M (LWM2M) standard. This technology uses CoAP (over UDP) to publish a node’s resources in a standard (LWM2M) format and make them available online.

In these examples, the nodes attempt to connect to a public online server (https://leshan.eclipseprojects.io), which is a Java implementation of an LWM2M server. Leshan also implements a GUI that communicates with the server through a REST API (see http://www.eclipse.org/leshan/).

The reference software package for the implementation of wireless sensor nodes compatible with the Wi-Fi bridge is FP-SNS-6LPNODE1, available at www.st.com.

Note: *The Leshan public LWM2M server is used only for evaluation purposes, to demonstrate end-to-end connectivity between a wireless sensor node and an Internet connected server, thanks to the 6LoWPAN-to-Wi-Fi bridge in the FP-NET-6LPWIFI1 software package.*

2.5.2.1 *Connecting the remote node to the Internet*

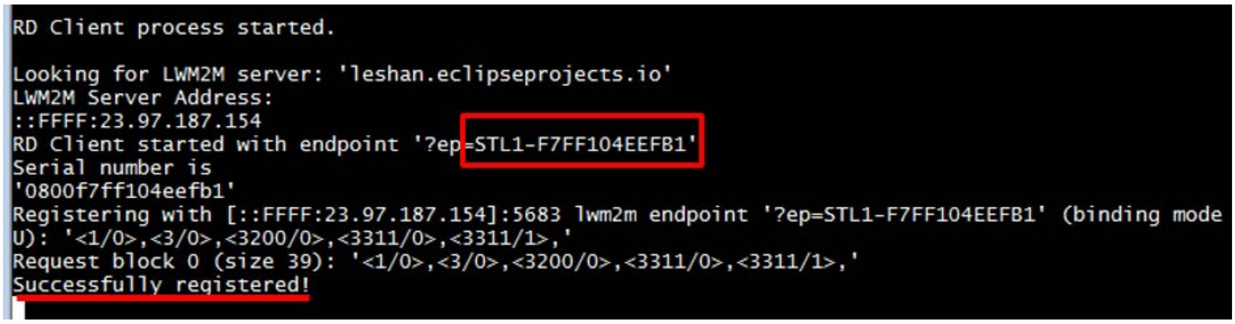
Step 1. Power the STM32 Nucleo board using a Mini-B USB cable connected to the PC.

Step 2. Program the firmware on the STM32 Nucleo board: you can copy (or drag and drop) the binary file (in the /Utility/Binary folder) to the USB mass storage that is automatically created when you connect the STM32 Nucleo board to your PC.

Step 3. Open a serial line monitor utility, select the serial port name to which the board is connected and configure it thus:
- Baud Rate = 115200
- Parity = None
- Bits = 8
- Stopbits = 1

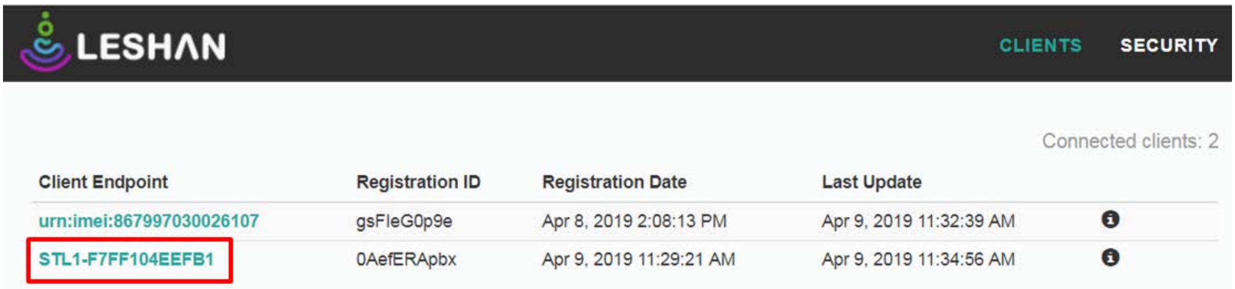
Step 4. Press the RESET (black) button on the STM32 Nucleo board and wait for the node to complete the registration

Figure 7. Client node registered on the remote server



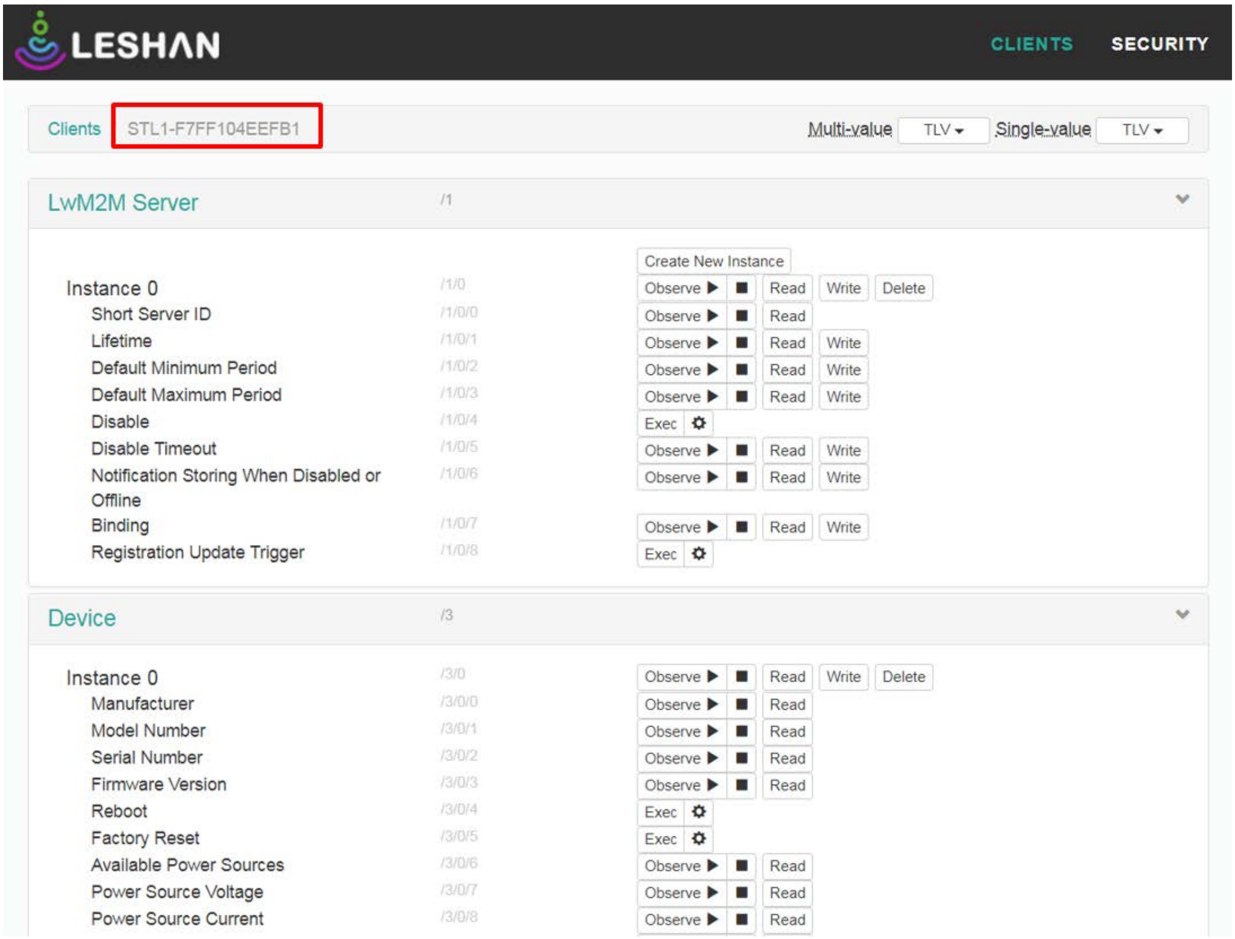
Step 5. Open your web browser and navigate to https://leshan.eclipseprojects.io

Figure 8. Leshan server homepage



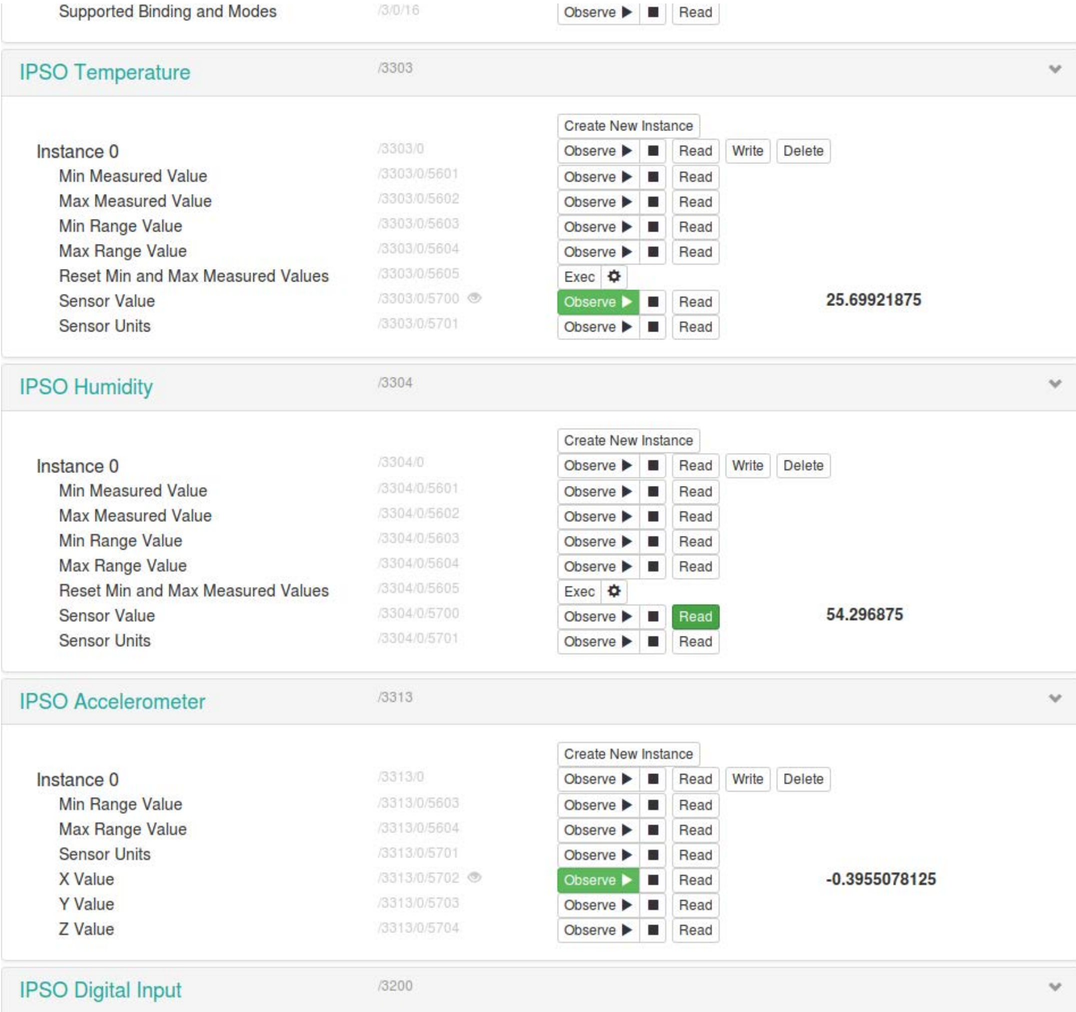
Step 6. Click on the corresponding Client Endpoint

Figure 9. Leshan server client homepage



Step 7. Observe or read resources

Figure 10. Leshan server, observing and reading resources



2.5.3 LwM2M to IBM

This sample application with ready-to-build projects for multiple IDEs is located in the **Projects** directory.

Use it to connect OMA LWM2M devices (implemented with the firmware available in the FP-SNS-6LPNODE1 function pack) to IBM Watson IoT cloud services via Wi-Fi.

According to a software template (see Section 2.5.3.1 Template) the user can pre-program the LWM2M_to_IBM gateway to automatically initiate a LWM2M observe/notify process or to issue periodic LWM2M read on predefined resources (i.e., humidity value and temperature max. value) on all 6LoWPAN network nodes.

This sample application implements an OMA LWM2M server that manages the OMA LWM2M clients inside the WSN network. As opposed to the Wi-Fi bridge sample application scenario, the LWM2M protocol is used only inside the 6LoWPAN network. Through the Wi-Fi module, it then connects to IBM Watson cloud, using the MQTT protocol.

This application is configured by default to send data via Wi-Fi to the IBM Watson IoT cloud in quickstart mode for data visualization only. However, it can be quickly modified to use the device in register mode. The latter requires an account on the IBM Watson IoT cloud (if the user wants to command the device; e.g., turn LED LD2 on or off). Further details are provided in the FP-CLD-WATSON1 function pack documentation available at www.st.com.

2.5.3.1 *Template*

The LWM2M to IBM gateway can automatically and periodically retrieve some specific resources values from the discovered nodes, as follows:

- using the observe/notification operation of LWM2M (mapped in a CoAP GET command including the Observe option), for the resources that support this option: the client node notifies the server when the resource value changes;

- or using the LWM2M read operation (mapped in a simple CoAP GET command) which is executed in polling mode.

You can find the template at the beginning of the file *Projects/Multi/Applications/LWM2M_to_IBM/Src/lwm2m-resource-directory.c.*

Figure 11. Template code for automatic sensor value retrieval

```
/* Syntax:
 * TEMPLATE(name,
 *          IPSO_RESOURCE_TYPE(OBJECT_ID, RESOURCE_ID, OPERATION, ALTERNATIVE_NAME),
 *          );
 *
 *          Note: The IPSO types as well as all the needed #define are in lwm2m-simple-server.h and lwm2m-defs.h
 */
TEMPLATE(template,
        IPSO_RESOURCE_FLOAT (IPSO_TEMPERATURE_SENSOR, SENSOR_VALUE, OPR_TO_OBSERVE, TEMPERATURE_VALUE_STR),
        IPSO_RESOURCE_FLOAT (IPSO_TEMPERATURE_SENSOR, MAX_MEASURED_VALUE, OPR_TO_GET, TEMPERATURE_MAX_VALUE_STR),
        IPSO_RESOURCE_INT (IPSO_BUTTON, BUTTON_COUNTER, OPR_TO_GET, BUTTON_COUNTER_STR),
        IPSO_RESOURCE_FLOAT (IPSO_ACCELEROMETER, Z_VALUE, OPR_TO_OBSERVE, ACCELERATION_Z_STR),
        IPSO_RESOURCE_FLOAT (IPSO_HUMIDITY_SENSOR, SENSOR_VALUE, OPR_TO_OBSERVE, HUMIDITY_VALUE_STR),
        );
```

The actual macro definitions can be found in the file *Projects/Multi/Applications/LWM2M_to_IBM/Inc/lwm2m-simple-server.h*. The LWM2M and IPSO related objects and resource definitions are included in the file *Projects/Multi/Applications/LWM2M_to_IBM/Inc/lwm2m-defs.h*, in compliance with the *"OMA Lightweight Machine to Machine Technical Specification V1.0"* and *"IPSO SmartObject Guideline - Smart Objects Starter Pack1.0"* documents.

The rationale is that by adding in the template a line like `IPSO_RESOURCE_TYPE(OBJECT_ID, RESOURCE_ID, OPERATION_TYPE, ALTERNATIVE_NAME)`, the LWM2M to IBM gateway automatically retrieves the URI `OBJECT_ID/INSTANCE_ID/RESOURCE_ID`

This is done for any object instance and for all the network nodes.

The type of resource is specified by `IPSO_RESOURCE_TYPE`:

- IPSO_RESOURCE_FLOAT for floating point values (i.e. temperature)
- IPSO_RESOURCE_INT for integer values (i.e. button counter)
- IPSO_RESOURCE_STRING for text resources (i.e. manufacturer)

The type of retrieval is specified by `OPERATION`:

- OPR_TO_GET for read operations (in loop)
- OPR_TO_OBSERVE for observe/notifications

The `ALTERNATIVE_NAME` is an optional string to send the datapoints to IBM cloud in a more readable way compared to the LWM2M/IPSO semantic.

This behavior can be triggered by the `USE_LWM2M_FORMAT_FOR_DATAPOINT_NAME` macro, in the project settings.

If this macro is set to 0 (this is the default value), the `ALTERNATIVE_NAME` is used, so with current value of the `TEMPERATURE_VALUE_STR`, the temperature value of node 0 datapoint is sent as `Temperature_Node_0`.

Otherwise the full LWM2M/IPSO semantic is used and the same datapoint is sent as `3303/0/5700_Node_0` with 3303 being the object ID for IPSO temperature, 0 the Instance ID and 5700 the Resource ID for sensor value.

Other URIs to be observed or periodically read can be added by sending commands from IBM Watson IoT to the LWM2M gateway, connecting the latter as a registered device.

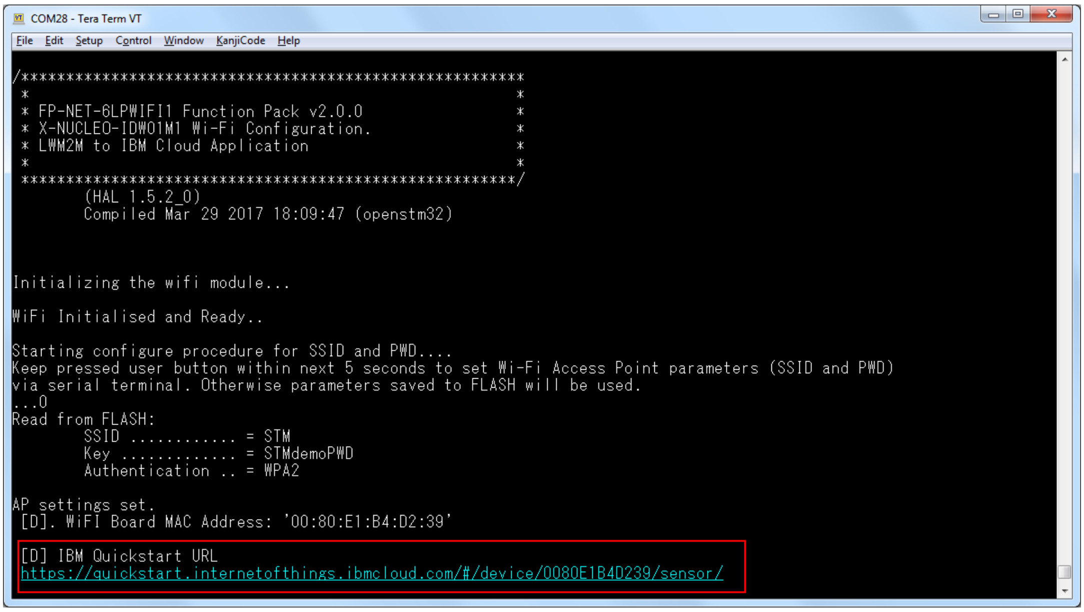
2.5.3.2 *Sensor data visualization in IBM Quickstart*

2.5.3.2.1 Setup based on STM32 Nucleo

The LWM2M to IBM sample application contains a default configuration to connect the STM32 Nucleo board to IBM Watson IoT cloud, enabling to display sensor data on an IBM web page (https://quickstart.internetofthings.ibmcloud.com), depending on the device MAC address.

Once the application is configured and running, you can use a serial line monitor to view messages from the STM32 Nucleo board and to configure the SSID and password for connecting the board to an available Wi-Fi network.

Figure 12. Startup and Wi-Fi credential configuration (STM32 Nucleo)

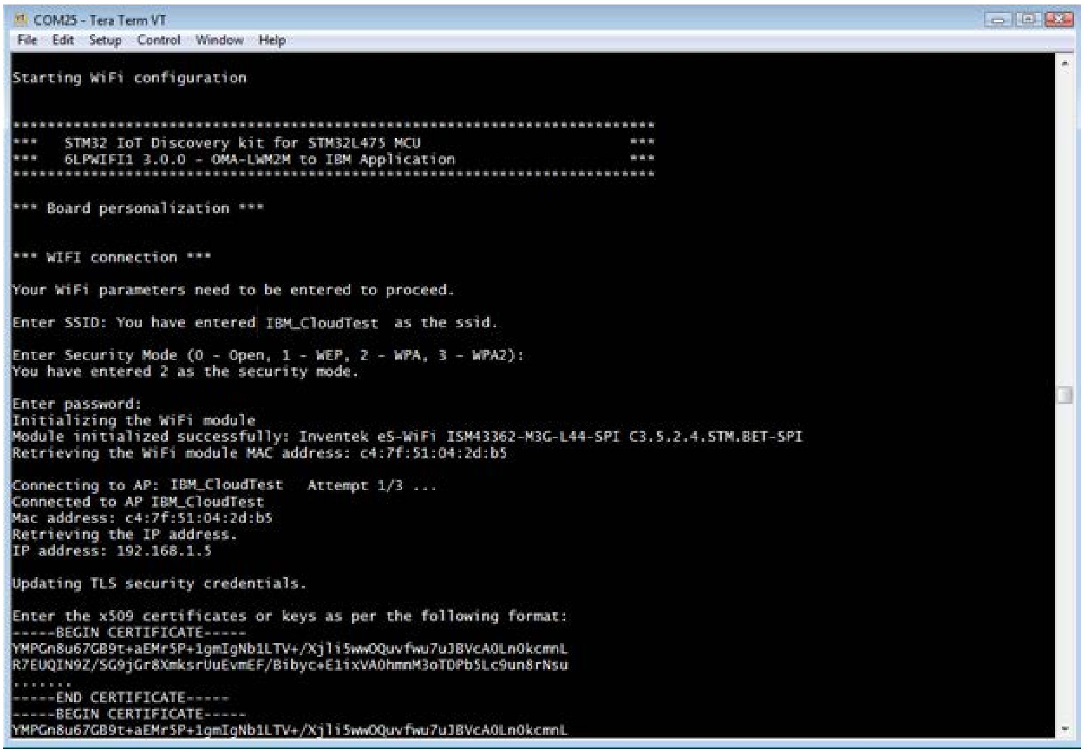


After connection to a Wi-Fi access point, the application shows the Wi-Fi expansion board MAC address and the IBM Quickstart URL in the serial console.

2.5.3.2.2 Setup based on the Discovery kit IoT node (B-L475E-IOT01A)

When using the IoT Discovery board the Wi-Fi, the provisioning phase is slightly different. The first time the board is powered on, you must enter the Wi-Fi credentials and paste the certificate in the Projects\B-L475E-IOT01A\Applications\LWM2M_to_IBM\Common\Bluemix\comodo_bluemix.pem file (these parameters will be saved in the flash memory, so you will not be asked to insert them anymore).

Figure 13. **Startup and Wi-Fi credential configuration for Discovery kit**

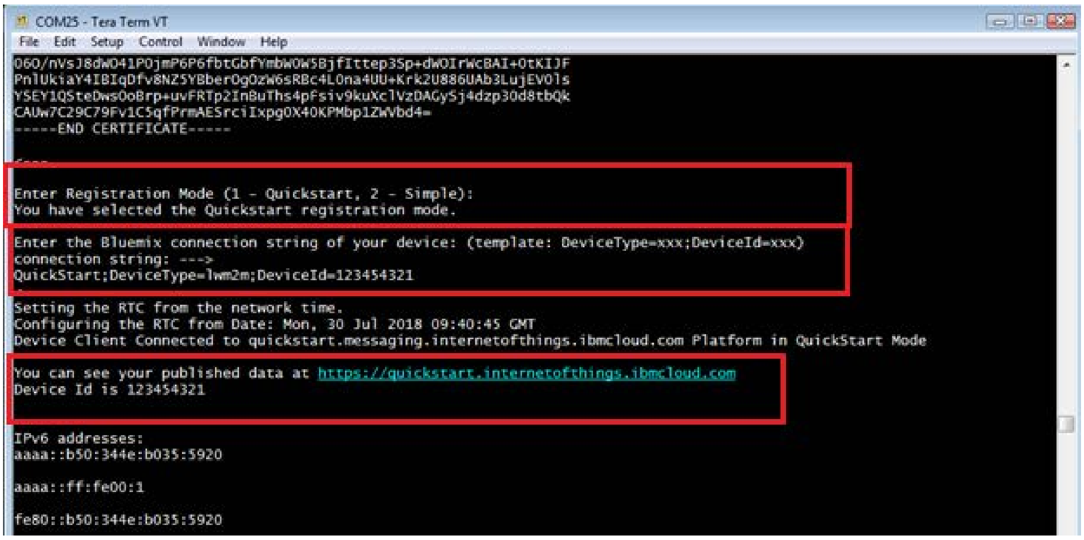


Step 1. Choose the **Registration mode** (1 for Quickstart)

Step 2. Enter a connection string in the form DeviceType=MY_DEV_TYPE;DeviceId=MY_DEV_ID.

Important: The DeviceId must be unique.

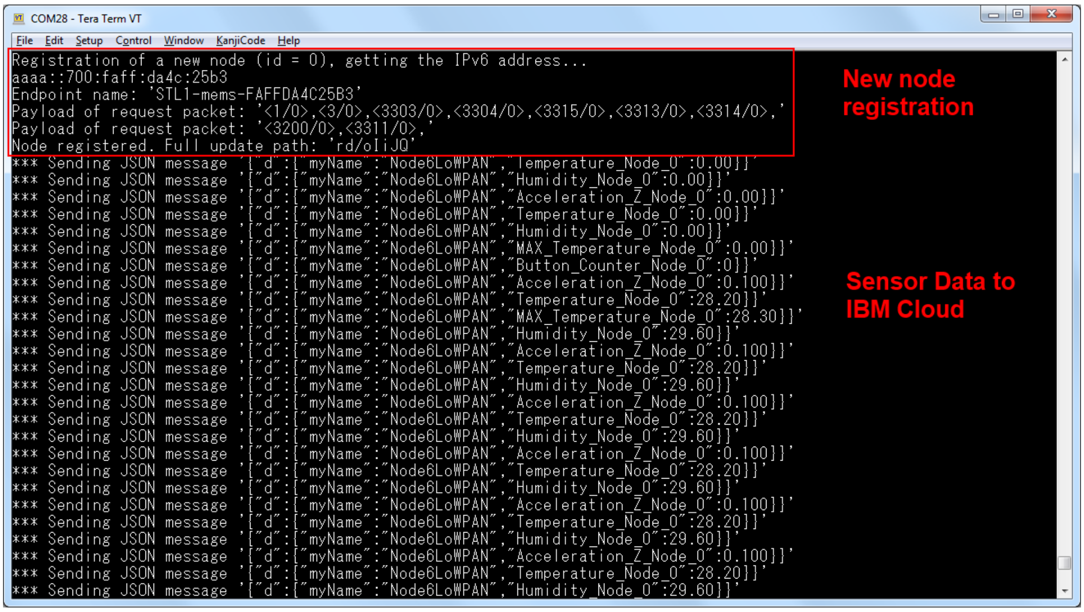
Figure 14. **Startup and Wi-Fi credential configuration for Discovery kit (continued)**



Step 3. Whichever the case (use of STM32 Nucleo or Discovery kit IoT node), power one or more wireless sensor nodes ("ipso-mems" node in this example) on.

Step 4. Wait for the nodes to register to the LWM2M server implemented by the LWM2M_to_IBM application.

Figure 15. **Wireless node registration to the LWM2M-to-IBM gateway**

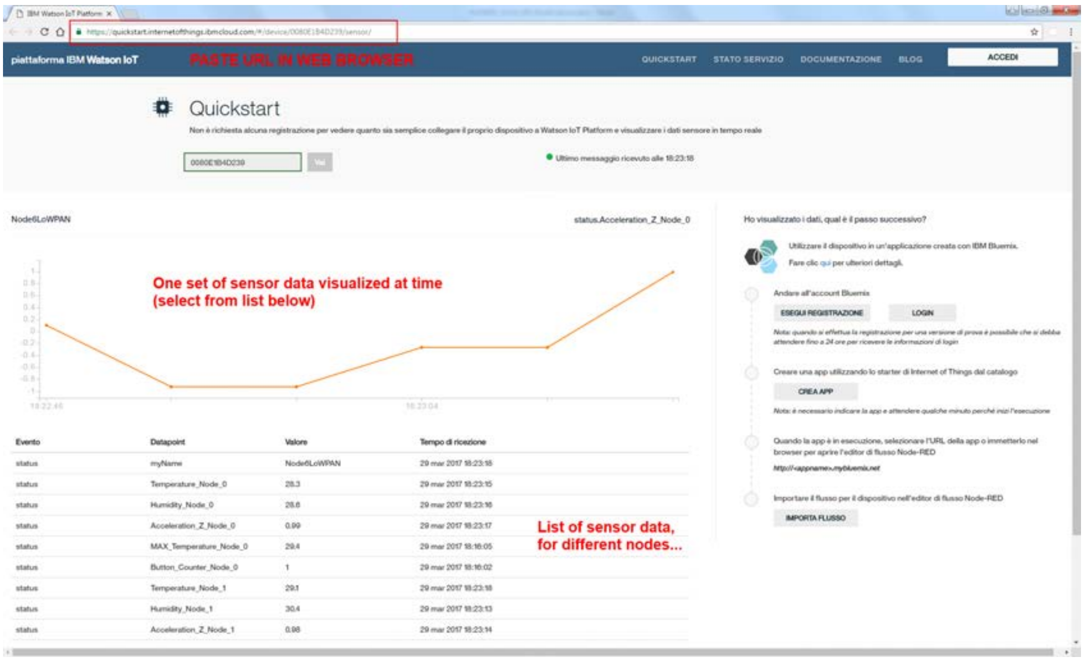


The LWM2M_to_IBM application processes the user-defined template and starts relevant observations and periodic read (as loop) on the discovered resources.

The values that are configured to be retrieved are published in the IBM cloud through a JSON message over MQTT (some values for temperature, acceleration and humidity are shown in the picture above).

Step 5. Paste the URL shown in Figure 12. Startup and Wi-Fi credential configuration (STM32 Nucleo) to a web browser URL bar to view real time sensor data, as shown below.

Figure 16. **Sensors data in IBM Quickstart web page**



2.5.3.3 Connection to IBM Watson IoT cloud as registered device

2.5.3.3.1 Setup based on STM32 Nucleo

To register the STM32 Nucleo-based microsystem to IBM Watson IoT cloud, you must create an account on IBM Watson cloud by following the instructions provided at https://www.ibm.com/marketplace/cloud/internet-of-things-cloud/us/en-us (for step-by-step screenshot details, see the FP-NET-6LPWIFI1 Quick Start Guide, available at www.st.com).

Once you have signed in to the IBM Watson IoT platform and you have selected the Internet of Things service, it is possible to register a new device. During the device registration procedure, several device properties are provided (they are also used to configure the hardware during the setup phase):

- organization ID (e.g. “cx44f7”);
- device type (e.g. “LWM2M_device”);
- authentication method (only the “use-token-auth” method is supported);
- authentication token (e.g. “6qZ60XfM!nPdx3c*)m”).

These properties must then be copied into the `Config_MQTT_IBM` function in the file Projects/Multi/Applications/LWM2M_to_IBM/Src/IBM_Bluemix_Config.c and `ibm_mode` must be set to “REGISTERED” as shown below.

Figure 17. Configuration for registering the STM32 device on IBM Watson IoT cloud

```c
void Config_MQTT_IBM ( MQTT_vars *mqtt_ibm_setup,  uint8_t *macadd )
{
  /* Default Configuration for QUICKSTART. REGISTERED mode requires account on Bluemix */
  mqtt_ibm_setup->ibm_mode = REGISTERED;

  /* Quickstart visualization */
  if ( mqtt_ibm_setup->ibm_mode == QUICKSTART )
  {
    strcpy((char*)mqtt_ibm_setup->pub_topic, "iot-2/evt/status/fmt/json");
    strcpy((char*)mqtt_ibm_setup->sub_topic, "");
    strcpy((char*)mqtt_ibm_setup->clientid,"d:quickstart:nucleo:");
    strcat((char*)mqtt_ibm_setup->clientid,(char *)macadd);
    mqtt_ibm_setup->qos = QOS0;
    strcpy((char*)mqtt_ibm_setup->username,"");
    strcpy((char*)mqtt_ibm_setup->password,"");
    strcpy((char*)mqtt_ibm_setup->hostname,"quickstart.messaging.internetofthings.ibmcloud.com");
    strcpy((char*)mqtt_ibm_setup->device_type,"");
    strcpy((char*)mqtt_ibm_setup->org_id,"");
    mqtt_ibm_setup->port = 8883; //TLS
    mqtt_ibm_setup->protocol = 's'; // TLS no certificates
  }
  else
  {
    /* REGISTERED DEVICE */
    /* Need to be customized */
    strcpy((char*)mqtt_ibm_setup->pub_topic,"iot-2/evt/status/fmt/json" ); //"iot-2/evt/status/fmt/json"
    strcpy((char*)mqtt_ibm_setup->sub_topic, "iot-2/cmd/+/fmt/json");
    mqtt_ibm_setup->qos = QOS0;
    strcpy((char*)mqtt_ibm_setup->username,"use-token-auth");
    strcpy((char*)mqtt_ibm_setup->password,"6qZ60XfM!nPdx3c*)m");
    strcpy((char*)mqtt_ibm_setup->hostname,"cx44f7.messaging.internetofthings.ibmcloud.com");
    strcpy((char*)mqtt_ibm_setup->device_type,"LWM2M_device");
    strcpy((char*)mqtt_ibm_setup->org_id,"cx44f7");

    strcpy((char *)mqtt_ibm_setup->clientid, "d:");
    strcat((char *)mqtt_ibm_setup->clientid, (char *)mqtt_ibm_setup->org_id);
    strcat((char *)mqtt_ibm_setup->clientid,":");
    strcat((char *)mqtt_ibm_setup->clientid,(char *)mqtt_ibm_setup->device_type);
    strcat((char *)mqtt_ibm_setup->clientid,":");
    strcat((char*)mqtt_ibm_setup->clientid,(char *)macadd);
    mqtt_ibm_setup->port = 8883; //TLS
    mqtt_ibm_setup->protocol = 's'; // TLS no certificates
  }

  return;
}
```

2.5.3.3.2 Setup based on the Discovery kit IoT node

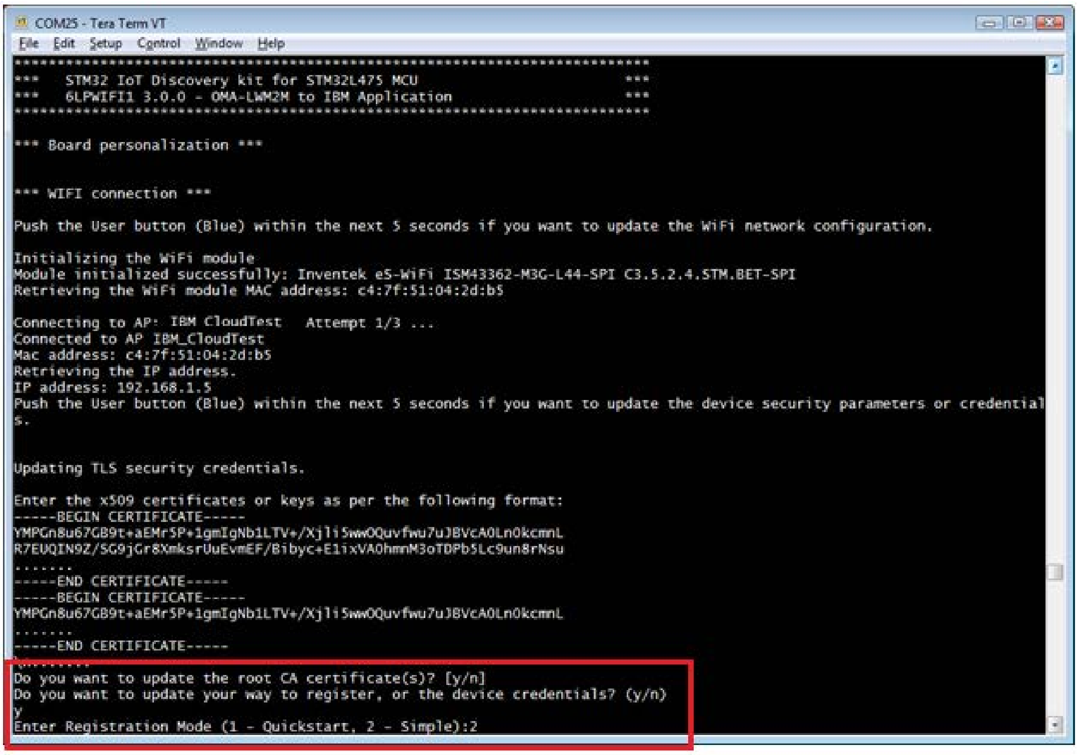
To register the Discovery-based microsystem to IBM Watson IoT cloud, you must create an account on IBM Watson cloud by following the instructions provided at https://www.ibm.com/marketplace/cloud/internet-of-things-cloud/us/en-us (for step-by-step screenshot details, see the FP-NET-6LPWIFI1 Quick Start Guide, available at www.st.com).

Once you have signed in to the IBM Watson IoT platform and you have selected the Internet of Things service, it is possible to register a new device. During the device registration procedure, several device properties are provided (they are also used to configure the hardware during the setup phase):

- organization ID (e.g. “yuzagl”);
- device type (e.g. “lwm2m”);
- authentication method (only the “use-token-auth” method is supported);
- authentication token (e.g. “6zfm)SlpQbr7r6jz23”).

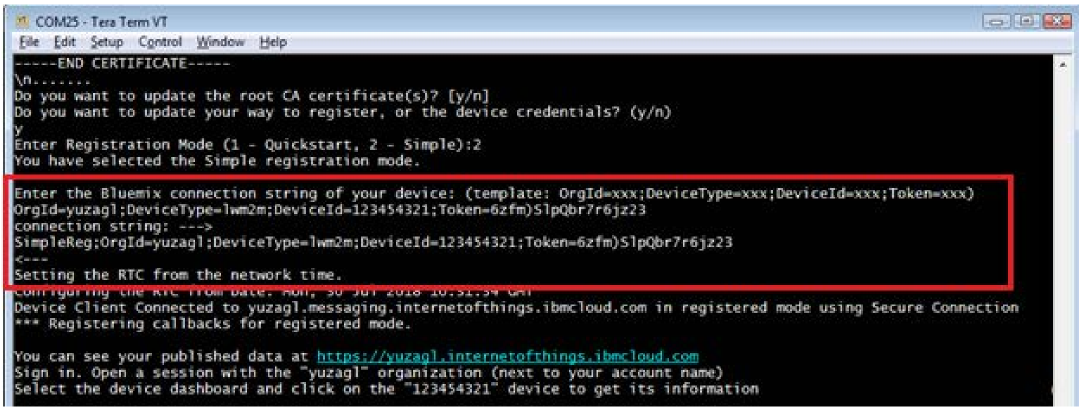
The “Simple Registered” mode can be chosen during the boot phase of the Discovery board. If you already have used it in Quickstart mode, you can boot normally and reply “y” only when prompted if you want to update the device credentials and choose option 2 (Simple) as registration mode.

Figure 18. “LWM2M to IBM” setup with Discovery kit



The parameters listed above must be entered in a single registration string (for example, OrgId=yuzagl;DeviceType=lwm2m;DeviceId=123454321;Token=6zfm)SlpQbr7r6jz23) when prompted, as shown in the next figure.

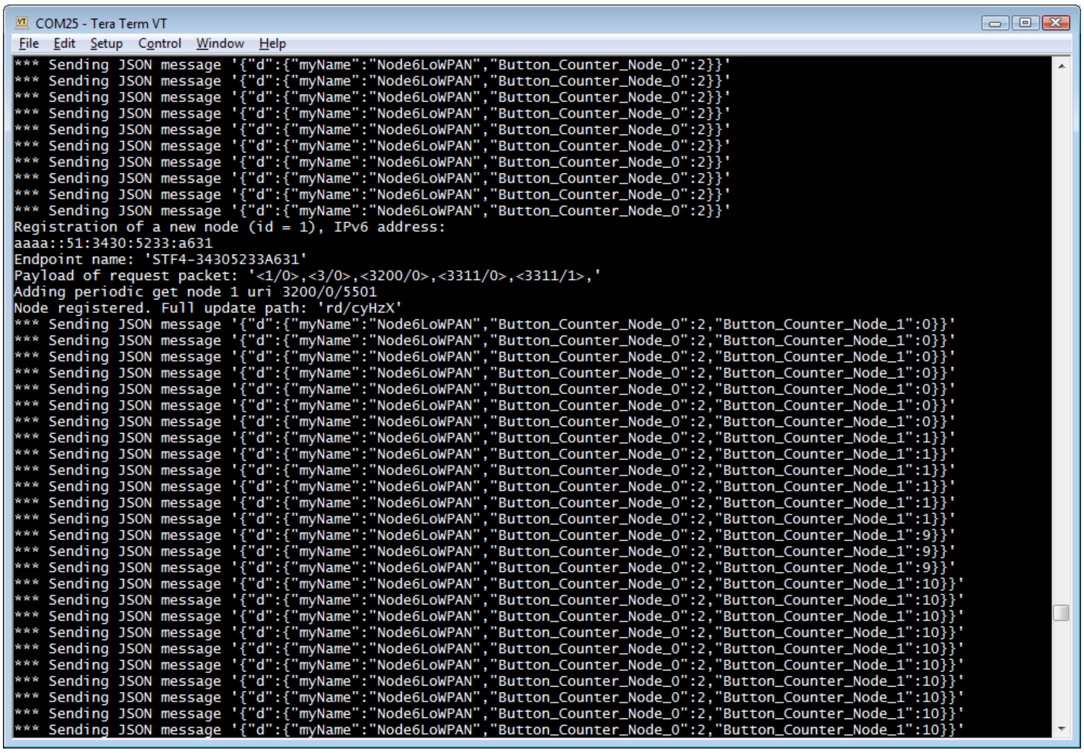
Figure 19. "LWM2M to IBM" setup with Discovery kit (continued)



Like printed in the device console, the data can be seen at the provided URL (https://ORGANIZATION_ID.internetofthings.ibmcloud.com.

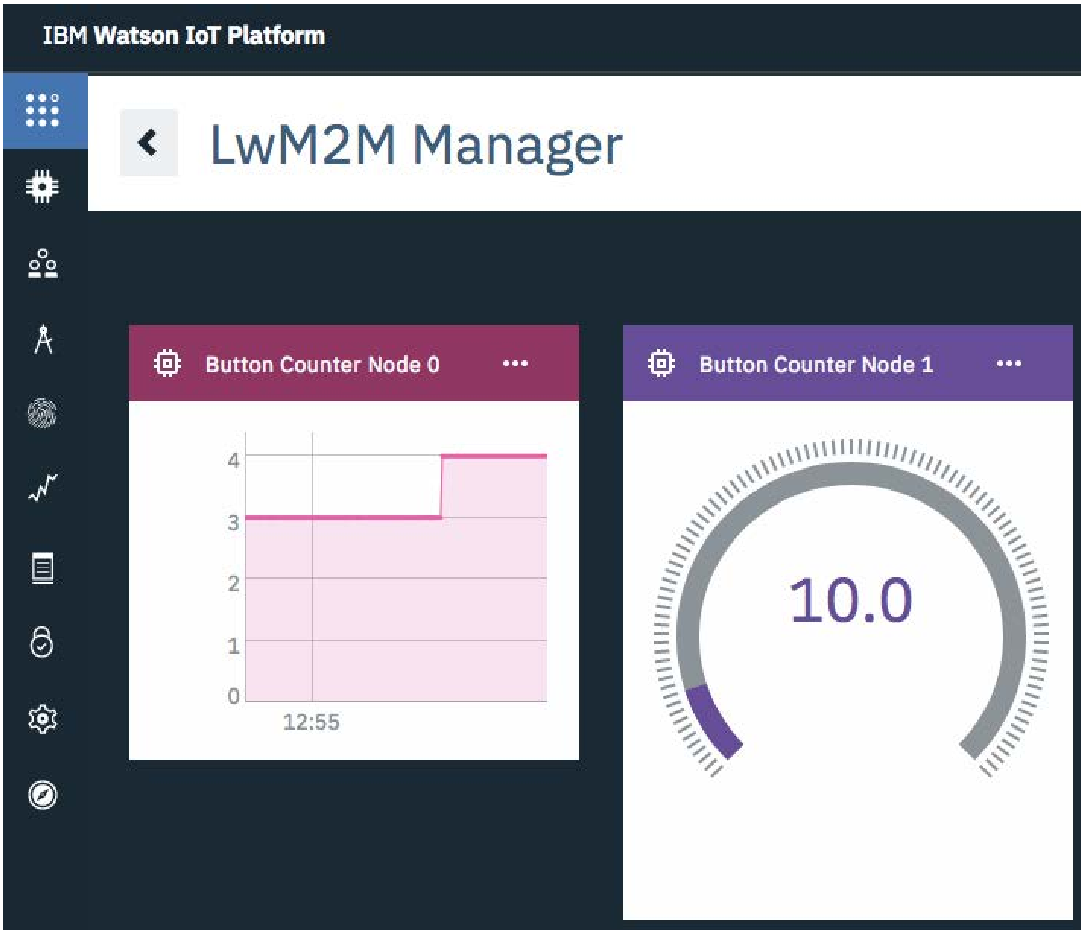
The data from the connected nodes are collected and sent to the cloud, as shown below.

Figure 20. Data sent to IBM cloud



Data can now be displayed by creating a dashboard and adding some dataset (for step-by-step instructions, see the FP-NET-6LPWIFI1 Quick Start Guide, available at www.st.com). For example, the next figure shows the visualization of the button counters of the two nodes (whose JSON data are shown in the figure above) using different chart types.

Figure 21. Dashboard example

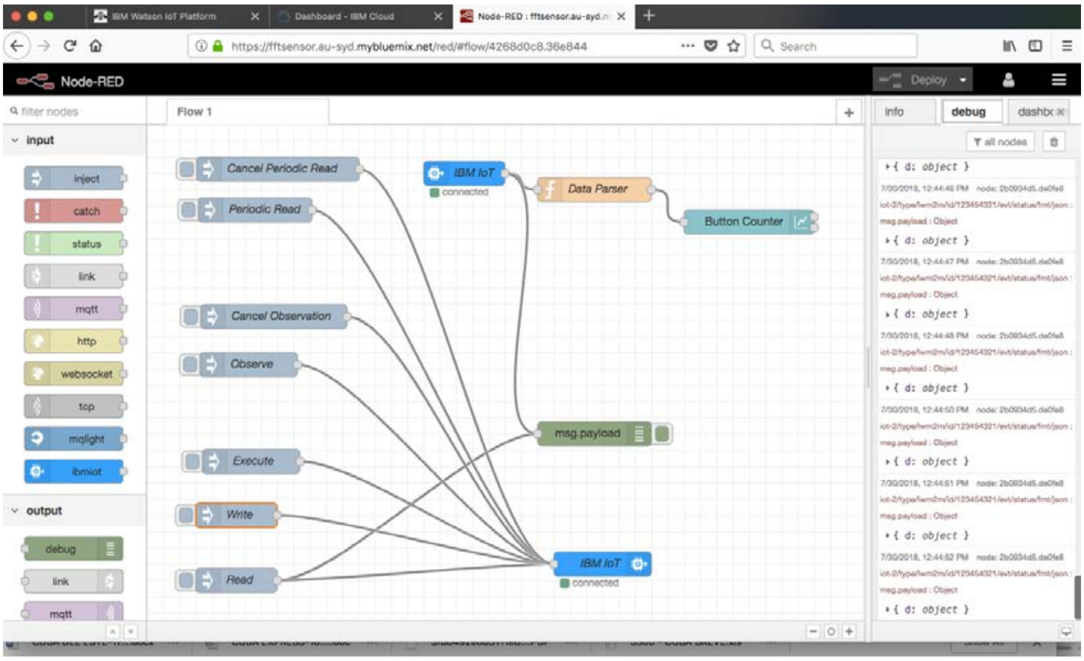


2.5.3.3.3 NodeRed

Once registered and connected to IBM Watson IoT cloud, the STM32 Nucleo or Discovery-based microsystem can send and receive data to and from IBM cloud applications and IoT services. More information about how to develop cloud applications and services can be found at https://www.ng.bluemix.net/docs/starters/Node-RED/nodered.html.

The following figure shows the screenshot of a possible Node-RED program in which the supported commands are shown.

Figure 22. **Node-RED program blocks**



The LWM2M to IBM application currently supports seven possible types of commands that can be sent from the IBM Bluemix application to the LWM2M gateway; the generic form is an MQTT message with a JSON payload containing:

- `{"Node":nodeID`
- `"Path":"resourceUri"`
- `"Type":String/Int/Float`
- `"Operation":"Read/Write/Execute/Observe/Cancel/PRead/CRead"`
- `"Value": value }`

In this way, it is possible to directly map five LWM2M standard operations (read, write, execute, observe and cancel observation) and to manage the periodic reads through the custom operations, *PRead* (to add a resource to this list) and *CRead* (to cancel this reporting), useful as the number of observable resources on each LWM2M client is limited.

The *"resourceUri"* path must be a valid resource path as defined by the LWM2M standard and *"nodeID"* is the index of the node the command is intended for.

The *"Type"* identifies the data type according to LWM2M / IPSO data model. The *"Value"* field is meaningful only for the Write operation.

The example implements the following operations:

1. Read the Float value of X axis (resource ID: 5702) of instance 0 of the magnetometer sensor (object ID: 3314), from node 0:
   `{"Node":0,"Path":"3314/0/5702","Operation":"Read","Type":"Float","Value":0}`
2. Set to the Integer value=1 the On/Off (resource ID: 5850) attribute of instance 0 of the light control (object ID: 3311, that is used in this case to map the green LED), on node 0 (i.e. to switch the green LED on):
   `{"Node":0,"Path":"3311/0/5850","Operation":"Write","Type":"Int","Value":1}`
3. Execute the Digital Input Counter Reset (resource ID: 5505) of instance 0 of the digital input (object ID: 3200, that is used in this case to map the user button):
   `{"Node":0,"Path":"3200/0/5505","Operation":"Execute","Type":"Int","Value":1}`
4. Observe the Float value of Z axis (resource ID: 5704) of instance 0 of the magnetometer sensor (object ID: 3314), from node 0:
   `{"Node":0,"Path":"3314/0/5704","Operation":"Observe","Type":"Float","Value":0}`

5. Cancel the observation of the Float value of Z axis (resource ID: 5704) of instance 0 of the magnetometer sensor (object ID: 3314), from node 0:
   `{"Node":0,"Path":"3314/0/5704","Operation":"Cancel","Type":"Float","Value":0}`
6. Add to the periodic Read list the Float value of Y axis (resource ID: 5703) of instance 0 of the magnetometer sensor (object ID: 3314), from node 0:
   `{"Node":0,"Path":"3314/0/5703","Operation":"PRead","Type":"Float","Value":0}`
7. Remove from the periodic Read list the Float value of Y axis (resource ID: 5703) of instance 0 of the magnetometer sensor (object ID: 3314), from node 0:
   `{"Node":0,"Path":"3314/0/5703","Operation":"CRead","Type":"Float","Value":0}`

For instance, by executing the example described in point 6, this new datapoint is added to the other ones (pre-programmed via the template).

Note: In this case the datapoint name is actually the full resource path.

Figure 23. Sensor data visualization in the IBM web page for a registered device

status	d.myName	Node6LoWPAN	30 mar 2017 19:37:33
status	d.3314/0/5703_Node_0	0.51	30 mar 2017 19:37:30
status	d.Acceleration_Z_Node_0	0.96	30 mar 2017 19:37:33
status	d.Temperature_Node_0	28.7	30 mar 2017 19:37:27
status	d.Button_Counter_Node_0	3	30 mar 2017 19:37:12

Both the Node-RED program and the LWM2M to IBM code can be easily modified to address different needs (for example, reading different resources, addressing the nodes by means of IPv6 address, adding other commands for the gateway).

Figure 22. Node-RED program blocks shows a data parser and a dashboard that can be used to add a real-time web-based dashboard visualization as shown below.

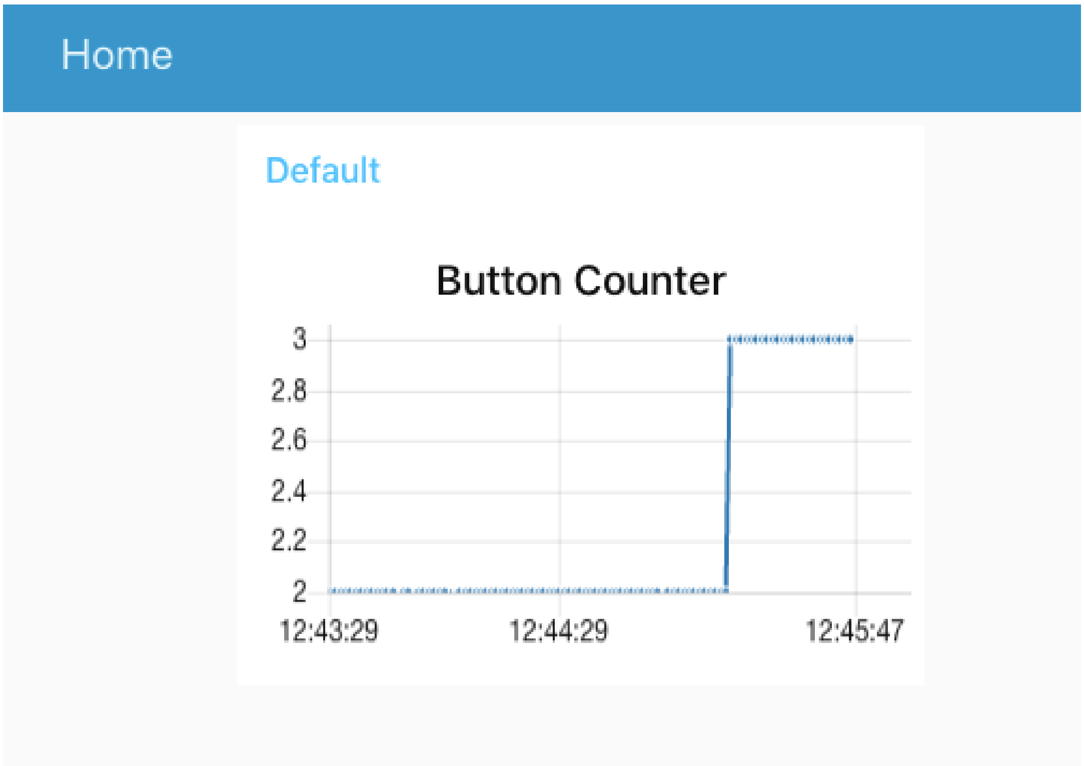


Figure 24. Button counter on the web-based dashboard

The source code related to the gateway functionality can be found in the file Projects/Multi/Applications/LWM2M_to_IBM/Src/lwm2m-simple-server.c, inside the *PROCESS_THREAD(command_process, …)* at the bottom of the file.

The Node-RED program source code can be found in \Utilities\NodeRED\LWM2M.json file. Simply copy and paste it into the Node-RED Flow Editor to be imported. You just have to adapt the application keys.

2.5.4 Wireless sensor node for LWM2M to IBM application

To enable user deployment and testing of end-to-end solutions between wireless sensor nodes and Internet based servers, some sample node applications are provided in the form of pre-compiled and ready-to-use binaries for STM32 Nucleo board equipped with STM32 Nucleo expansion boards. The applications export various resources, depending on the type of expansion boards stacked on the NUCLEO-F401RE board.

The supported hardware configurations and application examples for the wireless sensor nodes are the following (see Section 3.3.1 Hardware setup for more details):

1. NUCLEO-F401RE plus X-NUCLEO-IDS01A4 or X-NUCLEO-IDS01A5 (see example in /Utilities/Binary/LWM2M_to_IBM/Ipso_Example_Nosensors/): it exports common resources like LEDs and user buttons.
2. NUCLEO-F401RE plus X-NUCLEO-IDS01A4 or X-NUCLEO-IDS01A5 plus X-NUCLEO-IKS01A1 (see example in /Utilities/Binary/LWM2M_to_IBM/Ipso_Example_Mems/): it exports resources from the MEMS sensor expansion board (temperature, humidity and accelerometer sensors).
3. NUCLEO-F401RE plus X-NUCLEO-IDS01A4 or X-NUCLEO-IDS01A5 plus X-NUCLEO- 6180XA1 (see example in /Utilities/Binary/LWM2M_to_IBM/Ipso_Example_Proximity/): it exports resources from the FlightSense expansion board (proximity sensor).

These applications demonstrate how a node can connect to a local server using the OMA lightweight M2M (LWM2M) standard. This technology uses CoAP (over UDP) to publish a node resources in a standard format (as specified by LWM2M) and make them available to be accessed from a LWM2M server.

In these examples, the nodes connect to a local, hard-coded address that is assigned to the LWM2M to IBM gateway: **aaaa::ff:fe00:1** (this address is selected regardless of the actual MAC address associated to the interface).

This address can be changed at the top of the file Projects/Multi/Applications/LWM2M_to_IBM/Src/lwm2m-simple-server.c by modifying the following macro: `#define LWM2M_SERVER_ADDRESS_v6 "aaaa::ff:fe00:1"`.

It must be kept synchronized with the same macro that is used to set the LWM2M server IPV6 address in the node firmware.

2.5.4.1 *Connecting the remote node to the IBM cloud*

Step 1. Power the STM32 Nucleo board using a Mini-B USB cable connected to the PC.

Step 2. Program the firmware on the STM32 Nucleo board: you can copy (or drag and drop) the binary file (in the /Utility/Binary folder) to the USB mass storage that is automatically created when you connect the STM32 Nucleo board to your PC.

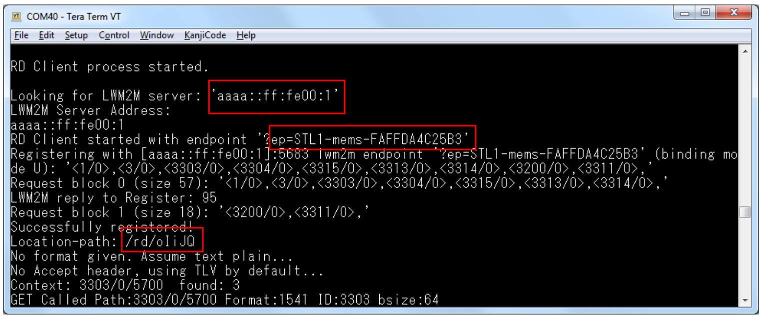
Step 3. Open a serial line monitor utility, select the serial port name to which the board is connected and configure it as follow:
- Baud Rate = 115200
- Parity = None
- Bits = 8
- Stopbits = 1

Step 4. Press the RESET (black) button on the STM32 Nucleo board and wait for the node to complete the registration.

Note: The whole process is similar to the one of the Wi-Fi bridge application node firmware, with the only difference that the wireless sensor node points to a different address for the LWM2M server.

The LWM2M address, client endpoint and location path (assigned by the server resource directory to the client) are shown below.

Figure 25. Client node registered on the local LWM2M server (gateway for IBM cloud)



3 System setup guide

3.1 Hardware description

This section describes the hardware components needed for developing a sensors based application.

The following sub-sections describe the individual components.

3.1.1 STM32 Nucleo platform

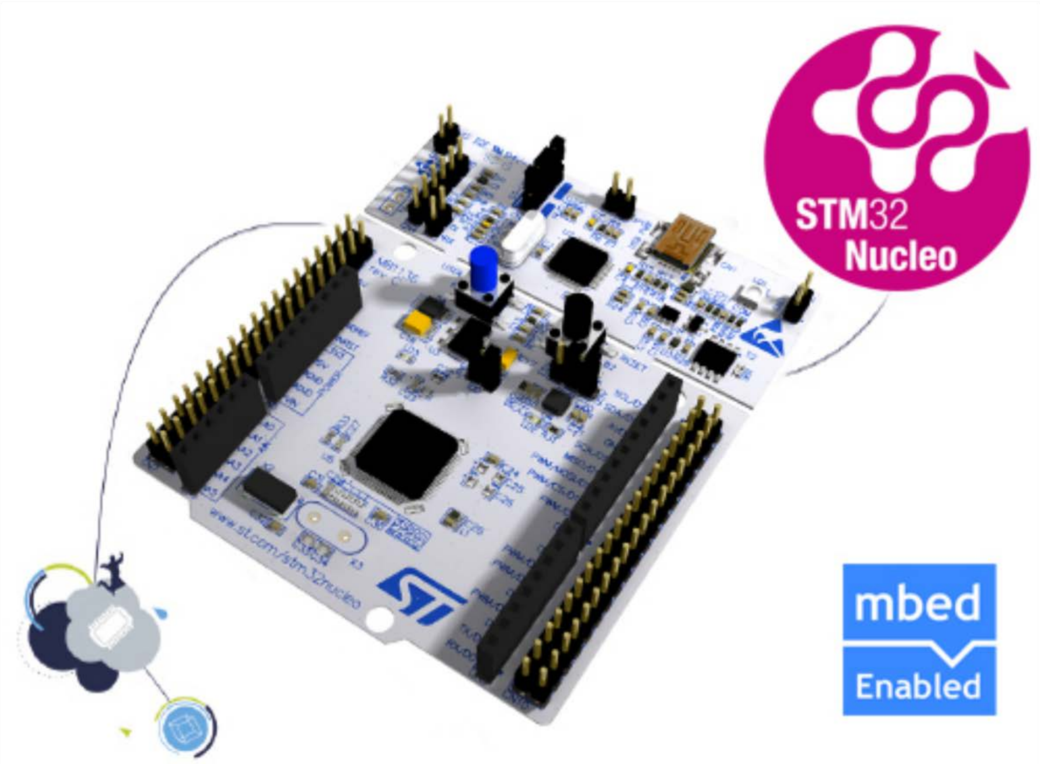
STM32 Nucleo development boards provide an affordable and flexible way for users to test solutions and build prototypes with any STM32 microcontroller line.

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.

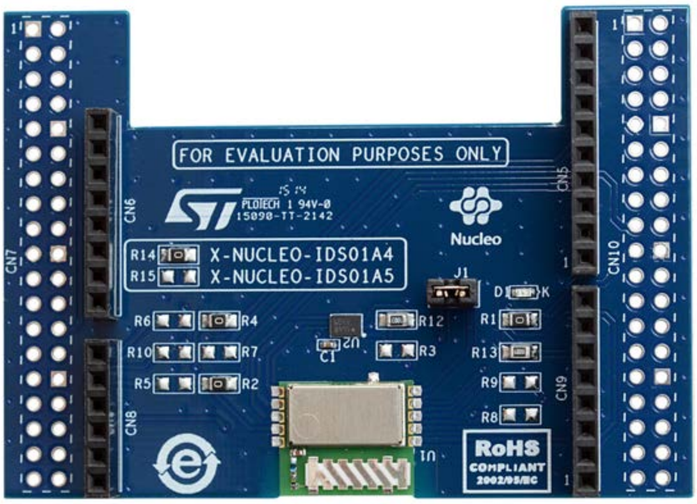
Figure 26. STM32 Nucleo board



Information regarding the STM32 Nucleo board is available at www.st.com/stm32nucleo

3.1.2 X-NUCLEO-IDS01A4 or X-NUCLEO-IDS01A5 expansion board

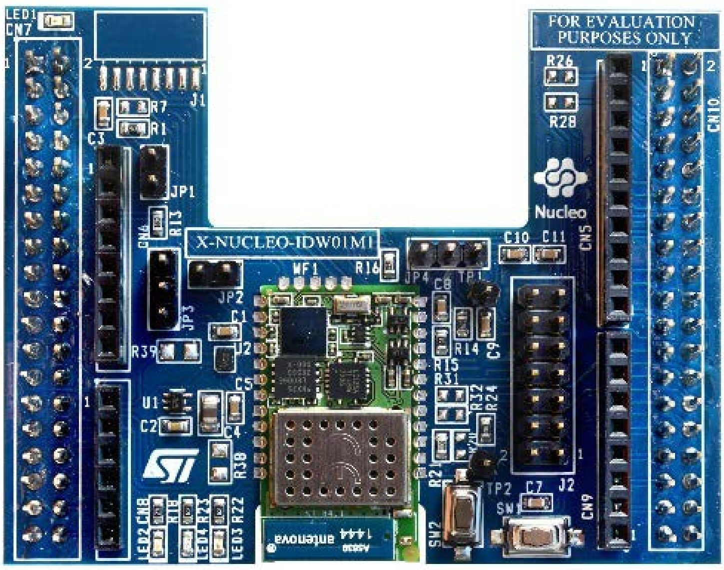
Figure 27. X-NUCLEO-IDS1A4 SPIRIT1 expansion board



Information about the X-NUCLEO-IDS01A4 and X-NUCLEO-IDS01A5 expansion board is available on www.st.com.

3.1.3 X-NUCLEO-IDW01M1 expansion board

Figure 28. X-NUCLEO-IDW01M1 Wi-Fi expansion board



Information about the X-NUCLEO-IDW01M1 expansion board is available on www.st.com.

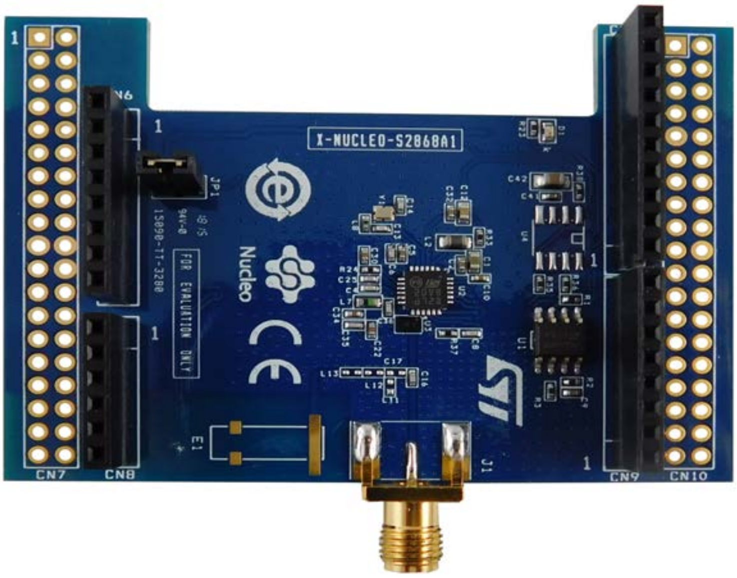
3.1.4 X-NUCLEO-S2868A1 expansion board

The X-NUCLEO-S2868A1 expansion board is based on the S2-LP radio and operates in the 868 MHz ISM frequency band.

The expansion board is compatible with ST morpho and Arduino UNO R3 connectors.

The X-NUCLEO-S2868A1 interfaces with the STM32 Nucleo microcontroller via SPI connections and GPIO pins. You can change some of the GPIOs by mounting or removing the resistors.

Figure 29. X-NUCLEO-S2868A1 expansion board



3.2 Software requirements

The following software components are required to set up a suitable development environment for creating applications for the STM32 Nucleo board with RF expansion board:

- FP-NET-6LPWIFI1 software, available on www.st.com.
- Development tool-chain and Compiler: The STM32Cube expansion software supports the three following environments:
  - IAR Embedded Workbench for ARM® (EWARM) toolchain + ST-LINK
  - RealView Microcontroller Development Kit (MDK-ARM) toolchain + ST-LINK
  - System Workbench for STM32 (SW4STM32) + ST-LINK

3.3 Hardware and software setup

3.3.1 Hardware setup

For the implementation of the bridge, the following hardware components are required:

- One STM32 Nucleo development platform (order code: NUCLEO-F401RE)
- One SPIRIT1 expansion board (order code: X-NUCLEO-IDS01A4 (for 868 MHz), or X-NUCLEO-IDS01A5 (for 915MHz))
- One Wi-Fi expansion board (order code: X-NUCLEO-IDW01M1)
- One USB type A to Mini-B USB cable to connect the STM32 Nucleo to the PC

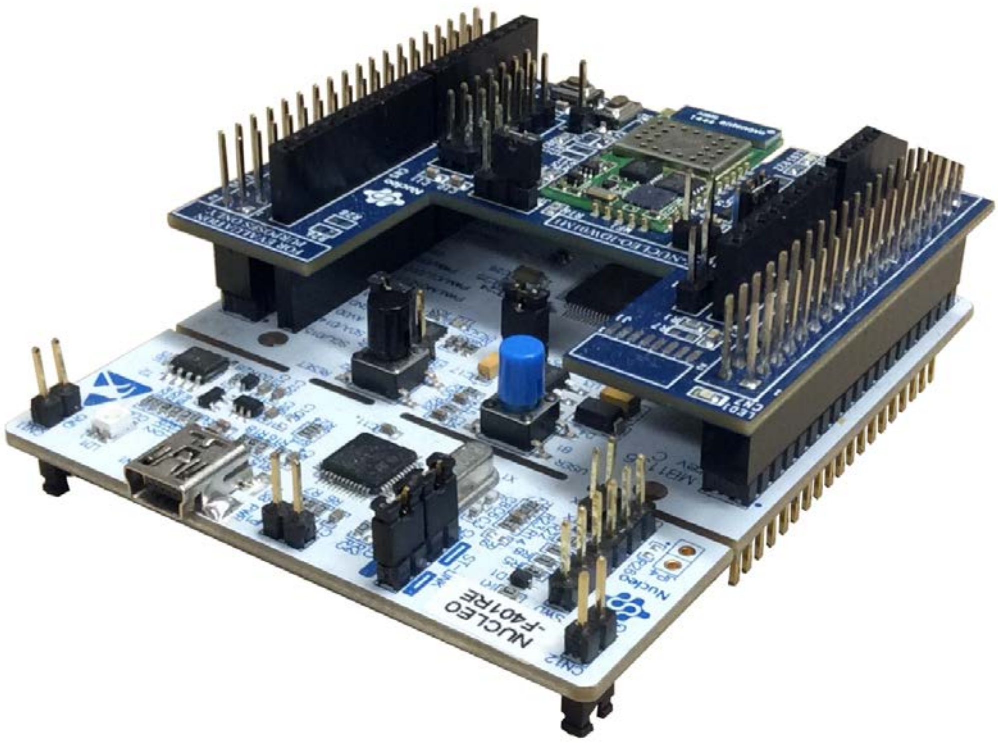
3.3.2 System setup guide

3.3.2.1 *Bridge implementation based on STM32 Nucleo*

The STM32 Nucleo board integrates the ST-LINK/V2-1 debugger/programmer; you can download the ST-LINK/ V2-1 USB driver by searching STSW-LINK009 www.st.com.

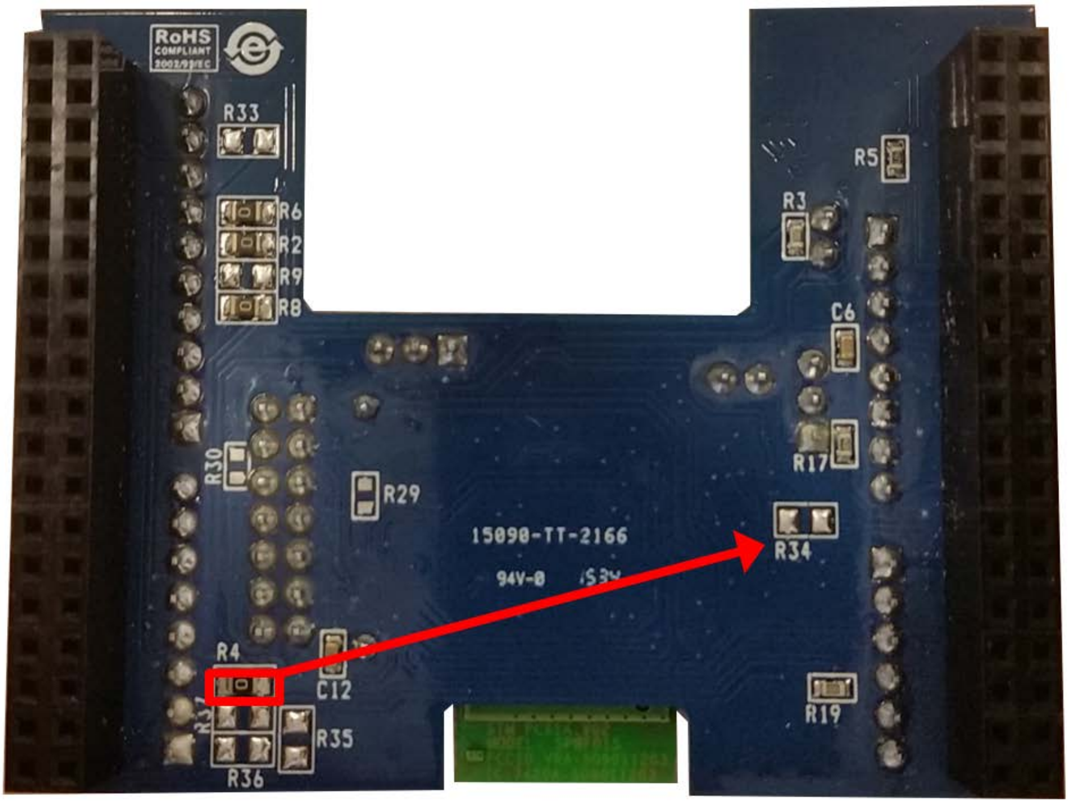
The X-NUCLEO-IDW01M1 Wi-Fi expansion board is easily connected to the STM32 Nucleo board ST morpho connector, as shown below.

Figure 30. **STM32 Nucleo plus the Wi-Fi expansion board**



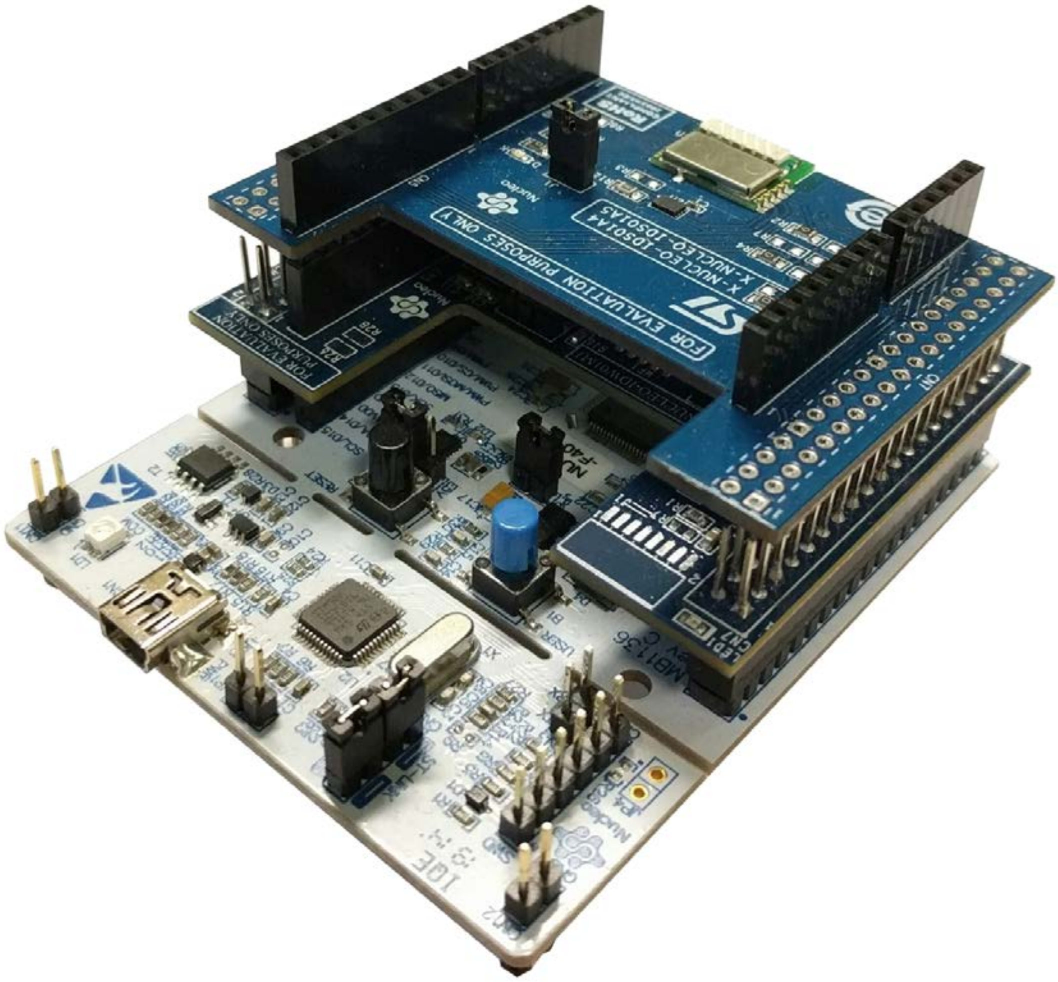
Note: To avoid a resource usage conflict between the X-NUCLEO-IDW01M1 expansion board and the X-NUCLEO-IDS1A4 or X-NUCLEO-IDS01A5 expansion board, the 0 Ω resistor at position R4 must be moved to R34, as shown below.

Figure 31. **Modification required on the X-NUCLEO-IDW01M1 expansion board**



The SPIRIT1 expansion board X-NUCLEO-IDS01A4 or X-NUCLEO-IDS01A5 is easily connected to X-NUCLEO-IDW01M1 expansion board through the Arduino UNO R3 extension connector, as shown below.

Figure 32. **STM32 Nucleo plus the Wi-Fi expansion board plus the SPIRIT1 expansion board**

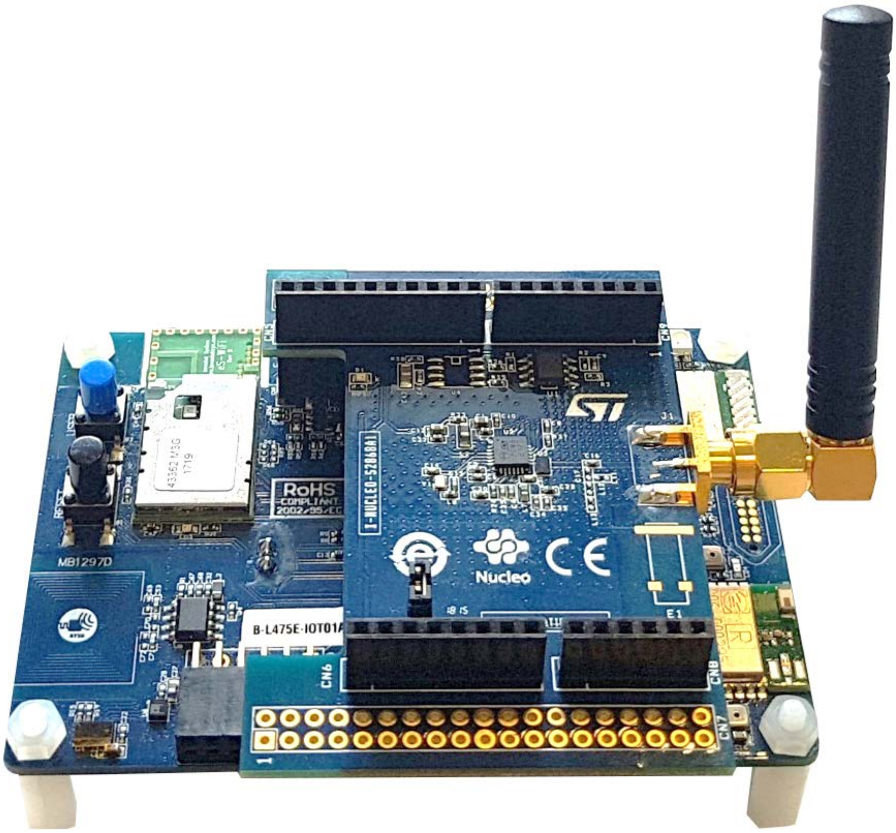


3.3.2.2 *Bridge implementation based on Discovery kit*

The Discovery kit IoT node (B-L475E-IOT01A) integrates the ST-LINK/V2-1 debugger/programmer; you can download the ST-LINK/V2-1 USB driver by searching STSW-LINK009 at www.st.com.

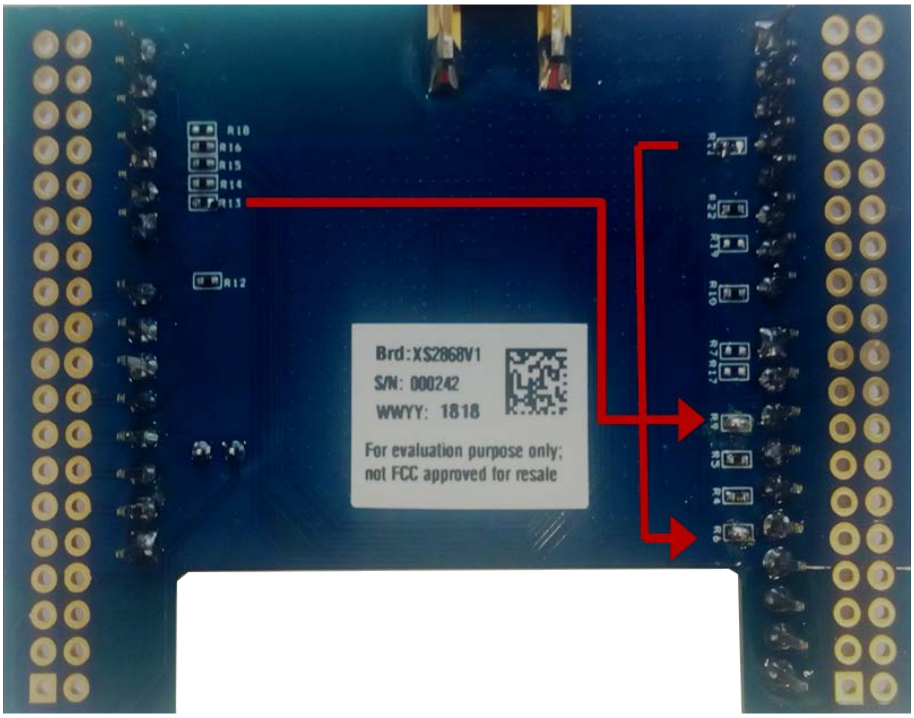
The X-NUCLEO-S2868A1 sub-1GHz expansion board can be easily connect to the Discovery kit, as shown in the next figure.

Figure 33. Discovery kit plus the Sub-1GHz expansion board (X-NUCLEO-S2868A1)



Note: A hardware modification is required on the X-NUCLEO-S2868A1 expansion board: in order to avoid a resource usage conflict between the X-NUCLEO-S2868A1 and the B-L475E-IOT01A board, the 0-Ohm resistances at position R11 and R13 must be unmounted and the 0-Ohm resistances must be mounted at positions R9 and R6, as shown below.

Figure 34. Modification required on the X-NUCLEO-S2868A1 expansion board



Revision history

Table 2. **Document revision history**

Date	Version	Changes
18-Jun-2016	1	Initial release.
14-Apr-2017	2	Updated Section "Introduction", Section 1: "Acronyms and abbreviations", Section 2.1: "Overview ", Section 2.3: "Folder structure", and Section 2.5.2: "Wireless sensor node for Wi-Fi bridge application". Added Section 2.5.3: "LwM2M to IBM", Section 2.5.3.1: "Template", Section 2.5.3.2: "Sensor data visualization in IBM Quickstart", Section 2.5.3.3: "Connection to IBM Watson IoT cloud as registered device", Section 2.5.4: "Wireless sensor node for LWM2M to IBM application" and Section 2.5.4.1: "Connecting the remote node to the IBM cloud".
05-Sep-2018	3	Updated Section Introduction, Section 2.1 Overview, Section 2.2 Architecture. Added Section 2.5.3.2.1 Setup based on STM32 Nucleo, Section 2.5.3.2.2 Setup based on the Discovery kit IoT node (B-L475EIOT01A), Section 2.5.3.3.1 Setup based on STM32 Nucleo, Section 2.5.3.3.2 Setup based on the Discovery kit IoT node, Section 2.5.3.3.3 NodeRed, , Section 3.3.2.2 Bridge implementation based on Discovery kit.
11-Apr-2019	4	Updated Section 2.5.2.1 Connecting the remote node to the Internet.

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