Introduction

This user manual describes the content of the STM32Cube software expansion package for the IBM Watson IoT™ (Internet of things) platform.

The IBM® IoT cloud software expansion package (X-CUBE-WATSON) for STM32Cube provides application examples that connect STMicroelectronics boards to the IBM Watson IoT™ platform. It uses the IBM® embedded C client library which is ported to the corresponding STM32 devices.

X-CUBE-WATSON runs on the B-L475E-IOT01, 32F413HDISCOVERY and 32F769IDISCOVERY boards.

Implementation examples are included for device-to-cloud telemetry reporting, and cloud-to-device messages for sending commands and notifications to the connected devices.

X-CUBE-WATSON offers the following features:

- Ready to run firmware example using Wi-Fi® and Ethernet connectivity to support quick evaluation and development of IBM Watson® device applications
- Board configuration interface
- Wi-Fi® connection
- Connection to the IBM Watson IoT™ platform and various call-back registrations
- The B-L475E-IOT01 board measures and reports the following values:
  - Humidity
  - Temperature
  - 3D magnetic data
  - 3D acceleration
  - 3D gyroscope data
  - Atmospheric pressure
  - Proximity
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The X-CUBE-WATSON package for the IBM Watson IoT™ platform runs on STM32 32-bit microcontrollers based on the Arm® Cortex®-M processor.

Table 1 presents the definition of acronyms that are relevant for a better understanding of this document.

### Table 1. List of acronyms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>API</td>
<td>Application programming interface</td>
</tr>
<tr>
<td>BSP</td>
<td>Board support package</td>
</tr>
<tr>
<td>CA</td>
<td>Certification authority</td>
</tr>
<tr>
<td>DHCP</td>
<td>Dynamic host configuration protocol</td>
</tr>
<tr>
<td>DNS</td>
<td>Domain name server</td>
</tr>
<tr>
<td>HAL</td>
<td>Hardware abstraction layer</td>
</tr>
<tr>
<td>IDE</td>
<td>Integrated development environment</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of things</td>
</tr>
<tr>
<td>IP</td>
<td>Internet protocol</td>
</tr>
<tr>
<td>JSON</td>
<td>JavaScript object notation</td>
</tr>
<tr>
<td>LED</td>
<td>Light-emitting diode</td>
</tr>
<tr>
<td>RTC</td>
<td>Real-time clock</td>
</tr>
<tr>
<td>UART</td>
<td>Universal asynchronous receiver/transmitter</td>
</tr>
</tbody>
</table>
This chapter introduces the IBM Watson IoT™ platform.

The X-CUBE-WATSON package implements the IBM® embedded C client library which allows the board to securely connect to the IBM Watson IoT™ platform.

A user can connect to the cloud with a smartphone or personal computer and have access to the information provided by the board at any time and from any location.

*Figure 1* presents the IBM Watson IoT™ ecosystem targeted by the X-CUBE-WATSON package.

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**Figure 1. IBM Watson IoT™ ecosystem**
3 Package description

This chapter details the X-CUBE-WATSON package content and the way to use it.

3.1 General description

The X-CUBE-WATSON package provides a Bluemix® stack middleware for STM32 microcontrollers.

It is ported to the B-L475E-IOT01, 32F413HDISCOVERY and 32F769IDISCOVERY boards and connects to the Internet through the on-board network interface:

- B-L475E-IOT01 supports Wi-Fi® connectivity with an on-board Inventek module. This board is equipped with a set of sensors able to report humidity, temperature, 3D-axis magnetic data, 3D accelerations, 3D gyroscope data, atmospheric pressure, proximity and gesture detection (X-CUBE-WATSON does not use the gesture detection capability).
- 32F413HDISCOVERY supports Wi-Fi® connectivity with an on-board Inventek module.
- 32F769IDISCOVERY natively provides an Ethernet interface.

The package is split into the following components:

- Client libraries and samples for connecting to IBM Watson IoT™ using Embedded C
- mbedtls
- LwIP
- FreeRTOS™
- Wi-Fi® drivers
- Ethernet driver for the 32F769IDISCOVERY board
- Sensor drivers for the B-L475E-IOT01 board
- STM32L4 Series, STM32F4 Series, and STM32F7 Series HAL
- Bluemix® application examples

The software is provided as a zip archive containing source code.

The following integrated development environments are supported:

- IAR Embedded Workbench® for Arm® (EWARM)
- Keil® Microcontroller Development Kit (MDK-ARM)
- System Workbench for STM32

Note: refer to the release note available in the package root folder for information about the IDE versions supported.
3.2 Architecture

This section describes the software components of the X-CUBE-WATSON package.

The X-CUBE-WATSON software is an expansion for the STM32Cube. Its main features and characteristics are:

- Fully compliant with STM32Cube architecture
- Expands STM32Cube in order to enable the development of applications accessing and using the IBM Watson IoT™ platform
- Based on the STM32CubeHAL, which is the hardware abstraction layer for STM32 microcontrollers

The software components used by the application software to access and use the IBM Watson IoT™ platform are the following:

- **STM32Cube HAL**
  The HAL driver layer provides a generic multi-instance simple set of APIs (application programming interfaces) to interact with the upper layers (application, libraries and stacks).
  It is composed of generic and extension APIs. It is directly built around a generic architecture and allows the layers that are built upon, such as the middleware layer, to implement their functionalities without dependencies on the specific hardware configuration for a given microcontroller unit (MCU).
  This structure improves the library code reusability and guarantees an easy portability onto other devices.

- **Board support package (BSP)**
  The software package needs to support the peripherals on the STM32 boards apart from the MCU. This software is included in the board support package (BSP). This is a limited set of APIs which provides a programming interface for certain board specific peripherals such as the LED and the user button.

- **Bluemix® middleware**
  It is composed of the Bluemix® IoT hub client library, a JSON parser, a JSON serializer, an MQTT client (used as a transport layer by the IoT hub client library), and various C utilities used by the client library.

- **mbedTLS**
  The Bluemix® middleware uses a TLS connection which is managed by the mbedTLS library.

- **TCP/IP**
  The TCP/IP connection can be handled either by the Wi-Fi® module (when a Wi-Fi® connection is being used) or by the LwIP middleware (when an Ethernet connection is being used). In the X-CUBE-WATSON package, only the 32F769IDISCOVERY board can connect via Ethernet.

- **FreeRTOS™**
  It is a real-time operating system required by LwIP for providing a socket-based interface to the user.

*Figure 2* outlines X-CUBE-WATSON software architecture.
Figure 2. X-CUBE-WATSON software architecture

Application level demonstrations
- Sample applications
- IBM® IoT cloud utilities
- User application

Middleware level
- Paho MQTT
- mbedTLS
- LwIP
- FreeRTOS™

Drivers
- Board support package (BSP)
- Hardware abstraction layer (HAL)

Hardware components
- STM32
- Wi-Fi® module
- Ethernet
- Sensors

Development boards
- B-L475E-IOT01
- 32F413DISCOVERY
- 32F769DISCOVERY

CMSIS

Utilities

PC software
3.3 Folder structure

*Figure 3* presents the folder structure of the X-CUBE-WATSON package.

**Figure 3. Project file structure**

- X.Y.Z is an abstraction to the version used
- BSP drivers for the B-L475E-IOT01 board
- Contains the board component drivers, for example the sensors for the B-L475E-IOT01 board
- BSP drivers for the 32F413HDISCOVERY and 32F769IDISCOVERY boards
- Embedded C client library for interacting with the IBM Watson IoT™ platform
- JSON parser
- Unit testing framework for C with support for mock
- FreeRTOS™ Real Time Open System, used with LwIP
- LwIP, in charge of TCP/IP connection with Ethernet
- mbedTLS
- Paho MQTT C/C++ client library for embedded platforms
- IBM Watson IoT™ application for the B-L475E-IOT01 board
- 32-tool-chain support
- User code specific to Bluemix® but platform generic
- Cloud and platform generic user code
- IBM Watson IoT™ applications for the 32F413HDISCOVERY and 32F769IDISCOVERY boards
- Utilities for the 32F769IDISCOVERY LCD display
- Utility to flash a new Inventek firmware
- TeraTerm initialization script parameters
3.4 B-L475E-IOT01 board sensors

The sensors that are present on the board and used by the sample application are:

- Capacitive digital sensor for relative humidity and temperature (HTS221)
- High-performance 3-axis magnetometer (LIS3MDL)
- 3D accelerometer and 3D gyroscope (LSM6DSL)
- 260-1260 hPa absolute digital output barometer (LPS22HB)
- Proximity sensor (VL53L0X)

Example of a published sensor message:

```json
{
  "d": {
    "temperature": 30.07,
    "humidity": 36.28,
    "pressure": 996.78,
    "proximity": 2066,
    "acc_x": -12,
    "acc_y": -8,
    "acc_z": 1050,
    "gyr_x": -1260,
    "gyr_y": -1610,
    "gyr_z": -1190,
    "mag_x": 283,
    "mag_y": -341,
    "mag_z": 512
  }
}
```

Table 2 presents the units for the values reported by the sensors of the B-L475E-IOT01 board.

<table>
<thead>
<tr>
<th>Data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>degree Celsius (°C)</td>
</tr>
<tr>
<td>Humidity</td>
<td>relative humidity (%)</td>
</tr>
<tr>
<td>Pressure</td>
<td>hectopascal (hPa)</td>
</tr>
<tr>
<td>Proximity</td>
<td>millimeter (mm)</td>
</tr>
<tr>
<td>Acceleration</td>
<td>milli g-force (mgforce)</td>
</tr>
<tr>
<td>Angular velocity</td>
<td>millidegree per second (mdps)</td>
</tr>
<tr>
<td>Magnetic induction</td>
<td>milligauss (mG)</td>
</tr>
</tbody>
</table>
3.5 Wi-Fi® components

The Wi-Fi® software is split over Drivers/BSP/Components for the module specific software and over Projects/<board>/WiFi for I/O operations and for the Wi-Fi® module abstraction.

3.6 Reset push-button

The reset push-button (black) is used to reset the board at any time. This action makes the board reboot.

3.7 User push-button

The user push-button (blue) is used in the following cases:

- To configure the Wi-Fi® and Bluemix® security credentials. This can be done from the time the board starts up and up to five seconds after that.
- When the board has been initialized, if the user push-button is pushed shortly, the application publishes the sensor values for the B-L475E-IOT01 board only, a 0/1 toggle value (the green LED switches accordingly), and a timestamp.
  
  On double button push, the application enters in a loop and publishes automatically every second. The next double push restores the previous mode.

The application configures and manages the user button via the board support package (BSP) functions.

The BSP functions are in the Drivers\BSP\<board name> directory.

When using the BSP button functions with the BUTTON_USER value, the application does not take into account the way this button is connected from a hardware standpoint for a given platform. The mapping is handled by the BSP.

3.8 User LED

The configuration of the user LED that is used by the applications is done via the board support package (BSP) functions.

The BSP functions are under the Drivers\BSP\<board name> directory.

Using the BSP button functions with the LED_GREEN value, the application does not take into account the way the LED is mapped for a given platform. The mapping is handled by the BSP.

3.9 Real-time clock

The STM32 RTC is updated at startup from the www.gandi.net web server.

The user can use the HAL_RTC_GetTime() function to get the time value.

This function can for instance be used to time stamp messages.
### 3.10 mbedTLS configuration

The mbedTLS middleware support is fully configurable by means of a `#include` configuration file.

The name of the configuration file can be overridden by means of the `MBEDTLS_CONFIG_FILE` `#define`.

The X-CUBE-WATSON package uses file `bluemix_mbedtls_config.h` for project configuration.

This is implemented by having the following `#` directives at the beginning of the mbedTLS.c and mbedTLS.h files:

```c
#if !defined(MBEDTLS_CONFIG_FILE)
#include "mbedtls/config.h"
#else
#include MBEDTLS_CONFIG_FILE
#endif
```

The configuration file specifies the ciphers to integrate.
4 Hardware and software environment setup

To set up the hardware and software environment, one of the three supported boards must be plugged into a personal computer via a USB cable. This connection with the PC allows the user to:

- Flash the board
- Store the Wi-Fi® and the Bluemix® security credentials
- Interact with the board via a UART console
- Debug

The B-L475E-IOT01 or 32F413HDISCOVERY boards must be connected to a Wi-Fi® access point while the 32F769IDISCOVERY board must be connected to an Ethernet interface as illustrated in Figure 4.

![Hardware and software setup environment](image)

The prerequisites for running the examples are:

- A Wi-Fi® access point, with a transparent Internet connectivity meaning that neither a proxy, nor a firewall are blocking the outgoing traffic. It has to run a DHCP server delivering the IP and DNS configuration to the board.
- No device management application is provided in X-CUBE-WATSON since it uses the IBM® dashboard to interact from the cloud to the device. In case a device management application is developed, it requires the availability of a computer having a transparent Internet connectivity meaning that neither a proxy, nor a firewall blocking the outgoing traffic. This can for instance be the development PC, a virtual private server or a single-board computer. It can be connected to the same router as the MCU board.
- A development PC for building the application, programming through ST-Link, and running the virtual console.
5 Application examples

This section introduces how to register and log on the IBM Watson IoT™ platform, and how to use the IBM® Bluemix® cloud IoT client application from the X-CUBE-WATSON package.

5.1 Application description

The application proposes two ways of connecting to the IBM® IoT platform:

- Quickstart registration: no account nor token is required, the connection is unsecured.
- Simple registration: an IBM IoT account is required, the device is authenticated by a token, the connection is secured using mbedTLS.

This application is ported to the B-L475E-IOT01, 32F413HDISCOVERY and 32F769IDISCOVERY boards and connects to the Internet through the on-board network interface.

It connects to the IBM® Bluemix® IoT cloud with the credentials provided by the user.

5.2 Bluemix® IoT account creation

An IBM® Bluemix® account is not required to use the Quickstart way of registering the device.

An IBM® Bluemix® account is required to use an IBM Watson IoT™ platform application or to use the simple way of registering the device.

To register, go to: https://console.bluemix.net/registration/

The registration procedure includes receiving an email asking to confirm the account creation.

5.3 Device creation on the IBM Watson® platform

Create the device (for the simple registering mode).

Follow the steps as indicated at: https://developer.ibm.com/recipes/tutorials/how-to-register-devices-in-ibm-iot-foundation/

5.4 Application build and flash

Caution: Before opening the project with any tool chain, make sure that the folder installation path is not too deep since the tool chain may report errors after the build otherwise.

Open and build the project with one of the supported development tool chains (see the release note for detailed information about the version requirements).

Program the firmware on the STM32 board: copy (or drag and drop) the binary file under Projects\<board name>\Applications\Cloud\Bluemix\Binary to the USB mass storage location created when the STM32 board is plugged to the PC. Alternatively, you can program the STM32 board directly through one of the supported development tool chains.
5.5 Application first launch

1. The board must be connected to a PC through USB (ST-LINK USB port). Open the console through a serial terminal emulator (such as Tera Term), select the ST-LINK COM port of the board, and configure it with:
   - 8N1, 115200 bauds, no HW flow control
   - Line endings set to LF
   For more details, see Chapter 6: Interacting with the boards on page 20.
   For the Wi-Fi®-enabled board, enter the Wifi SSID, encryption mode and password via the console.

2. Set the TLS root CA certificates:
   Copy-paste the content of Projects\Common\Bluemix\comodo_bluemix.pem. The device uses it to authenticate the remote hosts through TLS.
   Note: the sample application requires that a concatenation of 2 CA certificates is provided
   a) For the HTTPS server which is used to retrieve the current time and date at boot time (the "Comodo" certificate)
   b) For the IBM® IoT platform
      This one is used with the simple way of registering not with the Quickstart way.
      Chapter 7: How to get the IBM Watson IoT™ root CA certificate on page 22 describes the steps to get a new Bluemix® TLS root CA certificate.

3. Select on the console the way of registering between "Quickstart" and "simple" and enter the connection string as prompted.

4. After the parameters are configured, it is possible to change them by restarting the board and pushing the User button (blue button) when prompted.
5.6 Application runtime

1. RTC configuration
   The application makes an HTTPS request to retrieve the current time and date, and configures the RTC.

2. Device to cloud connection
   The device connects to the IBM® Bluemix® platform
   The application publishes the sensor values if the board is the B-L475E-IOT01, a 0/1 toggle value (green LED switches accordingly), and a timestamp:
   - once if the user button is pushed shortly
   - around every second or paused if the user button is double pushed
   The user can see the reported value at the URL as indicated in the serial terminal emulator
     - At `https://quickstart.internetofthings.ibmcloud.com` if registration was done using Quickstart.
     - At `https://<Organisation Id>.internetofthings.ibmcloud.com` with the simple registration mode.
   The device ID to use is also printed in the serial terminal emulator.

3. Cloud to device connection
   This interaction is available in simple register mode only. The device is a managed device and accepts the "Reboot" command.
   This action can be activated in the IBM Watson IoT™ platform Internet page for the device: a "Reboot" button exists (down and left in the Internet page).
   This sends a command to the device and makes it reboot.

5.7 Dashboard and plotting values

This section describes how to use the IBM Watson® dashboard for plotting client published values.
1. https://console.bluemix.net/dashboard

*Note:* Make sure Region is correctly set and Space is defined.

2. Select the *Internet of Things Platform* service and click on the *Launch* button

3. Sign in

4. In the top right corner, select the adequate organization. This leads to the *All boards dashboard*

5. In the *Usage overview*, a line chart can be added to plot the published values
   a) "+ Add New Card" button
   b) select "Line chart"
   c) select the Device ID
   d) "Next"
   e) "connect new data set"
   f) Event = Status
   g) Property: select the value to plot
   h) Type= Text or Number
   i) Next
   j) Next
   k) Submit
6 Interacting with the boards

A serial terminal is required to:
- Configure the board
- Display locally the received Bluemix® IoT cloud-to-device messages

The example in this document is illustrated with the use of Tera Term. Any other similar tool can be used instead.

When the board is used for the first time, it must be programmed with Bluemix® IoT identification data.
- Determine the STM32 ST-LINK Virtual COM port used on the PC for the Discovery board. On a Windows® PC, open the Device Manager.
- Open a virtual terminal on the PC and connect it to the above virtual COM port.

A Tera Term initialization script is provided in the package utility directory (refer to Figure 3); this script sets the correct parameters. To use it, open Tera Term, select Setup and then Restore setup.

Note: The information provided below in this chapter can be used to configure the UART terminal as an alternative to using the Tera Term initialization script.

Terminal setup is illustrated in Figure 5, which shows the terminal setup and the New-line recommended parameters.

The virtual terminal New-line transmit configuration must be set to LineFeed (\n or LF) in order to allow copy-paste from UNIX type text files. The Local echo option makes copy-paste visible on the console.

![Figure 5. Terminal setup](image)

The serial port must be configured with:
- COM port number
- 115200 baud rate
- 8-bit data
- Parity none
- 1 stop bit
- No flow control
Serial port setup is illustrated in Figure 6.

**Figure 6. Serial port setup**

Once the UART terminal and the serial port are set up, press the board reset button (black). Follow the indications on the UART terminal to upload Wi-Fi® and Bluemix® data. Those data remain in Flash and are reused the next time the board boots.
How to get the IBM Watson IoT™ root CA certificate

This chapter describes a procedure, from step 1 to step 8, to get the IBM Watson IoT™ root CA certificate. The whole procedure is illustrated with Mozilla® Firefox® screenshots.

It is possible to bypass all the steps presented below and directly use the certificate provided in step 8 at the end of the chapter. This only works until the root CA is not changed on the IBM Watson® side.

1. Ensure that Internet connections are not blocked by a firewall
2. Open a Mozilla® Firefox® at https://<domain name>.internetofthings.ibmcloud.com as shown in Figure 7.

Figure 7. IBM Watson® registration welcome screen (1 of 3)
3. Click on the security icon (padlock in the top-left corner) as shown in Figure 8.

Figure 8. IBM Watson® registration welcome screen (2 of 3)

4. A panel opens as shown in Figure 9. Click on the > button to view certificates.

Figure 9. IBM Watson® registration welcome screen (3 of 3)
5. The security panel opens as shown in Figure 10. Click on the View Certificate button.

![Security panel](image)

**Figure 10. Security panel**

6. The certificate panel for the IBM Watson IoT™ platform opens as shown in Figure 11.

![Certificate panel](image)

**Figure 11. IBM Watson IoT™ certificate panel**
7. Click the on the Details tab to view the certificate hierarchy and select the root CA as shown in Figure 12.

Figure 12. IBM Watson® certificate hierarchy

8. Finally, click on the export button. On November 10th, 2017, the following root CA certificate is obtained through this procedure:

```
-----BEGIN CERTIFICATE-----
MIIDrzCCApegAwIBAgIQCDvgVpBCRrGhdWrJWZHHSjANBgkqhkiG9w0BAQUFADBhMQs
wCQYDVQQGEwJVUzEVMBMGA1UEChMMRGlnaUNlcnQgSW5jMRkwFwYDVQQLExB3d3cuZG
1naVNlcnQy29tMSAwHgYDVQQDEExdaWdpQ2VydCBBG91YjWgUm9vdCBDQTAFaEgwN
jExMTAwMDAwMDBaFw0zMTExMTAwMDAwMDBaMGExCzAJBgNVBAYTA1VMRUwEwYDVQQK
EwxEaWdpQ2VydCBJbnMxGkxpbGV8bWVkaW5lZGluY29taW4uY3JlZQA0ggYDVR0gBG
ibCDv2M0bi8aB0gVAcTDEEUNBBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCgKCAQ
ejAmUIp87qso07WczKt1a6nBu6k6DqB94c5I1j7zfuXJh3/9xQ6groo516KBS5vM
60YUsh0jk181h9xJ0b638DhQ099L3Y3NvRw61LjW1jS3V不可能1/4k22yQ4CDFFJ
-----END CERTIFICATE-----
```
8 Frequently asked questions

Q: Why do I get this pop-up (refer to Figure 13) when I open the project with IAR™?

A: It is very likely that the IAR™ IDE version is older than the one used to develop the package (refer to the release note available in the package root folder for the IDE versions supported), hence the compatibility is not ensured. In this case, the IAR™ IDE version needs to be updated.

Q: How shall I modify the application to publish other messages?

A: Depending whether B-L475E-IOT01 or another board is used, an update of the function PrepareMqttPayload() or PrepareToggleMqttPayload() respectively is needed in the in the bluemix.c file.

Q: My device does not connect to Bluemix® IoT hub. How shall I proceed?

A: Things that need to be checked are:
1. Start in Quickstart mode and be able to see the data on the IBM Watson IoT™ platform with the URL provided via the console (this does not requires an account).
2. If not successful, the initial configuration must be done again carefully.
3. If 1. is successful and the connection still fails using the register mode, login and check that both account and device are available.
4. If there is still no connection, check that the connection string entered during the configuration phase matches with the data on the IoT platform (OrgId, DeviceType, DeviceId and Token).
5. If there is still no connection, check that the device security on the IBM Watson IoT™ platform is set with the “TLS with Token Authentication”.

Q: My device does not connect to the Wi-Fi® access point. How shall I proceed?

A: Make sure that another device can connect to the Wi-Fi® access point. If it can, enter the Wi-Fi® credentials by pressing the user button (blue) up to five seconds after board reset.
Q: The proximity sensor always reports "8190" even if I place an obstacle close to it.

A: Make sure that the liner (which is a very thin film placed on the proximity sensor) has been removed. Its color is orange and it is not very visible.
9 Revision history

Table 3. Document revision history

<table>
<thead>
<tr>
<th>Date</th>
<th>Revision</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>13-Nov-2017</td>
<td>1</td>
<td>Initial release.</td>
</tr>
</tbody>
</table>
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