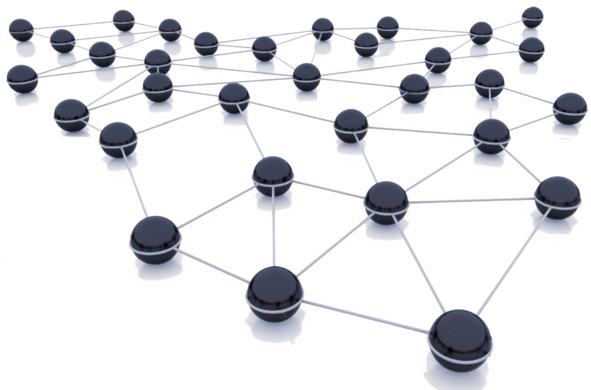
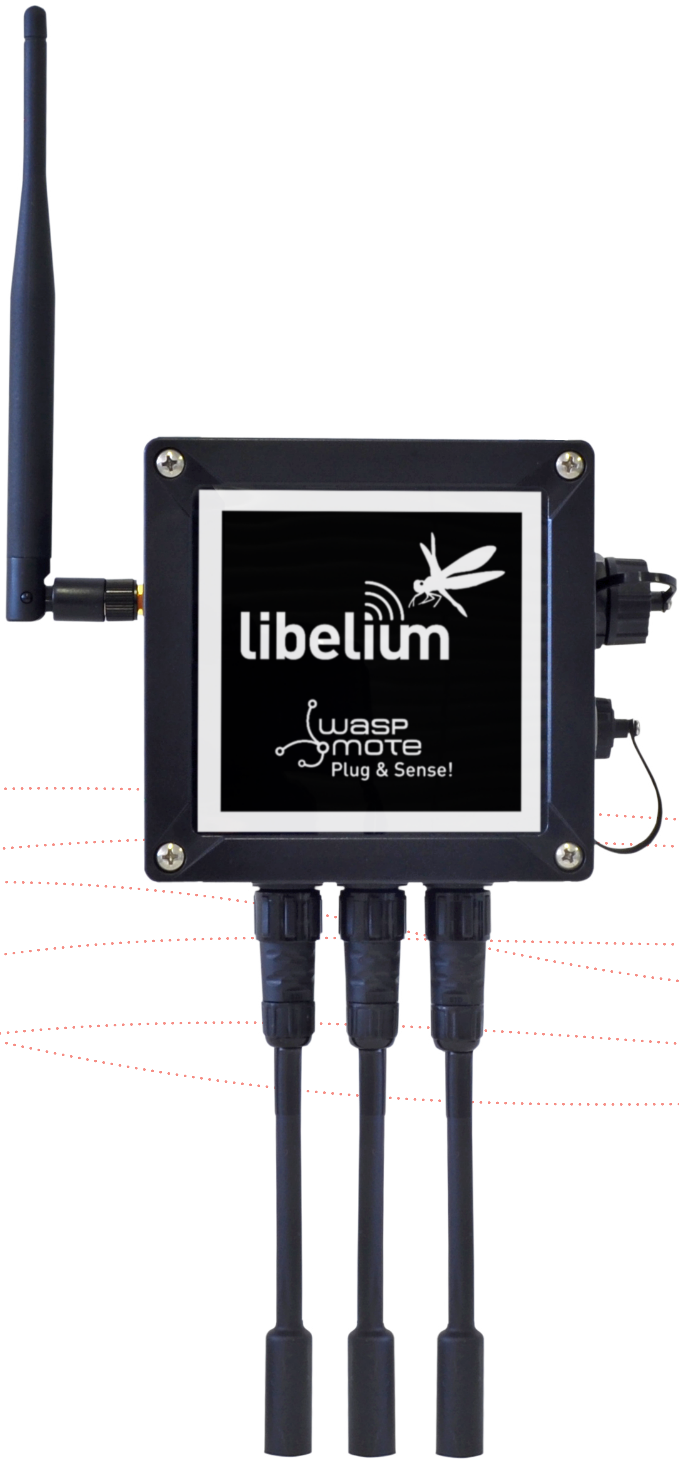
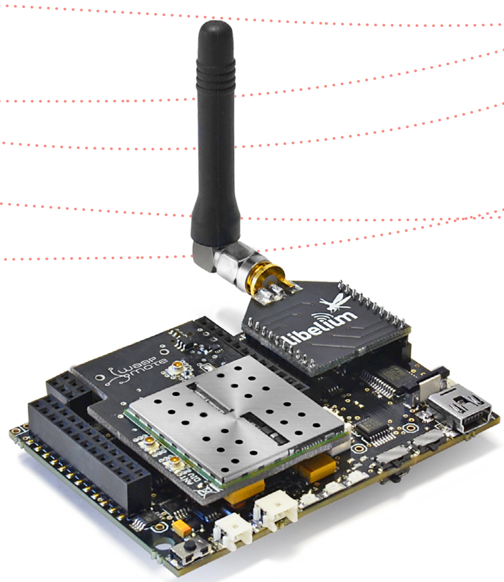
Waspmote LoRaWAN

Networking Guide







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1. Introduction

This guide explains the LoRaWAN modules features and functions. These products were designed for Waspmote v12 and Plug & Sense! v12 and continue with no changes for Waspmote v15 and Plug & Sense! v15. There are no great variations in this library for our new product lines Waspmote v15 and Plug & Sense! v15, released on October 2016.

Anyway, if you are using previous versions of our products, please use the corresponding guides, available on our Development website.

You can get more information about the generation change on the document "New generation of Libelium product lines".

The Libelium LoRaWAN module has been integrated into the main sensor lines Waspmote OEM and Plug & Sense!, so now you can create your own **Low Power Wide Area Network (LPWAN)**.

LoRaWAN is a new, private and spread-spectrum modulation technique which allows sending data at extremely low data-rates to extremely long ranges. The low data-rate (down to few bytes per second) and LoRaWAN modulation lead to very low receiver sensitivity (down to **-136 dBm**), which combined to an output power of **+14 dBm** means extremely large link budgets: up to **150 dB**, what means more than **22 km (13.6 miles)** in **LOS** links and up to **2 km (1.2 miles)** in **NLOS** links in urban environment (going through buildings).

Figure: Waspmote LoRaWAN

Libelium's LoRaWAN EU/433 module works in both **868** and **433 MHz** ISM bands and the LoRaWAN US module works in **900 MHz** ISM band, which makes them suitable for virtually any country. Those frequency bands are lower than the popular 2.4 GHz band, so path loss attenuation is better in LoRaWAN. In addition, 433, 868 and 900 MHz are bands with much fewer interference than the highly populated 2.4 GHz band. Besides, these low frequencies provide great penetration in possible materials (brick walls, trees, concrete), so these bands get less loss in the presence of obstacles than higher bands.

With the LoRaWAN modules we can send the data directly to any **Base Station (BS)** that is LoRaWAN compatible. Some companies already offering solutions are: Kerlink, Link-Labs, Multitech, Cisco, Augtek, Manthink, Gupsy, Gemteck, ExpEmb, Embedded Planet, Calao, RFI, etc. In order to visualize the information we will need also a Cloud platform where the data has to be sent. Normally when you acquire a BS you can install your preferred SW packet in order to make it work against the Cloud platform. We tested the LoRaWAN radios with three Cloud platforms: Actility, Orbiwise and Loriot, you can find more information about the configuration in this tutorial.

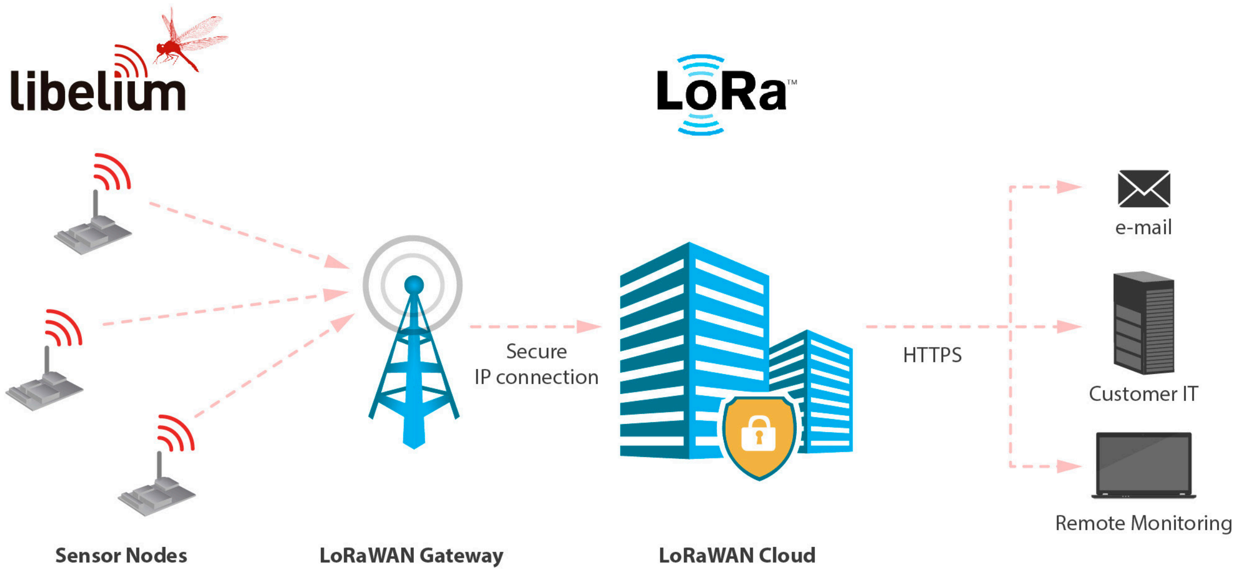

Figure: LoRaWAN network

Libelium currently offers two options of this type of radio technology: LoRa ("raw") and LoRaWAN:

- LoRa contains only the link layer protocol and is perfect to be used in P2P communications between nodes. You can set a topology of a maximum of 10 nodes to the same Gateway as LoRa does not make packet management.
- LoRaWAN can handle hundreds of connections at the same time.
- LoRaWAN includes the network layer too so it is possible to send the information to any LoRaWAN Base Station already connected to a Cloud platform. LoRaWAN modules may work in the 868/900/433 MHz bands.
- LoRa is available for the Waspmote OEM v15 platform but not for Plug & Sense! v15.
- LoRaWAN is available for both Waspmote OEM v15 and Plug & Sense! v15.
- Plug & Sense! with LoRaWAN radio is certified for Europe (CE), USA (FCC) and Canada (IC), while LoRa is not certified.

As well as the LoRaWAN to Base Station mode, the modules may be used in two different more configurations.

- P2P Mode - Direct Communication between nodes (LAN Interface)
- Hybrid Mode - LoRaWAN / P2P (P2P + GW to LoRaWAN Network)

- In the **P2P Mode** nodes may connect directly among them and send messages directly at no cost (as they are not using the LoRaWAN Network but just direct radio communication). This is useful as we can create secondary networks at any time as we don't need to change the firmware but just use specific AT Commands in the current library. **This mode works without the need of a Base Station or a Cloud account** so in case you don't want to purchase any license (or renew the license after the initial period) you will be able to keep on using the modules this way. For more info go to the section P2P Mode.

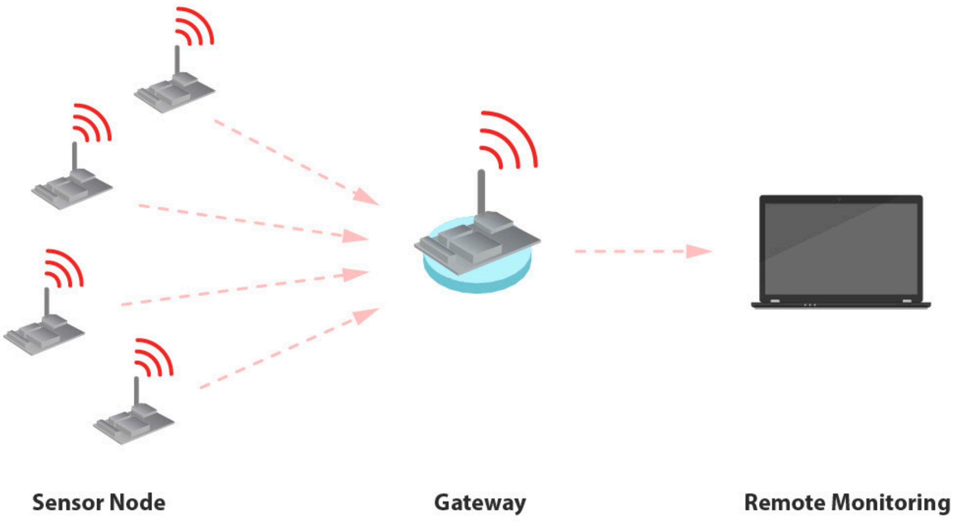

Figure: P2P mode

In the **Hybrid Mode** we use a combination of the LoRaWAN and P2P modes allowing to send just certain messages using the LoRaWAN Network. In this case we use one node as GW of the network (P2P + LoRaWAN mode) and the rest of the nodes in P2P mode. **This mode may work using just one LoRaWAN License.** For more info go to the section Hybrid Mode.

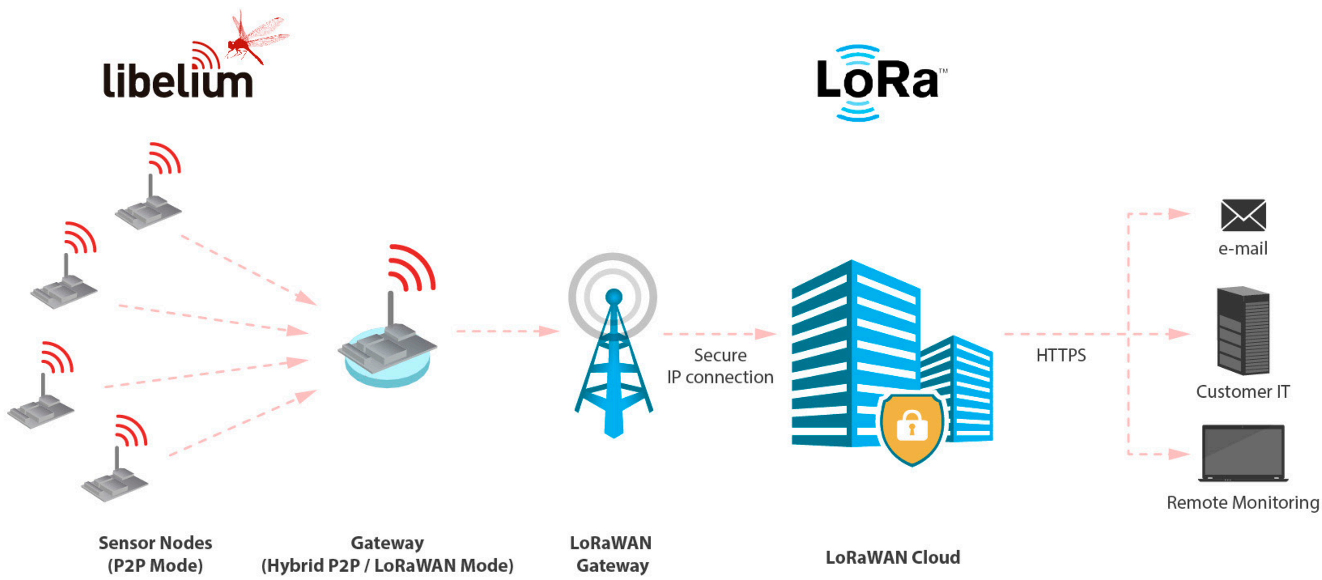

Figure: P2P mode

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- The information on Libelium's websites has been included in good faith for general informational purposes only. It should not be relied upon for any specific purpose and no representation or warranty is given as to its accuracy or completeness.

1.1. Technology overview

LoRaWAN is a Low Power Wide Area Network (LPWAN) specification intended for wireless battery operated devices in regional, national or global network. LoRaWAN target key requirements of Internet of things such as secure bi-directional communication, mobility and localization services. This standard will provide seamless interoperability among smart Things without the need of complex local installations and gives back the freedom to the user, developer, businesses enabling the role out of Internet of Things.

LoRaWAN network architecture is typically laid out in a star-of-stars topology in which **gateway**s is a transparent bridge relaying messages between **end-devices** and a central **network server** in the back-end. Gateways are connected to the network server via standard IP connections while end-devices use single-hop wireless communication to one or many gateways.

Communication between end-devices and gateways is spread out on different **frequency channels** and **data rates**. The selection of the data rate is a trade-off between communication range and message duration. Due to the spread spectrum technology, communications with different data rates do not interfere with each other and create a set of “virtual” channels increasing the capacity of the gateway. To maximize both battery life of the end-devices and overall network capacity, the LoRaWAN network server is managing the data rate and RF output for each end-device individually by means of an **adaptive data rate** (ADR) scheme.

National wide networks targeting Internet of Things such as critical infrastructure, confidential personal data or critical functions for the society has a special need for secure communication. This has been solved by several layer of encryption:

- Network Session Key (128-bit key) ensures security on network level
- Application Session Key (128-bit key) ensures end-to-end security on application level
- Application Key (128-bit key) ensures end-to-end security on application level (only OTAA procedure)

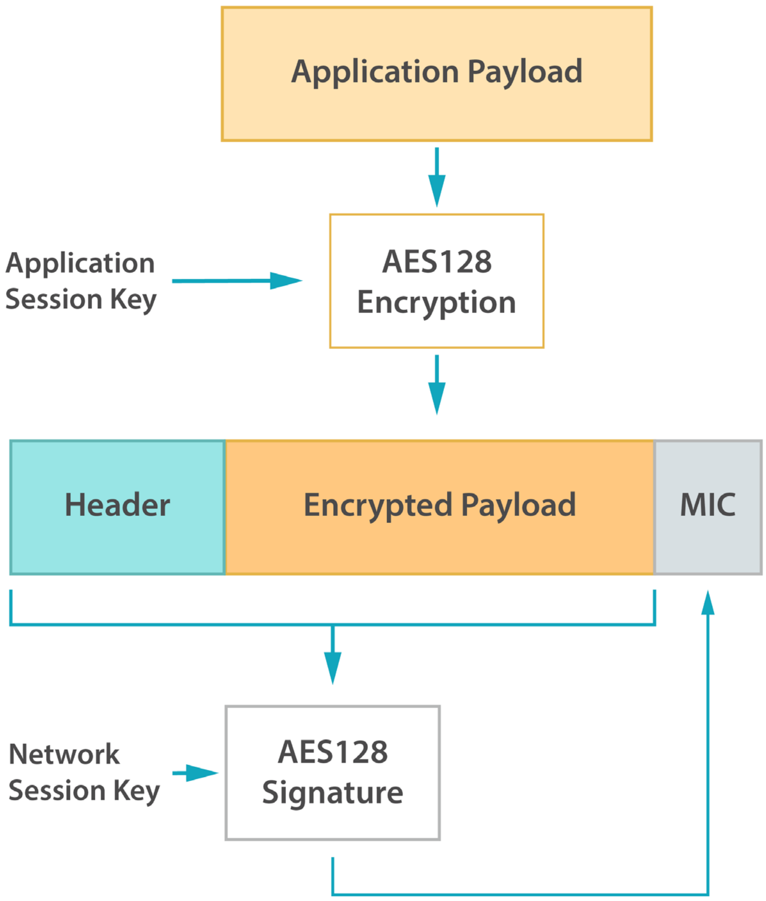


Figure: LoRaWAN security overview

2. Hardware

2.1. Specifications

The LoRaWAN module is managed via UART and it can be connected to SOCKET0 or SOCKET1.

2.1.1. LoRaWAN EU

The main features of the module are listed below:

- **Protocol:** LoRaWAN 1.0, Class A
- **LoRaWAN-ready**
- **Frequency:** EU 863-870 MHz and EU 433 MHz ISM frequency bands.
- **TX power:** up to +14 dBm
- **Sensitivity:** down to -136 dBm
- **Range:** >15 km at suburban and >5 km at urban area. Typically, each base station covers some km. Check the LoRaWAN Network in your area.
- **Chipset consumption:** 38.9 mA
- **Radio bit rate:** from 250 to 5470 bps
- **Receiver:** purchase your own base station or use networks from LoRaWAN operators

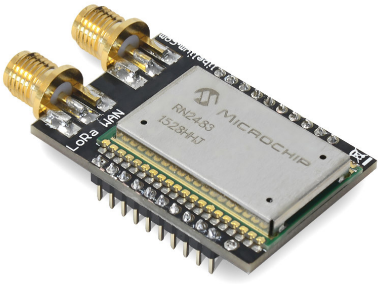


Figure: LoRaWAN EU module

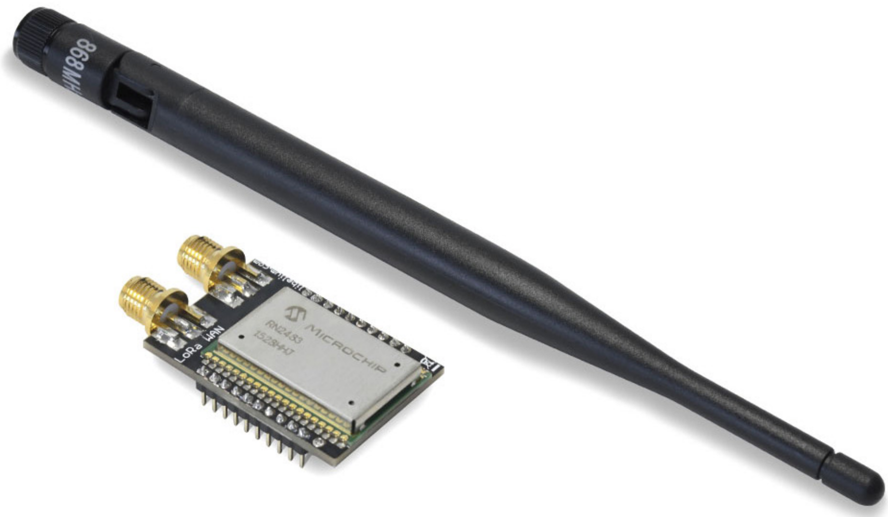


Figure: LoRaWAN EU module with antenna

2.1.2. LoRaWAN US

The main features of the module are listed below:

- **Protocol:** LoRaWAN 1.0, Class A
- **LoRaWAN-ready**
- **Frequency:** US 902-928 MHz ISM band
- **TX power:** up to +18.5 dBm
- **Sensitivity:** down to -136 dBm
- **Range:** >15 km at suburban and >5 km at urban area. Typically, each base station covers some km. Check the LoRaWAN Network in your area.
- **Chipset consumption:** 124.4 mA
- **Radio bit rate:** from 250 to 12500 bps
- **Receiver:** purchase your own base station or use networks from LoRaWAN operators

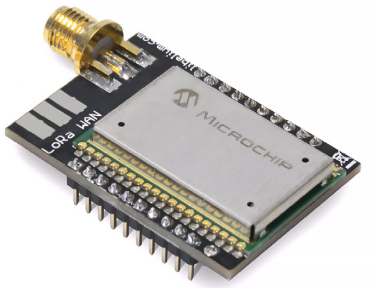


Figure: LoRaWAN US module

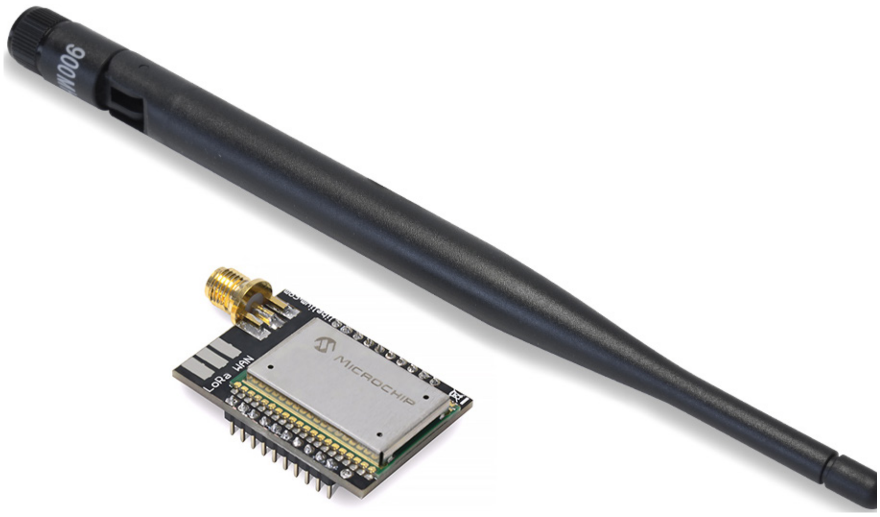


Figure: LoRaWAN US module with antenna

Note: *The US version does not support operation on the 433 MHz band.*

Note: *The user must check the allowed bands, channels and transmission power, in order to respect the regulations in the operation country.*

Libelium commercializes different items depending on the band the user wants to use. In the case of 868 and 433, the module is the same, but the antenna is different for each band. The module for EU (868) and 433 MHz includes 2 RP-SMA connectors for the antenna. One is for the 868 band and the other for the 433 band. A sticker on the bottom of the modules specifies clearly where to screw the antenna.

Note: *Any LoRaWAN module is provided with a special antenna (for 433* ***or*** *for 868* ***or*** *for 900 MHz), which enables maximum range.*

Note: *Due to the propagation characteristics of the sub-GHz bands, the near field effect could make that 2 modules cannot communicate if they are placed very close (< 1 m). We suggest to keep a minimum distance of 3 or 4 meters between modules.*

2.2. Region standards

The LoRaWAN Specification settled by the LoRa Alliance establishes the parameters that must be complied for every region. Check the compatibility table below, showing the areas supported by our LoRaWAN versions for the moment.

Region	Supported by
EU 863-870 MHz ISM Band (Europe)	LoRaWAN EU
US 902-928 MHz ISM Band (United States)	LoRaWAN US
CN 779-787 MHz ISM Band (China)	Not supported
AU 915-928 MHz ISM Band (Australia)	Not supported
CN 470-510 MHz ISM Band (China)	Not supported
AS 923 MHz ISM Band (Asia)	Not supported
KR 920-923 MHz ISM Band (South Korea)	Not supported

Figure: Regional compatibility table

2.3. Power consumption

2.3.1. LoRaWAN EU

The LoRaWAN EU module is powered at 3.3 V. The next table shows the module's average current consumption in different states of the module.

State	Power Consumption
On	2.8 mA
Transmitting data	38.9 mA
Receiving data	14.2 mA

Figure: Power consumption table

2.3.2. LoRaWAN US

The LoRaWAN US module is powered at 3.3 V. The next table shows the module's average current consumption in different states of the module.

State	Power Consumption
On	2.7 mA
Transmitting data	124.4 mA
Receiving data	13.5 mA

Figure: Power consumption table

2.4. Time consumption

The elapsed periods defined in this chapter take into account the following steps depending on the case:

- Join to a network and send unconfirmed data
- Join to a network and send confirmed data

These periods of time depend on the data rate set which is defined by the spreading factor and signal bandwidth configured.

Transmit mode	Time elapsed
Send unconfirmed at 5470 bps	~ 2.8 seconds
Send unconfirmed at 250 bps	~ 4.2 seconds
Send confirmed at 5470 bps	~ 1.7 seconds
Send confirmed at 250 bps	~ 4.2 seconds

Note: *When transmitting in ISM frequency bands, the user must ensure that the communication is not exceeding the permitted time using the chosen frequency channel (for example, 1% of time). This depends on the local regulations (CE, FCC, etc). It is the responsibility of the user to know the allowed time of use in the occupied frequency band and respect it. Ignoring this, could lead to considerable penalties. Also, a LoRaWAN back-end operator could cut off the service or apply extra fees, it they detect that the user is exceeding the maximum number of frames or data in a period of time.*

2.5. How to connect the module

This module can be connected to both SOCKET0 and SOCKET1 on the Waspmote board.

Figure: Module connected to Waspmote in SOCKET0

In order to connect the module to the SOCKET1, the user must use the Expansion Radio Board.

2.6. Expansion Radio Board

The Expansion Board allows to connect two communication modules at the same time in the Waspmote sensor platform. This means a lot of different combinations are possible using any of the wireless radios available for Waspmote: 802.15.4, ZigBee, DigiMesh, 868 MHz, 900 MHz, LoRa, WiFi, GPRS, GPRS+GPS, 3G, 4G, Sigfox, LoRaWAN, Bluetooth Pro, Bluetooth Low Energy and RFID/NFC. Besides, the following Industrial Protocols modules are available: RS-485/Modbus, RS-232 Serial/Modbus and CAN Bus.

Some of the possible combinations are:

- LoRaWAN - GPRS
- 802.15.4 - Sigfox
- 868 MHz - RS-485
- RS-232 - WiFi
- DigiMesh - 4G
- RS-232 - RFID/NFC
- WiFi - 3G
- CAN Bus - Bluetooth
- etc.

Remark: *GPRS, GPRS+GPS, 3G and 4G modules do not need the Expansion Board to be connected to Waspmote. They can be plugged directly in the socket1.*

In the next photo you can see the sockets available along with the UART assigned. On one hand, SOCKET0 allows to plug any kind of radio module through the UART0. On the other hand, SOCKET1 permits to connect a radio module through the UART1.

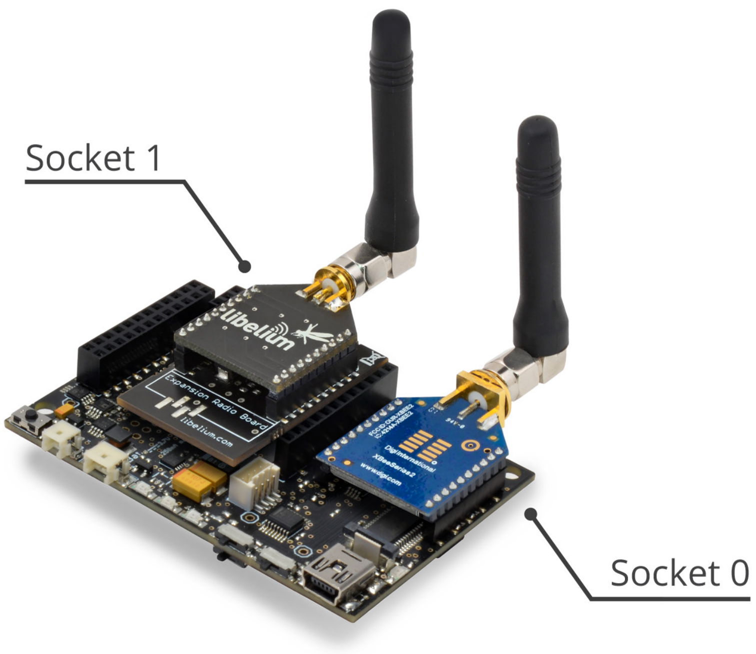


Figure: Use of the Expansion Board

The API provides a function called `ON()` in order to switch the module on. This function supports a parameter which permits to select the SOCKET. It is possible to choose between SOCKET0 and SOCKET1.

Selecting `SOCKET0`: `LoRaWAN.ON(SOCKET0);`

Selecting `SOCKET1`: `LoRaWAN.ON(SOCKET1);`

The rest of functions are used the same way as they are used with older API versions. In order to understand them, we recommend to read this guide.

Warnings:

- Avoid to use DIGITAL7 pin when working with the Expansion Board. This pin is used for setting the XBee into sleep mode.
- Avoid to use DIGITAL6 pin when working with the Expansion Board. This pin is used as power supply for the Expansion Board.
- Incompatibility with Sensor Boards:
  - Agriculture v30 and Agriculture PRO v30: Incompatible with Watermark and solar radiation sensors
  - Events v30: Incompatible with interruption shift register
  - Gases v30: DIGITAL6 is incompatible with CO2 (SOCKET_2) and DIGITAL7 is incompatible with NO2 (SOCKET_3)
  - Smart Water v30: DIGITAL7 incompatible with conductivity sensor
  - Smart Water Ions v30: Incompatible with ADC conversion (sensors cannot be read if the Expansion Board is in use)
  - Gases PRO v30: Incompatible with SOCKET_2 and SOCKET_3
  - Cities PRO v30: Incompatible with SOCKET_3. I2C bus can be used. No gas sensor can be used.

3. Software

The Waspmote device communicates with the LoRaWAN module via UART. So different commands are sent from the microcontroller unit to the module so as to perform different tasks.

3.1. Waspmote libraries

3.1.1. Waspmote LoRaWAN files

The files related to the LoRaWAN libraries are:

```
WaspLoRaWAN.h
WaspLoRaWAN.cpp
```

It is mandatory to include the LoRaWAN library when using this module. So the following line must be added at the beginning of the code:

```
#include <WaspLoRaWAN.h>
```

3.1.2. Class constructor

To start using the Waspmote LoRaWAN library, an object from the `WaspLoRaWAN` class must be created. This object, called `LoRaWAN`, is already created by default inside Waspmote LoRaWAN library. It will be used through this guide to show how Waspmote works.

When using the class constructor, all variables are initialized to a default value.

3.1.3. API constants

The API constants used in functions are:

Constant	Description
LORAWAN_ANSWER_OK	Successful response to a function
LORAWAN_ANSWER_ERROR	Erratic response to a function
LORAWAN_NO_ANSWER	No response to a function
LORAWAN_INIT_ERROR	Required keys to join to a network were not initialized
LORAWAN_LENGTH_ERROR	Data to be sent length limit exceeded
LORAWAN_SENDING_ERROR	Server did not response
LORAWAN_NOT_JOINED	Module has not joined a network
LORAWAN_INPUT_ERROR	Invalid input parameter
LORAWAN_VERSION_ERROR	The module does not support this function
RN2483_MODULE	LoRaWAN module plugged is LoRaWAN EU
RN2903_MODULE	LoRaWAN module plugged is LoRaWAN US

3.1.4. API variables

The variables used inside functions and Waspmote codes are:

Constant	Description
_buffer	The buffer of memory used for storing the responses from the module
_length	The useful length of the buffer
_def_delay	The time to wait after sending every command until listen for a response
_baudrate	The baudrate to be used when the module is switched on
_uart	The selected UART (regarding the socket used: SOCKET0 or SOCKET1)
_adr	The adaptive data rate state (on or off)
_ar	The automatic reply state (on or off)
_eui	The buffer used for storing the preprogrammed globally unique identifier from the module's hardware
_devEUI	The buffer used for storing the globally unique identifier for the module (software programmable)
_appEUI	The buffer used for storing the application identifier for the module
_nwkSKey	The buffer used for storing the network session key for the module
_appSKey	The buffer used for storing the application session key for the module
_appKey	The buffer used for storing the application key for the module
_devAddr	The buffer used for storing network device address for module
_band	The buffer used for storing the frequency band
_margin	The demodulation margin received in the last Link Check Answer frame
_gwNumber	The number of gateways successfully received the last Link Check Answer frame
_freq	The buffer used for storing the operating frequency for every channel
_radioFreq	The transceiver operating frequency
_radioFreqDev	The transceiver frequency deviation
_preambleLength	The preamble length for transceiver
_dCycle	The buffer used for storing the operating duty cycle for every channel
_drrMin	The minimum operating data rate range for every channel
_drrMax	The maximum operating data rate range for every channel
_dCyclePS	The duty cycle prescaler (which can only be configured by the server)
_crcStatus	The CRC status to determine if it is to be included during operation
_powerIndex	The output power to be used on LoRaWAN transmissions
_dataRate	The data rate to be used on LoRaWAN transmissions
_retries	The number of retransmissions for an uplink
_upCounter	The value of the uplink frame counter

_downCounter	The value of the downlink frame counter
_radioPower	The output power level used by the transceiver
_radioSF	The spreading factor to be used by the transceiver
_radioRxBW	The receiving bandwidth used by the transceiver
_radioCR	The coding rate used by the transceiver
_radioWDT	The time to be used by the transceiver watchdog timer
_radioBW	The value used for the transceiver bandwidth
_radioSNR	The SNR value for the last received packet by the transceiver
_radioMode	The buffer to save the operative radio mode
_radioBitRate	The operative radio bit rate
_supplyPower	The voltage level read by the module
_rx2DataRate	The second receiving window data rate
_rx2Frequency	The second receiving window frequency
_rx1Delay	The first receiving window delay
_macStatus	The MAC status register from the module
_status	The status of every LoRaWAN channel
_data	The buffer of memory used for storing data received from the back-end
_port	The port where data was received
_dataReceived	The flag used to inform if any data was received
_version	The version of the module plugged into Waspmote

3.1.5. API functions

Through this guide there are lots of examples of using functions. In these examples, API functions are called to execute the commands, storing in their related variables the parameter value in each case. The functions are called using the predefined object `LoRaWAN`.

All public functions return one of these possible values:

- `LORAWAN_ANSWER_OK` = 0
- `LORAWAN_ANSWER_ERROR` = 1
- `LORAWAN_NO_ANSWER` = 2
- `LORAWAN_INIT_ERROR` = 3
- `LORAWAN_DATA_LENGTH_ERROR` = 4
- `LORAWAN_SENDING_ERROR` = 5
- `LORAWAN_NOT_JOINED` = 6
- `LORAWAN_INPUT_ERROR` = 7
- `LORAWAN_VERSION_ERROR` = 8

3.2. Module system management features

3.2.1. Switch on

The `ON()` function allows to switch on the LoRaWAN module, it opens the MCU UART for communicating with the module and it automatically enters into command mode.

In addition, when the module has been powered and communication is opened, this function checks whether a module is plugged to the socket and which type of module has been plugged. This check is done within every function that reboots the module such as “ON”, “reset” or “factoryReset”.

After this step the module will be able to receive commands to configure it or send packets. It is necessary to indicate the socket that it is being used: `SOCKET0` or `SOCKET1`.

Example of use for SOCKET0:

```
{
   LoRaWAN.ON(SOCKET0);
}
```

Related variable:

`LoRaWAN._version` → Stores the module’s version

Figure: LoRaWAN module in SOCKET0

3.2.2. Switch off

The `OFF()` function allows the user to switch off the LoRaWAN module and close the UART. This function must be called in order to keep battery level when the module is not going to be managed. It is necessary to indicate the socket that it is being used: `SOCKET0` or `SOCKET1`.

Example of use for SOCKET0:

```
{
   LoRaWAN.OFF(SOCKET0);
}
```

3.2.3. Module software reset

The `reset()` function allows the user to reset and restart the LoRaWAN module. The stored internal configurations will be loaded automatically upon reboot.

Example of use:

```
{
   LoRaWAN.reset();
}
```

Related variable:

`LoRaWAN._version` → Stores the module's version

3.2.4. Module factory reset

The `factoryReset()` function allows the user to reset the module's configuration data and user EEPROM to factory default values and restart the module.

Example of use:

```
{
   LoRaWAN.factoryReset();
}
```

Related variable:

`LoRaWAN._version` → Stores the module's version

Examples of LoRaWAN configuration:

www.libelium.com/development/waspmote/examples/lorawan-01a-configure-module-eu

www.libelium.com/development/waspmote/examples/lorawan-01b-configure-module-us

3.2.5. Preprogrammed unique identifier (EUI)

The `getEUI()` function allows the user to query the preprogrammed EUI node address from the module. The preprogrammed EUI node address is a read-only value and cannot be changed or erased. It is a global unique 64-bit identifier.

Example of use:

```
{
   LoRaWAN.getEUI();
}
```

Related variable:

`LoRaWAN._eui` → Stores the module's EUI

3.3. LoRaWAN parameters

3.3.1. Device EUI

The `setDeviceEUI()` function allows the user to set the 64-bit hexadecimal number representing the device EUI. There are two function prototypes which are explained below:

- No input device EUI is specified, then the preprogrammed EUI is used as the device EUI.
- A user-provided device EUI is specified as input.

The `getDeviceEUI()` function allows the user to query the device EUI which was previously set by the user. The attribute `_devEUI` permits to access to the settings of the module. The default value is 0000000000000000.

Depending on the network to join, it is needed to configure a random device EUI or a fixed device EUI provided by the back-end. This matter relies on the registering process for new devices in each back-end. For further information please go to "LoRaWAN back-ends" chapter.

Example for preprogrammed EUI:

```
{
   LoRaWAN.setDeviceEUI();
   LoRaWAN.getDeviceEUI();
}
```

Example for user-provided device EUI:

```
{
   LoRaWAN.setDeviceEUI(“0102030405060708”);
   LoRaWAN.getDeviceEUI();
}
```

Related variable:

`LoRaWAN._devEUI` → Stores the previously set device EUI

Examples of LoRaWAN configuration:

www.libelium.com/development/waspmote/examples/lorawan-01a-configure-module-eu
www.libelium.com/development/waspmote/examples/lorawan-01b-configure-module-us

3.3.2. Device address

The `setDeviceAddr()` function allows the user to set the 32-bit hexadecimal number representing the device address. This address must be unique to the current network. There are two function prototypes which are explained below:

- No input device address is specified, then the last 4 bytes of the preprogrammed EUI are set as device address.
- A user-provided device address is specified as input.

The `getDeviceAddr()` function allows the user to query the device address which was previously set by the user. The attribute `_devAddr` permits to access to the settings of the module. The range goes from 00000000 to FFFFFFFF. The default value is 00000000.

Depending on the network to join, it is possible configure a random device address or a fixed device address. This matter depends on the back-end and the registering process for new devices. For further information please go to "LoRaWAN back-ends" chapter.

Example for using the preprogrammed EUI:

```
{
    LoRaWAN.setDeviceAddr();
    LoRaWAN.getDeviceAddr();
}
```

Example for user-provided device address:

```
{
    LoRaWAN.setDeviceAddr("01020304");
    LoRaWAN.getDeviceAddr();
}
```

Related variable:

`LoRaWAN._devAddr` → Stores the previously set device address

Examples of LoRaWAN configuration:
www.libelium.com/development/waspmote/examples/lorawan-01a-configure-module-eu
www.libelium.com/development/waspmote/examples/lorawan-01b-configure-module-us

3.3.3. Application Session Key

The `setAppSessionKey()` function allows the user to set the 128-bit hexadecimal number representing the application session key.

All payloads are encrypted using an AES algorithm with a 128-bit secret key, the Application Session Key. Each end-device has its own unique Application Session Key only known by the end-device and the application server.

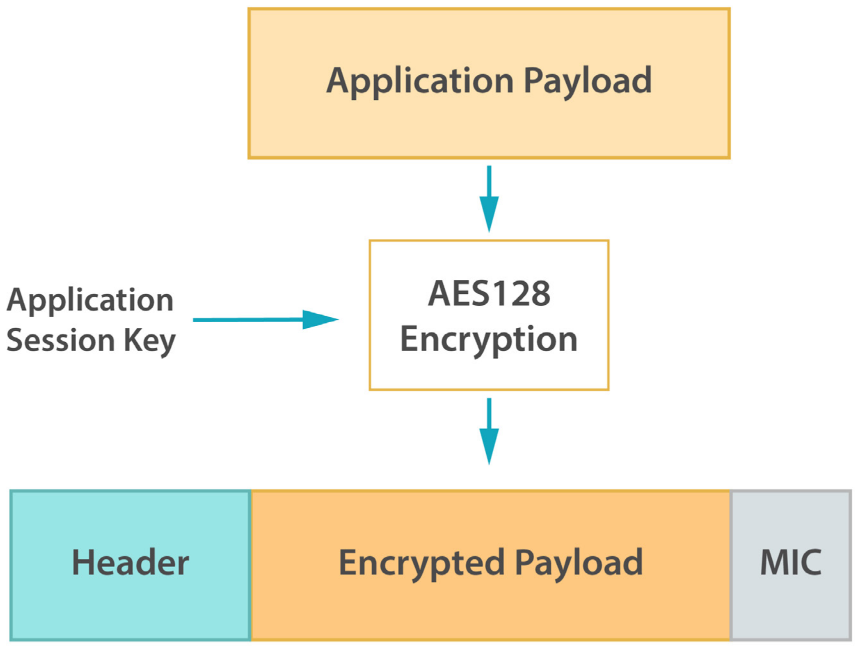


Figure: Use of application session key

The attribute `_appSKey` stores the application session key previously set by the user. The range goes from 000000 00000000000000000000000000 to FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF.

Example of use:

```
{
    LoRaWAN.setAppSessionKey("00102030405060708090A0B0C0D0E0F");
}
```

Related variable:

`LoRaWAN._appSKey` → Stores the previously set application session key

Examples of LoRaWAN configuration:
www.libelium.com/development/waspmote/examples/lorawan-01a-configure-module-eu
www.libelium.com/development/waspmote/examples/lorawan-01b-configure-module-us

3.3.4. Network session key

The `setNwkSessionKey()` function allows the user to set the 128-bit hexadecimal number representing the network session key.

All frames contain a 32-bit cryptographic Message Integrity Check (MIC) signature computed using the AES algorithm with a 128-bit secret key, the Network Session Key. Each end-device has its own Network Session Key only known by the end-device and the network server.

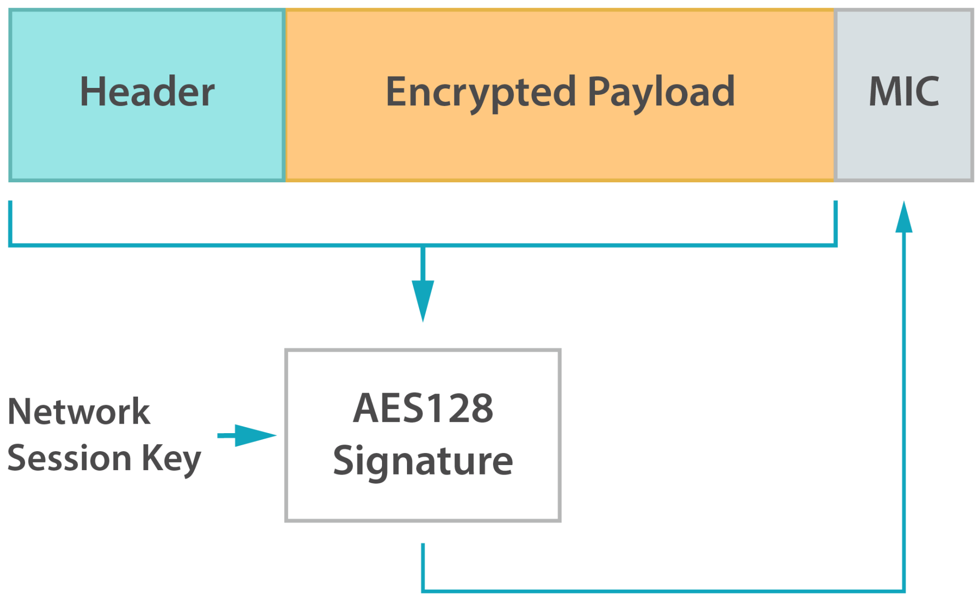


Figure: Use of network session key

The attribute `_nwkSKey` stores the network session key previously set by the user. The range goes from 00000000 000000000000000000000000 to FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF.

Example of use:

```
{
    LoRaWAN.setNwkSessionKey(“000102030405060708090A0B0C0D0E0F”);
}
```

Related variable:

`LoRaWAN._nwkSKey` → Stores the previously set network session key

Examples of LoRaWAN configuration:

www.libelium.com/development/waspmote/examples/lorawan-01a-configure-module-eu

www.libelium.com/development/waspmote/examples/lorawan-01b-configure-module-us

3.3.5. Application EUI

The `setAppEUI()` function allows the user to set the 64-bit hexadecimal number representing the application identifier. This parameters is a global application identifier that uniquely identifies the application provider (i.e., owner) of the module.

Example of use:

```
{
    LoRaWAN.setAppEUI(“1112131415161718”);
}
```

Related variable:

`LoRaWAN._appEUI` → Stores the previously set application EUI

3.3.6. Application key

The `setAppKey()` function allows the user to set the 128-bit hexadecimal number representing the application key. Whenever an end-device joins a network via OTAA, the Application Key is used to derive the session keys, Network Session Key and Application Session Key, which are specific for that end-device to encrypt and verify network communication and application data.

The attribute `_appKey` stores the application session key previously set by the user. The range goes from 000000 00000000000000000000000000 to FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF.

Example of use:

```
{
    LoRaWAN.setAppKey(“000102030405060708090A0B0C0D0E0F”);
}
```

Related variable:

`LoRaWAN._appKey` → Stores the previously set application key

Examples of LoRaWAN configuration:

www.libelium.com/development/waspmote/examples/lorawan-01a-configure-module-eu

www.libelium.com/development/waspmote/examples/lorawan-01b-configure-module-us

3.4. LoRaWAN module activation

To participate in a LoRaWAN network, each module has to be personalized and activated.

Activation of a module can be achieved in two ways, either via Over-The-Air Activation (OTAA) when an end-device is deployed or reset, or via Activation By Personalization (ABP) in which the two steps of end-device personalization and activation are done as one step.

3.4.1. Over-The-Air Activation (OTAA)

For OTAA, modules must follow a join procedure prior to participating in data exchanges with the network server. A module has to go through a new join procedure every time it has lost the session context information.

The OTAA join procedure requires the module to be personalized with the following information before its starts the join procedure:

- Device EUI (64-bit)
- Application EUI (64-bit)
- Application Key (128-bit)

After joining through OTAA, the module and the network exchanged the Network Session Key and the Application Session Key which are needed to perform communications.

3.4.2. Activation By Personalization (ABP)

Activating a module by ABP means that the device address and the two session keys are directly stored into the module instead of the Device EUI, Application EUI and the Application Key. The module is equipped with the required information for participating in a specific LoRa network when started.

Each module should have a unique set of Network Session Key and Application Session Key. Compromising the keys of one module shouldn't compromise the security of the communications of other devices. The process to build those keys should be such that the keys cannot be derived in any way from publicly available information.

The ABP join procedure requires the module to be personalized with the following information before its starts the join procedure:

- Device address (32-bit)
- Network Session Key (128-bit key) ensures security on network level
- Application Session Key (128-bit key) ensures end-to-end security on application level

3.4.3. Join a network

Before sending packets to a gateway, the node must join a network first. The joinABP() function allows the user to attempt joining the network using the Activation By Personalization mode (ABP). The joinOTAA() function allows the user to attempt joining the network using the Over the Air Activation mode (OTAA). Before joining the network, the specific parameters for activation should be configured depending on the joining procedure.

- **Join ABP**

Before joining the network, the specific parameters for activation should be configured: device EUI, device address, network session key and application session key.

Example of use:

```
{
    LoRaWAN.joinABP();
}
```

- **Join OTAA**

Before joining the network, the specific parameters for activation should be configured: device EUI, application EUI and application key.

Example of use:

```
{
    LoRaWAN.joinOTAA();
}
```

After joining via OTAA successfully, the module will be able to join the network in ABP mode in future joining procedures. The session keys are stored in module's memory, so it is possible to power down the module and restart it using ABP for joining the network with the previously stored keys.

3.5. LoRaWAN mode features

3.5.1. Operational ISM bands

The `resetMacConfig()` function allows the user to reset the software LoRaWAN stack and initialize it with the parameters for the selected band: 433 MHz, 868 MHz or 900 MHz.

The `getBand()` function allows the user to query the current frequency band of operation. This function is not available for the LoRaWAN US module since it can only work in the 902-928 MHz ISM band. The attribute `saveConfig()` function due to keep the band configuration after a reboot. Value can be either 433 or 868.

Example of use:

```
{
    LoRaWAN.resetMacConfig(433);
    LoRaWAN.getBand();
}
```

Related variable:

`LoRaWAN._band` → Stores the current frequency band of operation

3.5.2. Send data to a LoRaWAN gateway

- **Sending unconfirmed packets**

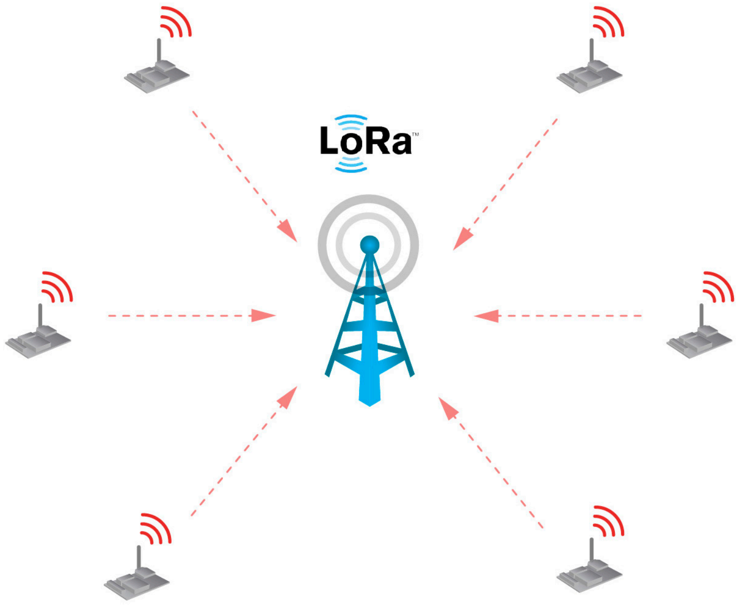


Figure: Sending unconfirmed packets without ACK

The `sendUnconfirmed()` function allows the user to transmit data on a specified port number. This function will not expect any acknowledgement back from the server. It is necessary to indicate the port to use. The range is from 1 to 223. The second input of the sending function is the payload of the packet to send. The payload must be specified in hexadecimal format as a string.

Example of use:

```
{
 uint8_t port = 1;
 char data[]  = “010203040506070809”;

 LoRaWAN.sendUnconfirmed( port, data);
}
```

Example of sending a packet without ACK:

www.libelium.com/development/waspmote/examples/lorawan-06-join-abp-send-unconfirmed

www.libelium.com/development/waspmote/examples/lorawan-09-join-otaa-send-unconfirmed

There is a second `sendUnconfirmed()` function prototype which permits to send a packet defined as an array of bytes. So the function expects three inputs: port, pointer to the data and length of the data.

Example of use:

```
{
 uint8_t port = 1;
 uint8_t data[] = {0x01, 0x02, 0x03, 0x04, 0x05, 0x06};

 LoRaWAN.sendUnconfirmed( port, data, 6);
}
```

Examples of sending a packet using the alternative prototype:

www.libelium.com/development/waspmote/examples/lorawan-08-join-abp-send-frame

www.libelium.com/development/waspmote/examples/lorawan-11-join-otaa-send-frame

The length of the payload capable of being transmitted is dependent upon the set data rate. Please refer to the "Data rate" section for the payload length values.

- **Sending confirmed packets (with ACK)**

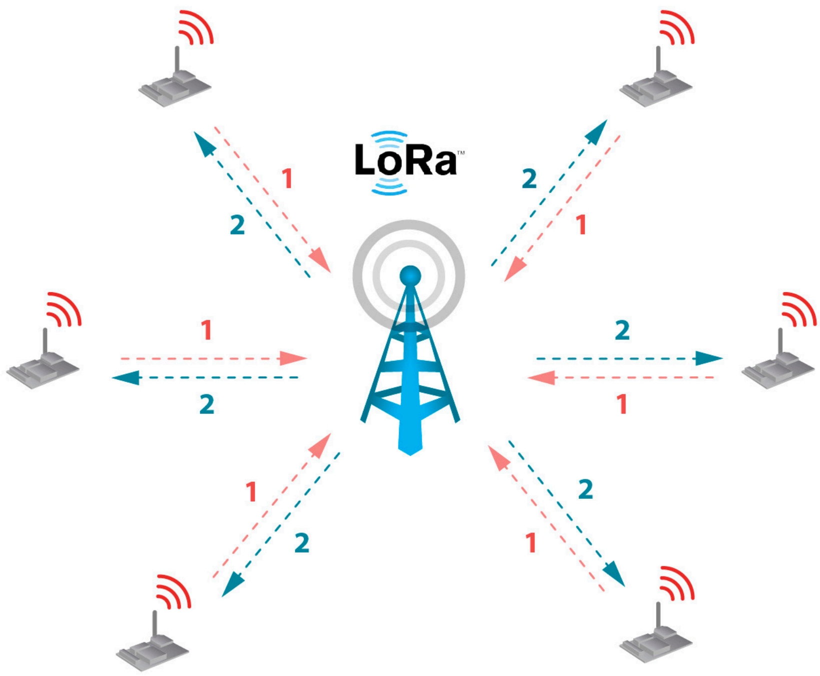


Figure: Sending confirmed packets with ACK

The `sendConfirmed()` function allows the user to transmit data on a specified port number. This function will expect an acknowledgement from the server. If no ACK is received, the message will be retransmitted automatically up to a maximum of times specified by the `setRetries()` function. It is necessary to indicate the port to use. The range is from 1 to 223. The second input of the sending function is the payload of the packet to send. The payload must be specified in hexadecimal format as a string.

Example of use:

```
{
 uint8_t port = 1;
 char data[]  = "010203040506070809";

 LoRaWAN.sendConfirmed( port, data);
}
```

Example of sending a packet with ACK:

www.libelium.com/development/waspmote/examples/lorawan-07-join-abp-send-confirmed

www.libelium.com/development/waspmote/examples/lorawan-10-join-otaa-send-confirmed

There is a second `sendConfirmed()` function prototype which permits to send a packet defined as an array of bytes. So the function expects three inputs: port, pointer to the data and length of the data.

Example of use:

```
{
 uint8_t port = 1;
 uint8_t data[]  = {0x01, 0x02, 0x03, 0x04, 0x05, 0x06};

 LoRaWAN.sendConfirmed( port, data, 6);
}
```

Examples of sending a packet using the alternative prototype:

www.libelium.com/development/waspmote/examples/lorawan-08-join-abp-send-frame

www.libelium.com/development/waspmote/examples/lorawan-11-join-otaa-send-frame

The length of the payload capable of being transmitted is dependent upon the set data rate. Please refer to the "Data rate" section for the payload length values.

3.5.3. Receiving data from a LoRaWAN gateway

Note that not every back-end is able to send data to end devices. The back-ends which are able to perform data downlink use the ACK process to send a special ACK frame containing data. So once the user programs a downlink process, this downlink data will be received by the target module the next time it performs a transmission.

There is no specific function to receive data from back-ends in this library. The `sendUnconfirmed()` and the `sendConfirmed()` functions check if any special ACK is received and store data if any has been received. In case data has been received, `_dataReceived` flag will be set to true.

Related variables:

`LoRaWAN._port` → Stores the port used by the back-ends to send data

`LoRaWAN._data` → Stores the received data

`LoRaWAN._dataReceived` → Data received flag

3.5.4. Save configuration

The `saveConfig()` function allows the user to save LoRaWAN Class A protocol configuration parameters to the module's non-volatile memory. This function must be issued after the configuration parameters have been appropriately set.

The LoRaWAN Class A protocol configuration savable parameters are:

- Band
- Uplink Frame Counter
- Downlink Frame Counter
- Data Rate
- Adaptive Data Rate state
- Device EUI
- Application EUI
- Application Key
- Network Session Key
- Application Session Key
- Device Address
- All Channel Parameter
  - Frequency
  - Duty Cycle
  - Data Rate Range
  - Status

There are some exceptions for the LoRaWAN US module, it does **not** save:

- Band, since it does not use this parameter
- Data rate
- Channel frequency, preset according to specification
- Duty cycle, since it does not use this parameter

Example of use:

```
{
    LoRaWAN.saveConfig();
}
```

Examples of LoRaWAN configuration:

www.libelium.com/development/waspmote/examples/lorawan-01a-configure-module-eu

www.libelium.com/development/waspmote/examples/lorawan-01b-configure-module-us

The `macResume()` function allows the user to enable LoRaWAN mode. After switching on the module it is not mandatory to call this function because the default mode upon reboot is LoRaWAN mode. However, if P2P mode was previously set and the user needs to switch back to LoRaWAN mode, then this function must be called.

Example of use:

```
{
    LoRaWAN.macResume();
}
```

3.5.5. Power level

The `setPower()` function allows the user to set the output power to be used on the next transmissions.

The `getPower()` function allows the user to query the device power index which was previously set by the user. The attribute `_powerIndex` permits to access to the settings of the module. The range goes from 0 to 5 for the 433 MHz frequency band and from 1 to 5 for the 868 MHz frequency band. LoRaWAN US power index values can be: 5, 7, 8, 9 or 10.

Power Index	Power level (868 MHz)	Power level (433 MHz)
0	N / A	10 dBm
1	14 dBm	7 dBm
2	11 dBm	4 dBm
3	8 dBm	1 dBm
4	5 dBm	-2 dBm
5	2 dBm	-5 dBm

Figure: Power levels table (LoRaWAN EU /433 module)

Power Index	Power level (900 MHz)
5	20 dBm
7	16 dBm
8	14 dBm
9	12 dBm
10	10 dBm

Figure: Power levels table (LoRaWAN US module)

Example of use:

```
{
   LoRaWAN.setPower(1);
   LoRaWAN.getPower();
}
```

Related variable:

`LoRaWAN._powerIndex` → Stores the previously set power

Example of setting power level:
www.libelium.com/development/waspmote/examples/lorawan-03-power-level

3.5.6. Adaptive data rate (ADR)

The `setADR()` function allows the user to enable or disable the adaptive data rate (ADR). The server is informed about the status of the module's ADR in every uplink frame it receives from ADR field in uplink data packet. If ADR is enabled, the server will optimize the data rate and the transmission power based on the information collected from the network: the RSSI / SNR of the last received packets.

The `getADR()` function allows the user to query the device adaptive data rate status. The attribute `_adr` permits to access to the settings of the module. This attribute is set to 'true' if ADR is enabled or 'false' if ADR is disabled.

Example of use:

```
{
   LoRaWAN.setADR("on");
   LoRaWAN.setADR("off");

   LoRaWAN.getADR();
}
```

Related variable:

`LoRaWAN._adr` → Stores the previously set ADR status

Example of setting adaptive data rate:
www.libelium.com/development/waspmote/examples/lorawan-05-adaptive-data-rate

3.5.7. Data rate

The `setDataRate()` function allows the user to set the data rate to be used for the next transmission. The following encoding is used for Data Rate (DR):

Data Rate	Configuration	Indicative physical bit rate [bits/s]	Maximum payload [bytes]
0	LoRa: SF12 / 125 kHz	250	51
1	LoRa: SF11 / 125 kHz	440	51
2	LoRa: SF10 / 125 kHz	980	51
3	LoRa: SF9 / 125 kHz	1760	115
4	LoRa: SF8 / 125 kHz	3125	222
5	LoRa: SF7 / 125 kHz	5470	222

Figure: Data rates table for the LoRaWAN EU module

Data Rate	Configuration	Indicative physical bit rate [bits/s]	Maximum payload [bytes]
0	LoRa: SF10 / 125 kHz	980	11
1	LoRa: SF9 / 125 kHz	1760	53
2	LoRa: SF8 / 125 kHz	3125	129
3	LoRa: SF7 / 125 kHz	5470	242
4	LoRa: SF8 / 500 kHz	12500	242

Figure: Data rates table for the LoRaWAN US module

The `getDataRate()` function allows the user to query the device data rate. The attribute `_dataRate` permits to access to the settings of the module.

Example of use:

```
{
   LoRaWAN.setDatarate(0);
   LoRaWAN.getDataRate();
}
```

Related variable:

`LoRaWAN._dataRate` → Stores the previously set data rate

Example of setting data rate:
www.libelium.com/development/waspmote/examples/lorawan-04-data-rate

3.5.8. Transmission retries

The `setRetries()` function allows the user to set the number of retransmissions to be used for an uplink confirmed packet, if no downlink acknowledgment is received from the server.

The `getRetries()` function allows the user to query the number of retransmissions which was previously set by the user. The attribute `_retries` permits to access to the settings of the module. The attribute range is from 0 to 255.

Example of use:

```
{
   LoRaWAN.setRetries (3);
   LoRaWAN.getRetries ();
}
```

Related variable:

LoRaWAN._retries → Stores the previously set number of retransmissions

Examples of LoRaWAN configuration:
www.libelium.com/development/waspmote/examples/lorawan-01a-configure-module-eu
www.libelium.com/development/waspmote/examples/lorawan-01b-configure-module-us

3.5.9. Receiving windows

As it has been described in the section "Receiving data from a LoRaWAN gateway", there is no specific function to receive data. The module is only capable of receiving gateway messages after a transmission has been done from the module during shorts periods of time named receiving windows.

The first receiving window has a fixed data rate and frequency that matches with those used in the last transmission. The `setRX1Delay()` function allows the user to set the delay between the transmission and the first reception window.

The `getRX1Delay()` function allows the user to query the delay between the transmission and the first reception window. The attribute `_rx1Delay` permits to access to the settings of the module. The attribute range is from 0 to 65535.

The second receiving delay is set internally by the module calculated with the first window delay plus 1000 ms. The `setRX2Parameters()` function allows the user to set the data rate and frequency that will be used by the second reception window.

The `getRX2Delay()` function allows the user to query the delay between the transmission and the second reception window. The attribute `_rx2Delay` permits to access to the settings of the module. The attribute range is from 0 to 65535. The `getRX2Parameters()` function allows the user to query the data rate and frequency used in the second reception window. This function expects a parameter that indicates the band of the parameters that are queried. The attribute `_rx2DataRate` permits to access to the settings of the module. The attribute range is from 0 to 7. The attribute `_rx2Frequency` permits to access to the settings of the module. The attribute range is from 863000000 to 870000000 for the 868 band and from 433050000 to 434790000 for the 433 band, in Hz.

Example of use:

```
{
   LoRaWAN.setRX1Delay(1000); // set a 1000 ms delay
   LoRaWAN.getRX1Delay();
   LoRaWAN.getRX2Delay();
   LoRaWAN.setRX2Parameters(0,864500000); // set DR0 and 864.5 MHz
   LoRaWAN.getRX2Delay(868);
}
```

Related variable:

LoRaWAN._ rx1Delay → Stores the RX1 delay
LoRaWAN._ rx2Delay → Stores the RX2 delay
LoRaWAN._ rx2DataRate → Stores the RX2 data rate
LoRaWAN._ rx2Frequency → Stores the RX2 frequency

3.5.10. Automatic reply (AR)

The `setAR()` function allows the user to enable or disable the module's automatic reply. By enabling the automatic reply, the module will transmit a packet without a payload immediately after a confirmed downlink is received, or when the Frame Pending bit has been set by the server. If set to OFF, no automatic reply will be transmitted.

The `getAR()` function allows the user to query the automatic reply status to the module. The attribute _ar permits to access to the settings of the module. This attribute is set to 'true' if AR is enabled or 'false' if AR is disabled.

This parameter cannot be stored in the module's EEPROM using the `saveConfig()` function. To get to know the previous state of this parameter user can use the attribute _ar.

Example of use:

```
{
   LoRaWAN.setAR("on");
   LoRaWAN.setAR("off");

   LoRaWAN.getAR();
}
```

Related variable:

`LoRaWAN._ar` → Stores the previously set ADR status

Examples of LoRaWAN configuration:
www.libelium.com/development/waspmote/examples/lorawan-01a-configure-lorawan-868
www.libelium.com/development/waspmote/examples/lorawan-01b-configure-lorawan-900

3.5.11. Uplink counter

The `setUpCounter()` function allows the user to set the uplink frame counter that will be used for the next uplink transmission.

The `getUpCounter()` function allows the user to query the uplink frame counter that will be used for the next uplink transmission. The attribute `_upCounter` permits to access to the settings of the module. The attribute range is from 0 to 4294967295.

If the back-end's sequence number check is set to strict, this uplink counter must be synchronized with the back-end uplink counter. The `_upCounter` is saved into the module's memory after every transmission.

Example of use:

```
{
   LoRaWAN.setUpCounter(10);
   LoRaWAN.getUpCounter();
}
```

Related variable:

`LoRaWAN._upCounter` → Stores the previously set uplink frame sequence number

3.5.12. Downlink counter

The setDownCounter() function allows the user to set the downlink frame counter that will be used for the next downlink reception.

The getDownCounter() function allows the user to query the downlink frame counter that will be used for the next downlink reception. The attribute _downCounter permits to access the settings of the module. The attribute range is from 0 to 4294967295.

If the back-end check sequence number function is set to strict, this downlink counter must be synchronized with the back-end downlink counter. The _downCounter is saved into the module's memory after every reception.

Example of use:

```
{
    LoRaWAN.setDownCounter(10);
    LoRaWAN.getDownCounter();
}
```

Related variable:

LoRaWAN._downCounter → Stores the previously set downlink frame sequence number

3.5.13. Channel parameters

The LoRaWAN EU module has 16 channels available to be configured. The channel parameters are:

- Frequency
- Duty cycle
- Data rate range
- Status

Channel Number	Parameters	Frequency band	
		868	433
Channel 0	Frequency (Hz)	868100000	433175000
	Duty cycle	302	302
	Data rate range	0-5	0-5
	Status	On	On
Channel 1	Frequency (Hz)	868300000	433375000
	Duty cycle	302	302
	Data rate range	0-5	0-5
	Status	On	On
Channel 2	Frequency (Hz)	868500000	433575000
	Duty cycle	302	302
	Data rate range	0-5	0-5
	Status	On	On
Channel 3 - 15	Frequency (Hz)	0 (to be configured by the user)	0 (to be configured by the user)
	Duty cycle	65535	65535
	Data rate range	15 -15	15- 15
	Status	Off	Off

Figure: Channel parameters table for LoRaWAN EU

The LoRaWAN US module has 72 channels with a preset fixed frequency for every channel. Data rate range and channel status are the only settable parameters.

Channel Number	Parameters	Default Values
Channel 0-63	Frequency (Hz)	902300000 + 200000 * channel Index
	Data rate range (min - max)	0 - 3
	Status	On
Channel 64-71	Frequency (Hz)	903000000 + 1600000 * channel Index
	Data rate range (min - max)	4 - 4
	Status	On

Figure: Channel parameters table for LoRaWAN US

Below you can see how the parameters can be configured.

- **Channel frequency**

The first three channels have a fixed frequency value. The rest of them can be configured in the following ranges: from 863250000 to 869750000 Hz for the 868 MHz band, and from 433050000 to 434790000 Hz for the 433 MHz band. Though frequency is not a settable parameter in LoRaWAN US module frequency can be queried with ranges from 902300000 to 914900000 Hz.

The `setChannelFreq()` function allows the user to set the operational frequency on the given channel number (from 3 to 15). The default channels (0-2) cannot be modified in terms of frequency. This function is not available for LoRaWAN US module because channels have a fixed frequency.

The `getChannelFreq()` function allows the user to query the channel frequency which was previously set by the user. This function can query channels from 0 to 15 when using LoRaWAN EU module and channels from 0 to 71 when using LoRaWAN US module. The attribute `_freq` permits to access to the settings of the module.

Example of use:

```
{
   LoRaWAN.setChannelFreq(3,868000000);
   LoRaWAN.getChannelFreq(3);
}
```

Related variable:

`LoRaWAN._freq[n]` → Stores the previously set frequency for channel ‘n’

Example of channel settings configuration:

www.libelium.com/development/waspmote/examples/lorawan-02a-channels-configuration-eu

www.libelium.com/development/waspmote/examples/lorawan-02b-channels-configuration-us

- **Channel duty cycle**

The `setChannelDutyCycle()` function allows the user to set the operational duty cycle on the given channel number (from 0 to 15). The duty cycle value that needs to be used as input argument can be obtained from the wanted duty cycle X (in percentage) using the following formula: duty cycle = (100/X) – 1. The default settings consider only the three default channels (0-2), and their default duty cycle is 0.33%. If a new channel is created either by the server or by the user, all the channels (including the default ones) must be updated by the user in terms of duty cycle to comply with the applicable regulations in the country. This function is not available for LoRaWAN US module.

The getChannelDutyCycle() function allows the user to query the channel duty cycle which was previously set by the user. The attribute _dCycle permits to access to the settings of the module. The attribute range goes from 0 to 65535. The _dCycle value that needs to be configured can be obtained from the actual duty cycle X (in percentage) using the following formula: X = 100/(_dCycle + 1). This function is not available for LoRaWAN US module.

Example of use:

```
{
   LoRaWAN.setChannelDutyCycle(3,9);
   LoRaWAN.getChannelDutyCycle(3);
}
```

Related variable:

LoRaWAN._dCycle[n] → Stores the previously set duty cycle for channel 'n'

Example of channel settings configuration:
www.libelium.com/development/waspmote/examples/lorawan-02a-channels-configuration-eu
www.libelium.com/development/waspmote/examples/lorawan-02b-channels-configuration-us

- **Channel data rate range (DRR)**

The setChannelDRRange() function allows the user to set the operational data rate range, from minimum to maximum values, for the given channel number.

The LoRaWAN EU module supports data rate ranges from 0 to 7 on channels 0 to 15.

The LoRaWAN US module supports data rate ranges from 0 to 4 on channels 0 to 63. Channels from 64 to 71 have a fixed data rate range.

The getChannelDRRange() function allows the user to query the data rate range which was previously set by the user. The attributes to store the maximum and minimum data rates are _drrMax and _drrMin respectively.

Example of use:

```
{
   LoRaWAN.setChannelDRRange(3,0,6);
   LoRaWAN.getChannelDRRange(3);
}
```

Related variable:

LoRaWAN._drrMax[n] → Stores the previously set maximum data rate for channel 'n'

LoRaWAN._drrMin[n] → Stores the previously set minimum data rate for channel 'n'

Example of channel settings configuration:
www.libelium.com/development/waspmote/examples/lorawan-02a-channels-configuration-eu
www.libelium.com/development/waspmote/examples/lorawan-02b-channels-configuration-us

- **Channel status**

The setChannelStatus() function allows the user to set the operation of the given channel, either "on" or "off".

LoRaWAN EU allows to configure the channel status on channels from 0 to 15.

LoRaWAN US allows to configure the channel status on channels from 0 to 71.

The getChannelStatus() function allows the user to query the operation channel status. The attribute _status permits to access to the settings of the module.

Example of use:

```
{
   LoRaWAN.setChannelStatus(3,"on");
   LoRaWAN.setChannelStatus(3,"off");

   LoRaWAN.getChannelStatus(3);
}
```

Related variable:

`LoRaWAN._status[n]` → Stores the previously set status for channel 'n'

Example of channel settings configuration:
www.libelium.com/development/waspmote/examples/lorawan-02a-channels-configuration-eu
www.libelium.com/development/waspmote/examples/lorawan-02b-channels-configuration-us

3.5.14. Duty cycle prescaler

The `getDutyCyclePrescaler()` function allows the user to query the duty cycle prescaler. The value of the prescaler can be configured only by the server through use of the Duty Cycle Request frame. Upon reception of this command from the server, the duty cycle prescaler is changed for all enabled channels. The attribute `_dCyclePS` permits to access to the settings of the module.

Example of use:

```
{
   LoRaWAN.getDutyCyclePrescaler();
}
```

Related variable:

`LoRaWAN._dCyclePS` → Stores the duty cycle prescaler established by the server

3.5.15. Margin

The `getMargin()` function allows the user to query the demodulation margin as received in the last Link Check Answer frame. The attribute `_margin` permits to access to the settings of the module.

Example of use:

```
{
   LoRaWAN.getMargin();
}
```

Related variable:

`LoRaWAN._margin` → Stores the margin received in the last Link Check Answer frame

3.5.16. Gateway number

The `getGatewayNumber()` function allows the user to query the number of gateways that successfully received the last Link Check Request frame command, as received in the last Link Check Answer. The attribute `_gwNumber` permits to access to the settings of the module.

Example of use:

```
{
   LoRaWAN.getGatewayNumber();
}
```

Related variable:

`LoRaWAN._gwNumber` → Stores the number of gateways that received the last Link Check Request frame

3.6. P2P mode – Direct communication between nodes

3.6.1. Enable P2P mode

The `macPause()` function allows the user to disable LoRaWAN mode and enable P2P mode. After power reboot, the module's default mode is LoRaWAN. So, it is mandatory to call this function in order to work with the P2P mode. After calling this function, all P2P functions explained in this section will be able to be run.

Example of use:

```
{
   LoRaWAN.macPause();
}
```

3.6.2. Send data

The `sendRadio()` function allows the user to transmit data using the radio transceiver. This function will not expect any acknowledgement back from the receiver. The maximum length of the frame is 255 bytes (510 ASCII digits).

Example of use:

```
{
 char data[] = "010203040506070809";

 LoRaWAN.macPause();
 LoRaWAN.sendRadio(data);
}
```

3.6.3. Receive data

The `receiveRadio()` function allows the user to receive data using the radio transceiver. This function needs a timeout parameter to keep the module listening for any data. The range for this timeout input parameter is from 0 ms to 4294967295 ms. If any data frame is received, it is stored in `_buffer`. The length of the buffer is specified in `_length`. The user must keep in mind that this buffer structure is used for all functions in the API. So, the packet contents should be stored in a program buffer for being used after reception.

Example of use:

```
{
 uint32_t time = 10000;

 LoRaWAN.macPause();
 LoRaWAN.receiveRadio(time);
}
```

Related variable:

`LoRaWAN._buffer` → Stores data received through radio transceiver

`LoRaWAN._length` → Stores length of the data stored in _buffer

3.6.4. Power level

The `setRadioPower()` function allows the user to set the operating output power in P2P mode.

The `getRadioPower()` function allows the user to query the operating output power level in P2P mode which was previously set by the user. The attribute `_radioPower` permits to access to the settings of the module.

The range of this attribute goes from -3 to 15 for the LoRaWAN EU module.

The range of this attribute goes from 2 to 20 for the LoRaWAN US module.

The output power level in dBm can be consulted in the radio transceiver module datasheet, RN2483 to see about LoRaWAN EU and RN2903 to see about LoRaWAN US.

Example of use:

```
{
 LoRaWAN.setRadioPower(3);
 LoRaWAN.getRadioPower();
}
```

Related variable:

`LoRaWAN._radioPower` → Stores the previously set output power level

3.6.5. Spreading Factor

The `setRadioSF()` function allows the user to set the operating spreading factor (SF) in P2P mode.

The `getRadioSF()` function allows the user to query the operating Spreading Factor (SF) in P2P mode which was previously set by the user. The attribute `_radioSF` permits to access to the settings of the module. The spreading factor can take the following values: “sf7”, “sf8”, “sf9”, “sf10”, “sf11” and “sf12”

Example of use:

```
{
 LoRaWAN.setRadioSF(“sf7”);
 LoRaWAN.getRadioSF();
}
```

Related variable:

`LoRaWAN._radioSF` → Stores the previously set Spreading Factor

3.6.6. Frequency deviation

The `setRadioFreqDeviation()` function allows the user to set the frequency deviation during operation in P2P mode.

The `getRadioFreqDeviation()` function allows the user to query the operating frequency deviation which was previously set by the user. The attribute `_radioFreqDev` permits to access to the settings of the module. The frequency deviation range goes from 0 to 200000.

Example of use:

```
{
 LoRaWAN.setRadioFreqDeviation(5000);
 LoRaWAN.getRadioFreqDeviation();
}
```

Related variable:

`LoRaWAN._radioFreqDev` → Stores the previously set frequency deviation

3.6.7. Preamble length

The `setRadioPreamble()` function allows the user to set the preamble length for transmit/receive in P2P mode.

The `getRadioPreamble()` function allows the user to query the preamble length which was previously set by the user. The attribute `_preambleLength` permits to access to the settings of the module. The preamble length range goes from 0 to 65535.

Example of use:

```
{
 LoRaWAN.setRadioPreamble(8);
 LoRaWAN.getRadioPreamble();
}
```

Related variable:

`LoRaWAN._preambleLength` → Stores the previously set preamble length

3.6.8. CRC header

The `setRadioCRC()` function allows the user to set the Cyclic Redundancy Check (CRC) header status for transmit/receive in P2P mode.

The `getRadioCRC()` function allows the user to query the CRC status which was previously set by the user. The attribute `_crcStatus` permits to access to the settings of the module. This attribute is set to "on" if CRC is enabled or "off" if CRC is disabled.

Example of use:

```
{
 LoRaWAN.setRadioCRC("on");
 LoRaWAN.setRadioCRC("off");

 LoRaWAN.getRadioCRC();
}
```

Related variable:

`LoRaWAN._crcStatus` → Stores the previously set CRC status

3.6.9. Coding Rate

The `setRadioCR()` function allows the user to set the Coding Rate (CR) for communications in P2P mode.

The `getRadioCR()` function allows the user to query the CR which was previously set by the user. The attribute `_radioCR` permits to access to the settings of the module. The CR can take the following values: "4/5", "4/6", "4/7" and "4/8".

Example of use:

```
{
 LoRaWAN.setRadioCR("4/5");

 LoRaWAN.getRadioCR();
}
```

Related variable:

`LoRaWAN._radioCR` → Stores the previously set coding rate

3.6.10. Bandwidth

The `setRadioBandwidth()` function allows the user to set the operating radio bandwidth (BW) for LoRa operation.

The getRadioBandwidth() function allows the user to query radio bandwidth which was previously set by the user. The attribute _radioBW permits to access to the settings of the module. The radio bandwidth can take the following values: 125 kHz, 250 kHz and 500 kHz.

Example of use:

```
{
  LoRaWAN.setRadioBandwidth(250);

  LoRaWAN.getRadioBandwidth();
}
```

Related variable:

`LoRaWAN._radioBW` → Stores the previously set radio bandwidth

3.6.11. Frequency

The `setRadioFrequency()` function allows the user to set the communication frequency of the radio transceiver.

The `getRadioFrequency()` function allows the user to query radio frequency which was previously set by the user. The attribute `_radioFreq` permits to access to the settings of the module.

When using the LoRaWAN EU module, the operation frequency can take values from 433250000 to 434550000 or from 863250000 to 869750000, for the 433 and 868 MHz bands.

When using the LoRaWAN US module, the operation frequency can take values from 902000000 to 928000000.

Example of use:

```
{
  LoRaWAN.setRadioFrequency(868100000);

  LoRaWAN.getRadioFrequency();
}
```

Related variable:

`LoRaWAN._radioFreq` → Stores the previously set communication frequency

3.6.12. Signal to noise ratio (SNR)

The `getRadioSNR()` function allows the user to query the Signal to Noise Ratio (SNR) for the last received packet. The attribute `_radioSNR` permits to access to the settings of the module. The SNR can take values from -127 to 128.

Example of use:

```
{
  LoRaWAN.getRadioSNR();
}
```

Related variable:

`LoRaWAN._radioSNR` → Stores the previously set communication frequency

3.7. Hybrid LoRaWAN / P2P mode

It is possible to set up hybrid networks using both Radio and LoRaWAN protocols. Therefore, several nodes can use a P2P star topology to reach a central node which will access to the LoRaWAN network to route the information. The basis of this operation is that the central node listens to P2P packets and sends them to the LoRaWAN infrastructure. See the following diagram to understand this hybrid network:

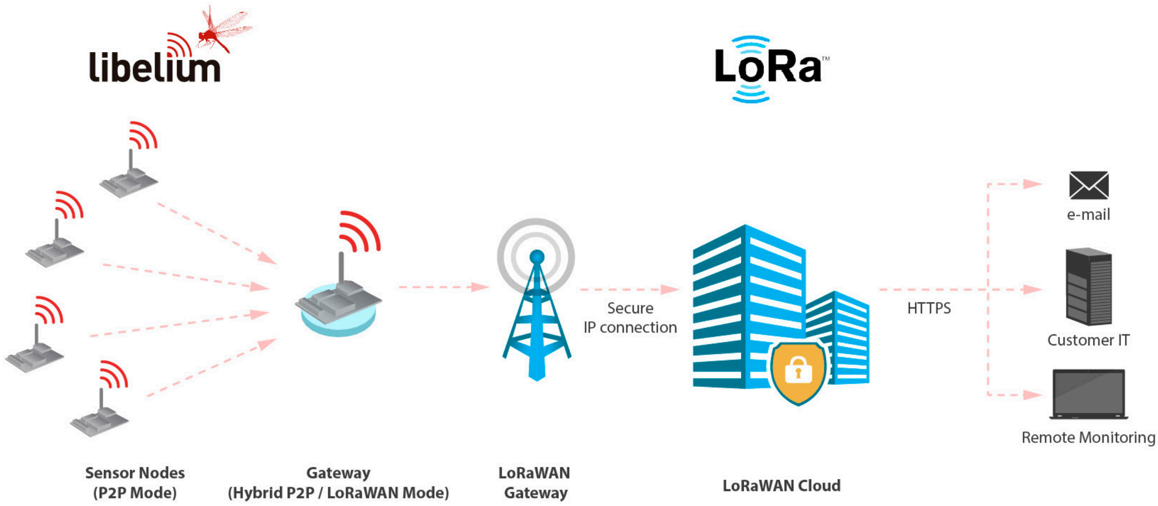


Figure: Hybrid LoRaWAN / P2P mode

The user must keep in mind that there is a mismatch between the maximum payload in P2P networks (255 bytes) and LoRaWAN networks (292 bytes). Therefore, the central node will be able to resend all received frames from the other P2P nodes. The following example shows how to operate as a central node sending data of the incoming P2P packets to the LoRaWAN network:

www.libelium.com/development/waspmote/examples/lorawan-p2p-04-hybrid-p2p-to-lorawan

4. LoRaWAN back-ends

LoRaWAN network architecture is typically laid out in a star-of-stars topology in which a **gateway** is a transparent bridge relaying messages between **end-devices** and a central **network server** in the back-end.

4.1. Waspmote recommended configuration

Before using a LoRaWAN module with the back-ends explained below or any other back-end, it is strongly recommended to know the configuration that the LoRaWAN gateway is using so we can configure Waspmote the same way.

We will need to pay attention to some of these parameters:

- Number of channels supported
- Receiving windows configurations
- Gateway's firmware version

Depending on the LoRaWAN module version we work with, it will be necessary to configure different parameters.

Make sure that the gateway's firmware is always up to date. If there is no certain about it, contact the gateway provider or the back-end provider.

4.1.1. LoRaWAN EU

As we can see in the section "Channel parameters", the LoRaWAN EU module supports up to 16 channels to transmit information. According to the *LoRa Alliance: LoRaWAN Specification* document, it has 3 channels configured by default with fixed frequencies.

Depending on the gateway manufacturer, the number of supported channels may vary. To get the best performance it is recommended to configure the module to use as many channels as the gateway may support.

There is a set of functions to configure these channels parameters, and to turn on channels so the module can use them. Before turning on channels we must configure them, otherwise the module will not allow the user to activate them.

So set frequencies for every channel according to the gateway's configuration. Set the data rate (max range depends on that) as desired. Keep in mind that the duty cycle must be set and modified for the existence of other channels so it complies with the applicable regulations in the country as shown in the "Channel Duty Cycle" section.

Once the configuration has been correctly done, channels can be activated.

Window reception parameters may also vary from a gateway to another. They should be configured according to the parameters given by the back-end provider.

You can see an example of configuration in this code:
www.libelium.com/development/waspmote/examples/lorawan-01a-configure-module-eu

4.1.2. LoRaWAN US

As we can see in the section "Channel parameters", LoRaWAN US module supports up to 64 channels to transmit uplink messages. By default, the whole set of channels is activated when the module starts working.

Depending on the gateway manufacturer, the number of supported channels may vary. To get the best performance it is recommended to configure the module to use as many channels as gateway may support. It is strongly recommended to deactivate channels that are not supported by the gateway so the module does not try to send information on these channels.

Before setting on any channel, it is necessary to configure the data rate (max range depends on that) as desired.

Window reception parameters may also vary from a gateway to another. They should be configured according to the parameters given by the back-end provider.

You can see an example of configuration in this code:
www.libelium.com/development/waspmote/examples/lorawan-01b-configure-module-us

4.2. Actility

The ThingPark Wireless Device Manager is the back-end User Interface (UI) which allows you to manage all of your LoRaWAN devices.

This Guide will provide the guidelines on the entire GUI, the device provisioning, device configuration and management, alarm and routing profile management and connectivity plan association.

The Device Manager can be fully integrated into a third party customer UI, through all the ThingPark Wireless OSS REST API.

4.2.1. Device registration

The device provisioning is the process that allows users to create devices and register them on the network. There are two ways to register a new device: Activation By Personalization (ABP) and Over The Air Activation(OTAA).

Activation By Personalization:

Information required to create a new device:

- Device Address (**DevAddr**)
- Network Session Key (**NwkSKey**)
- Application Session Key (**AppSKey**)

These parameters match with the ones which must be configured in the ThingPark Actility Portal (back-end).

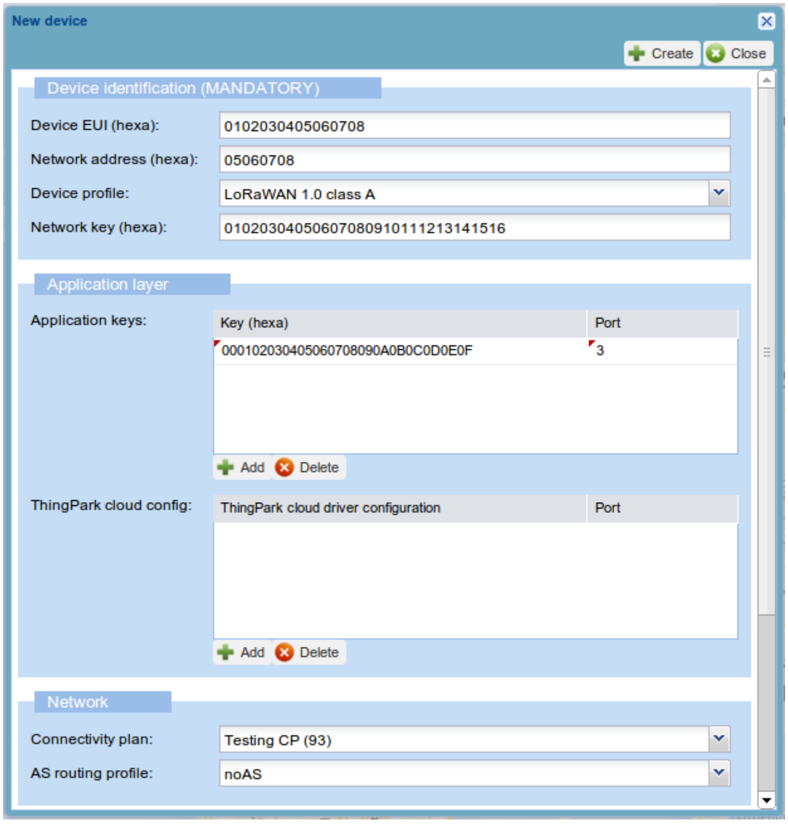


Figure: ThingPark Wireless Device Manager (new device creation)

Over The Air Activation:

Information required to create a new device:

- Device EUI (**DevEUI**)
- Application EUI (**AppEUI**)
- Application key (**AppKey**)

There parameters match with the ones used by the server and defined by user. They will be used to negotiate necessary keys for the module to send data.

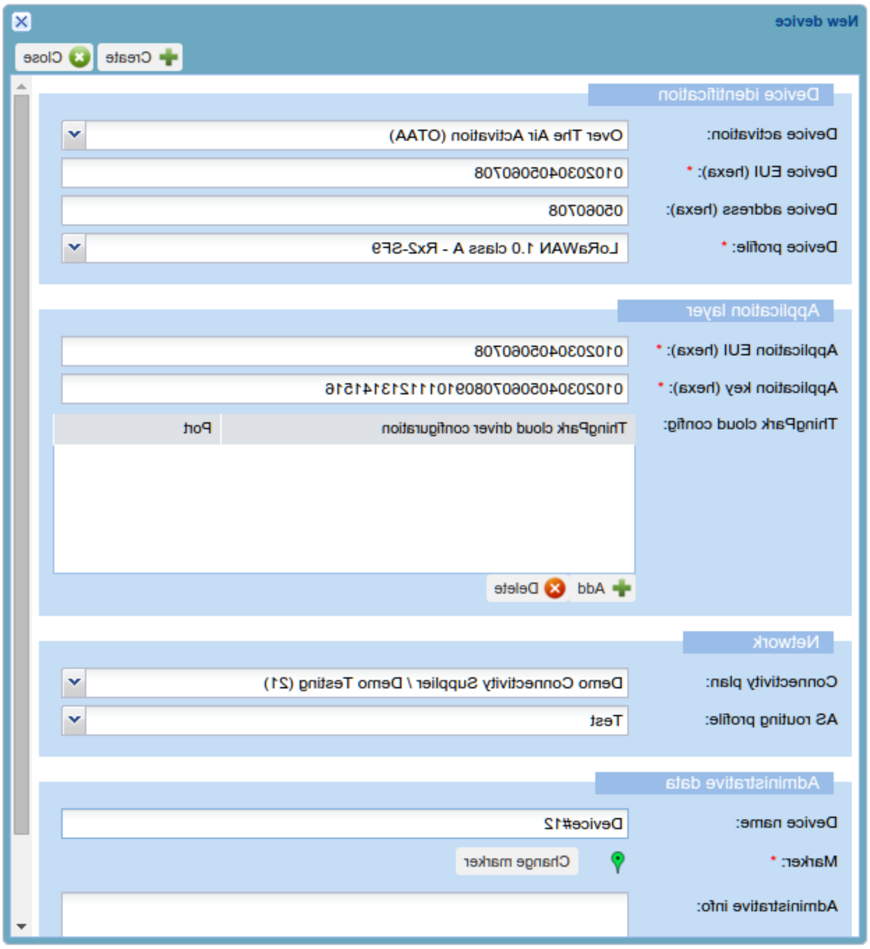


Figure: ThingPark Wireless Device Manager (new device creation, OTAA)

4.2.2. Waspmote programming

Actility Portal lets the user configure all parameters needed to connect into a network. **NwkSKey** and **AppSKey** are 128-bit keys specific for the end-device, used to calculate and verify an application-level MIC (message integrity code) and also used by both network server and end-device to encrypt and decrypt the payload field of application-specific data messages.

Both **NwkSKey** and **AppSKey** will be configured by the user in the Actility Portal and set into the end-device. These keys are not shown in the ThingPark Wireless Device Manager once they have been configured so it is strongly recommended to set them into the end-device before configuring the end-device creation in the Actility Portal.

About **DevEUI** and **DevAddr**, there are two ways to configure it into the module with Waspmote.

- On one hand they may be set by user manually. When using thivs method always keep in mind they must be unique for every module.
- On the other and they can be configured automatically by Waspmote. This method uses the preprogrammed by manufacturer module's identifier, that matches **DevEUI** length, ensuring it will be unique. **DevAddr** will be extracted from this manufacturer module's identifier taking its last 32 bit. E.g., Microchip Module: EUI: 0004A30B001A836D, **DevEUI:** 0004A30B001A836D, **DevAddr:** 001A836D.

Examples of setting configuration necessary to connect into a network and send packets:

www.libelium.com/development/waspmote/examples/lorawan-06-join-abp-send-unconfirmed

www.libelium.com/development/waspmote/examples/lorawan-07-join-abp-send-confirmed

4.3. OrbiWise

OrbiWise introduces its comprehensive UbiQ core network solution for Low-Power Wide-Area (LPWA) networks taking full advantage of LoRaTM bidirectional communication technology.

LPWA networks are of special interest to wireless operators, utilities and industrial companies that want to serve many applications in the Internet-of-Things domain with a single low-cost infrastructure.

OrbiWise's UbiQ solution enables the deployment of such infrastructure from city-scale to nation-wide coverage with seamless expansion and support for millions of connected objects. Furthermore, UbiQ's O&M tool suite allows operations and maintenance of the entire network from a single web-based graphical user interface.

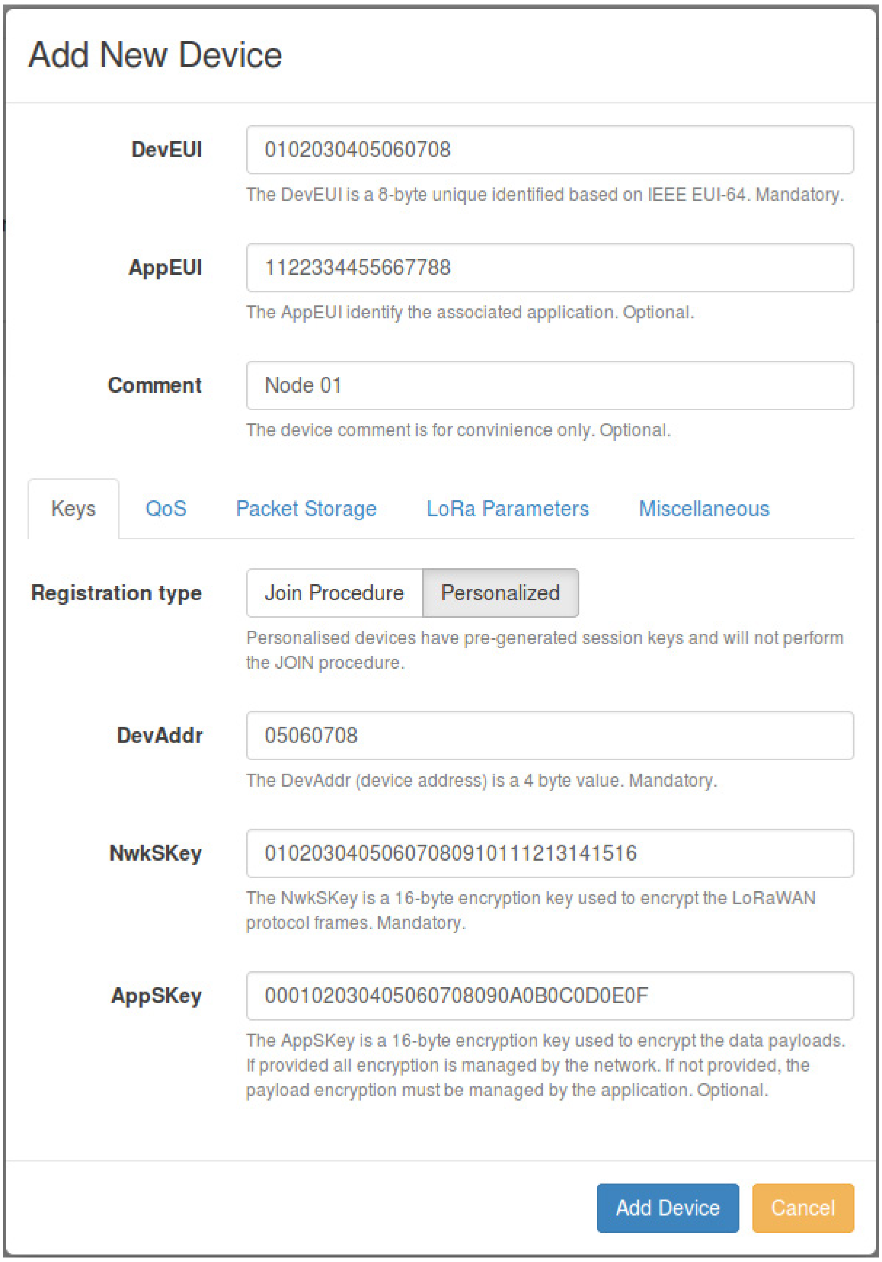
4.3.1. Device registration

The Add New Device process allows users to create devices and register them on the network through Activation By Personalization (ABP).

Information required to create a new device:

- Device EUI (**DevEUI**)
- Device Address (**DevAddr**)
- Network Session Key (**NwkSKey**)
- Application EUI (**AppEUI**)
- Comment (Cloud API device's identifier)
- Application Session Key (**AppSKey**)

- Always have in mind to select the Personalized Registration Type. Despite **AppSKey** is an optional parameter to create the device in the server, it is mandatory to be configured in the module. In any case, it is always better to set an **AppSKey** both in server and module (same for both) so data can be decrypted by server.



4.3.2. Data downlink

To perform data downlinks, a button called "Send Data" can be found in Data section. Clicking on it will open a pop-up that the user can fill with data for the payload and select the message type. Data will be received by the module after the next data uplink. It does not matter if the next uplink process is confirmed or unconfirmed, the downlink will be performed.

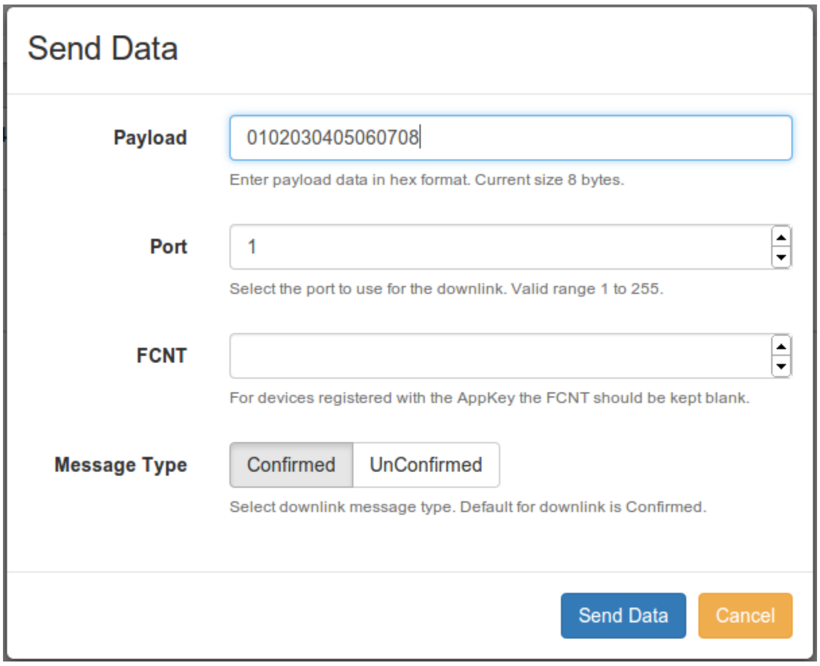


Figure: OrbiWise Wireless Device Manager (sending data downlink)

4.3.3. Waspmote programming

Once the new device was created in the OrbiWise portal only **DevEUI** will be shown, so user should set the device address, network session key and application session key in both portal and module at the same time.

Examples of setting configuration necessary to connect into a network and send packets:

www.libelium.com/development/waspmote/examples/lorawan-06-join-abp-send-unconfirmed

www.libelium.com/development/waspmote/examples/lorawan-07-join-abp-send-confirmed

4.4. LORIOT

LORIOT.io is a provider of a LoRaWAN Network Server and Application Server software, which is commercially offered through a set of business models.

They provide:

- Software for the supported LoRa gateways
- Cloud-based LoRaWAN Network Server
- Programming interface (APIs) for Internet of Things applications to access the end node data
- Output of end node data to number of 3rd party services

As a gateway owner, users can use LORIOT.io software on gateways to connect them to their cloud. From then on, all data received by the gateways will be relayed to the user through the LORIOT.io APIs or 3rd party services.

The network servr components fulfills to role of protocol processor. It is a TLS connection end-point for the gateways and the customer applications. It is responsible for processing the incoming end node data according to the LoRaWAN protocol.

The specific roles of LORIOT.io Network Server are:

- Gateway population management
- Application population management
- Device population management
- Collection of billing records
- Security management
- Data distribution

4.4.1. Device registration

Some parameters must be set into the module so it can join to a network through Activation By Personalization (ABP).

- Device EUI (**DevEUI**)
- Device Address (**DevAddr**)
- Network Session Key (**NwkSKey**)
- Application Session Key (**AppSKey**)

When a new device is generated in the LORIOT.io portal these parameters are provided. The user will have to configure the module according to these parameters.

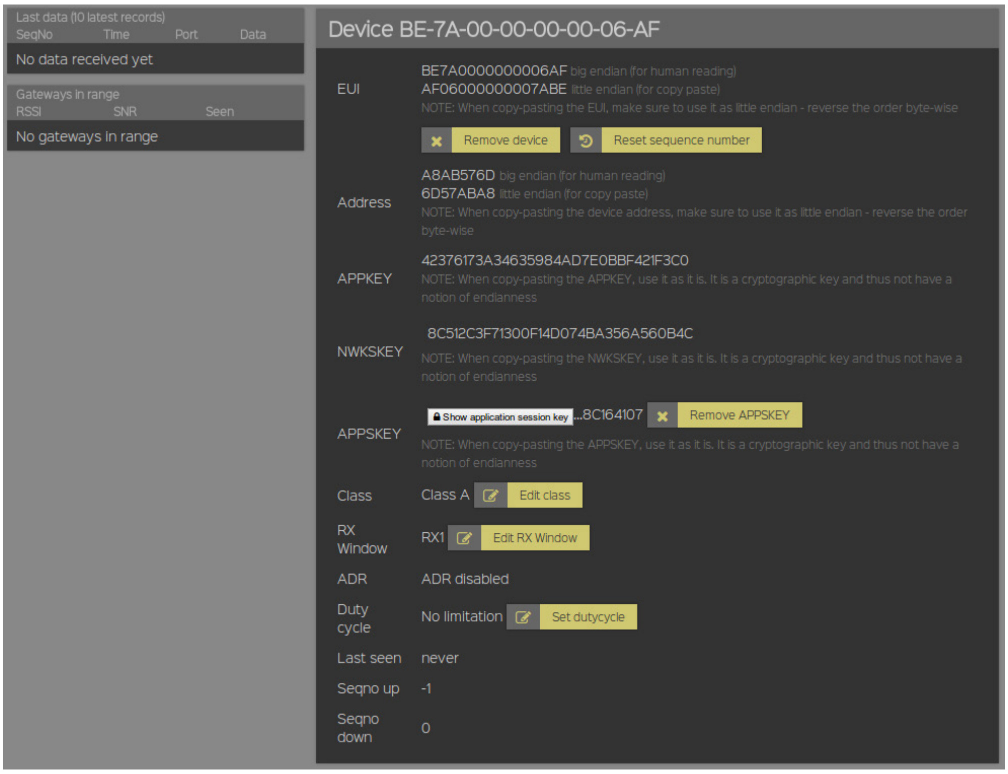
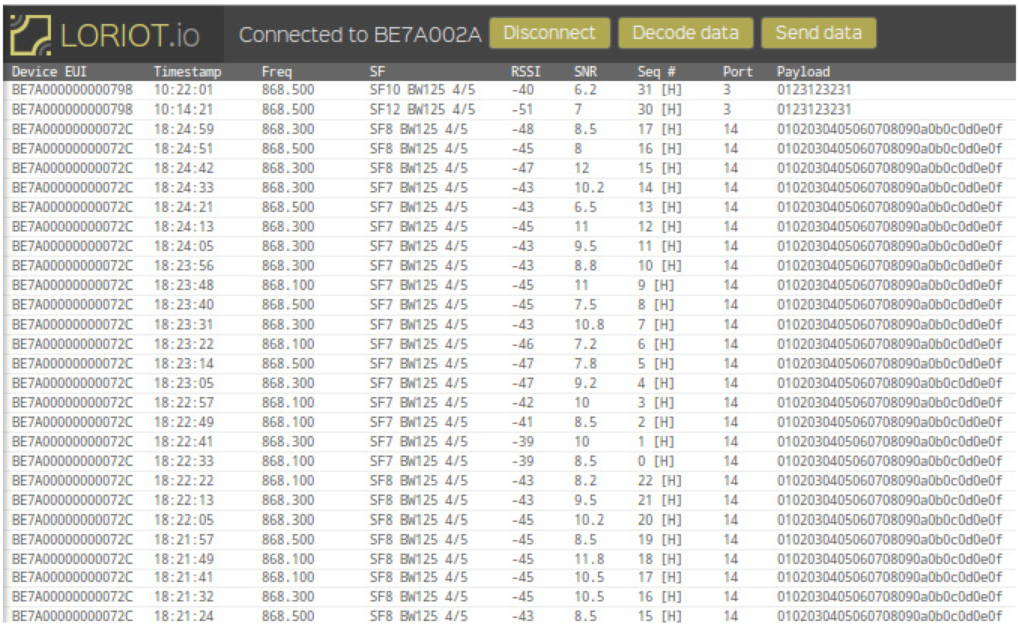


Figure: LOIRIOT.io Wireless Device Manager (new device creation)

Once the device is created you can access to its configuration and data clicking over the Device EUI field with the mouse. Data messages can be seen there.

4.4.2. Data downlink

Data sent to the back-end can be found inside every device page. Data could also be found in the WebSocket API section.



Device EUI	Timestamp	Freq	SF	RSSI	SNR	Seq #	Port	Payload
BE7A00000000798	10:22:01	868.500	SF10 BW125 4/5	-40	6.2	31 [H]	3	0123123231
BE7A00000000798	10:14:21	868.500	SF12 BW125 4/5	-51	7	30 [H]	3	0123123231
BE7A0000000072C	18:24:59	868.300	SF8 BW125 4/5	-48	8.5	17 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:24:51	868.500	SF8 BW125 4/5	-45	8	16 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:24:42	868.300	SF8 BW125 4/5	-47	12	15 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:24:33	868.300	SF7 BW125 4/5	-43	10.2	14 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:24:21	868.500	SF7 BW125 4/5	-43	6.5	13 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:24:13	868.300	SF7 BW125 4/5	-45	11	12 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:24:05	868.300	SF7 BW125 4/5	-43	9.5	11 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:23:56	868.300	SF7 BW125 4/5	-43	8.8	10 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:23:48	868.100	SF7 BW125 4/5	-45	11	9 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:23:40	868.500	SF7 BW125 4/5	-45	7.5	8 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:23:31	868.300	SF7 BW125 4/5	-43	10.8	7 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:23:22	868.100	SF7 BW125 4/5	-46	7.2	6 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:23:14	868.500	SF7 BW125 4/5	-47	7.8	5 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:23:05	868.300	SF7 BW125 4/5	-47	9.2	4 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:22:57	868.100	SF7 BW125 4/5	-42	10	3 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:22:49	868.100	SF7 BW125 4/5	-41	8.5	2 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:22:41	868.300	SF7 BW125 4/5	-39	10	1 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:22:33	868.100	SF7 BW125 4/5	-39	8.5	0 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:22:22	868.100	SF8 BW125 4/5	-43	8.2	22 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:22:13	868.300	SF8 BW125 4/5	-43	9.5	21 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:22:05	868.300	SF8 BW125 4/5	-45	10.2	20 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:21:57	868.500	SF8 BW125 4/5	-45	8.5	19 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:21:49	868.100	SF8 BW125 4/5	-45	11.8	18 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:21:41	868.100	SF8 BW125 4/5	-45	10.5	17 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:21:32	868.300	SF8 BW125 4/5	-45	10.5	16 [H]	14	0102030405060708090a0b0c0d0e0f
BE7A0000000072C	18:21:24	868.500	SF8 BW125 4/5	-43	8.5	15 [H]	14	0102030405060708090a0b0c0d0e0f

Figure: LORIOT WebSocket API

To perform data downlinks click on the “Send data” button and the “Send to device” section will be displayed. In this section, Device EUI, port number and data payload to send must be filled. Finally, the “Send to device” button will enqueue the data to be downloaded. Data will be received by the module after the next data uplink. It does not matter if the next uplink process is confirmed or unconfirmed, the downlink will be performed.

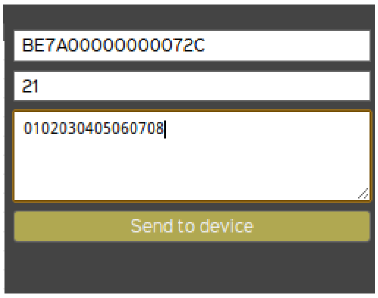


Figure: LORIOT WebSocket API (sending data downlink)

4.4.3. Waspmote programming

LORIOT.io portal provides by default the whole configuration required by the module to connect to a network.

The mandatory field to field are the ones which where mentioned in the previous section. They can be copied as is to the code so module is configured the same way it was created in the portal.

Inside the device description in the LORIOT.io portal they warn to copy **EUI** and **Address** in little endian format, but it won’t be necessary for the Waspmote code, it can be copied big endian format.

Examples of setting configuration necessary to connect into a network and send packets:
www.libelium.com/development/waspmote/examples/lorawan-02-send-unconfirmed
www.libelium.com/development/waspmote/examples/lorawan-03-send-confirmed

5. When is LoRaWAN recommended?

LoRaWAN is a protocol with a good long-range performance. It is achieved thanks to the excellent receiver sensitivity of the LoRa modulation, which is possible due to very low data rates (few bps). The main drawback of LoRaWAN is the low data rate of the transmission modes with high Spreading Factor. The better range, the worse bitrate. This may be a problem in crowded networks, because the shared channel could be too busy because it can take several seconds to send each frame. The base station and the back-end server will try to find an efficient balance in the network thanks to the LoRaWAN algorithms. So:

- LoRaWAN is not advised for projects with a duty-cycle which require sending one frame every few minutes.
- The downlink data rate is very low too, so OTA programming is not possible.
- LoRaWAN is NOT recommended for real time streaming. Transmission is not done in real time as there is a minimum delay for packet arrival.
- LoRaWAN is recommended for long-range device communications in cities, where base stations by some LoRaWAN operator are deployed, so the user can take advantage of this infrastructure.
- Otherwise, the user can purchase his own LoRaWAN-compliant gateways and deploy a private LoRaWAN network for a specific project.

6. Certifications

Libelium offers 2 types of IoT sensor platforms, Waspmote OEM and Plug & Sense!:

- **Waspmote OEM** is intended to be used for research purposes or as part of a major product so it needs final certification on the client side. More info at: www.libelium.com/products/waspmote
- **Plug & Sense!** is the line ready to be used out-of-the-box. It includes market certifications. See below the specific list of regulations passed. More info at: www.libelium.com/products/plug-sense

Besides, Meshlium, our multiprotocol router for the IoT, is also certified with the certifications below. Get more info at:

www.libelium.com/products/meshlium

List of certifications for Plug & Sense! and Meshlium:

- CE (Europe)
- FCC (US)
- IC (Canada)
- ANATEL (Brazil)
- RCM (Australia)
- PTCRB (cellular certification for the US)
- AT&T (cellular certification for the US)

Figure: Certifications of the Plug & Sense! product line

You can find all the certification documents at:

www.libelium.com/certifications

7. Code examples and extended information

In the Waspmote Development section you can find complete examples:

www.libelium.com/development/waspmote/examples

Example:

```
/*
 *  ------ LoRaWAN Code Example --------
 *
 *  Explanation: This example shows how to configure the module
 *  and all general settings related to back-end registration
 *  process.
 *
 *  Copyright (C) 2016 Libelium Comunicaciones Distribuidas S.L.
 *  http://www.libelium.com
 *
 *  This program is free software: you can redistribute it and/or modify
 *  it under the terms of the GNU General Public License as published by
 *  the Free Software Foundation, either version 3 of the License, or
 *  (at your option) any later version.
 *
 *  This program is distributed in the hope that it will be useful,
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 *  GNU General Public License for more details.
 *
 *  You should have received a copy of the GNU General Public License
 *  along with this program.  If not, see <http://www.gnu.org/licenses/>.
 *
 *  Version:           3.1
 *  Design:            David Gascon
 *  Implementation:    Luis Miguel Marti
 */

#include <WaspLoRaWAN.h>

//////////////////////////////////////////////
uint8_t socket = SOCKET0;
//////////////////////////////////////////////

// Device parameters for Back-End registration
////////////////////////////////////////////////////////////
char DEVICE_EUI[]  = “0102030405060708”;
char DEVICE_ADDR[] = “05060708”;
char NWK_SESSION_KEY[] = “01020304050607080910111213141516”;
char APP_SESSION_KEY[] = “000102030405060708090A0B0C0D0E0F”;
char APP_KEY[] = “000102030405060708090A0B0C0D0E0F”;
////////////////////////////////////////////////////////////

// variable
uint8_t error;



void setup()
{
  USB.ON();
  USB.println(F(“LoRaWAN example - Module configuration”));


  USB.println(F(“ _____________________________________________________”));
  USB.println(F(“|                                                      |”));
  USB.println(F(“| It is not mandatory to configure channel parameters.|”));
```

```
USB.println(F("| Server should configure the module during the       |"));
USB.println(F("| Over The Air Activation process.                     |"));
USB.println(F("|_____________________________________________________|"));
USB.println();

//////////////////////////////////////////////
// 1. switch on
//////////////////////////////////////////////

error = LoRaWAN.ON(socket);

// Check status
if( error == 0 )
{
  USB.println(F("1. Switch ON OK"));
}
else
{
  USB.print(F("1. Switch ON error = "));
  USB.println(error, DEC);
}


//////////////////////////////////////////////
// 2. Reset to factory default values
//////////////////////////////////////////////

error = LoRaWAN.factoryReset();

// Check status
if( error == 0 )
{
  USB.println(F("2. Reset to factory default values OK"));
}
else
{
  USB.print(F("2. Reset to factory error = "));
  USB.println(error, DEC);
}


//////////////////////////////////////////////
// 3. Set/Get Device EUI
//////////////////////////////////////////////

// Set Device EUI
error = LoRaWAN.setDeviceEUI(DEVICE_EUI);

// Check status
if( error == 0 )
{
  USB.println(F("3.1. Set Device EUI OK"));
}
else
{
  USB.print(F("3.1. Set Device EUI error = "));
  USB.println(error, DEC);
}

// Get Device EUI
error = LoRaWAN.getDeviceEUI();

// Check status
if( error == 0 )
{
  USB.print(F("3.2. Get Device EUI OK. "));
```

```
    USB.print(F("Device EUI: "));
    USB.println(LoRaWAN._devEUI);
  }
  else
  {
    USB.print(F("3.2. Get Device EUI error = "));
    USB.println(error, DEC);
  }


  //////////////////////////////////////////////
  // 4. Set/Get Device Address
  //////////////////////////////////////////////

  // Set Device Address
  error = LoRaWAN.setDeviceAddr(DEVICE_ADDR);

  // Check status
  if( error == 0 )
  {
    USB.println(F("4.1. Set Device address OK"));
  }
  else
  {
    USB.print(F("4.1. Set Device address error = "));
    USB.println(error, DEC);
  }

  // Get Device Address
  error = LoRaWAN.getDeviceAddr();

  // Check status
  if( error == 0 )
  {
    USB.print(F("4.2. Get Device address OK. "));
    USB.print(F("Device address: "));
    USB.println(LoRaWAN._devAddr);
  }
  else
  {
    USB.print(F("4.2. Get Device address error = "));
    USB.println(error, DEC);
  }


  //////////////////////////////////////////////
  // 5. Set Network Session Key
  //////////////////////////////////////////////

  error = LoRaWAN.setNwkSessionKey(NWK_SESSION_KEY);

  // Check status
  if( error == 0 )
  {
    USB.println(F("5. Set Network Session Key OK"));
  }
  else
  {
    USB.print(F("5. Set Network Session Key error = "));
    USB.println(error, DEC);
  }


  //////////////////////////////////////////////
  // 6. Set Application Session Key
  //////////////////////////////////////////////
```

```
error = LoRaWAN.setAppSessionKey(APP_SESSION_KEY);

// Check status
if( error == 0 )
{
  USB.println(F("6. Set Application Session Key OK"));
}
else
{
  USB.print(F("6. Set Application Session Key error = "));
  USB.println(error, DEC);
}


//////////////////////////////////////////////
// 7. Set retransmissions for uplink confirmed packet
//////////////////////////////////////////////

// set retries
error = LoRaWAN.setRetries(7);

// Check status
if( error == 0 )
{
  USB.println(F("7.1. Set Retransmissions for uplink confirmed packet OK"));
}
else
{
  USB.print(F("7.1. Set Retransmissions for uplink confirmed packet error = "));
  USB.println(error, DEC);
}

// Get retries
error = LoRaWAN.getRetries();

// Check status
if( error == 0 )
{
  USB.print(F("7.2. Get Retransmissions for uplink confirmed packet OK. "));
  USB.print(F("TX retries: "));
  USB.println(LoRaWAN._retries, DEC);
}
else
{
  USB.print(F("7.2. Get Retransmissions for uplink confirmed packet error = "));
  USB.println(error, DEC);
}


//////////////////////////////////////////////
// 8. Set application key
//////////////////////////////////////////////

error = LoRaWAN.setAppKey(APP_KEY);

// Check status
if( error == 0 )
{
  USB.println(F("8. Application key set OK"));
}
else
{
  USB.print(F("8. Application key set error = "));
  USB.println(error, DEC);
}
```

```
////////////////////////////////////////////////////////
  //  ______________________________________________________
  // |                                                      |
  // |  It is not mandatory to configure channel parameters.|
  // |  Server should configure the module during the       |
  // |  Over The Air Activation process. If channels aren't |
  // |  configured, please uncomment channel configuration  |
  // |  functions below these lines.                        |
  // |______________________________________________________|
  //
  ////////////////////////////////////////////////////////

  //////////////////////////////////////////////
  // 9. Channel configuration. (Recommended)
  // Consult your Network Operator and Backend Provider
  //////////////////////////////////////////////

  // Set channel 3 -> 867.1 MHz
  // Set channel 4 -> 867.3 MHz
  // Set channel 5 -> 867.5 MHz
  // Set channel 6 -> 867.7 MHz
  // Set channel 7 -> 867.9 MHz

//  uint32_t freq = 867100000;
//
//  for (uint8_t ch = 3; ch <= 7; ch++)
//  {
//    error = LoRaWAN.setChannelFreq(ch, freq);
//    freq += 200000;
//
//    // Check status
//    if( error == 0 )
//    {
//      USB.println(F("9. Frequency channel set OK"));
//    }
//    else
//    {
//      USB.print(F("9. Frequency channel set error = "));
//      USB.println(error, DEC);
//    }
//
//
//  }



  //////////////////////////////////////////////
  // 10. Set Duty Cycle for specific channel. (Recommended)
  // Consult your Network Operator and Backend Provider
  //////////////////////////////////////////////

//  for (uint8_t ch = 0; ch <= 2; ch++)
//  {
//    error = LoRaWAN.setChannelDutyCycle(ch, 33333);
//
//    // Check status
//    if( error == 0 )
//    {
//      USB.println(F("10. Duty cycle channel set OK"));
//    }
//    else
//    {
//      USB.print(F("10. Duty cycle channel set error = "));
//      USB.println(error, DEC);
//    }
//  }
```

```
//
//  for (uint8_t ch = 3; ch <= 7; ch++)
//  {
//    error = LoRaWAN.setChannelDutyCycle(ch, 40000);
//
//    // Check status
//    if( error == 0 )
//    {
//      USB.println(F("10. Duty cycle channel set OK"));
//    }
//    else
//    {
//      USB.print(F("10. Duty cycle channel set error = "));
//      USB.println(error, DEC);
//    }
//  }

  //////////////////////////////////////////////
  // 11. Set Data Range for specific channel. (Recommended)
  // Consult your Network Operator and Backend Provider
  //////////////////////////////////////////////

//  for (int ch = 0; ch <= 7; ch++)
//  {
//    error = LoRaWAN.setChannelDRRange(ch, 0, 5);
//
//    // Check status
//    if( error == 0 )
//    {
//      USB.println(F("11. Data rate range channel set OK"));
//    }
//    else
//    {
//      USB.print(F("11. Data rate range channel set error = "));
//      USB.println(error, DEC);
//    }
//  }



  //////////////////////////////////////////////
  // 12. Set Data rate range for specific channel. (Recommended)
  // Consult your Network Operator and Backend Provider
  //////////////////////////////////////////////

//  for (int ch = 0; ch <= 7; ch++)
//  {
//    error = LoRaWAN.setChannelStatus(ch, "on");
//
//    // Check status
//    if( error == 0 )
//    {
//      USB.println(F("12. Channel status set OK"));
//    }
//    else
//    {
//      USB.print(F("12. Channel status set error = "));
//      USB.println(error, DEC);
//    }
//  }


  //////////////////////////////////////////////
  // 13. Set Adaptive Data Rate (recommended)
  //////////////////////////////////////////////
```

```
// set ADR
error = LoRaWAN.setADR("on");

// Check status
if( error == 0 )
{
  USB.println(F("13.1. Set Adaptive data rate status to on OK"));
}
else
{
  USB.print(F("13.1. Set Adaptive data rate status to on error = "));
  USB.println(error, DEC);
}

// Get ADR
error = LoRaWAN.getADR();

// Check status
if( error == 0 )
{
  USB.print(F("13.2. Get Adaptive data rate status OK. "));
  USB.print(F("Adaptive data rate status: "));
  if (LoRaWAN._adr == true)
  {
    USB.println("on");
  }
  else
  {
    USB.println("off");
  }
}
else
{
  USB.print(F("13.2. Get Adaptive data rate status error = "));
  USB.println(error, DEC);
}


//////////////////////////////////////////////
// 14. Set Automatic Reply
//////////////////////////////////////////////

// set AR
error = LoRaWAN.setAR("on");

// Check status
if( error == 0 )
{
  USB.println(F("14.1. Set automatic reply status to on OK"));
}
else
{
  USB.print(F("14.1. Set automatic reply status to on error = "));
  USB.println(error, DEC);
}

// Get AR
error = LoRaWAN.getAR();

// Check status
if( error == 0 )
{
  USB.print(F("14.2. Get automatic reply status OK. "));
  USB.print(F("Automatic reply status: "));
  if (LoRaWAN._ar == true)
  {
```

```
        USB.println("on");
      }
      else
      {
        USB.println("off");
      }
    }
    else
    {
      USB.print(F("14.2. Get automatic reply status error = "));
      USB.println(error, DEC);
    }


    //////////////////////////////////////////////
    // 15. Save configuration
    //////////////////////////////////////////////

    error = LoRaWAN.saveConfig();

    // Check status
    if( error == 0 )
    {
      USB.println(F("15. Save configuration OK"));
    }
    else
    {
      USB.print(F("15. Save configuration error = "));
      USB.println(error, DEC);
    }


    USB.println(F("------------------------------------"));
    USB.println(F("Now the LoRaWAN module is ready for"));
    USB.println(F("joining networks and send messages."));
    USB.println(F("Please check the next examples..."));
    USB.println(F("------------------------------------\n"));

  }


  void loop()
  {
    // do nothing
  }
```

8. API changelog

Keep track of the software changes on this link:
[www.libelium.com/development/waspmote/documentation/changelog/#LoRaWAN 23. Documentation changelog](www.libelium.com/development/waspmote/documentation/changelog/#LoRaWAN)

9. Documentation changelog

From v7.1 to v7.2:

- Added a new section to show the user how to connect the module to Waspmote
- Added OTAA explanation in the Actility back-end section
- New description about the LoRa and LoRaWAN differences
- Fixed errata in “Regional compatibility table”

From v7.0 to v7.1:

- The 868 module is officially called EU, and the 900 module is officially called US
- Clarification about compatible areas
- Added allowed payload for each data rate
- New links for the code examples