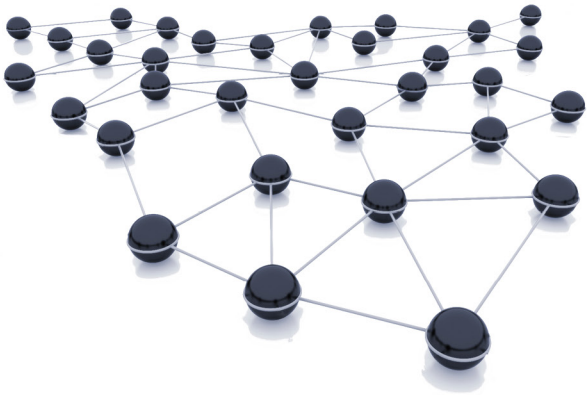
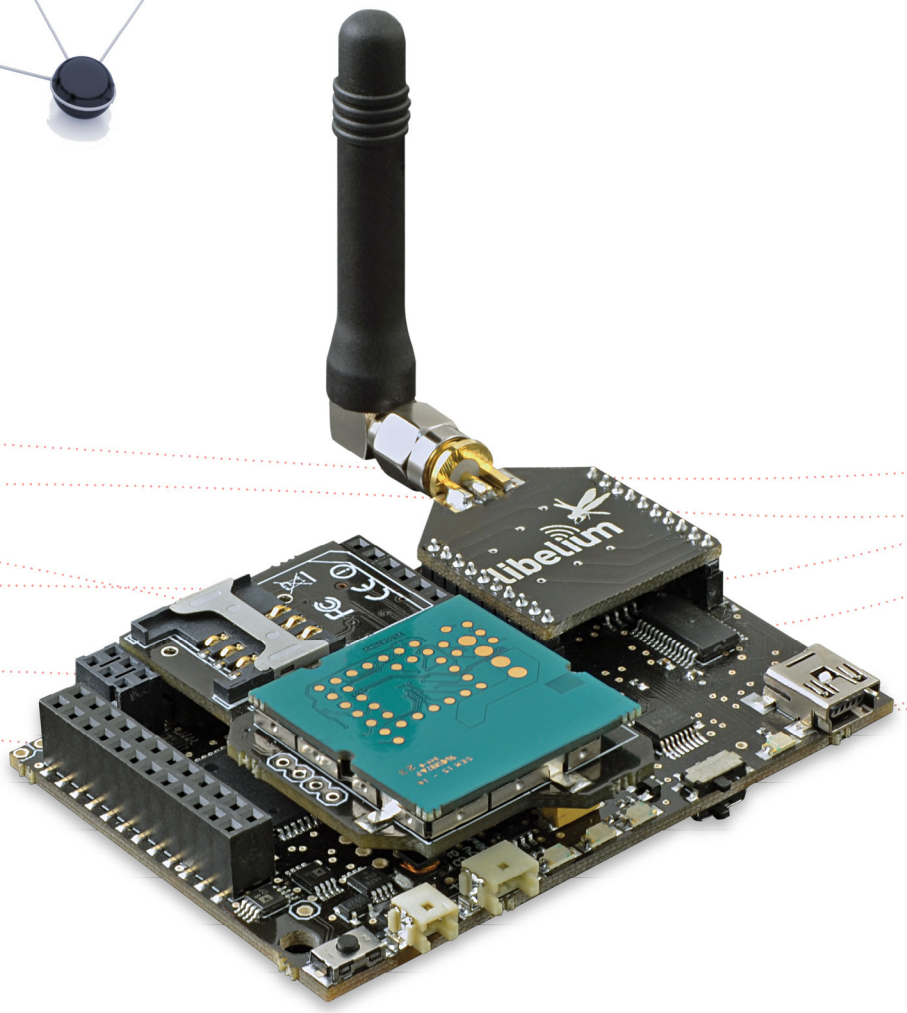
# Waspmote LoRa 868MHz 915MHz SX1272

## Networking Guide



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# INDEX

# 1. LoRa and LoRaWAN

Libelium currently offers two options of this type of radio technology: LoRa and LoRaWAN

- LoRa contains only the link layer protocol and is perfect to be used in P2P communications between nodes. LoRa modules are a little cheaper that the LoRaWAN ones.
- LoRaWAN includes the network layer too so it is possible to send the information to any Base Station already connected to a Cloud platform. LoRaWAN modules may work in different frequencies by just connecting the right antenna to its socket.

These modules are based on the same modulation technology (the same PHY layer): LoRa™, developed by Semtech. The LoRa module implements a simple link protocol, created by Libelium. However, the LoRaWAN module runs the LoRaWAN protocol, a much richer and more advanced protocol, created by the LoRa Alliance.

The LoRa module and the LoRaWAN module are not compatible because the protocols are different.

This guide talks about the LoRa module, not about LoRaWAN. If you are interested in the LoRaWAN module, please read the LoRaWAN Networking Guide:

http://www.libelium.com/development/waspmote/documentation/waspmote-lorawan-networking-guide/

Libelium offers two types of 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: http://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. http://www.libelium.com/products/plug-sense/

**CE**

In accordance with the 1999/5/EC (R&TTE) and the EU Directive 2011/65/EU (RoHS2), Libelium Comunicaciones Distribuidas S.L. declares that the "Plug & Sense! LoRaWAN 868" device conforms to the following regulations:

- EN 301 489-1(1.9.2)- (1.6.1)
- EN 55022:2010
- EN 60950-1: 2006
- A11: 2009 + A1: 2010 + A12: 2011 + Ac: 2011 +A2: 2013


If desired, the Declaration of Conformity document can be requested using the Contact section at:

http://www.libelium.com/contact

**FCC**

Libelium is currently certifying the model "Plug & Sense! LoRaWAN 900-915" for US. Specifically under the Part 15 Spread Spectrum Transmitter (FCC Rule Part 15 C). Complete process will be finished by 2016. If you want to know more, contact the Libelium Sales Department.

**IC**

Libelium is currently certifying the model "Plug & Sense! LoRaWAN 900-915" for Canada. Specifically under the Industry Canada Regulation (IC) - (RSS-210). Complete process will be finished by 2016. If you want to know more, contact the Libelium Sales Department.

# 2. Hardware

The SX1272 module has been developed by the company Semtech.

| Module | Dual Frequency Band | Transmission Power | Sensitivity | Channels | Distance |
|---|---|---|---|---|---|
| SX1272 | 863-870 MHz (Europe) | 14 dBm | -134 dBm | 8 | 22+ km (13.4+ miles) |
| | 902-928 MHz (US) | | | 13 | |

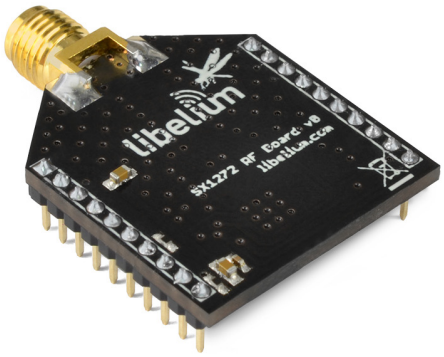


*Figure: SX1272 module*

*Figure: SX1272 module with special 4.5 dBi antenna*

*Figure: SX1272 module with 0 dBi antenna*

The antenna used for this module is a special model. It is not recommended to use any regular 4.5dBi antenna for 868/900 MHz band. Besides, the user must keep in mind that there are two different antennas for LoRa modules regarding the frequency band: 868 or 900 MHz. Although the appearance of these antennas is the same, the user must choose which one needs to be purchased.

***Note:*** *The SX1272 module is provided with a special 4.5 dBi antenna, which enables maximum range. The only exception is Smart Parking; in this case the antenna is smaller, 0 dBi, to fit inside the enclosure.*

***Note:*** *It is not recommended to work without an antenna screwed to the module. The module could be damaged due to RF reflections.*

The frequency used in Europe is the free ISM band of 868 MHz, using 8 channels with a bandwidth of 0.3 MHz per channel. That is shown in the following figure.

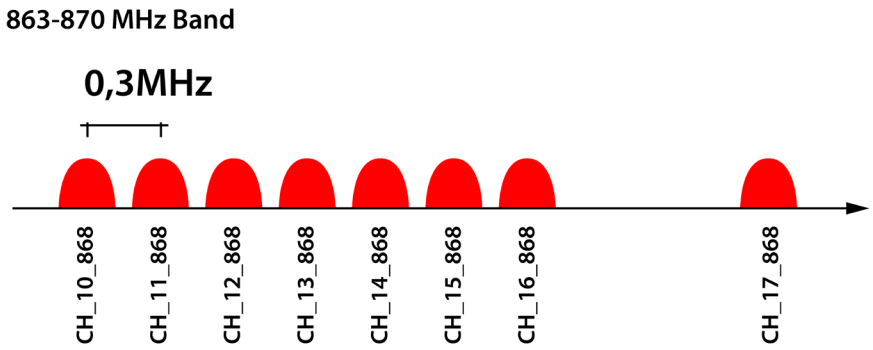


*Figure: Frequency channels in the 868 MHz band*

***Note:*** *These channels were chosen arbitrarily, according to the UN-111 appeared in the Spanish BOE-A-2013-4845. If necessary, users can select the appropriate channels according to their country regulations.*

The frequency used in USA, Canada, Australia, Singapore or Israel is the free ISM band of 900 MHz, using 13 channels with a bandwidth of 2.16 MHz per channel. It is shown in the following figure.

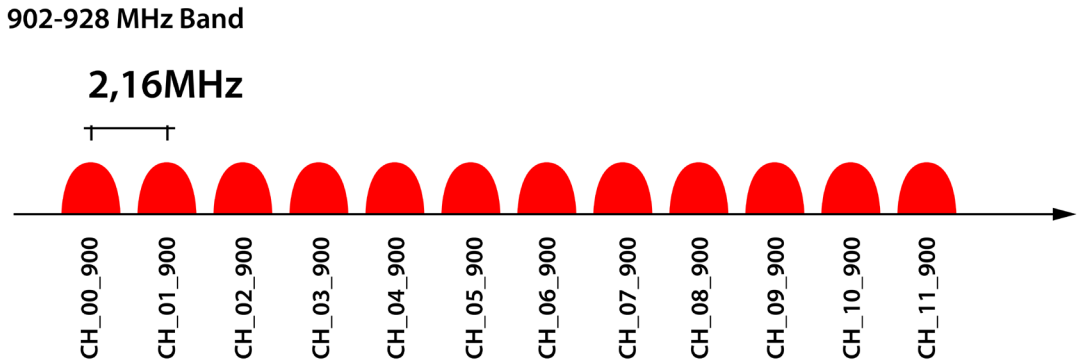


*Figure: Frequency channels in the 900 MHz band*

***Note:*** *These channels were chosen arbitrarily; they fit the channels used by the equivalent XBee 900 MHz. If necessary, users can select the appropriate channels according to their country regulations.*

| Channel Number | Central Frequency |
|---|---|
| CH_10_868 | 865.20 MHz |
| CH_11_868 | 865.50 MHz |
| CH_12_868 | 865.80 MHz |
| CH_13_868 | 866.10 MHz |
| CH_14_868 | 866.40 MHz |
| CH_15_868 | 866.70 MHz |
| CH_16_868 | 867 MHz |
| CH_17_868 | 868 MHz |

| Channel Number | Central Frequency |
|---|---|
| CH_00_900 | 903.08 MHz |
| CH_01_900 | 905.24 MHz |
| CH_02_900 | 907.40 MHz |
| CH_03_900 | 909.56 MHz |
| CH_04_900 | 911.72 MHz |
| CH_05_900 | 913.88 MHz |
| CH_06_900 | 916.04 MHz |
| CH_07_900 | 918.20 MHz |
| CH_08_900 | 920.36 MHz |
| CH_09_900 | 922.52 MHz |
| CH_10_900 | 924.68 MHz |
| CH_11_900 | 926.84 MHz |
| CH_12_900 | 915 MHz |

*Figure: Channels used by the SX1272 modules in 868 MHz and 900 MHz*

***Note:*** *Due to the propagation characteristics of the 868/900 MHz 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.*

Regarding the energy section, the transmission power can be adjusted to several values:

| Parameter | SX1272 power level |
|---|---|
| 'L' | 0 dBm |
| 'H' | 7 dBm |
| 'M' | 14 dBm |

*Figure: Transmission power value*

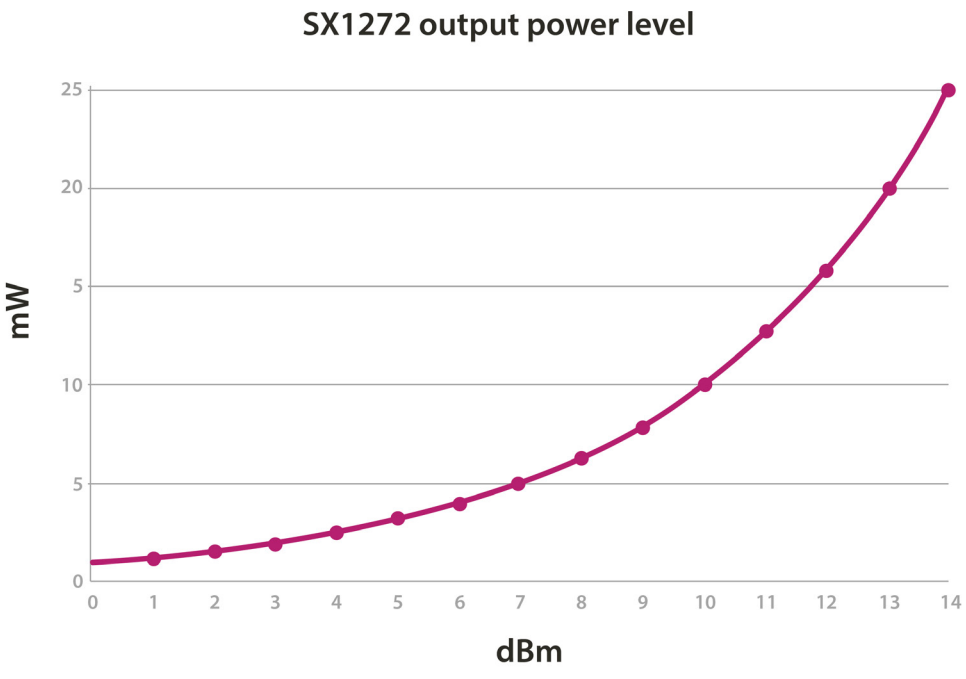


*Figure: SX1272 Output power level*

The sx1272 module uses the SPI pins for communication. The SPI port allows more speed communication and frees up the Waspmote's UART for other purposes. 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 radios available for Waspmote (802.15.4, ZigBee, Bluetooth Pro/Low Energy, NFC/RFID, WiFi and GPRS/3G) and the SX1272 module.

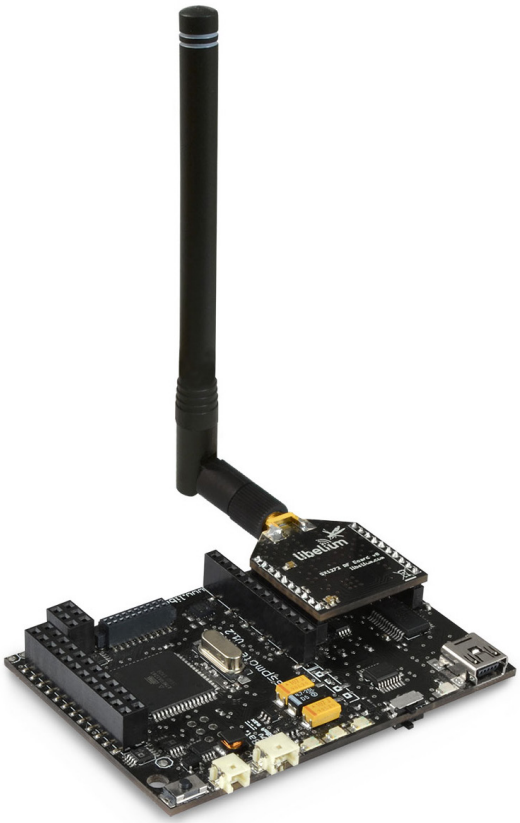

*Figure: SX1272 module with special 4.5 dBi antenna in Socket 0*

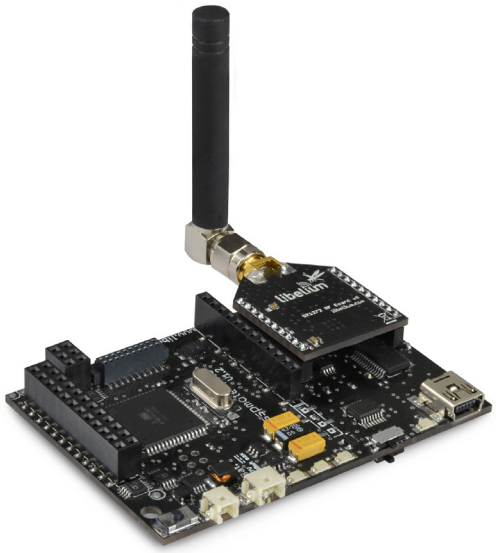

*Figure: SX1272 module with 0 dBi antenna in Socket 0*

***Note:*** *The SX1272 module can only be used in special Waspmote v12 units which have been modified to drive the SPI pins to socket 0.*

The SX1272 module does not implement any security method. Encryption is provided through the Waspmote Encryption library. Specifically, through the AES algorithm with symmetric key, with a length of 128, 192 or 256 bits.

The classic layout of this type of network is Star topology (shown in the figure), as the nodes establish point to point connections with brother nodes through the use of parameters such as the Node Address.

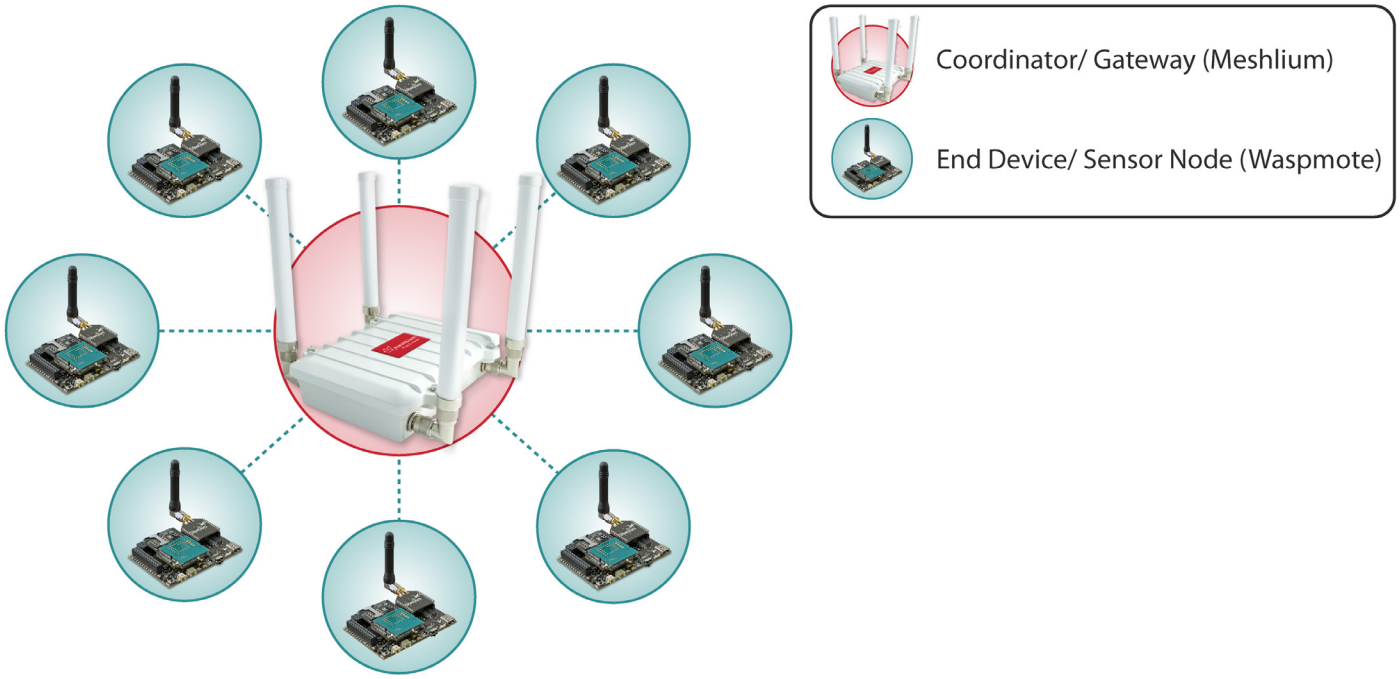


*Figure: Star topology with Meshlium as central node*

***Note:*** *OTA programming is not implemented for the SX1272 module. Due to its low datarate, it would take much time to send one program.*

# 3. Dual Radio with Expansion Board

## 3.1. 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, LoRaWAN, LoRa, Sigfox, Bluetooth Pro, Bluetooth Low Energy, RFID/NFC, WiFi, GPRS Pro, GPRS+GPS and 3G/GPRS. 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 - 3G/GPRS
- RS-232 - RFID/NFC
- WiFi - 3G/GPRS
- CAN bus - Bluetooth
- etc.

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

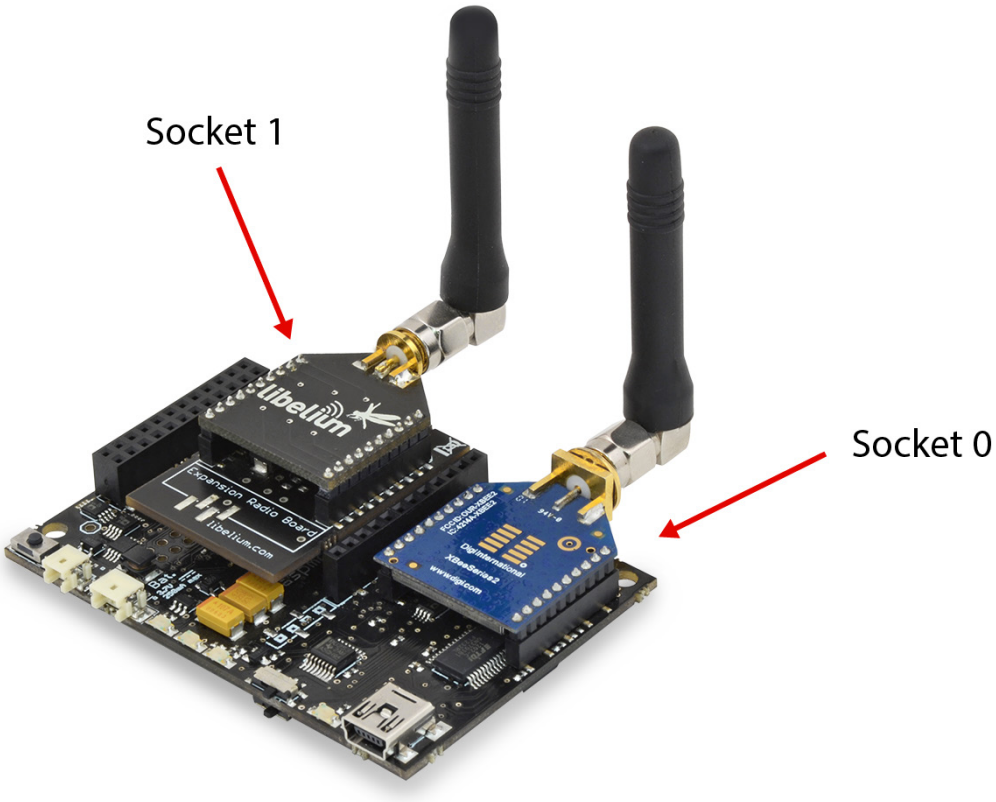


*Figure: Waspmote with XBee radio on socket0 and Bluetooth Pro module on socket 1*

*The SX1272 module can be used only in the socket 0. If the user wants to use a wireless radio, they must use the socket 1.*

***WARNING:***

*Avoid to use DIGITAL7 pin when working with Expansion Board. This pin is used for setting the XBee into sleep.*

*Avoid to use DIGITAL6 pin when working with Expansion Board. This pin is used as power supply for the Expansion Board.*

Incompatibility with Sensor Boards:

- Gases Board: Incompatible with SOCKET3B and $NO_2$ sensor.
- Agriculture Board: Incompatible with Sensirion and the atmospheric pressure sensor.
- Smart Metering Board: Incompatible with SOCKET2, SOCKET3, SOCKET4 and SOCKET5.
- Smart Cities Board: Incompatible with microphone and the CLK of the interruption shift register.
- Events Board: Incompatible with interruption shift register.

# 4. General considerations

## 4.1. Waspmote libraries

### 4.1.1. Waspmote SX1272 files

WaspSX1272.h, WaspSX1272.cpp

It is mandatory to include the SX1272 library when using this module. The following line must be introduced at the beginning of the code:

```
#include <WaspSX1272.h>
```

### 4.1.2. Constructor

To start using the Waspmote SX1272 library, an object from class `WaspSX1272` must be created. This object, called `sx1272`, is created inside the Waspmote SX1272 library and it is public to all libraries. It is used through the guide to show how the Waspmote SX1272 library works.

When creating this object, some variables are defined with a value by default.

## 4.2. API functions

Through the guide there are many examples of using parameters. In these examples, API functions are called to execute the commands, storing in their related variables the parameter value in each case.

Example of use:

```
{
  sx1272.getPreambleLength(); // Gets the preamble length that is going to be send
}
```

Related Variables:

`sx1272._preamblelength` → stores the preamble length

When returning from `sx1272.getPreambleLength()` the variable `sx1272._preamblelength` will be filled with the appropriate values.

Before calling the function, the related variable is created but it is empty.

All the functions return a flag to know if the function called was successful or not. Available values for this flag:

- 0 : Success. The function was executed without errors and the variable was filled.
- 1 : Error. The function was executed but an error occurred while executing.
- 2 : Not executed. An error occurred before executing the function.
- -1 : Function not allowed in this mode.

The main functions are listed here:

**Basic functions**

| | |
|---|---|
| `WaspSX1272();` | Class constructor. |
| `ON();` | Opens the SPI and switches the SX1272 module ON. |
| `OFF();` | Closes the SPI and switches the SX1272 module OFF. |
| `readRegister();` | Reads the indicated internal register. |
| `writeRegister();` | Writes the indicated internal register. |
| `clearFlags();` | Clears the interruption flags. |

**Configuration functions**

| | |
|---|---|
| `setLORA();` | Sets the module in LoRa™ transmission mode. |
| `getMode();` | Gets the BW, CR and SF of the LoRa™ modulation. |
| `setMode();` | Sets the BW, CR and SF of the LoRa™ modulation. |
| `getHeader();` | Indicates if module is configured in implicit or explicit header mode. |
| `setHeaderON();` | Sets the module in explicit header mode (header is sent). |
| `setHeaderOFF();` | Sets the module in implicit header mode (header is not sent). |
| `getCRC();` | Indicates if module is configured with or without checking CRC. |
| `setCRC_ON();` | Sets the module with CRC on. |
| `setCRC_OFF();` | Sets the module with CRC off. |
| `getChannel();` | Indicates the frequency channel within the module is configured. |
| `setChannel();` | Sets the indicated frequency channel in the module. |
| `getPower();` | Gets the signal power within the module is configured. |
| `setPower();` | Sets the signal power indicated in the module. |
| `setPowerNum();` | Sets the signal power indicated in the module. |
| `getPreambleLength();` | Gets the preamble length from the module. |
| `setPreambleLength();` | Sets the preamble length in the module. |
| `getPayloadLength();` | Gets the payload length from the module. |
| `setPacketLength();` | Sets the packet length in the module. |
| `getNodeAddress();` | Gets the node address in the module. |
| `setNodeAddress();` | Sets the node address in the module. |
| `setRetries();` | Sets the maximum number of retries. |
| `getMaxCurrent();` | Gets the current supply limit of the internal power amplifier. |
| `setMaxCurrent();` | Limits the current supply of the internal power amplifier. |
| `getTemp();` | Gets the temperature from the measurement block module. |
| `getRegs();` | Gets the content of different registers. |

**Link information functions**

| | |
|---|---|
| `getSNR();` | Gets the SNR value in LoRa™ mode. |
| `getRSSI();` | Gets the current value of RSSI from the channel. |
| `getRSSIpacket();` | Gets the RSSI of the last packet received in LoRa™ mode. |

**Sending functions**

| | |
|---|---|
| `sendPacketTimeout();` | Sends a packet to the specified destination before a timeout expires. |
| `sendPacketMaxTimeout();` | Same as previous function with maximum timeout. |
| `sendPacketTimeoutACK();` | Sends a packet to a destination before a timeout and wait for an ACK response. |
| `sendPacketMaxTimeoutACK();` | Same as previous function with maximum timeout. |
| `sendPacketTimeoutACKRetries();` | Sends a packet to a destination before a timeout, wait for an ACK response and retry to send the packet if ACK is lost. |
| `sendPacketMaxTimeoutACKRetries();` | Same as previous function with maximum timeout. |

**Receiving functions**

| | |
|---|---|
| `receivePacketTimeout();` | Receives information before a timeout expires. |
| `receivePacketMAXTimeout();` | Same as previous function with maximum timeout. |
| `receivePacketTimeoutACK();` | Receives information before a timeout expires and responds with ACK. |
| `receivePacketMAXTimeoutACK();` | Same as previous function with maximum timeout. |
| `receiveAll();` | Receives all the information on air with maximum timeout. |
| `showFramefromPacket();` | Prints a frame received in a packet. |

# 4.3. Additional functions

## 4.3.1. Getting temperature

It reads the module temperature in Celsius. Negative temperatures can be expected. It stores the information in the global `_temp` variable in Celsius.

***Note:*** *this feature has not a good accuracy because it requires internal calibration. Libelium recommends to use dedicated temperature sensor.*

Example of use:

```
{
  sx1272.getTemp(); // Gets the temperature of the module
}
```

Related Variables:

`sx1272._temp` → stores the temperature of the module

- SX1272 getting temperature example:
  www.libelium.com/development/waspmote/examples/sx-13-get-temp

### 4.3.2. Getting maximum allowed current supply

It reads the current supply limit of the power amplifier. This value is set to 240 mA at the beginning of the configuration when the module is switched ON. Parameter range: from 0x00 to 0x1B corresponding to a range from 45 to 240 mA.

Example of use:

```
{
  sx1272.getMaxCurrent(); // Gets the maximum current supply
}
```

Related Variables:

`sx1272._maxCurrent` → stores the maximum current supply of the module

- SX1272 getting current supply example:
  www.libelium.com/development/waspmote/examples/sx-14-currentsupply

## 4.4. Waspmote reboot

When Waspmote is rebooted, the application code will start again, creating all the variables and objects from the beginning.

# 5. Transmission Modes

The module has two different modulations, LoRa™ modulation, owned by Semtech, and standard FSK modulation. Libelium has decided to only use the LoRa™ modulation due to the range improvement it provides.

When setting the SX1272 module ON, the module is prepared to use LoRa mode.

About the operation states, it is not necessary to control them manually. It is done automatically by the API functions.

## 5.1. LoRa™ mode

The innovative LoRa™ mode is the most interesting included in this module. It is an advanced and private modulation that increases the range comparing to classic modulations. The LoRa™ long range mode provides ultra-long range spread spectrum communication and high interference immunity whilst minimizing current consumption. It combines digital spread spectrum, digital signal processing, and forward error correction coding to achieve unprecedented performance. LoRa™ also provides significant advantages in both blocking and selectivity over conventional modulation techniques.

LoRa has three configurable parameters:

- Bandwidth (BW)
- Coding Rate (CR)
- Spreading Factor (SF)

The combination of these values defines the transmission mode. It is possible to set a predefined mode or to set these three parameters manually.

There are ten predefined modes in the API, including the largest distance mode, the fastest mode, and eight other intermediate modes that Libelium has found interesting. All of them can be modified or deleted, and also it is possible to attach new modes in the appropriate function. The predefined modes and its properties are shown in the next table.

| Mode | BW | CR | SF | Sensitivity (dB) | Transmission time (ms) for a 100-byte packet sent | Transmission time (ms) for a 100-byte packet sent and ACK received | Comments |
|---|---|---|---|---|---|---|---|
| 1 | 125 | 4/5 | 12 | -134 | 4245 | 5781 | max range, slow data rate |
| 2 | 250 | 4/5 | 12 | -131 | 2193 | 3287 | - |
| 3 | 125 | 4/5 | 10 | -129 | 1208 | 2120 | - |
| 4 | 500 | 4/5 | 12 | -128 | 1167 | 2040 | - |
| 5 | 250 | 4/5 | 10 | -126 | 674 | 1457 | - |
| 6 | 500 | 4/5 | 11 | -125,5 | 715 | 1499 | - |
| 7 | 250 | 4/5 | 9 | -123 | 428 | 1145 | - |
| 8 | 500 | 4/5 | 9 | -120 | 284 | 970 | - |
| 9 | 500 | 4/5 | 8 | -117 | 220 | 890 | - |
| 10 | 500 | 4/5 | 7 | -114 | 186 | 848 | min range, fast data rate, minimum battery impact |

*Figure: LoRa configuration modes*

The transmission times have been measured for a whole transmission process: power the module on, configure the module, send a 100-byte packet and power the module off.

The user will be able to choose the most suitable mode for that application after the appropriate test phase because there is not a perfect mode for any situation. In fact, it exists a compromise between distance range and speed of transmission.

***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). 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.*

Example of use:

```
{
  sx1272.setMode(3); // Sets the LoRa mode in transmission mode 3
}
```

- SX1272 configuration example:
  www.libelium.com/development/waspmote/examples/sx-01-configure-lora-parameters

If the user is going to select a mode with this function, it is not necessary to set also the bandwidth, coding rate and spreading factor later.

### 5.1.1. Bandwidth

The value of the bandwidth shows how wide is going to be the transmission signal. It only can be chosen among 3 options: 125 KHz, 250 KHz or 500 KHz. If a fast transmission is required, a 500 KHz value is better. But if a great reach is needed, a 125 KHz value must be configured. The smaller the bandwidth is, the higher the time-on-air is in a transmission but also the better the sensitivity is, so the communication has better link budget. The user should also note that the increasing in time-on-air involves an increasing in battery consumption.

Example of use:

```
{
  sx1272.setBW(BW_250); // Sets the 250 KHz bandwidth in LoRa mode
}
```

### 5.1.2. Coding Rate

The coding rate value must be chosen among 4 options: 4/5, 4/6, 4/7 and 4/8. It denotes that every 4 useful bits are going to be encoded by 5, 6, 7 or 8 transmission bits depending on its value. The smaller the coding rate is (the smallest is 4/8), the higher the time-on-air is in a transmission, so it takes more time to transmit a packet. This will ease the task of receiving, because each symbol is wider in time, so the receiver can demodulate packets with lower reception power. This means the receiver has better sensitivity, so the user has better link budget. But slow data transmissions have an impact in the battery consumption: spending more time in transmission mode involves more battery consumption.

Example of use:

```
{
  sx1272.setCR(CR_7); // Sets the 4/7 coding rate in LoRa mode
}
```

### 5.1.3. Spreading Factor

The spreading factor is the number of chips per symbol used in the data treatment before the transmission signal. Its value is an integer number between 6 and 12. This parameter is relevant in the spread spectrum technique. In the spread spectrum techniques, the greater value of this parameter, the more capability the receiver has to move away the noise from the signal. So the greater value taken, the more time it takes to send a packet, but also the better range is reached because the receiver sensitivity is better.

Example of use:

```
{
  sx1272.setSF(SF_9); // Sets the 9 spreading factor in LoRa mode
}
```

# 6. Initialization

Before starting to use a module, it needs to be initialized. During this process, Waspmote's SPI bus has to be opened to communicate with the module, and the SX1272 module's switch has to be set ON.

***Note:*** This module does not save the configuration. So, the network settings as the mode or the channel MUST be configured every time it is switched on.

## 6.1. Setting ON

It initializes all the global variables, opens the SPI bus and switches the SX1272 module ON.

When setting ON, the module always has the configuration by default shown in the next table:

| Global variable | Description | Initial value |
|---|---|---|
| `modem` | activated mode | `LORA` |
| `bandwidth` | bandwidth to use in LoRa™ mode | `BW_125` |
| `codingRate` | coding rate to use in LoRa™ mode | `CR_5` |
| `spreadingFactor` | spreading factor to use in LoRa™ mode | `SF_7` |
| `channel` | transmission frequency channel | `CH_12_900` |
| `header` | specifies if header is enabled | `HEADER_ON` |
| `CRC` | specifies if CRC is enabled | `CRC_OFF` |
| `power` | power transmission level | 15 |

*Figure: Configuration by default*

Also, there are other global variables initialized when this function is called, shown in the following table:

| Global variable | Description | Initial value |
|---|---|---|
| `packetNumber` | packet number to send | 0 |
| `reception` | specifies if packet is correctly received | `CORRECT_PACKET` |
| `retries` | number of the current retrying that is being executed in the protocol | 0 |
| `maxRetries` | maximum number of retries permitted in each case | 3 |

*Figure: Global variables initialized by software*

Example of use:

```
{
  sx1272.ON(); // Opens the SPI and switches the SX1272 module ON
}
```

## 6.2. Setting OFF

It closes the SPI and switches the SX1272 module OFF.

Example of use:

```
{
  sx1272.OFF(); // Closes the SPI and switches the SX1272 module OFF
}
```

# 7. Node parameters

When configuring a node, it is necessary to set some parameters which will be used lately in the network, and some parameters needed for using the API functions.

## 7.1. Node Address

Each module must have a unique address of 8 bits.

It identifies uniquely a node inside a network. It is necessary to assign the address value each time the module is set ON.

The node address 0 and the node address 1 are reserved to broadcast communication and to the network central node respectively. In order to respect this, users must assign the node address 1 to the module in the central node and node addresses from 2 to 255 to all the other nodes in their network. That means a network will consist of:

- 1 central node. Address value equal to 1
- Up to 254 nodes. Address values from 2 to 255

The user must not assign the node address 0 to any node since it is reserved to indicate the module we want to perform a broadcast transmission.

Example of use:

```
{
  sx1272.setNodeAddress(2); // Set the Node address into REG_NODE_ADDRESS register
  sx1272.getNodeAddress(); // Get the assigned Node address
}
```

Related Variables:

`sx1272._nodeAddress` → stores the Node address

The module rejects packets destined to other nodes, although it is actually receiving all the packets in the network while it is in receiving state.

## 7.2. Frequency Band

There are two frequency bands available to work with this module, 868 MHz and 900 MHz ISM bands. Depending on the country the user is located, one or the other will be chosen. Inside each frequency band there are several channels, so the user can choose among them.

***Note:*** *To know what band is legal in your country, please check the ITU region map. Region 1 ISM free band is 868 MHz and Region 2 ISM free band is 900 MHz. You must also check the legal restrictions by region to use the proper configuration and channel. It is the responsibility of the users to know the allowed frequency band and channels in their country, and use them. Ignoring this, could lead to considerable penalties.*

# 7.3. Channel

This parameter defines the frequency channel used by the module to transmit and receive.

There are 8 channels defined to be used in the 868 MHz band and 13 channels to be used in the 900 MHz band. They can be observed in the following figures.

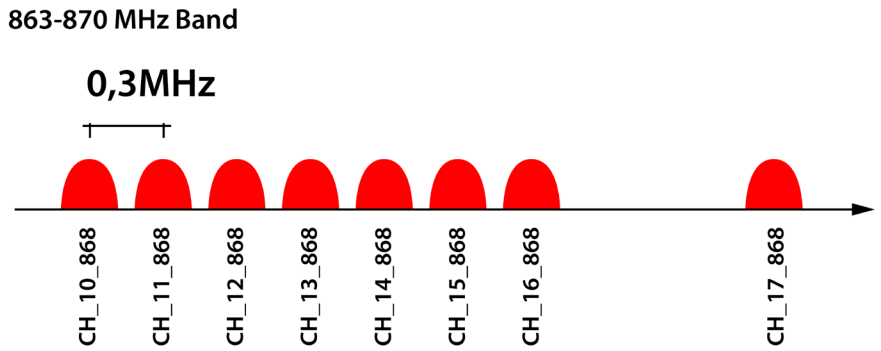


*Figure: Frequency channels in the 868 MHz band*

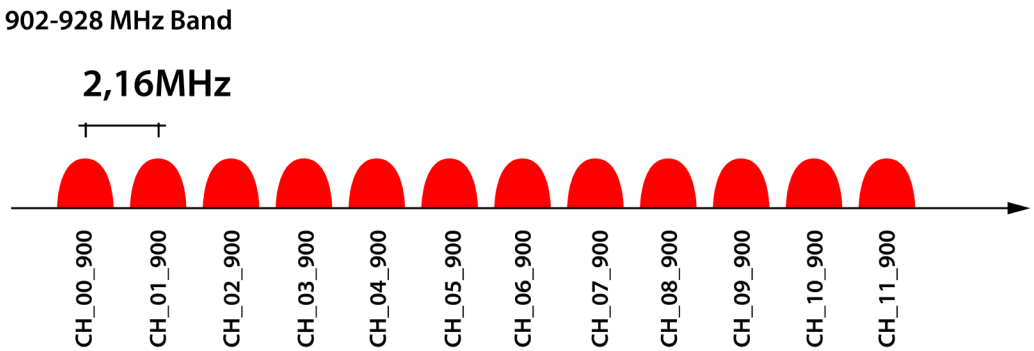


*Figure: Frequency channels in the 900 MHz band*

| Channel Number | Central Frequency |
|---|---|
| CH_10_868 | 865.20 MHz |
| CH_11_868 | 865.50 MHz |
| CH_12_868 | 865.80 MHz |
| CH_13_868 | 866.10 MHz |
| CH_14_868 | 866.40 MHz |
| CH_15_868 | 866.70 MHz |
| CH_16_868 | 867 MHz |
| CH_17_868 | 868 MHz |

| Channel Number | Central Frequency |
|---|---|
| CH_00_900 | 903.08 MHz |
| CH_01_900 | 905.24 MHz |
| CH_02_900 | 907.40 MHz |
| CH_03_900 | 909.56 MHz |
| CH_04_900 | 911.72 MHz |
| CH_05_900 | 913.88 MHz |
| CH_06_900 | 916.04 MHz |
| CH_07_900 | 918.20 MHz |
| CH_08_900 | 920.36 MHz |
| CH_09_900 | 922.52 MHz |
| CH_10_900 | 924.68 MHz |
| CH_11_900 | 926.84 MHz |
| CH_12_900 | 915 MHz |

*Figure: Channels used by the SX1272 modules in 868 MHz and 900 MHz*

Example of use:

```
{
  sx1272.setChannel(CH_00_900); // Set channel
  sx1272.getChannel(); // Get Channel
}
```

Related Variables:

`sx1272._channel` → stores the operating channel

- SX1272 configuration example:

  www.libelium.com/development/waspmote/examples/sx-01-configure-lora-parameters

# 8. Packet parameters

## 8.1. Structure used in packets

Packets are structured in WaspSX1272.h using a defined structure called `pack`. This structure has many fields to be filled by the user or the application:

- `dst`

Destination node address: this parameter is indicated as an input in the function used by the user.

- `src`

Source node address: this parameter is filled by the application with the module's address (previously set by the user).

- `packnum`

Packet number: this parameter indicates the packet number and is filled by the application. It is a byte field, so it starts in 0 and reaches 255 before restarting. If the packet is trying to be retransmitted, the packet number is not incremented.

- `length`

Packet length: this parameter indicates the total packet length and is filled by the application.

- `data[MAX_PAYLOAD]`

Data to send in the packet: It is used to store the data to send to other nodes. All the data to send must be stored in this field. Its maximum size is defined by `MAX_PAYLOAD`, a constant defined in the library.

- `retry`

Retry counter: this parameter is filled by the application. It is usually equal to 0. Only when we use the retries feature, this value is incremented from 0 to the maximum number of retries stored in the global variable `_maxRetries` which value is 3 by default. If the packet is sent successfully, or if the maximum number of retries is reached without success, the retry counter is set to 0.

| dst | src | packnum | length | data | retry |
|---|---|---|---|---|---|
| (1 Byte) | (1 Byte) | (1 Byte) | (1 Byte) | (Variable Bytes) | (1 Byte) |

*Figure: Packet structure*

## 8.2. Maximum payload

The maximum data payload is defined as:

| LoRa™ |
|---|
| 250 Bytes |

*Figure: Maximum Payload Size*

Due to the limit on maximum payloads it could happen that the packet has to be truncated to the maximum possible length.

The current available payload when operating in LoRa™ mode can be retrieved in real time.

Example of use:

```
{
  sx1272.getPayloadLength(); // Get Maximum Payload Bytes
}
```

Related Variables:

`sx1272._payloadlength` → stores the maximum payload is available at the moment

# 9. Power gain and sensibility

When configuring a node and a network, one important parameter is related with power gain and sensibility.

## 9.1. Power level

Power level (dBm) at which the module transmits conducted power.

The possible values are Low ('L'), High ('H') and Max ('M'):

| Parameter | SX1272 power level |
|---|---|
| `'L'` | 0 dBm |
| `'H'` | 7 dBm |
| `'M'` | 14 dBm |

*Figure: Transmission power values*

It is also possible to set the conducted power indicating the quantity as a parameter in the function `setPower`.

***Note:*** *dBm is a standard unit to measure power level taking as reference a 1 mW signal.*

Values expressed in dBm can be easily converted to mW using the next formula:

mW = 10^(value dBm/10)

Graphic about transmission power is exposed next:

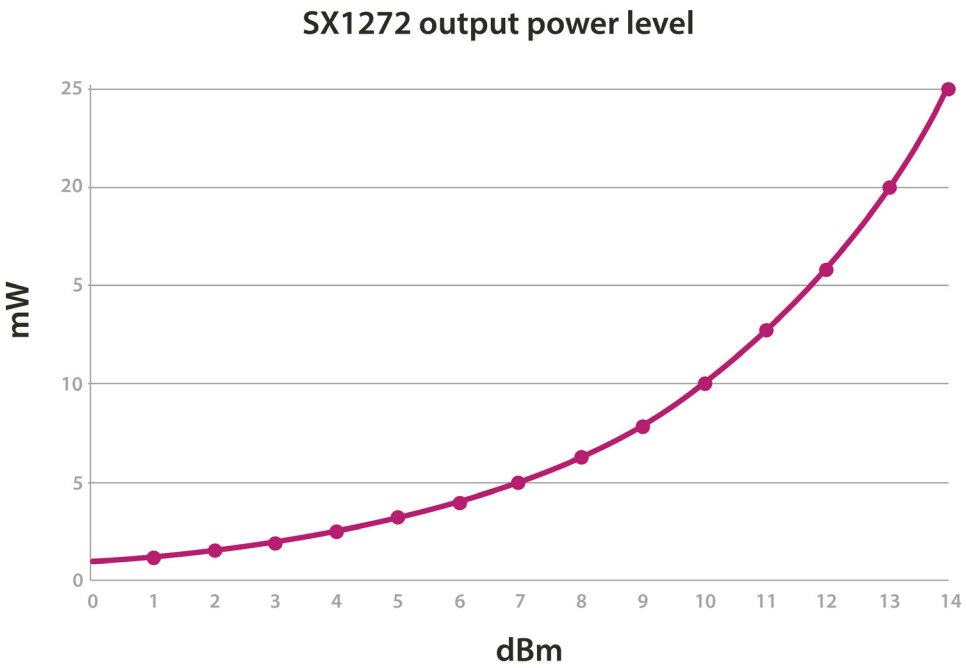


*Figure: SX1272 Output Power Level*

Example of use:

```
{
  sx1272.setPower(0); // Set Power Output Level to the minimum value
  sx1272.getPower(); // Get Power Output Level
}
```

Related Variables:

`sx1272._power` → stores the selected power output level

***Note:*** *It is the responsibility of the users to know the maximum allowed power level in their country (if any), and use levels below it. Ignoring this could lead to considerable penalties.*

## 9.2. RSSI of one packet and RSSI of the channel

It reports the Received Signal Strength of the last received packet and the current value of the Received Signal Strength in the selected channel. The RSSI of the packet is the meaningful one: if its value is greater than the sensitivity the packet sent is going to be successfully detected, otherwise the packet will be lost. The RSSI of the channel reports the signal level detected in every moment, even if it is not signal being transmitted, so it provides also noise level information. In the case the user develops a multi-hop network, this parameters only indicate the signal strength of the last hop, so it does not provide an accurate quality measurement of a multihop link.

Example of use:

```
{
  sx1272.getRSSIpacket(); // Get the Receive Signal Strength Indicator
  sx1272.getRSSI(); // Get the current Receive Signal Strength Indicator
}
```

Related Variables:

`sx1272._RSSIpacket` → stores the RSSI of the last received packet

`sx1272._RSSI` → stores the current RSSI value

- SX1272 RSSI example:
  www.libelium.com/development/waspmote/examples/sx-12-rssilora

The ideal working mode is at getting maximum coverage with the minimum power level. Thereby, a compromise between power level and coverage appears. Each application scenario will need some tests to find the best combination of both parameters.

## 9.3. SNR

It reports the Signal-to-Noise Ratio of the last received packet. The SX1272 module is capable to demodulate received signals with SNR values as low as -20 dB. Getting the SNR, it is possible to have an idea about the link's quality or health, and thus the additional distance we could get in a communication link.

Example of use:

```
{
  sx1272.getSNR(); // Get the Signal Noise Ratio
}
```

Related Variables:

`sx1272._SNR` → stores the SNR of the last received packet

- SX1272 RSSI example:
  www.libelium.com/development/waspmote/examples/sx-12-rssilora

# 10. Long Range Tests

## 10.1. Line of Sight test

The Line of Sight (LOS) tests were taken between two different points next to the surrounding area of Zaragoza (Spain). The emitter was set in the point A : viewpoint of 'La Plana de Cadrete'. The receiver was set in the point B: viewpoint of the village of Alfocea. These points are 21.6 km (13.4 miles) apart.


*Figure: Map of the LOS long range tests in Zaragoza*

The following picture represents the profile of the link. The blue line indicates the line of sight conditions taken in the test. Besides, the purple ellipse indicates the Fresnel zone clearance achieved in this path.

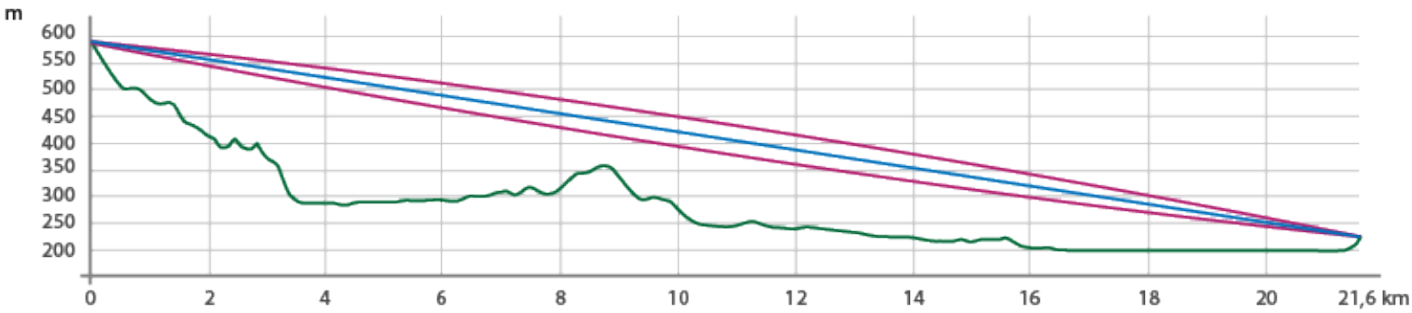


*Figure: Profile of the LOS path*

Test features:

- Several LoRa modes, frequency channels and output-power modes were tested in order to know the performance of the SX1272 module depending on great distances
- All packets were set to a fixed 90-byte payload
- More than one hundred attempts were performed in every trial

Results:

| LoRa Mode | Range | Power | Channel | Success (%) | Mean SNR (dB) | Mean RSSI (dBm) | Mean RSSI packet( dBm) | Sensitivity (dB) | Margin (dB) |
|---|---|---|---|---|---|---|---|---|---|
| Mode 1 | 21.6 km (13.4 miles) | High | CH_12_868 | 100 | -9.79 | -113.72 | -126.79 | -134 | 7.21 |
| | | Max | | 100 | -4.33 | -113.76 | -121.76 | -134 | 12.24 |
| | | High | CH_16_868 | 100 | -10.06 | -114.28 | -127.06 | -134 | 6.94 |
| | | Max | | 100 | -3.20 | -113.97 | -120.21 | -134 | 13.79 |
| Mode 3 | 21.6 km (13.4 miles) | High | CH_12_868 | 95 | -10.29 | -114.16 | -127.29 | -129 | 1.71 |
| | | Max | | 95 | -3.73 | -114.08 | -120.73 | -129 | 8.27 |
| Mode 6 | 21.6 km (13.4 miles) | High | CH_12_868 | 99 | -14.77 | -107.22 | -125.77 | -125.5 | -0.27 |
| | | Max | | 100 | -8.42 | -106.60 | -119.43 | -125.5 | 6.07 |
| Mode 9 | 21.6 km (13.4 miles) | High | CH_12_868 | 0 | - | - | - | -117 | - |
| | | Max | | 49 | -9.95 | -107.68 | -120.95 | -117 | -3.95 |

# 10.2. Non Line of Sight tests

## 10.2.1. Tests in Zaragoza

The Non Line of Sight (NLOS) tests were taken between several points in the surrounding areas of the Libelium's headquarters in Zaragoza (Spain).

The receiver is a Meshlium device, installed on the roof of the Libelium's headquarters. The emitter was set in several points in order to know the performance of this module in NLOS conditions within a city area.

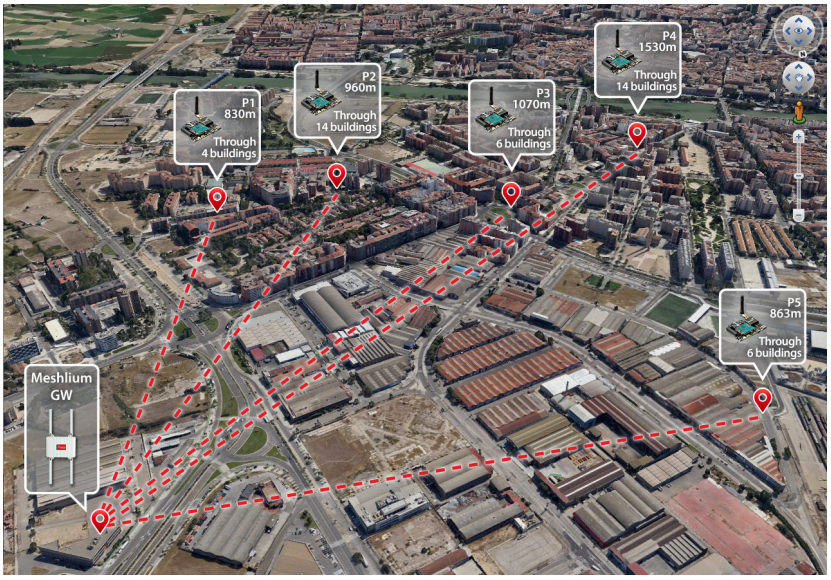


*Figure: Map of the NLOS long range tests in Zaragoza*

Test features:

- Lora Mode 1: maximum range
- Maximum output power: 14dBm
- Frequency channel: CH_12_868 in the 868mHz band
- Packets were set to a Waspmote Frame reaching around a 80-byte payload
- Fifty attempts were performed for every point

Results:

| Point | Range (m) | Number of Buildings (signal going through) | Success (%) | Mean SNR (dB) | Mean RSSI (dBm) | Mean RSSI packet (dBm) | Margin (dB) |
|---|---|---|---|---|---|---|---|
| Point 1 | 830 | 4 | 96 | -7.89 | -112.95 | -124.89 | 9,11 |
| Point 2 | 960 | 14 | 92 | -14.26 | -111.26 | -131.26 | 2,74 |
| Point 3 | 1070 | 6 | 98 | -3.22 | -114.14 | -120.24 | 13,76 |
| Point 4 | 1530 | 14 | 98 | -13.16 | -112.24 | -130.16 | 3,84 |
| Point 5 | 863 | 6 | 100 | -3.42 | -113.48 | -120.42 | 13,58 |

Paths description:

- **Point 1**: The signal goes through four buildings. Three high-rise housing buildings and a low building do not permit to have line of sight in this path. Then, an open space is found in the way to the receiver.
- **Point 2**: The signal goes through fourteen buildings. In this case, a large group of low residential houses are close to the point 2. Also, a residential block is found in the way to the receiver.
- **Point 3**: The signal goes through six buildings. This point is placed at the side of a big square of the neighborhood. The path finds out a big residential building and after this, some industrial buildings too.
- **Point 4**: The signal goes through fourteen buildings. This is the largest path. This point comes across four high residential buildings. Then there is an open space with no obstacles before reaching another group of high housing buildings again. Finally, several industrial buildings are found before ending the path to the receiver.
- **Point 5**: The signal goes through six buildings. This point is separated from the receiver by several industrial buildings with no open spaces between them.

## 10.2.2. Test in Paris

This tests were developed in an office area into Paris city. The transmitter is outside the first floor of an office building, at a height of about 3 meters. The receiver is at street except in one of them that is situated bellow ground floor, in a garage. There is no line of sight between the points.

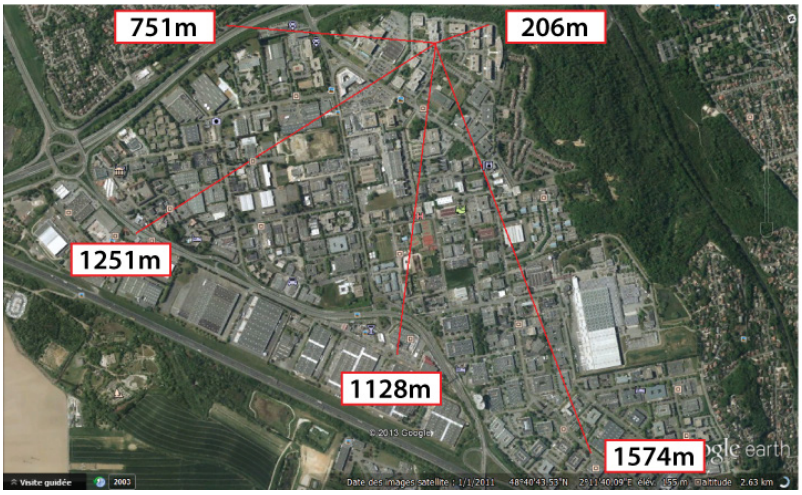


*Figure: Test distance on the map*

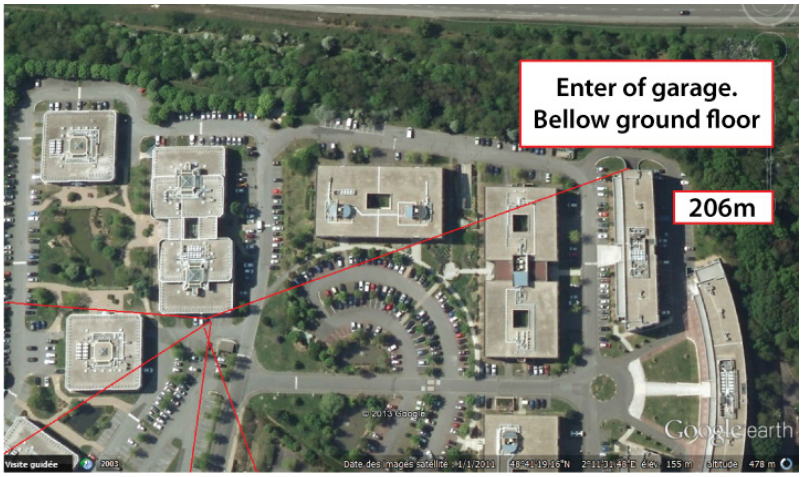


*Figure: Detail of the garage test point*

# 11. Connectivity

## 11.1. Topologies

Several SX1272 modules can be set in a star topology to create a network. A star network has a central node, which is linked to all other nodes in the network. The central node gathers all data coming from the network nodes.

It is not possible to set mesh networks with the SX1272 module.

Libelium offers the following options for the central node:

- **Meshlium:** It is the more advanced, automated and easy to use option. Thus, this is the most recommended choice for the central node in a SX1272 network. Meshlium can receive and parse packets with the Frame format; information is automatically stored in a standard MySQL database, and then the user can push data to the Cloud. Besides, Meshlium is the central node needed for outdoor networks and real projects.

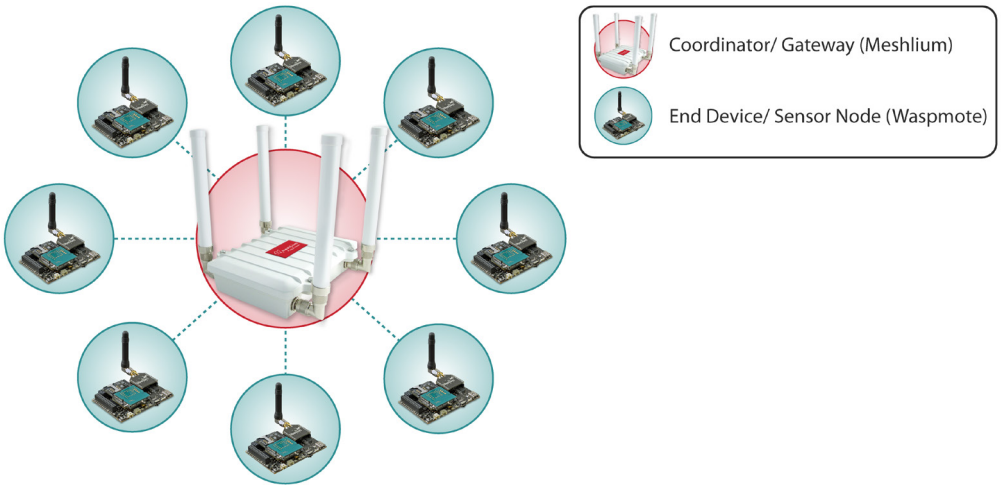


*Figure: Star topology with Meshlium as central node*

- **Gateway LoRa™:** It is an intermediate option, less automated than Meshlium. This special Gateway enables the user to receive data directly in a standard PC. It is interesting for the first development phase, and can be used to test a real project or to do less advanced tasks.

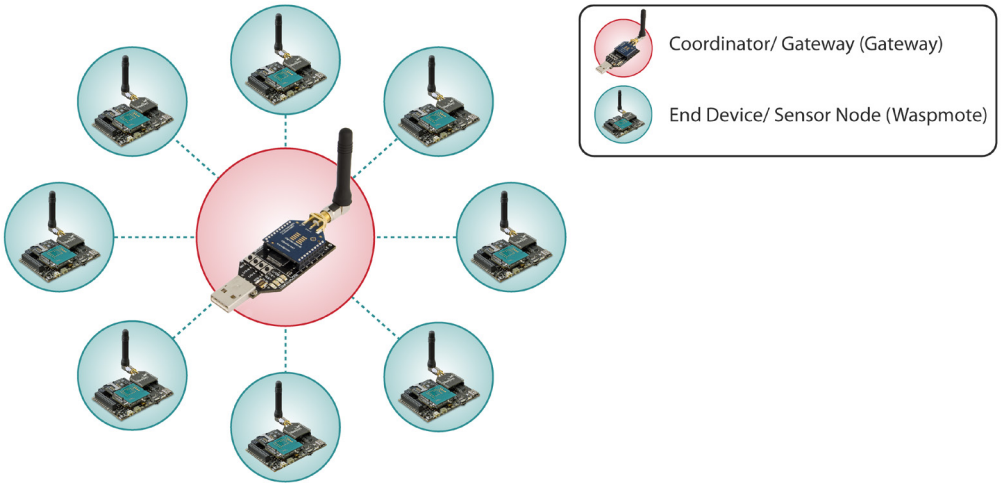


*Figure: Star topology with Gateway as central node*

- **Waspmote:** It is the less interactive option. In order to send the data to Cloud or via wireless, it is necessary to have another radio module available. Since Plug & Sense! can only have one radio, the user can just receive packets and output them via USB port.

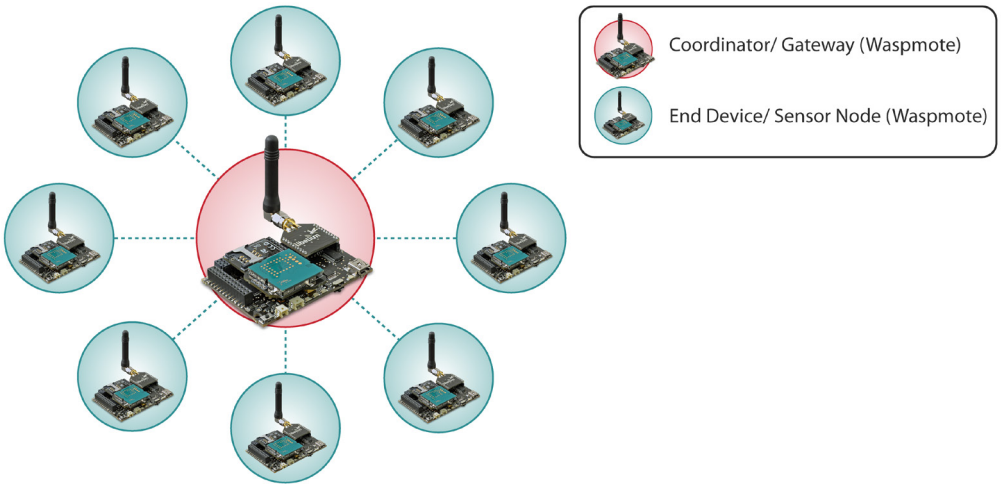


*Figure: Star topology with Waspmote as central node*

# 11.2. Connections

Every packet sent contains a Source Address byte and Destination Address byte in its payload field. The module supports only 8-bit addresses. For every node, a unique 8-bit Source Address (Node Address) must be chosen by the user and assigned each time the module is powered ON. This address can be set and read with the functions explained in chapter "Node Parameters".

The SX1272 module supports Unicast and Broadcast transmissions.

## 11.2.1. Unicast

Unicast is used to send a packet to one specific node in a network through its Node Address. Unicast always performs control time mechanisms (time-out) to prevent perpetual waiting for a packet. Unicast mode is the only one that supports additional services for more robust communication like:

**1-ACK confirmation:** if the developer uses functions like `sendPacketTimeoutACK()` and `receivePacketWithTimeoutACK()`, receiving modules will send an ACK (packet which aim is to confirm the packet was correctly received) to the transmitter.

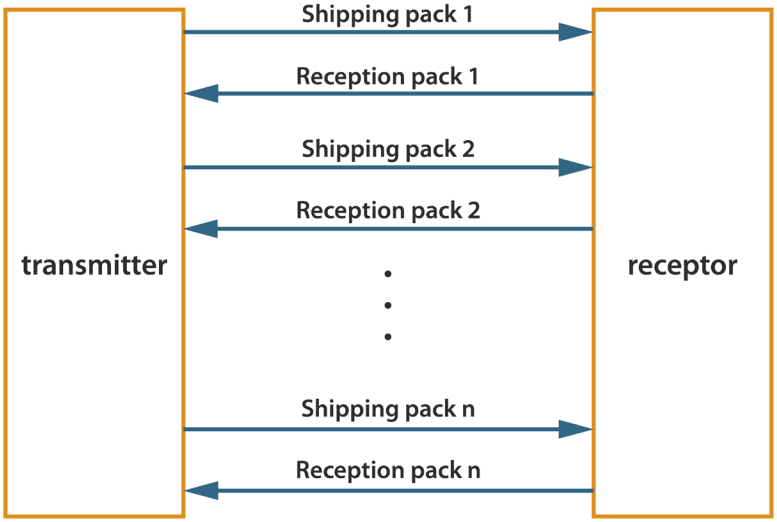


*Figure: ACK confirmation diagram*

- Unicast mode with ACK example:
  www.libelium.com/development/waspmote/examples/sx-03a-tx-lora-ack

**2 - Retries:** this option is only available with ACK confirmation. If the transmitting module does not receive the ACK, it will re-send the packet up to the configured number of times or until the ACK is received.

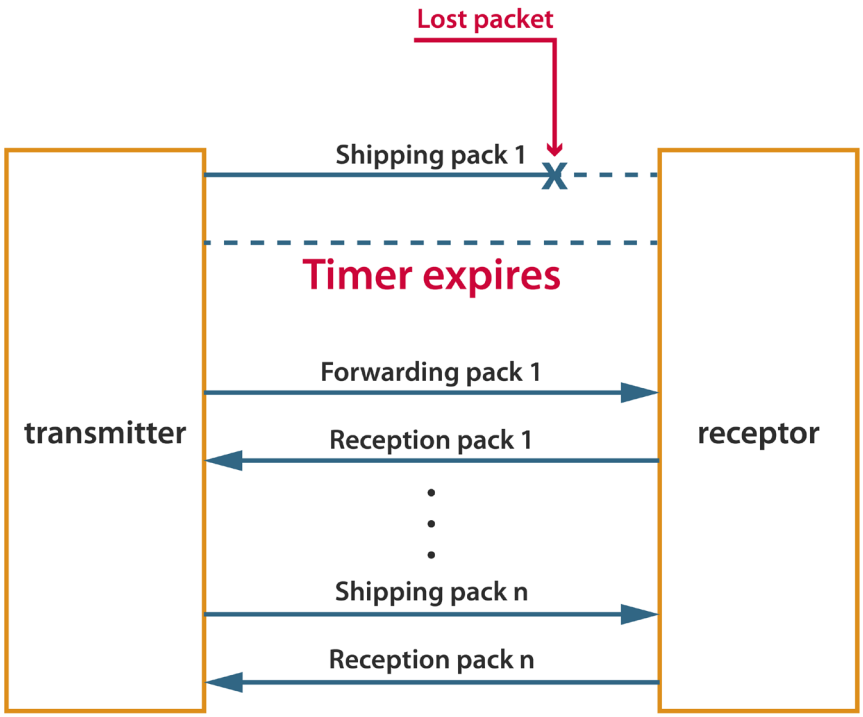


*Figure: ACK and retries diagram*

- Unicast mode with ACK and retries example:
  www.libelium.com/development/waspmote/examples/sx-04a-tx-lora-ackwretries

## 11.2.2. Broadcast

Broadcast is used to send a packet to all nodes in a network. Any module within range will accept a packet that contains the broadcast address (0). To send a broadcast message, the Destination Address should be set to `BROADCAST_0`. While in this mode, there is no possibility to use ACK confirmations or retries.

# 11.3. Connection parameters

There are some parameters related to connections and their configurations.

## 11.3.1. Setting retries

It specifies the number of retries than can be sent for a given Unicast packet and stores it in the global variable `_maxRetries`. Parameter range: from 0x00 to 0x05. Default value: 0x03.

Example of use:

```
{
  sx1272.setRetries(2); // Sets the number of retries that can be sent
}
```

Related Variables:

`sx1272._maxRetries` → stores the maximum number of retries that can be sent

# 11.4. Sending process

Sending data is a complex process which needs some special structures and functions.

## 11.4.1. SX1272 API packet structure

The API packet structure used to transmit packets with SX1272 modules is specified in the following figure. It shows how the payload is included inside the RF Data field:

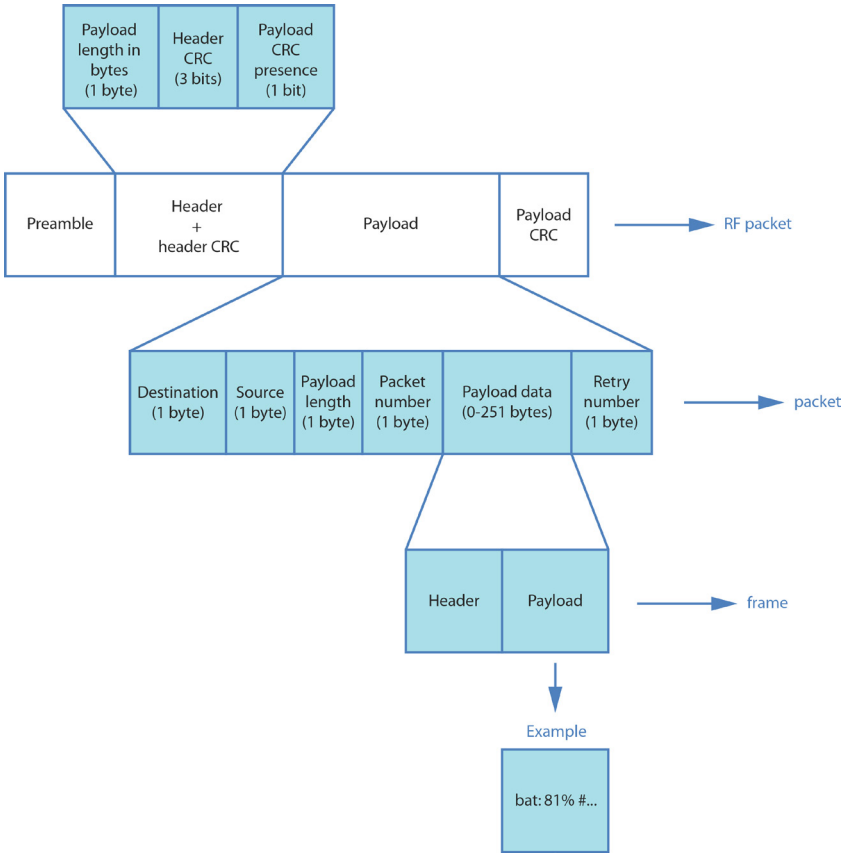


*Figure: Frame structure inside a packet structure*

Generally, the user will add the information to be sent with the Frame library (`frame.addSensor()`). The Frame library encapsulates it in a frame instance. Then, the user will pass this frame instance to the send function, which will encapsulate it inside a packet. Finally, the SX1272 module will encapsulate that in a RF packet and send it.

## 11.4.2. Using Frame class to create SX1272 packets

Frame is a class that allows the user to create data frames with a specified format. It is a very useful tool to set the payload of the packet to be sent. It is recommended to read the Waspmote Data Frame Guide in order to understand the SX1272 module examples:

www.libelium.com/development/waspmote/documentation/data-frame-guide/

- SX1272 sending Frame examples:
  www.libelium.com/development/waspmote/examples/sx-05a-tx-lora-waspframe

  www.libelium.com/development/waspmote/examples/sx-06a-tx-lora-ack-waspframe

  www.libelium.com/development/waspmote/examples/sx-07a-tx-lora-ackwretries-waspframe

## 11.4.3. Sending data

This is the process to send a packet between SX1272 devices.

**Send data**

The API function responsible for sending data is called indicating the Destination Node Address and the payload data to send:

```
sx1272.sendPacketTimeout(destination, payload);
```

Related Variables:

`sx1272.packet_sent` → stores the structure of the packet to send

- SX1272 sending example:
  www.libelium.com/development/waspmote/examples/sx-02a-tx-lora

The user may want to add services for more robust communication, like ACK confirmation or retries. In order to send ACK confirmation, there are some special functions and a specific packet format, shown in the following figure. We also show examples for these services next:

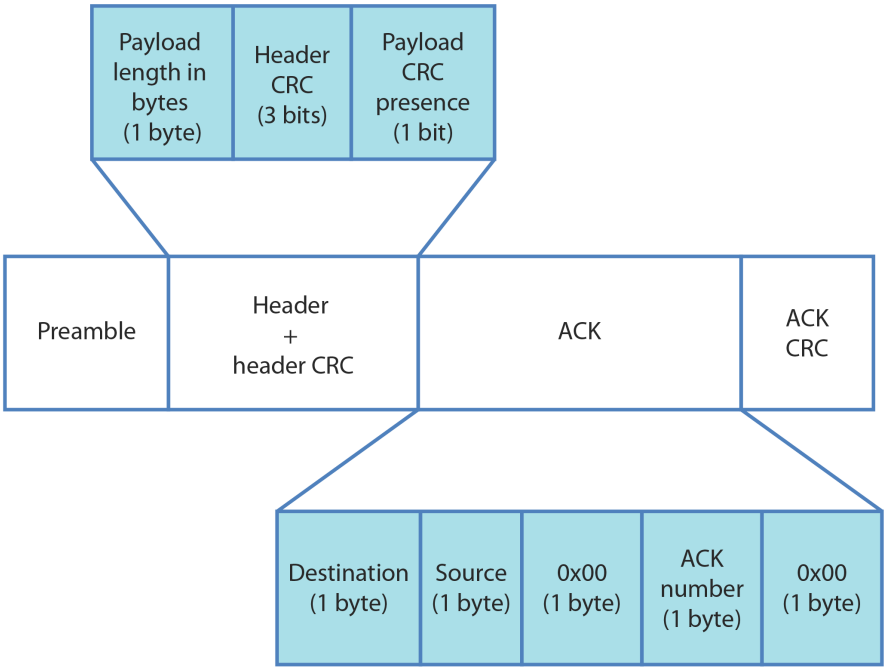


*Figure: ACK structure inside a packet structure*

- Send packets in unicast mode and wait for a response:
  www.libelium.com/development/waspmote/examples/sx-03a-tx-lora-ack

- Send packets in unicast mode, wait for a response and retry to send the packet if there is no response:
  www.libelium.com/development/waspmote/examples/sx-04a-tx-lora-ackwretries

## 11.5. Receiving data

Normally, the only receiver node in a network is the central node. Besides, this central node should be a Meshlium. In the case of Meshlium, receiving data is an automatic process, once it is configured.

On the other hand, receiving data in Waspmote is a complex process which needs some special structures to carry out. These operations are transparent to the API user, so it is going to be explained the necessary information to be able to read properly a received packet.

Before any packet has been received, an structure of `pack` is created. This pack is called `packet_received`.

The size of this array is defined by a field in the structure.

### 11.5.1. How to receive packets in Waspmote

To receive any packet, first it is necessary to know what kind of communication is being used. The used function will be different if we want to receive packets or if we want to receive packets and answer with an ACK confirmation too. All receiving functions are protected with a time-out method to avoid perpetual waiting.

In the case of ACK receiving functions, the SX1272 library automatically sets the destination address of the ACK packet to the sender node.

Example of use:

```
{
  sx1272.receivePacketTimeout(); // Receive packets
  sx1272.receivePacketTimeoutACK(); // Receive packets and response to the sender with ACK
}
```

Related Variables:

`sx1272.packet_received` → stores the structure of the last packet received

`sx1272.ACK` → stores the structure of the ACK

- Receiving packets example:
  www.libelium.com/development/waspmote/examples/sx-02b-rx-lora

- Receiving packets and answering with ACK example:
  www.libelium.com/development/waspmote/examples/sx-03b-rx-lora-ack

- Receiving packets, sending a response and retrying to receive the packet example:
  www.libelium.com/development/waspmote/examples/sx-04b-rx-lora-ackwretries

### 11.5.2. How to show received Frames

If the received packet has the structure of a Waspmote Frame inside the payload, there is a specific function to show it correctly, after being received.

Example of use:

```
{
  sx1272.showFramefromPacket(); // Show a Waspmote frame properly
}
```

If the received packet is just a plain-text message or the user prefers to know the packet contents: destination, source, packet number and retry fields, there is other function for that purpose.

Example of use

```
{
  sx1272.showReceivedPacket(); // Show received packet contents
}
```

- Receiving frames insides packets examples:
  www.libelium.com/development/waspmote/examples/sx-05b-rx-lora-waspframe

  www.libelium.com/development/waspmote/examples/sx-06b-rx-lora-ack-waspframe

  www.libelium.com/development/waspmote/examples/sx-07b-rx-lora-ackwretries-waspframe

### 11.5.3. Receiving all packets

Due to the architecture of the SX1272 module, all nodes in a channel with the same configuration mode listen any packet. Depending on the destination address, each node will hold packets addressed to it, and discard others.

The user can decide to receive all packets, no matter the destination address. This is called promiscuous mode. The user should know that the only way to protect transmissions is using Encryption libraries.

- Receive all the packets sent to any destination:
  www.libelium.com/development/waspmote/examples/sx-10-receiveall-lora

- Receive all the packets sent to any destination and send a response back to the sender:
  www.libelium.com/development/waspmote/examples/sx-11-receiveall-ack-lora

# 12. Starting a Network

To create a network it is only necessary to set 2 parameters in LoRa: channel and mode. These parameters are the base of a network and we need to be careful choosing them.

Encryption is optional. There are more parameters used to create a network like security parameters, which are not necessary but recommended (see chapter "Security and Data Encryption").

Two nodes are in the same LoRa network if they are using the same channel and mode.

## 12.1. Choosing a channel

As explained in chapter "Node Parameters", there are different channels to choose. Depends on the frequency band used, a random value between `CH_10_868` – `CH_17_868` or `CH_00_900` – `CH_12_900` should be chosen. This value will be used as the input parameter in the API function responsible for setting the channel.

Example of use:

```
{
  sx1272.setChannel(CH_04_900); // Set channel
}
```

- SX1272 configuration example:
  www.libelium.com/development/waspmote/examples/sx-01-configure-lora-parameters

## 12.2. Choosing a mode

This parameter is only intended for LoRa. Mode is different depending on the BW, CR and SF parameters chosen. There are 10 different modes in the Waspmote API, shown in the figure, but it is possible to add any other combination of BW, CR and SF values.

| Mode | BW | CR | SF |
|---|---|---|---|
| 1 | 125 | 4/5 | 12 |
| 2 | 250 | 4/5 | 12 |
| 3 | 125 | 4/5 | 10 |
| 4 | 500 | 4/5 | 12 |
| 5 | 250 | 4/5 | 10 |
| 6 | 500 | 4/5 | 11 |
| 7 | 250 | 4/5 | 9 |
| 8 | 500 | 4/5 | 9 |
| 9 | 500 | 4/5 | 8 |
| 10 | 500 | 4/5 | 7 |

*Figure: LoRa configuration modes*

Example of use:

```
{
  sx1272.setMode(3); // Set LoRa mode
}
```

- SX1272 configuration example:
  www.libelium.com/development/waspmote/examples/sx-01-configure-lora-parameters

# 13. Joining an existing network

Joining an existing network process requires some information about the network to join. In LoRa mode, two parameters are needed: channel and mode.

Encryption is optional.

## 13.1. Channel

To set channel, use the API function responsible for that matter.

Example of use:

```
{
  sx1272.setChannel(CH_04_900); // Set channel number 4 in 900 band
}
```

- SX1272 configuration example:
  www.libelium.com/development/waspmote/examples/sx-01-configure-lora-parameters

## 13.2. Mode

To set mode, use the API function responsible for that matter.

Example of use:

```
{
  sx1272.setMode(3); // Set LoRa mode number 3
}
```

- SX1272 configuration example:
  www.libelium.com/development/waspmote/examples/sx-01-configure-lora-parameters

# 14. Security and data encryption

The SX1272 does not implement any security method. Data encryption is an optional feature provided by the Waspmote's API, and it is highly recommended to take advantage of it using in real projects. That means we can make the SX1272 module send packets previously encrypted by Waspmote micro-controller. This way we will ensure nobody can read our packets, and the authenticity of the senders is verified.

Advanced Encryption Standard (AES) is a symmetric key encryption algorithm that supports key lengths of 128, 192, and 256 bits and encrypts a block of elements (set of bits) at the same time, unlike stream ciphers that encode each single item individually. This feature allows the algorithm to be very fast. It has the advantage of occupying very little memory and consequently makes it very suitable for low memory capacity devices.

AES is able to encrypt and decrypt a block of data using a key. The key and the block of data have a fixed length. The input is always 128-bit (16 bytes), while the key can be 128-bit, 192-bit or 256-bit (16, 24 and 32 bytes respectively). The information is encrypted with AES using a private key shared exclusively between the origin and the destination.

AES is classified as a block cipher algorithm. This means it has different modes of operation, like ECB or CBC mode. In this case it has been used ECB (electronic codebook) mode, which is the simplest of the encryption modes, with a ZEROS padding scheme.

For further information, please check the Waspmote Encryption Programming Guide:

www.libelium.com/development/waspmote/documentation/encryption-programming-guide/

And also the Encryption examples:

www.libelium.com/development/waspmote/examples/

## 14.1. Security in transmissions

When creating or joining a network, using security is highly recommended to prevent the network from attacks or intruder nodes. It is necessary to enable security and set the same encryption key in all nodes in order to set security in a network. If not, it will not be possible to communicate between different SX1272 modules.

When creating a link between 2 nodes, it is possible to use the Waspmote encryption libraries to make the communication secure.

- SX1272 encryption example:

  www.libelium.com/development/waspmote/examples/sx-08a-encrypted

  www.libelium.com/development/waspmote/examples/sx-08b-decrypted

It is also possible to make the communication secure between Waspmote and Meshlium or between two Waspmotes using the Waspmote Frame.

- SX1272 encryption example transmitting a frame:

  www.libelium.com/development/waspmote/examples/sx-09a-encrypted-waspframe

  www.libelium.com/development/waspmote/examples/sx-09b-decrypted-waspframe

# 15. Understanding LoRa

## 15.1. Introduction

LoRa 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 LoRa modulation lead to very low receiver sensitivity (down to -134 dBm), which combined to an output power of +14 dBm means extremely large link budgets: up to 148 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.

Libelium's LoRa module works in both 868 and 900 MHz ISM bands, which makes it suitable for virtually any country. Those frequency bands are lower than the popular 2.4 GHz band, so path loss attenuation is better in LoRa. In addition, 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.

The great performance of LoRa in all these 3 features (good sensitivity, low path loss, good obstacle penetration) makes LoRa a disruptive technology enabling really long range links. This is specially important in urban scenarios, with very difficult transmission conditions. To sum up, LoRa can get long ranges in Smart Cities deployments, so it reduces dramatically the size of the backbone network (repeaters, gateways or concentrators).

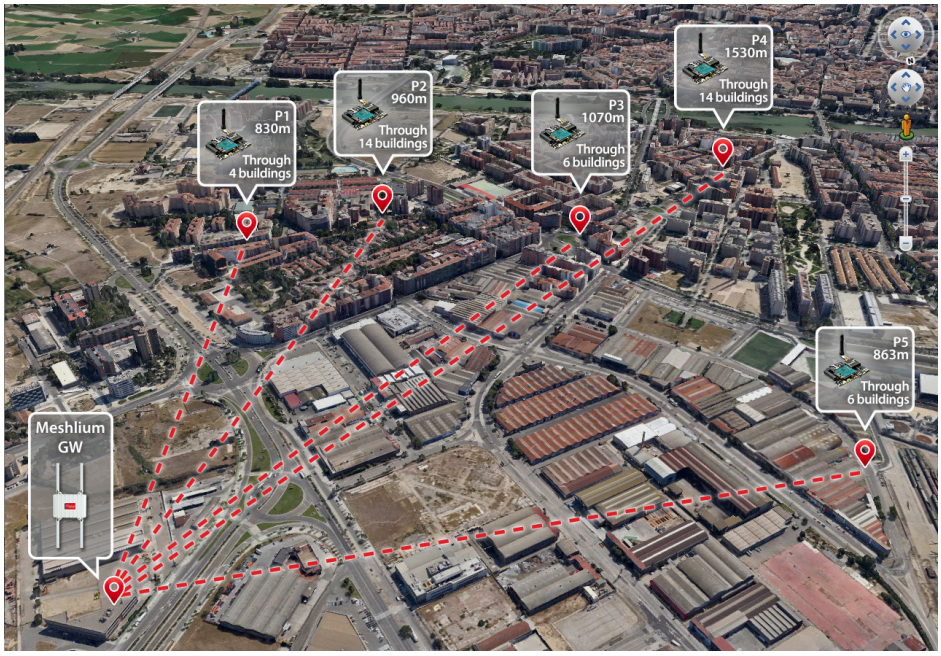


*Figure: Map of the NLOS long range tests in Zaragoza*

As shown in the chapter "Long Range Tests", Libelium performed long range tests, getting the awesome distance of 22 km (13.6 miles) in LOS configurations and 2 km (1.2 miles) in urban scenarios (going through buildings). The margin in those conditions would allow even more distance (x2, x3), the only problem was to keep the line-of-sight condition.

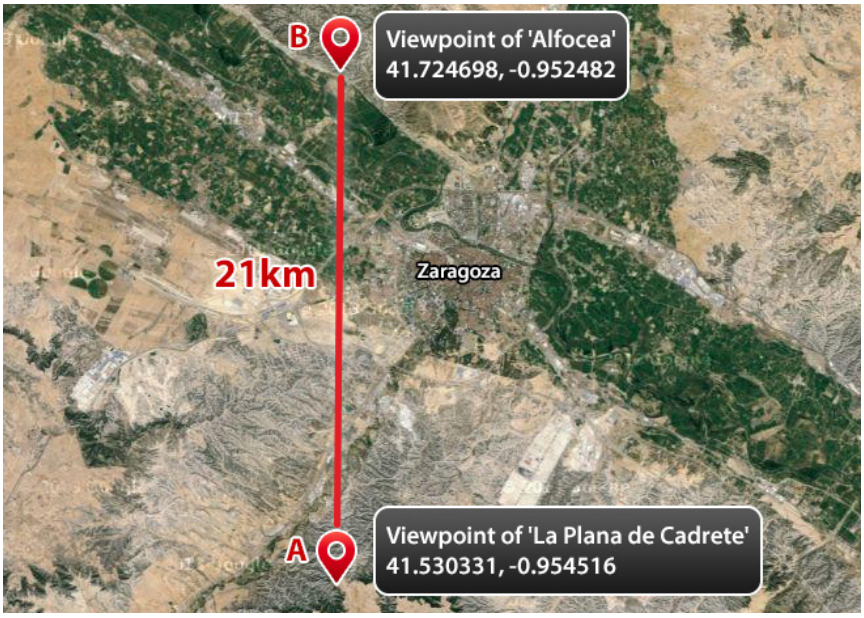


*Figure: Map of the LOS long range tests in Zaragoza*

## 15.2. Long Range VS Transmission Time / Consumption

It is really important to study the table in the chapter "Transmission Modes". There are 10 predefined transmission modes. Mode 1 gives the best range performance because the sensitivity is minimum; however, we must take into account that the transmission time of a typical packet is high.

| Mode | BW | CR | SF | Sensitivity (dB) | Transmission time (ms) for a 100-byte packet sent | Power consumption (mA·ms/1000) (reference = 35 mA in TX mode) | Transmission time (ms) for a 100-byte packet sent and ACK received | Comments |
|---|---|---|---|---|---|---|---|---|
| 1 | 125 | 4/5 | 12 | -134 | 4245 | 149 | 5781 | max range, slow data rate |
| 2 | 250 | 4/5 | 12 | -131 | 2193 | 77 | 3287 | - |
| 3 | 125 | 4/5 | 10 | -129 | 1208 | 42 | 2120 | - |
| 4 | 500 | 4/5 | 12 | -128 | 1167 | 41 | 2040 | - |
| 5 | 250 | 4/5 | 10 | -126 | 674 | 24 | 1457 | - |
| 6 | 500 | 4/5 | 11 | -125,5 | 715 | 25 | 1499 | - |
| 7 | 250 | 4/5 | 9 | -123 | 428 | 15 | 1145 | - |
| 8 | 500 | 4/5 | 9 | -120 | 284 | 10 | 970 | - |
| 9 | 500 | 4/5 | 8 | -117 | 220 | 8 | 890 | - |
| 10 | 500 | 4/5 | 7 | -114 | 186 | 7 | 848 | min range, fast data rate, minimum battery impact |

*Figure: LoRa configuration modes and power consumption*

The transmission mode is set to 1 by default. The user should explore other transmission modes, with a better range-time balance. For example, if we go from mode 1 to mode 5, sensitivity is reduced in 8 dB, thus range will be 40-50%. But on the other hand, packets will be sent in just 20% of time. This makes a great difference in terms of energy consumption, because in general terms, more time transmitting means more battery consumption.

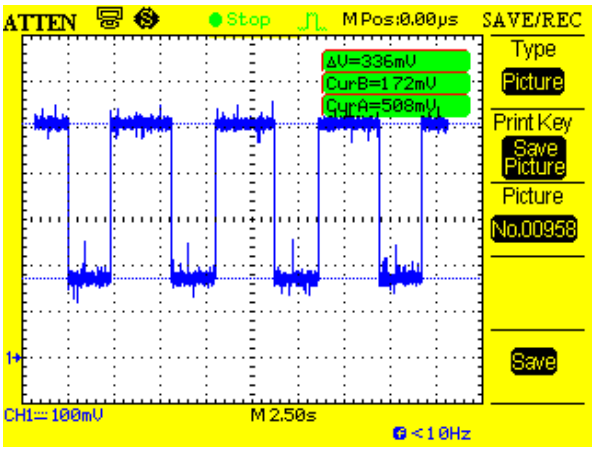


*Figure: Example of simple transmissions in LoRa (no ACK)*

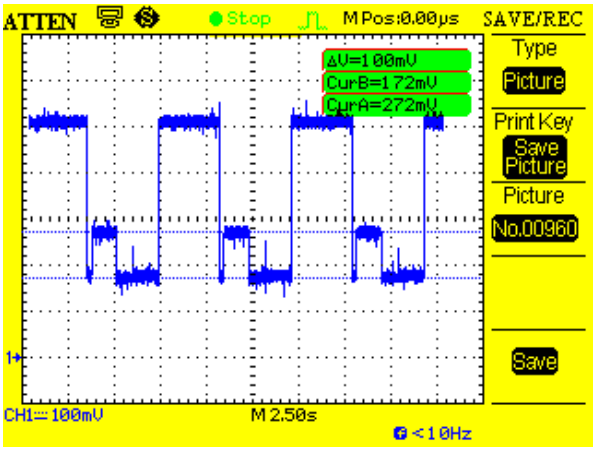


*Figure: Example of transmissions with ACK reception in LoRa*

Besides, we should consider that the transmission channel is shared by all the nodes in the network. This is important since only one packet can be transmitted at the same time. So the slower the packet transmission is, the worse is the channel availability. This fact has a dramatic impact in the number of nodes that a LoRa network can have. The developer must consider the number of nodes to install and run careful availability tests before deploying the network.

Libelium tests have checked that there is possible to set up a network with 8 different nodes sending frames every minute. This has been done using mode 1 which implies the worst time restrictions but best range. For the time synchronization, the RTC of Waspmote has been used to open temporal windows so as to perform the sending process.

## 15.3. LoRa VS XBee 868/900 MHz

Tests demonstrate that the LoRa module has much better long-range performance than any other communication module, including XBee 868 or 900. Dozens of km are easily achievable in good conditions thanks to the extremely low sensitivity that the disruptive LoRa technology offers. Even in urban environment, LoRa can reach some km in range. Both things are impossible for XBee.

However, XBee 868 or 900 win in terms of time of transmission. Basically, they complete a transmission cycle, including ACK reception, in less than 200 ms. The LoRa module takes more time as seen in the previous table (even in mode 10, which is the fastest mode).

Time of transmission is directly related to battery consumption, so XBees 868 and 900 need less energy to work (60-80% less than LoRa). In other words, a battery will live longer with XBee.

## 15.4. For what applications is LoRa a good option?

LoRa is a very good choice for solar or mains-powered nodes transmitting every 10 or 15 minutes in networks with low or medium number of nodes.

LoRa is also the best option for very wide networks, with long-range links. Other communication modules just cannot get more than few km.

## 15.5. For what applications is NOT LoRa a good option?

Definitely, LoRa is not suitable for projects which require high data-rate and/or very frequent transmissions (e.g., each 10 seconds).

Also, LoRa is probably not suitable for highly populated networks. Anyway, it depends on the number of nodes, and on the number of packets per hour that each node sends.

Power consumption is a major challenge, so probably any LoRa node should be powered by a solar panel, or even better, connected to mains electricity.

Last, we must note that due to the low bandwidth, LoRa by itself does not support Over the Air Programming (OTA), however many of our clients use as a second radio the 3G, GPRS or WiFi modules that allow to perform OTA easily retrieving the binary image from a FTP server in just a couple of seconds.

# 16. Code examples and extended information

In the Waspmote Development section you can find complete examples:

www.libelium.com/development/waspmote/examples

Example:

```
#include <WaspSX1272.h>
#include <WaspFrame.h>

// variable to show the flag from some functions
int e;

void setup()
{
  // Init USB port
  USB.ON();
  USB.println(F("SX1272 module TX in LoRa, complete example"));

  // Init SX1272 module
  sx1272.ON();


  // Select frequency channel
  e = sx1272.setChannel(CH_11_868);
  USB.print("Setting Channel: state ");
  USB.println(e);

  // Select implicit (off) or explicit (on) header mode
  e = sx1272.setHeaderON();
  USB.print("Setting Header ON: state ");
  USB.println(e);

  // Select mode (mode 1 is the better reach one)
  e = sx1272.setMode(1);
  USB.print("Setting Mode 1: state ");
  USB.println(e);

  // select CRC on or off
  e = sx1272.setCRC_ON();
  USB.print("Setting CRC on: state ");
  USB.println(e);

  // Select output power (Max, High or Low)
  e = sx1272.setPower('H');
  USB.print("Setting Power: state ");
  USB.println(e);

  // Select the node address value
  e = sx1272.setNodeAddress(6);
  USB.print("Setting Node Address: state ");
  USB.println(e);

  delay(1000);
  USB.println(F("Configuration finished"));
}

void loop()
{
    // Creating frame to send
    frame.createFrame(ASCII,"WASP_PRO");

    // Adding sensor battery
```

```
    frame.addSensor(SENSOR_BAT, (uint8_t) PWR.getBatteryLevel());

    // Printing frame via USB
    frame.showFrame();

    // Sending packet with timeout protection
    sx1272.sendPacketTimeout(5, frame.buffer, frame.length);

    delay(1000);

}
```

# 17. API changelog

Keep track of the software changes on this link:

www.libelium.com/development/waspmote/documentation/changelog/#LoRa

# 18. Documentation changelog

**From v4.1 to v4.2**

- References to the new LoRaWAN module

**From v4.0 to v4.1**

- References to the new Sigfox module

**From v4.0**

- Documentation released for the new LoRa module