UNIVERSITÉ CÔTE D'AZUR

ELLIOT
Workshop 23-24 November

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AiOT Elliot Dev Kit

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1 | IoT Dev kit

Development Kit : AIoT circuit with integrated Compact Right Hand Circularly Polarized Antenna

1.1 | Introduction

The AIoT dev kit is a communicating terminal integrating LP-WAN transceiver (SX1262), GPS receiver (L96) and several sensors. A Right Hand Circularly Polarizaed (RHCP) antenna is integrated withing the electronics. The antenna provides a 110° wide beam angle RHCP radiation. The device can be tuned for 3 different frequency bands : 868, 915 or 923 MHz.
The terminal is perfect for low-power tracking application with ultra fast GPS positioning and long-range communication. This system is compatible with LoRaWAN® terrestrial network. The kit will include a IP65 protective enclosure. The board include a fast connection header to connect any additional sensors and components required in your experiment. Two battery options are available. 3*AA alkaline battery support is recommended. The terminal can also be powered by one or two 18650 lithium batteries.

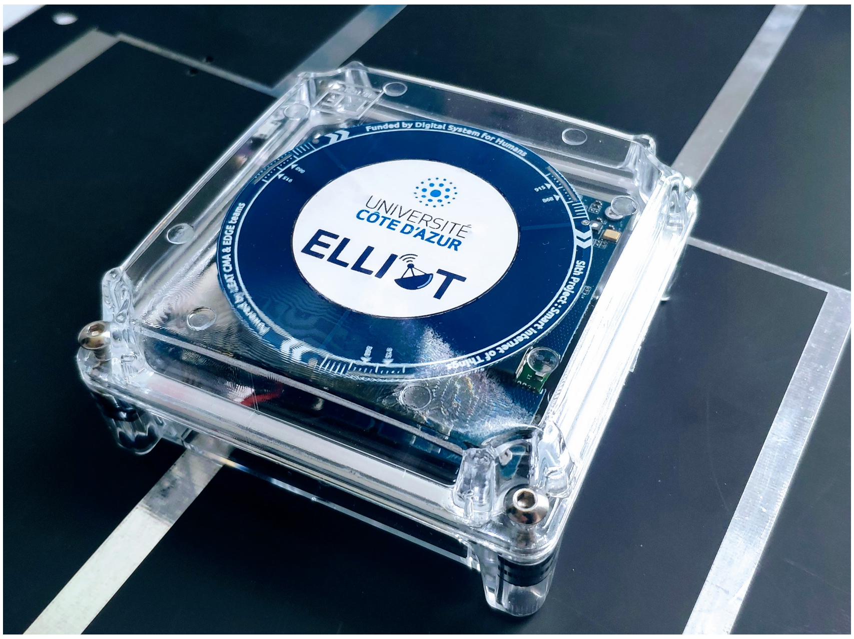

Figure 1.1: UCA board

1.2 | Bill of material

The number of components used in the Dev Kit is small as we used a System-in-module approach. A low-power MCU from STM is selected with the USB 2.0 features in order to flash it easily using DFU mode. The LoRa IC is controlled by the MCU using SPI. A GNSS receiver is also integrated in the dev kit in order to synchronize the system in time and position. These information are needed in order to predict when the satellite will be in view.

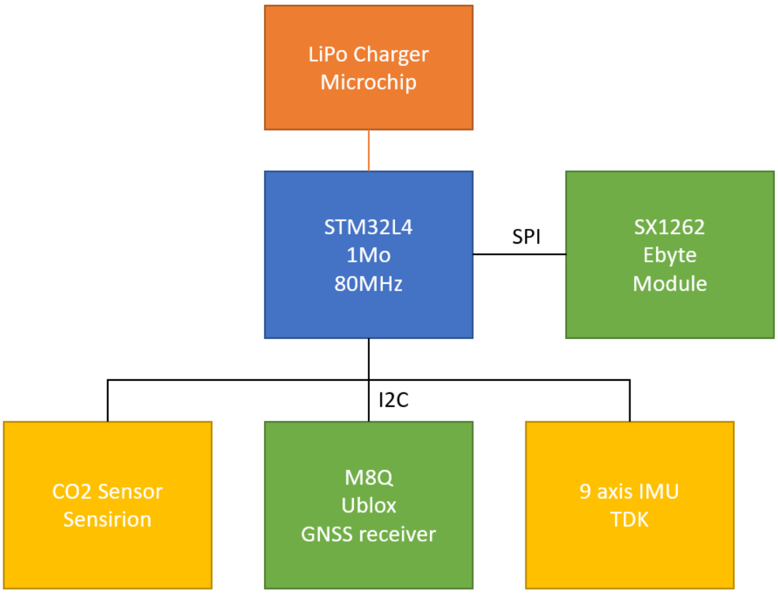

Figure 1.2: Dev kit simplified schematic

Table 1.1: Bill of material

Part	MPN	Manufacturer	Description	Package
GPS Modules GNSS	CAM-M8Q-0-10	U-Blox	Receiver GNSS L1	chip module
ARM® Cortex®-M4 Low Pow	STM32L476RCT6	STM	MCU IC 32-Bit 80MHz	64-LQFP
SX1262 Module	E22-900M22S	EByte	3	chip Module
SGP30	SGP30-2.5k	Sensorion	CO2 sensor	QFN
ICM	ICM-20948k	TDK	9 axis IMU	QFN
MCP7381	MCP73831T-2ATI/OT	Microchip	Charger IC LiPo	SOT-23-5
DRV	DRV5023AJQLPGM	Texas Instruments	Switch Hall Effect	TRH

1.3 | SX1262 from Semtech

The communication feature of AIoT is based on Semtech SX1262 chip. This is the second generation of LoRa transciever. Compare with the previous SX1272 and SX1276, the sensitivity and power consumption has been improved. Compared with SX1276, SX1262 can support natively the LR-FHSS modulation. The SX1262 is a low-cost electronic chip with price per unit lower than 3$ in volume. The transciever can support various waveforms like ASK, FSK, LoRa and LR-FHSS.

1.4 | UHF Antenna with circular polarization

The terminal is built around the circular polarized antenna presented in this reference []. The tri-element configuration is used to provide a wide beamwidth radiation pattern to optimize the budget link with Low Earth Orbit satellites. The feeding circuit of the CP antenna is co-integrated with the electronic components. The antenna is narrow bandwidth and has to be tune to operational frequency (868MHz in Europe and 915MHz in US).

1.5 | Casing

The terminal is designed to be operated outdoor, so it needs a waterproof casing. The antenna has been optimized with the effect of the casing (which is down-shifting the resonance frequency). The casing is in PLC material.

2 | C Library

2.1 | Introduction

The library used to control the dev kit has been developed from the Semtech reference Library.
In order to make it easy to modify and program on the dev kit, the Arduino IDE has been selected
The library is available on : https://github.com/FabienFerrero/UCA$_{A}IOT/$

2.2 | Arduino IDE configuration

2.2.1 | Installing Board Manager

Please install use the official Arduino Core from

```
https://fabienferrero.github.io/ArduinoBoardManagerJSON/package_uca-dkaiot_index.json
```

All examples & libraries used in this repository are integrated into the Arduino Core. Make sure that the installed core version is **0.0.61 (or above)** to be compatible with all examples in this repository!*

2.2.2 | Getting Started with Examples

After installing the core, select the RFThings-DKAIoT board by

```
Tools > Board > RFThings STM32L4 Boards > RFThings-DKAIoT.
Examples will be available in File > Examples > ELLIOT_Examples > ...
```

For more information on the examples, some documentation can be found on :

- 0. Sensors Link for Sensors
- 1. LoRa PHY Link for LoRa PHY examples
- 2. LoRaWAN Link for LoRaWan examples
- 3. LR-FHSS Link for LR-FHSS examples
- 4. Relay Link for Relay examples
- 5. GNSS Link for GNSS examples
- 6. CW (Continuous wave) Link for CW examples

3 | Sensors

Several sensors are integrated in the dev kit.

3.1 | Gaz sensor

3.1.1 | Description

The SGP30 is a digital multipixel gas sensor designed for easy integration into air purifier, demand-controlled ventilation, and IoT applications. Sensirion's CMOSens® technology offers a complete sensor system on a single chip featuring a digital I2C interface, a temperature controlled micro hotplate, and two preprocessed indoor air quality signals. As the first metal-oxide gas sensor featuring multiple sensing elements on one chip, the SGP30 provides more detailed information about the air quality. The sensing element features an unmatched robustness against contaminating gases present in real-world applications enabling a unique long-term stability and low drift. The very small 2.45 x 2.45 x 0.9 mm3 DFN package enables applications in limited spaces. Sensirion's state-of-the-art production process guarantees high reproducibility and reliability. Tape and reel packaging, together with suitability for standard SMD assembly processes make the SGP30 predestined for high-volume applications.

3.1.2 | Library and examples

In the example, the sensor will provide the CO2 level
The lib and example can be found here : GazSensor

3.2 | Temperature and Pressure sensor

3.2.1 | Description

The HP203B employs a MEMS pressure sensor with an I^2C interface to provide accurate temperature, pressure or altitude data. The sensor pressure and temperature outputs are digitized by a high resolution 24-bit ADC. The altitude value is calculated by a specific patented algorithm according to the pressure and temperature data. Data compensation is integrated internally to save the effort of the external host MCU system.
Easy command-based data acquisition interface and programmable interrupt control is available. Typical active supply current is 5.3 A per measurement-second while the ADC output is filtered and decimated by 256. Pressure output can be resolved with output in fractions of a Pascal, and altitude can be resolved in 0.1meter. The HP203B is offered in a 3.6mm x3.8 mm x 1.2 mm package and specified for operation from -40°C to +85°C.

3.2.2 | Library and examples

The lib and example can be found here : PressureSensor

3.3 | IMU

3.3.1 | Description

The ICM-20948 is the world's lowest power 9-axis MotionTracking device that is ideally suited for Smartphones, Tablets, Wearable Sensors, and IoT applications. • 3-axis gyroscope, 3-axis accelerometer, 3-axis compass, and a Digital Motion Processor™ (DMPTM) in a 3 mm x 3 mm x 1 mm (24-pin QFN) package • DMP offloads computation of motion processing algorithms from the host processor, improving system power performance • Software drivers are fully compliant with Google's latest Android release • EIS FSYNC support ICM-20948 supports an auxiliary I2C interface to external sensors, on-chip 16-bit ADCs, programmable digital filters, an embedded temperature sensor, and programmable interrupts. The device features an operating voltage range down to 1.71V. Communication ports include I 2C and high speed SPI at 7 MHz.

3.3.2 | Example

The lib and example can be found here : IMUSensor

4 | Tx and Rx LoRa PHY

In this section, the transmission and reception of a LoRa (chirp based) is described.

4.1 | Introduction

LoRa (short for long range) is a spread spectrum modulation technique derived from chirp spread spectrum (CSS) technology. LoRa Physical layer was developed and patented in 2009 by Nicolas Sornin and Olivier Seller. In 2010, they met their third partner, François Sforza, and together they started the company Cycleo. Initially, the three founders were targeting the metering industry and aimed at adding wireless communication capabilities for gas, water and electricity meters. For this purpose, they used Chirp Spread Spectrum (CSS) modulation technology, a technology widely in use for sonar in the maritime industry and radar in aviation. Convinced about the long range and low power capabilities of the invention, Semtech acquired Cycleo in May 2012. Semtech's LoRa is a long range, low power wireless platform that has become the de facto wireless platform of Internet of Things (IoT). LoRa devices and networks such as the LoRaWAN® enable smart IoT applications that solve some of the biggest challenges facing our planet: energy management, natural resource reduction, pollution control, infrastructure efficiency, and disaster prevention. Semtech's LoRa devices have amassed several hundred known uses cases for smart cities, homes and buildings, communities, metering, supply chain and logistics, agriculture, and more.

4.2 | Principle of LoRa modulation

In LoRa modulation the spreading of the spectrum is achieved by generating a chirp signal that continuously varies in frequency. An advantage of this method is that timing and frequency offsets between transmitter and receiver are equivalent, greatly reducing the complexity of the receiver design. The frequency bandwidth of this chirp is equivalent to the spectral bandwidth of the signal. The wanted data signal is chipped at a higher data rate and modulated onto the chirp signal. The relationship between the wanted data bit rate, symbol rate and chip rate for LoRa modulation can be expressed as follows:
We can define the modulation bit rate, Rb, as:

$$\mathrm{R_b} = SF * \frac{1}{\frac{2^{SF}}{BW}} \tag{4.1}$$

4.3 | Packet structure

While the LoRa modulation can be used to send arbitrary frames, Semtech has a physical frame format that is specified and implemented in its transmitters and receivers. The bandwidth and spreading factor are constant for a frame. A LoRa packet is structured as follows:

- 1. Preamble: it is used for synchronization purposes. The preamble is composed mainly of constant upchirps that cover the whole frequency band.
- 2. Header (optional): indicates the size of the payload, the code rates used for the transmission and a presence of CRC in the frame. It is optional to allow disabling it in situations where these parameters are already known by the receiver. The header also includes a CRC, and its coding rate is 4/8.
- 3. Payload: Maximum payload varies between 2 and 255 bytes.
- 4. Payload CRC (optional): its length depends on the coding rate.

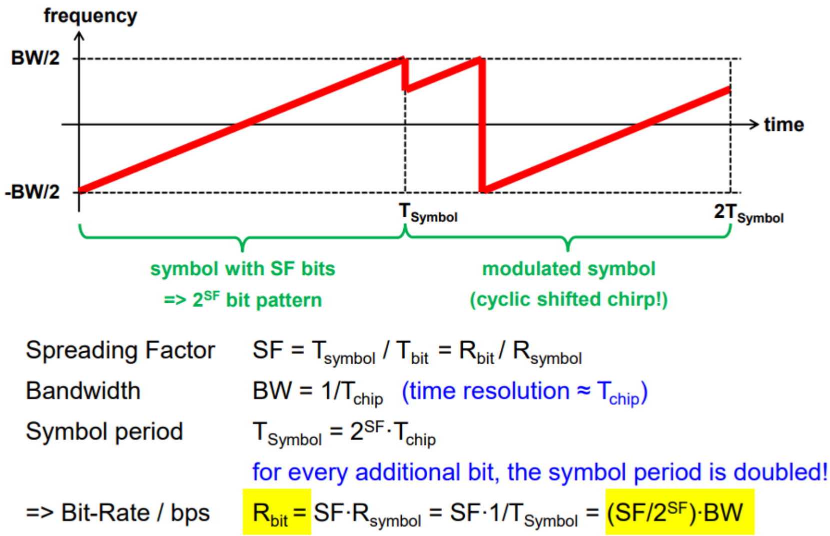

Figure 4.1: LoRa coding schemes

4.4 | LDRO

The LDRO allows to relax the oscillator requirements and improves the packet reception ratio when a symbol lasts for more than 16 ms, e.g., when using a BW of 125 kHz and a SF of 11 or 12. This optimization can be enabled manually by simply configuring a bit in the corresponding register before transmission. As per the SX1261/2 datasheet, it is advised to use the low data rate optimization (LDRO) feature when the symbol time exceeds 16.38 ms, which corresponds to the data rates with SF11 and SF12. For these configurations, the LDRO ensures an optimized packet reception, even if the long packet duration might provoke a carrier frequency deviation due to the PCB heating mechanism.

4.5 | Examples

3 different examples are available to test the Lora PHy communication. Link for LoRa PHY examples

- lora_phy_sender_example : it send a LoRa PHY packet every TX_INTERVAL seconds.
- lora_phy_receiver_example : it listen continuously for LoRa PHY packets and print packet's information to serial monitor.
- lora_phy_send_doppler_example: it continuously sends LoRa PHY packets with a sequential shift on the center frequency.

5 | LoRAWAN

In this section, the transmission of a LoRaWan packet to a gateway is proposed.

5.1 | Introduction

LoRaWAN is a cloud-based medium access control (MAC) sublayer (layer 2) protocol but acts mainly as a network layer (layer 3) protocol for managing communication between LPWAN gateways and end-node devices as a routing protocol, maintained by the LoRa Alliance. The MAC sublayer and the logical link control (LLC) sublayer together make up layer 2, the data link layer, of the OSI model.

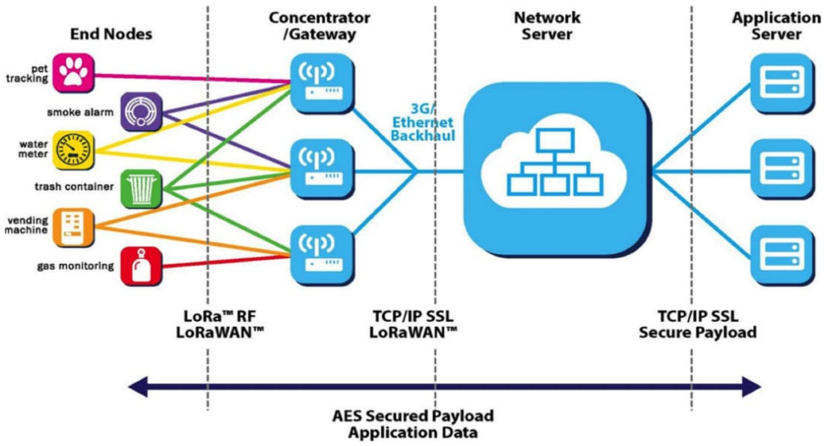

Figure 5.1: UCA board

5.2 | Activation

LoRaWAN supports two ways for a device connect to the network.

- ABP: Activation by personalization
- OTAA: Over the air activation

When using ABP there is no handshaking between the endnode and the network. As soon as the endnode performs a join action it can start sending data. The Application Session Key (AppSKey) and the Network Session Key are set once in both the endnode and the network server and must match.
When using OTAA a join action results in a join request being sent from the RM1xx to the network. The network then checks the Application Identifier (AppEUI) and Application Key (AppKey) provided by the endnode. If the APPEUI and APPKey are valid, a join accept message is sent back to the ennode which triggers an EVLORAMACJOINED event to be thrown in smart BASIC.
OTAA is the recommended method to join an ennode to a LoRaWAN network as it more secure, with the session keys being derived from the APPEUI and APPKey on each connection. Whereas the session keys for ABP remain the same throughout the life of the ennode.

5.3 | Examples

1 example is available to test the Lora PHy communication. Link for LoRaWan examples
The example in this section demonstrates sending simple LoRaWAN packets in Activation by Personalization (ABP) activation. The lorawan_abp_example send a "hello world" packet every TX_INTERVAL seconds to the Gateway.

6 | LR-FHSS

The Long Range Frequency Hopping Spread Spectrum (LR-FHSS) modulation is only used on the uplink. This modulation was developped in order to solve the LoRa chirp based capacity limitation. Indeed, two LoRa transmission using the same SF and frequency bands will have collision. The LR-FHSS is using a frequency hopping technique with orthogonal patterns in order to limit as much as possible the collision risk. It enables intra-packet frequency-hopping to achieve better capacity, sensitivity, and interference rejection than traditional modulation schemes that use a single channel. At the same time this improvement does not come at the cost of reduced communication range or power efficiency, which are the two main characteristics of these types of Low Power Wide Area Networks (LPWAN). Last, but not least it is designed to improve LoRa Satellite communication in order to promote its more widespread adoption.

6.1 | Introduction

LR-FHSS is a fast frequency hopping spread spectrum (FHSS) modulation with bit rates ranging from 162bits/s to 7.8kbits/s. Only the two lowest data rates (162bits/s and 325bits/s) are currently implemented. When a device transmits a packet using LR-FHSS on a given channel, the packet content is modulated across several pseudo-random frequencies that span the interval:
For FCC 47 CFR Part 15 compliance, the end-device frequency hops across 60 physical channels on a 25.4kHz frequency grid. For ETSI based countries, the end-device frequency hops across 35 or 86 physical channels on a 3.9kHz frequency grid. All physical channels are statistically used equally. The transmission starts on a random frequency inside the interval, and the following frequency hopping pattern is also randomly selected and announced in the LR-FHSS packet physical header. The transmission carrier frequency changes every 50mSec.
The instantaneous LR-FHSS modulation bandwidth (Occupied Band Width - OBW) is 488Hz. Therefore, a single LR-FHSS channel corresponds to many physical frequency channels. The LR-FHSS frequency hopping bandwidth (Operating Channel Width – OCW) is region specific.

6.2 | Parameters

LR-FHSS is solely designed to be used for Uplink, downlink in class A still uses LoRa and the same RX1/RX2 windows. LR – FHSS encodes a low data rate bit stream onto a comparatively wide bandwidth by switching frequency rapidly during the transmission of a single radio packet. The bandwidth used by the frequency-hopping algorithm can be set between 39.06 kHz and 1.5742 MHz. The 6 dB modulation bandwidth is 500 Hz. The LR-FHSS instantaneous modulation baud rate is 488.28125 baud, using 2-GMSK modulation and BT=1 (Chirp Spread Spectrum modulation is not used anymore). With hopping enabled, each LR-FHSS packet is spread over multiple frequency grids. The packet header contains information used by the gateway to compute the frequencies that the packet will use. Multiple headers are transmitted to ensure reception robustness. Table 1 below compares the narrowest bandwidth channel to the widest one, so one can gain perspective on how wide a range of hopping grids and channels one can have.

Table 6.1: LR-FHSS parameters

LR-FHSS Frequency Hopping BW (all hops)	LR-FHSS BW of a single hop	Minimum separation between LR-FHSS hopping channels (grid)	Nb of physical channels usable for frequency hopping per end-device transmission	Nb of physical channels available for frequency hopping	Coding Rate	Physical bit rate
39.06 kHz	488 Hz	3.9 kHz	35	80	1/3 2/3	162bits/s 325bits/s
1.574 MHz	488 Hz	25.39 kHz	60	3224	1/3 2/3	162bits/s 325bits/s

As an example of how a packet would be transmitted consider the figure below. The packet is split over several frequency grids, covering the allotted bandwidth for the channel. In particular we have the packet header replicated 3 times (HRD 1, HDR2, HDR3) in addition to the original one (HDR0). This is option, but recommended for robustness. Next the data payload is split over multiple frequency grids (PL1 to PLN) till the whole of it is transmitted (the number of grids used would depend on the packet size, where the header is pre-defined).

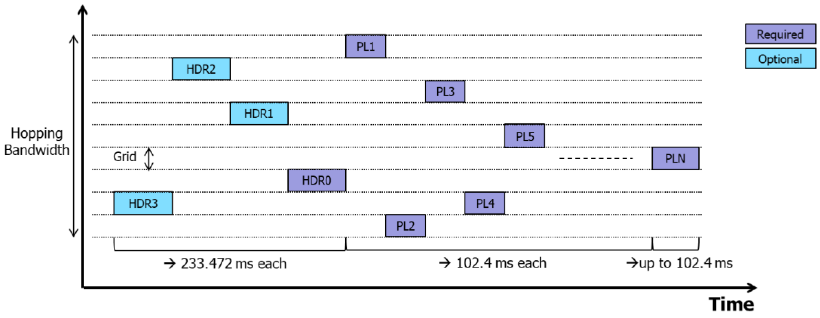

Figure 6.1: LR-FHSS packet transmission

6.3 | Capacity

Using a mathematical model to simulate performance, in case a single gateway is considered, the following has been found by Semtech.
Single channel LoRa network, using ALOHA channel access (PER target of 10%) can achieve capacity of: 150k packets per day (ADR turned on, mostly SF7 traffic) 5k packets (SF12 is used instead, no ADR). For the same PER of 10%, LR-FHSS achieves much greater capacity. The comparison can be seen in the following graphs (1st for a 125kHz channel, 2nd for a 1.5MHz one).
I both graphs it can be observed that LR-FHSS's PER grows linearly, rather exponentially like LoRa, resulting into the following improvement
1 mil packets per day (ETSI 125kHz bandwidth, PER 10%) 11 mil packets per day (FCC 1.5MHz bandwidth, PER 10%) The numbers are summarized in the following table and are theoretical only, in practice the limit is 700k due to DSP processing limitations.
As a summary LR-FHSS achieves a 140x improvement (700k/5k) for devices that are far (low data rate SF12).

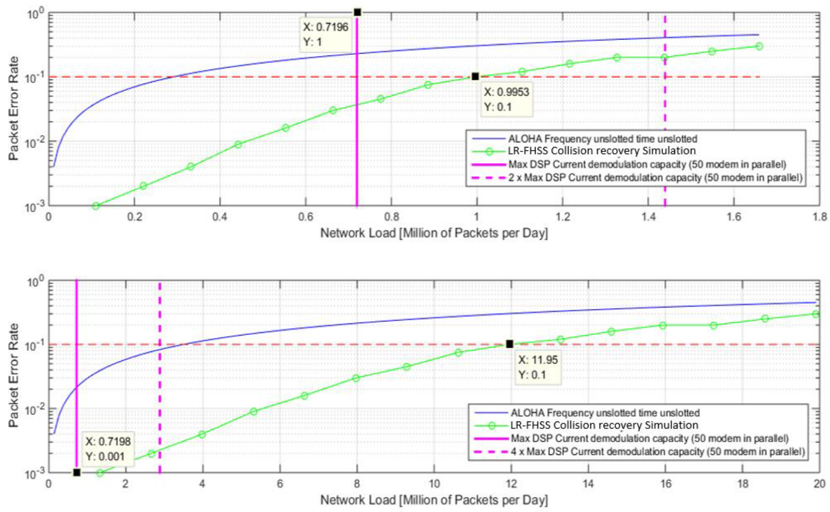

Figure 6.2: LR-CSS and LR-FHSS comparison

6.4 | Examples

Examples in this section demonstrate sending LR-FHSS packets with or without LoRaWAN packet format. Every TX_INTERVAL seconds, a LR-FHSS packet is sent. The library supports uplink LR-FHSS communication only.
Link for LR-FHSS examples

7 | Relay

In this section, the transmission and reception of a LoRa (chirp based).

7.1 | Introduction

In a relay configuration, the main objective is to lower as much as possible the power consumption of a receiver unit. Considering LoRa technology, the SX1262 transciever [?] is consuming 5 to 10mA when the Rx mode is enabled. A simple solution to reduce this power consumption is to duty-cycled the Rx mode, waking-up to receiver mode during a very short time over a given period. This approach implies an overhead on the end-node side which need to have a continuous transmission during the relay period to ensure detection as shown in Fig. **??**. Many experiments have been using a one-second wake-up period which is providing a good trade-off. Several parameters can be chosen to optimize the ratio between power consumption and receiver sensitivity. For example, bandwidth and spreading factor(SF) have a direct effect on this ratio.

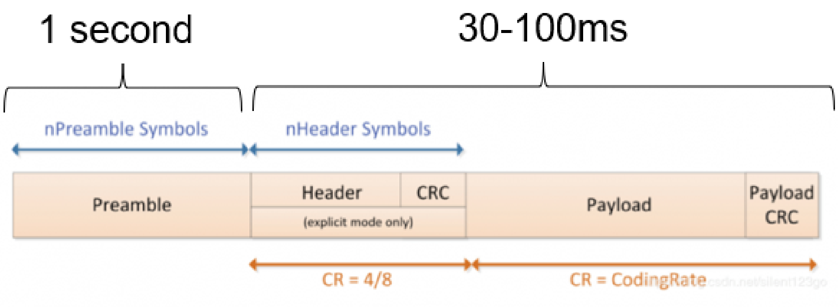

Figure 7.1: UCA board

7.2 | Examples

Examples in this section demonstrate a simple LoRaWAN Relay application.
sensor_to_relay_example sends a "Hello world" LoRaWAN packet with 1-second extended preamble length every TX_INTERVAL seconds.
Link for Relay examples
relay_example continuously listens for LoRaWAN packets from sensors (or other LoRaWAN device) prints packet information to Serial Monitor if it's successfully received. This sketch is NOT included packet integrity check, packet sender address filter, and repeat the received packet.

8 | GNSS

In this section, the positonning using GNSS receiver is shown

8.1 | Introduction

The u-blox concurrent CAM-M8 series GNSS antenna modules is based on the u-blox M8 multi-GNSS (GPS/QZSS, GLONASS, GALILEO and BeiDou) engine in an industry proven form factor. The CAM-M8 modules offer high sensitivity and strong signal levels in an ultra-compact form factor. The CAM-M8 series modules utilize concurrent reception of up to three GNSS systems (GPS/Galileo together with BeiDou or GLONASS), recognize multiple constellations simultaneously, and provide outstanding positioning accuracy in scenarios where urban canyon or weak signals are involved. For even better and faster positioning improvement, the CAM-M8 series supports augmentation of QZSS, GAGAN and IMES together with WAAS, EGNOS, MSAS. The CAM-M8 series also supports message integrity protection, geofencing, and spoofing detection with configurable interface settings to easily fit to customer applications. Incorporating the CAM-M8 modules into customer designs is simple and straightforward, thanks to the embedded GNSS chip antenna, a small footprint of 9.6 x 14.0 x 1.95 mm, and sophisticated interference suppression that ensures maximum performance even in GNSS-hostile environments. The low power consumption, and thin design allow end devices to be slimmer and smaller. Despite the miniature size, the GNSS chip antenna in the CAM-M8 series performs extremely well compared to traditional patch antennas. The omni-directional radiation pattern increases flexibility for device installation.
The CAM-M8 series modules target industrial and consumer applications that require concurrent GPS/Galileo and GLONASS or GPS/Galileo and BeiDou reception. The CAM-M8C is optimized for cost sensitive applications and has the lowest power consumption, while the CAM-M8Q provides best performance. The CAM-M8 series modules use GNSS chips qualified according to AEC-Q100, are manufactured in ISO/TS 16949 certified sites, and fully tested on a system level. Qualification tests are performed as stipulated in the ISO16750 standard: “Road vehicles – Environmental conditions and testing for electrical and electronic equipment

8.2 | Example

Examples in this section demonstrate GPS operations. There are 2 different sketchs: gnss_quectel_example for Quectel L96 gnss_ublox_example for Ublox CAM-M8Q.
Link for GNSS examples

[1] Opportunities Capabilities Created by the Inclusion of the LR-FHSS Modulation in LoRaWAN, Technical Webinar, 12 April
[2] AN1200.22, Semtech Application Note, LoRa™ Modulation Basics, May 2015
[3] Semtech Application Note: SX1261/2 Recommendations for Best Performance, 2018
[4] "LR-FHSS: Overview and Performance Analysis", Guillem Boquet, Pere Tuset-Peir ´o, Ferran Adelantado, Thomas Watteyne, Xavier Vilajosana