Protocols for WSN

1.Introduction

Sigfox is a french company founded in 2010 in Toulouse now present in 72 countries. It's a global network dedicated to the Internet of Things based on low power, long range and small data that offers an end-to-end connectivity service. It's the LPWA network.
Sigfox provides the network, the technology and creates the ecosystem essential for help businesses and organizations achieve their IoT goals.

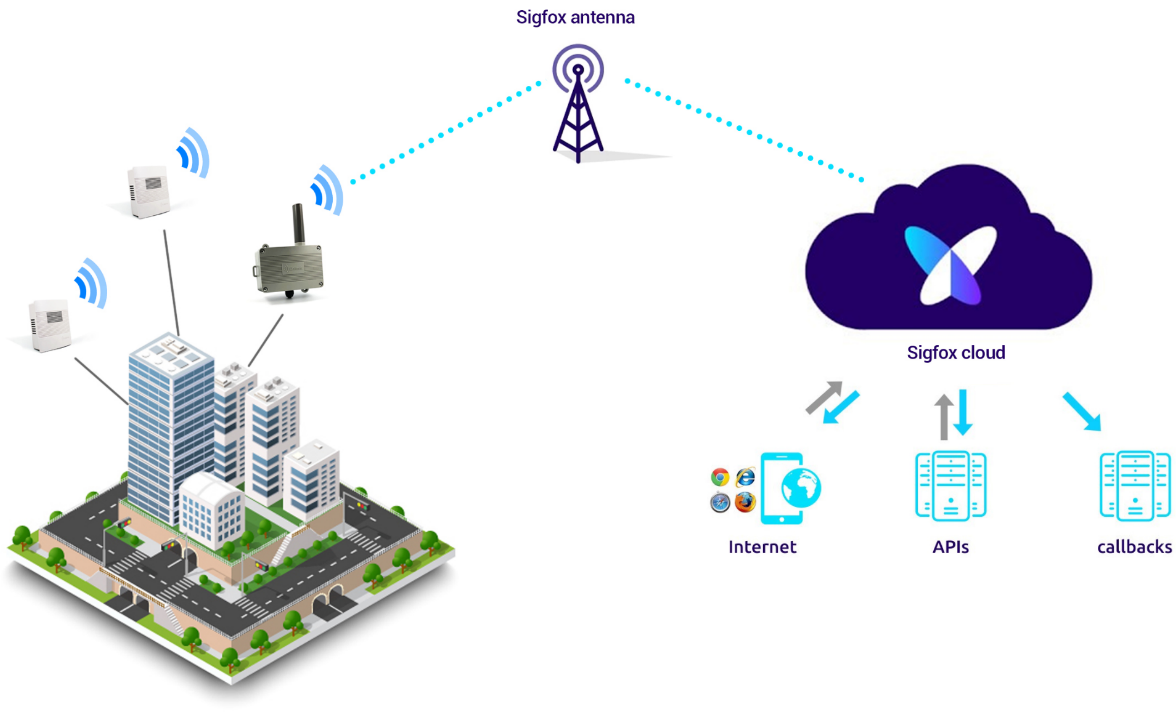

Figure 1 : Sigfox radio transmissions

2.Physical layer

a. Ultra-Narrow Band (UNB)

The multiple transmissions are performed at a carrier frequency chosen in a much larger band B (typically 192 kHz in the 868 MHz (resp 915 MHz) ISM band in Europe (resp in the America)).

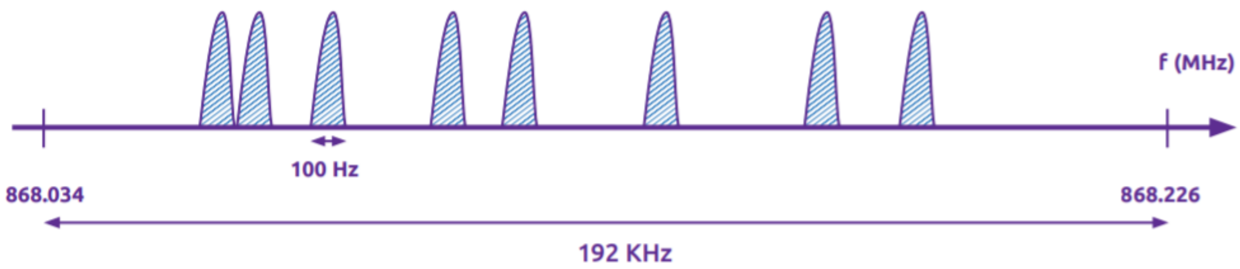

Figure 2 : Sigfox radio transmissions

Sigfox is based on an ultra-narrow band (UNB) physical layer where the binary data are broadcast with a differential binary phase shift keying (DBPSK) modulation at a very low rate Rb,s = 100 bps. Indeed, phase modulation has a very low spectral efficiency. Since the signal must be transmitted over a very narrow frequency band, the throughput is greatly reduced.

spectral efficiency = D/B,

with D the throughput in bit/s and B the frequency band in Hz. However, DBPSK offers greater resistance to noise.

Thus, the transmitted signal occupies a band of approximatively Ws = 100Hz. Transmitting a message on such a narrow frequency band allows to concentrate the power of the transmitted wave, and thus to pass over the noise. In addition, as the signal strength is improved, its range is also increased. Therefore the medium can be shared by more frequencies. However, the oscillators used to modulate the signal generally have an uncertainty of 200 Hz in the frequency range used by Sigfox .

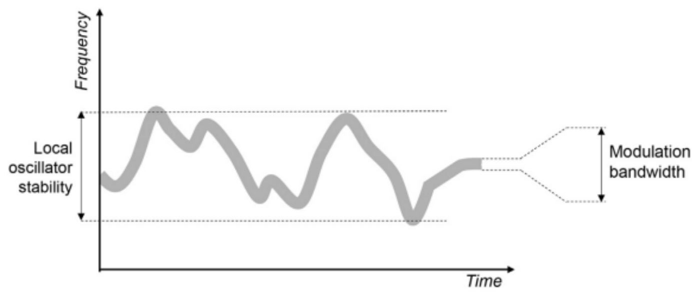

Figure 2. UNB modulation bandwidth

As illustrated in figure 2, this uncertainty is therefore higher than the frequency band dedicated to the signals (100 Hz). This is why Sigfox nodes use a Random Frequency and Time Division Multiple Access (RFTDMA) to transmit their signals (see next section).

In addition, to reduce costs, Sigfox uses an SDR, Software Defined Radio to replace functionality traditionally provided by hardware components, like modulation. Christope Fourtet and Benoit Ponsard also show the interest of the SDR used in reception. Because the bandwidth of the modulated signal is smaller than the drift of the oscillators at the origin of the emitted signal's modulation, the SDR makes it possible to scan the whole spectrum of interest (here 192 kHz) in search of a signal to then follow the central frequency of the carrier.

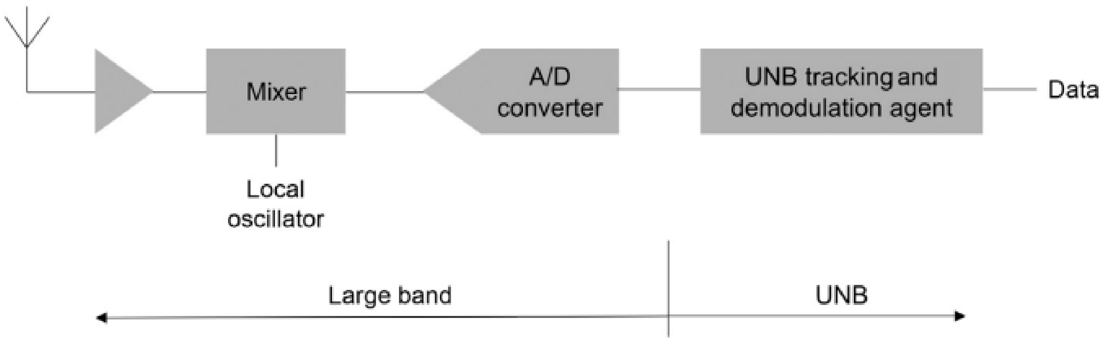

Figure 3 : SDR for UNB reception

Furthemore, objects do not have to worry about the choice of the transmission channel nor about an extremely precise modulation because the base stations manage these issues. All the complexity is in the base stations.

b. Information rate

Sigfox is characterized by a very low throughput, whether in uplink or downlink.

Communication	Symbol rate name	Symbol rate (in baud)	Cumulated error over full length of radio burst
uplink	$BR100_{UL}$	100	+/- 3%
	$BR600_{UL}$	600	+/- 3%
downlink	$BR600_{DL}$	600	+/- 0,01%

c. Ramp-up and ramp-down

Before the first symbol corresponding to the first bit of a frame, a radio burst may start with a ramp-up and extra symbols. In the same manner, a radio burst may end with extra symbols and a ramp-down.

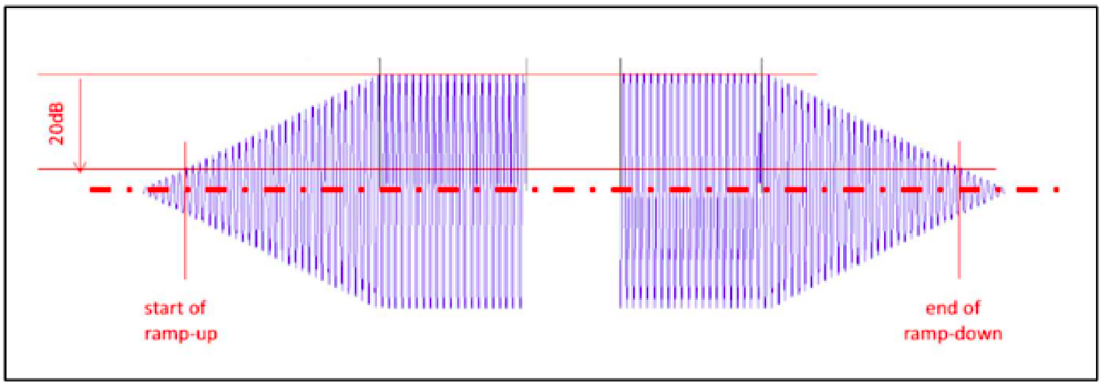

Figure 4 : Sigfox radio transmissions

The beginning and the end of the emission of a radio signal correspond to an increase and a decrease, respectively, of 20 dB (figure 4).

d. An international adaptation

Frequency (in MHz)	RC1	RC2	RC3	RC4	RC5	RC6	RC7
UL low boundary	868.034	902.104	923.104	920.704	923.204	865.104	868.704
UL center	868.130	902.200	923.200	920.800	923.300	865.200	868.800
UL high boundary	868.226	902.296	923.296	920.896	923.396	865.296	868.896
DL low boundary	869.429	905.104	922.104	922.204	922.204	866.204	869.004
DL center	869.525	905.200	922.200	922.300	922.300	866.300	869.100
DL high boundary	869.621	905.296	922.296	922.396	922.396	866.396	869.196

Table 1. Frequency bands according to the different Radio (RC), uplink (UL) and downlink (DL) configurations.

Sigfox offers coverage on the whole world, it has to adapt to the regulation of each geographical area with different radio configurations (Table 1).

e. Random access

The random access is a key feature to achieve a high quality of service. The transmission is unsynchronized between the network and the device. The device emits a message on a random frequency and then sends 2 replicas on different frequencies and time, which is called “time and frequency diversity”.

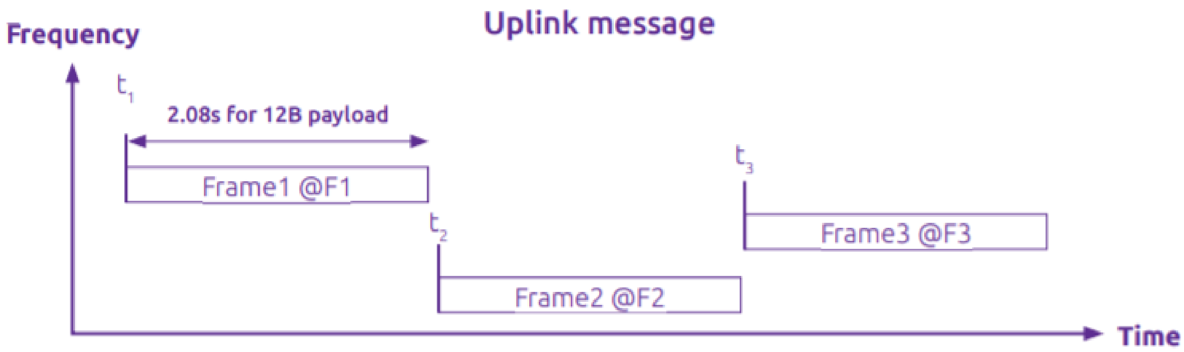

Figure 5 : Frequency hopping on replicas

f. Cooperative reception

The principle of the cooperative reception is that an object is not attached to a specific base station unlike cellular protocols. The emited message is received by any base stations that are nearby and on average the number of base stations is 3. This is called “spatial diversity”.

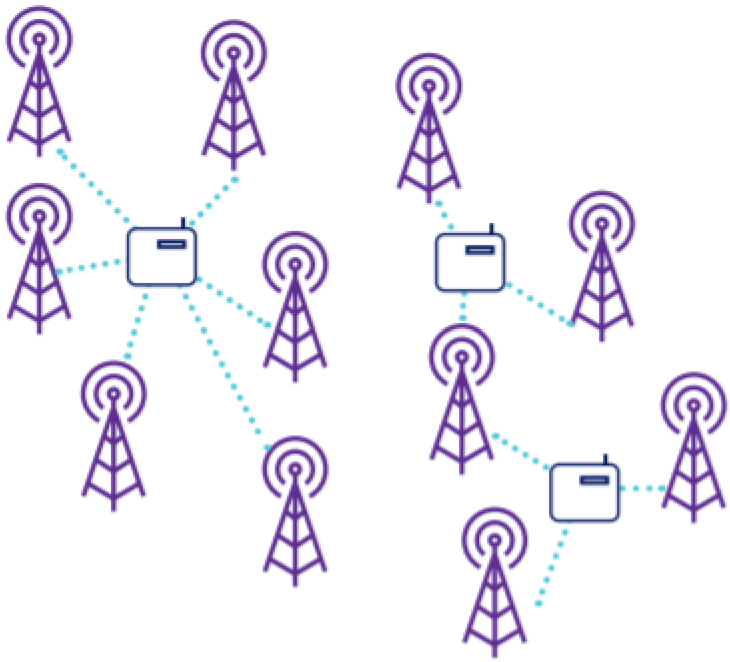

Figure 6 : Frequency hopping on replicas

Spatial diversity coupled with the time and frequency diversity of the repetitions are the main factors behind the high quality of service of the Sigfox network.

g. Small messages

In order to address the cost and autonomy constraints of remote objects, Sigfox has designed a communication protocol for small messages. The message size goes from 0 to 12 bytes. A 12-byte payload is enough to transfer sensor data, the status of an event like an alert, GPS coordinates or even application data.
We have listed some payload size examples:

GPS coordinates -----------------------------------> 6 bytes

Temperature ------------------------------------>2 bytes

Speed Reporting ------------------------------------>1 bytes

Object status ------------------------------------>1 bytes

“Keep alive” payload ------------------------------------>0 bytes

The regulation in Europe states that we can occupy the public band for 1% of the time. This translates into 6 12-byte messages per hour or 140 messages per day. While the regulation differs in other regions, the Sigfox commercial offer remains the same at the moment.

For downlink messages, the size of the payload is static: 8 bytes. Again, a lot of information can be transferred on 8 bytes. This is enough for triggering an action, managing a device or setting application parameters remotely.

The duty cycle for the base station is 10% that guarantees 4 downlink messages per device per day. If there are extra resources left, the device can receive more.

h. Bi-directional

The downlink message is initiated by the object. There is a delay of 20 seconds between the first frame transmitted and the reception window that lasts for 25 seconds maximum. The downlink frequency is the frequency of the first uplink message plus a known delta.
Therefore, in downlink communication the modulation used is GMSK (Gaussian Frequency Shift Keying).

3. MAC layer :

Sigfox Mac layer relies on RFTDMA. It allows active nodes to access randomly in time and frequency to the wireless medium without any contention-based protocol (resource saving), and also cost saving with cheap oscillators. It can be referred to ALOHA-based protocol, however the carrier frequencies are chosen in band inside a continuous 2 interval, instead of a predefined discrete set. Indeed, at the receiver side, the demodulator listens on the totality of the bandwidth without recognizing a priori the carrier frequency used by the emitting device. Therefore, identifying the emitted message can be obtained only after decoding all received signals in bandwidth. The random access seems to be efficient in protecting the device from interferences and seems to be likewise of interest since it limits the device's energy consumption. Nevertheless, the uncontrolled medium access leads to introduce interferences between active nodes. According to a feature of Sigfox protocol (linked to the duty cycle of the considered ISM band), an active node could transmit about 140 packets per day containing 12 bytes of payload. In addition, each message can be sent up to 3 times on different frequencies with the aim of improving reliability.

This feature is part of Sigfox's commitment to improve the robustness of its communication system, the triple diversity (3D-UNB). In addition to sending the message at three different times, the data is also sent on three different frequencies, and three base stations are likely to receive it. This approach naturally supports device mobility.

a. Uplink frame

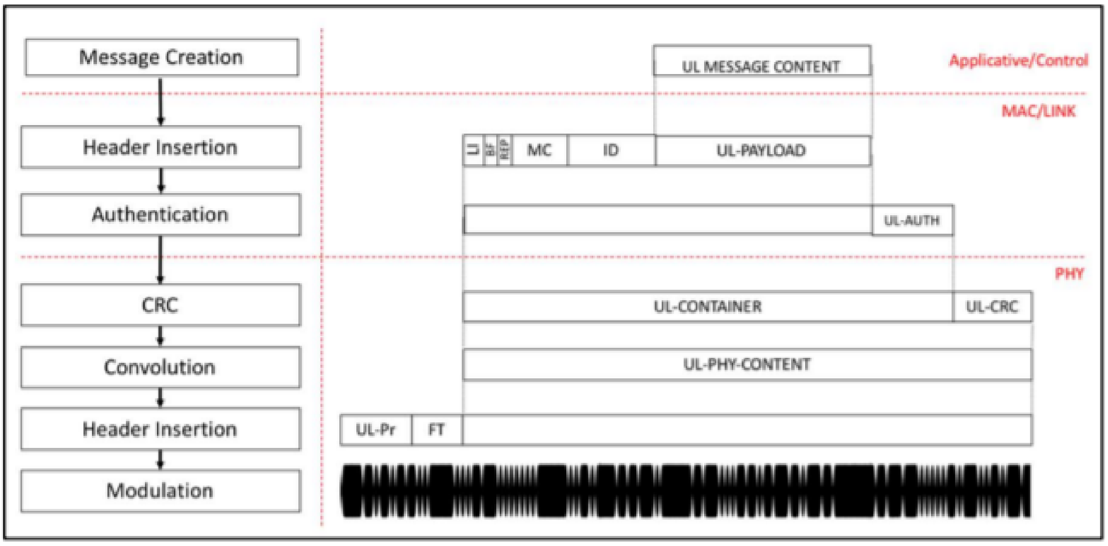

Figure 7. Uplink frame

- ID :

Each object is linked to an application by its ID (4 bytes). There is no destination address since the Sigfox service knows directly to which application the data should be transmitted with the object ID.

- Message counter (MC) :

This 12-bits field is incremented as soon as a message is sent. It allows to fight against replay attacks.

- Length indicator (LI) :

These two bits are defined by the size of the message.

- Bidirectional frag (BF) :

To indicate the communication procedure: unidirectional or bidirectional (1 bit).

- Repeated flag (REP) :

One bit constant for all the objects.

- Uplink Authentification (UL) :

It’s a variable length field build from previous fields using AES128 in mode CBC.

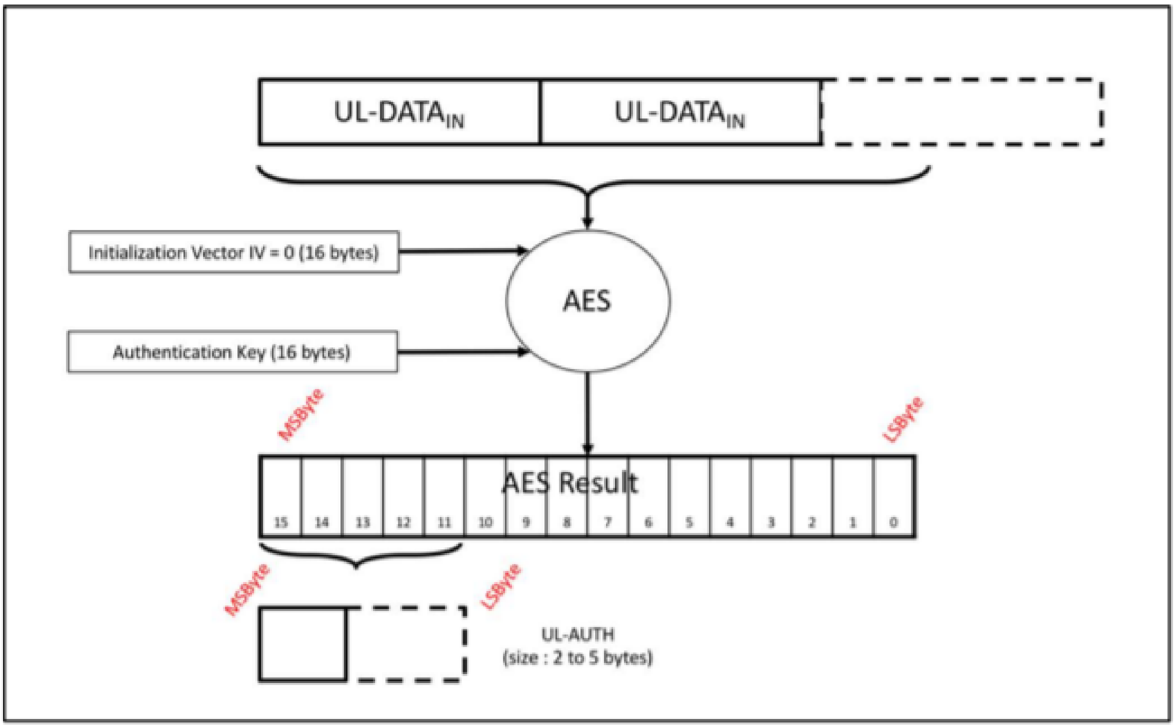

Figure 8. Principle of UL-AUTH field evaluation

- Uplink error detection field (UL-CRC)

Error detection is handled with CRC, frame division by a polynomial function, and a XOR function.

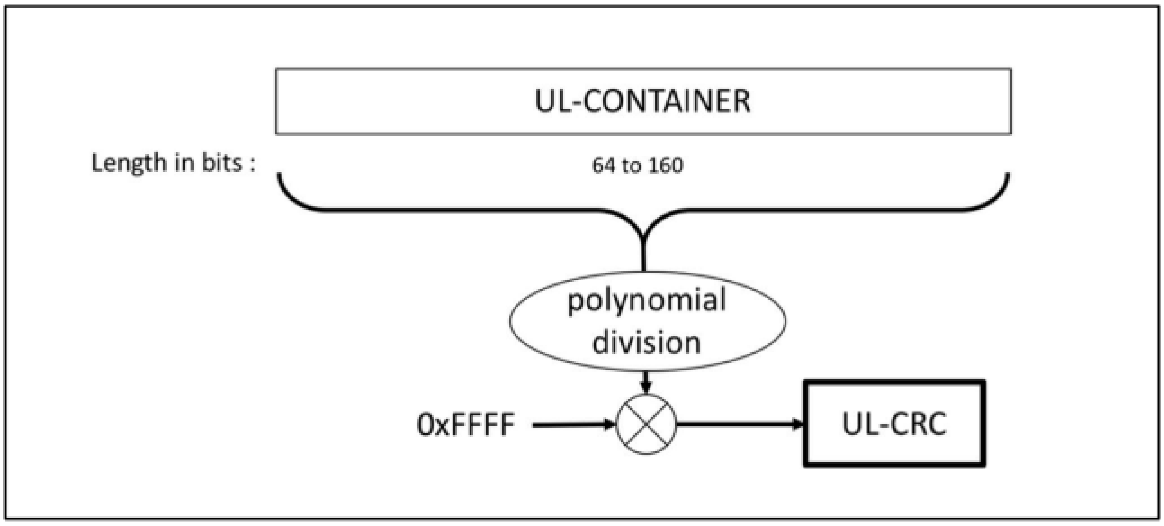

Figure 7. CRC computation in uplink transmission

- Uplink convolutional coding function :

The objects encode the frame following figure 8 to increase the transmission robustness.

Number of frames	Frame emission rank	Polynomial
multiple	First	R=1 (identity)
multiple	Second	$R=1+X+X^2$
multiple	Third	$R=1+X^2$
single	/	R=1 (identity)

Figure 8. Polynomials for convolution coding of UL frames

- Uplink frame type (FT)

This is a 13-bits field built from the payload length and the frame emission rank.

- Uplink preamble (UL-Pr)

A constant 19 bits field shared by all the objects : 0b1010101010101010101.

b. Bidirectional procedure

A user cannot directly initiate a communication with an object. It is the object that must indicate to the user that it is waiting for a message. The procedure is shown in figure 9.

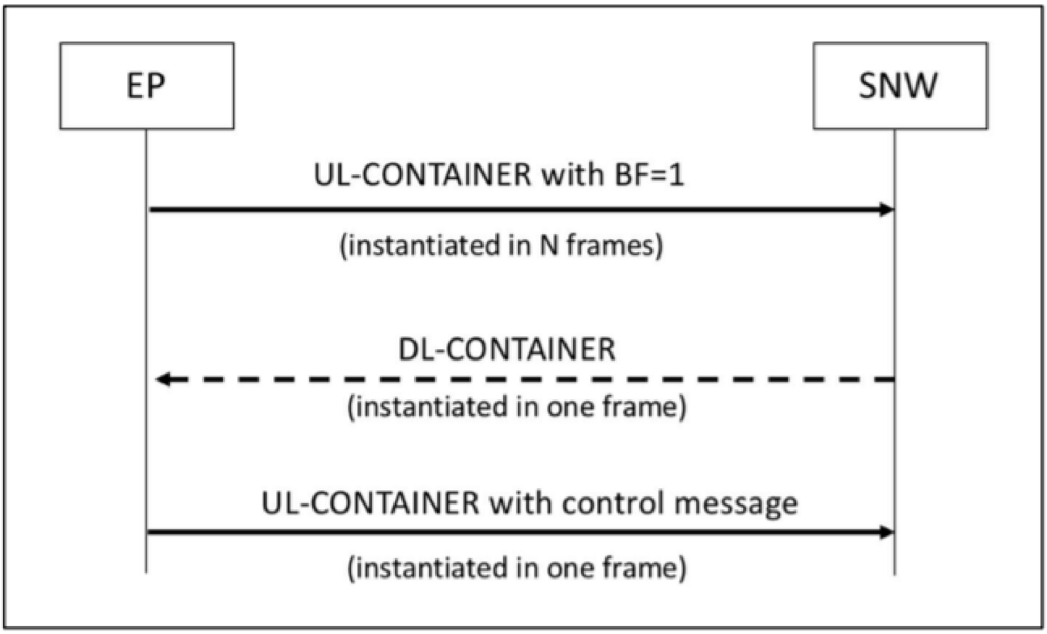

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Figure 9. Bidirectional procedure sequence diagram at MAC level. EP : End Point (objects). SNW : Sigfox Network.

4. Security/Authentification

Like it is described in the previous section, header contains a message counter (MC) that is incremented after each message transmission. It is used in authentication algorithms as a rolling counter for replay attack protection. In addition, an authentication algorithm is used with AES128 and an authentification key. This corresponds to the bytes Auth. (figure 7).

Despite numerous mechanisms to improve the robustness of the signal, the data itself is not encrypted by default and is potentially interceptable in the radius of emission of the device (a few kilometers). However Sigfox provides the user with an encryption solution which does not change the volume of emitted data.

5. Power consumption :

For SigFox, the emission power may vary up to 14 dBm. Besides, the circuit consumption depends on the device state. During idle or sleep mode, the supply current is negligible (around 1 µA), while reception (resp. transmission) consumes up to 11 mA (resp. 125 mA). A complete simulator, which takes into account all specificities of the device behavior is available at [2].

Concerning the power transmission, in uplink communication we have 25 mW maximum in Europe (158 mW in USA) and 500 mW in downlink communication in Europe (4 W in USA). So with a bit rate of 100 bit/s we have 0,25 mJ/bit in the worst case in uplink transmission. In dowlink the rate is 600 bit/s so for the consumption we have 0,83 mJ/bit.

Nevertheless, a recent study has focused on calculating precisely the consumption of Sigfox and finds greater energy consumption. Indeed, their modeling takes into account many parameters such as frame losses.

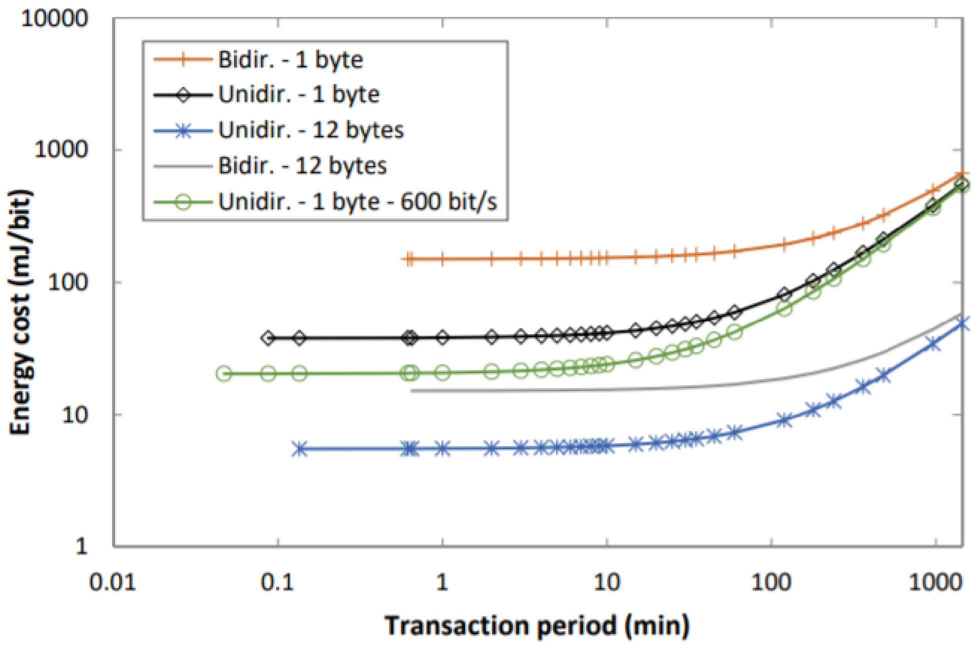

Figure 10. Energy cost of data delivery, for unidirectional and bidirectional transactions, as a function of Transaction Period, and for uplink payload sizes of 1 byte and 12 bytes, for FLR (Frame loss rate) = 0.

We observe that the energy consumption increases with the time elapsing between two data exchanges. Indeed, we have to take into account the energy consumption during the standby time which increases with the standby time of the devices.

In the worst case figure 10 shows an energy consumption almost equal to 1000 mJ/bit.

Concerning devices lifetime figure 11 also describes the huge sensibility caused by the transaction period.

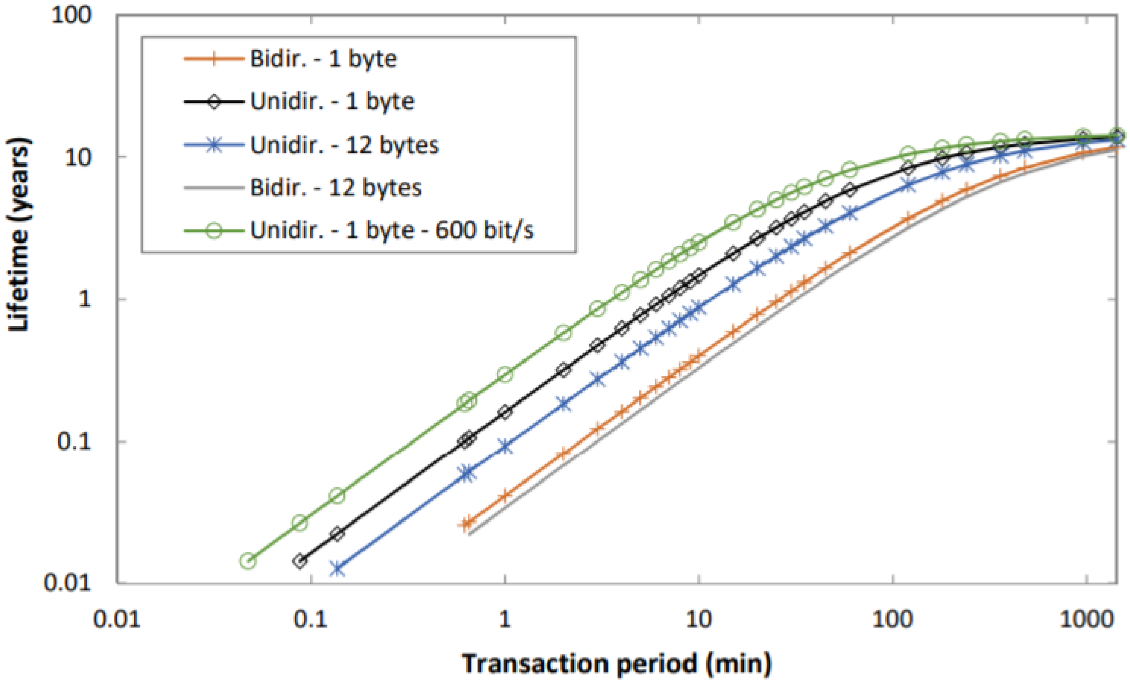

Figure 10. Device lifetime, for unidirectional and bidirectional transactions, as a function of TPeriod, and for uplink payload sizes of 1 byte and 12 bytes, for FLR = 0.

The lifespan of the devices is estimated at 10 years in the best of cases, and at less than one year in the worst of cases. A remarkable result is that, for an uplink bit rate of 100 bit/s, the energy cost of delivering a 12-byte payload with a bidirectional transaction is from 2 to 10 times lower than that of delivering a 1-byte payload with a unidirectional transaction.

Another value is given by Benoit Ponsard and christophe Fourtet (working at Sigfox), 1.8 mJ/bit.

https://www.researchgate.net/publication/330947889_A_Sigfox_Energy_Consumption_Model/link/5c5ced9d45851582c3d5a09e/download

Sources :

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