Study of physical layer of Sigfox protocol

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Introduction

Communication protocols are an essential concern in IoT networks. We studied different communication protocols and in particular Sigfox. Sigfox is a well known protocol for wireless sensor network. In this report, we will present the physical layer characteristics of Sigfox. We will then present its performances and radio range with an outdoor application example.

Sigfox physical layer

The bandwidth used by Sigfox depends on the location of the network. In Europe, Sigfox emits between **868 and 868.2 MHz** while in the rest of the world it uses bandwidth between 902 and 928 MHz (depending on local regulation).

Sigfox is using **Ultra-Narrow Band (UNB)** modulation. This protocol uses **192KH**z of the publicly available band to send messages. The message range is of **100 Hz** and messages are sent with a data rate of **100 to 600 bits per second** depending on the regions.

Sigfox uses **Differential Binary Phase Shift-Keying (DBPSK)** to modulate the signal. This modulation technique is a specific application of BPSK, which is a technique using the phase to encode 0 and 1.

DBSPK, unlike BPSK, does not need a reference of phase to identify a 0 or a 1. In fact, “differential” means that this technique is based on **phase changes.** When there is changing in the signal we can assume it is a 1, and when there is no change it is a 0, as shown in the fig 1.

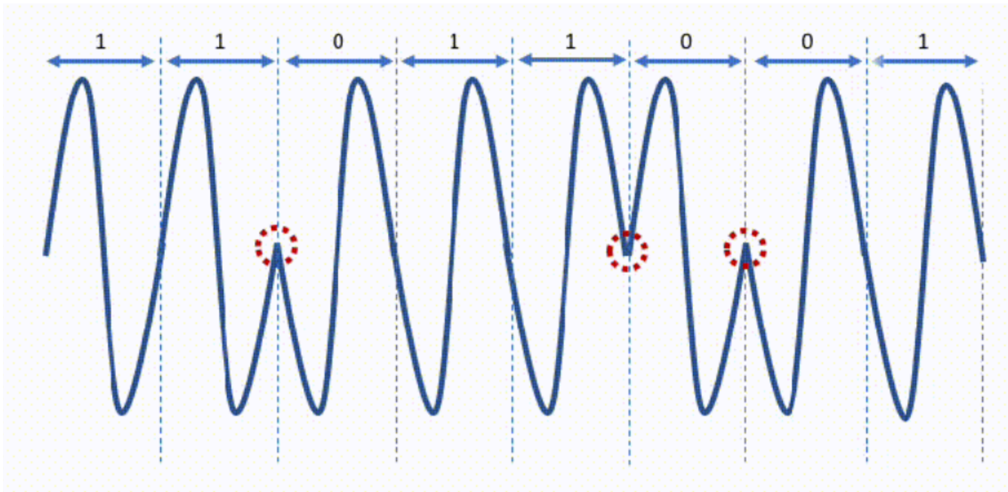

Fig 1 : DBPSK modulation

Sigfox uses small messages in order to reach the best performances. The packet structure of Sigfox messages is defined in fig 2. Each cell represents 4 bits.

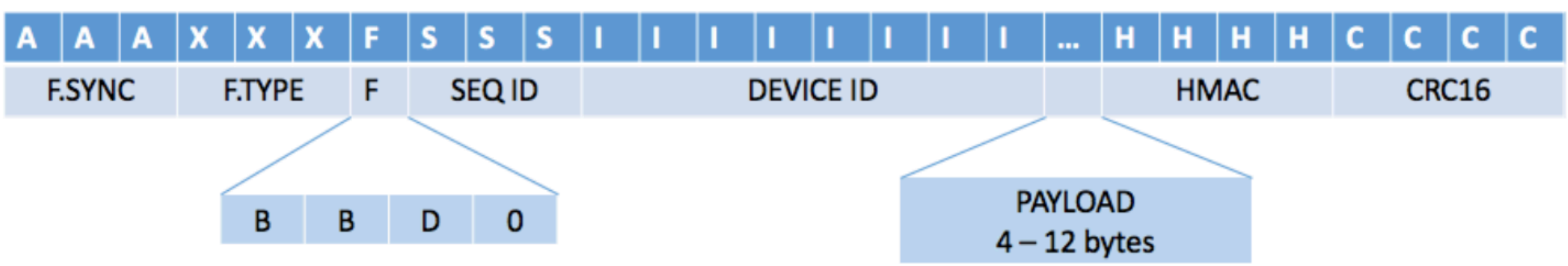

Fig 2 : DBPSK modulation

Frame synchronization

The content of this first part is a suite of 0 and 1 (A = '1010'). The receiver synchronizes its clock thanks to this sequence and can find the beginning of each of the bits.

Frame type

This part informs about the type of data : the size of the payload and information about the repetition. Indeed, in Sigfox each message is sent 3 times for QoS concerns.

The synchronization defined above ends when '00' or '11' appears in the suite, depending on the frame type.

F Flags

- BB bits : BB presents the number of bytes which are unused by the payload. As a fixed frame size is dedicated to the payload, if payload is shorter than it, it has to be completed. For example, if the payload is 6-bytes long it will be sent on an 8-bytes frame with 2 bytes to complete it, BB will be ‘10’.

- D bits: This bit is set to 1 when a downlink is expected by the transmitter. The receiver knows, thanks to this bit, that it has to respond.
- The last bit of these flags is always 0.

Device ID

The device ID is 32-bytes long, it is unique in order to define the device.

Payload

The payload is the data to be transmitted. It can be 12 bytes, 8 bytes or 4 bytes. The payload is encoded and you need the information transmitted in the other part of the message to understand it.

The length of the data depends on its type : GPS coordinates are 6 bytes. Temperature is 2 bytes. Speed reporting is 1 byte. Object status is 1 byte. “Keep alive” payload is 0 byte.

HMAC

The HMAC is a signature. Each device has its own unique hash competed from its private key. Sigfox knows the private key and can verify the signature. If the signature is not recognized, the frame is rejected.

CRC

A 16-bytes Cyclic Redundancy Check is used to ensure the transmission of the whole frame.

Sigfox performances

Sigfox throughput depends on the localization. Sigfox reports a **14 dBmW** output power in Europe, which corresponds to **25 mW** power, and a 22 dBmW in the US (158mW). The **time on air** can be calculated thanks to these values, Sigfox reports a time on air of **2 seconds**.

When it comes to wireless communication, one of the main issues is the sensitivity to noise and interferences. Sigfox uses different features to reduce the effect of interferences.

- **Ultra Narrow Band modulation** : as Sigfox messages are using ultra narrow bandwidth they are less sensitive to noise. It seems to be the best modulation technique for operations in public ISM band.

- **Time & frequency diversity** : The message is sent 3 times with different time and frequency as shown on fig 3.

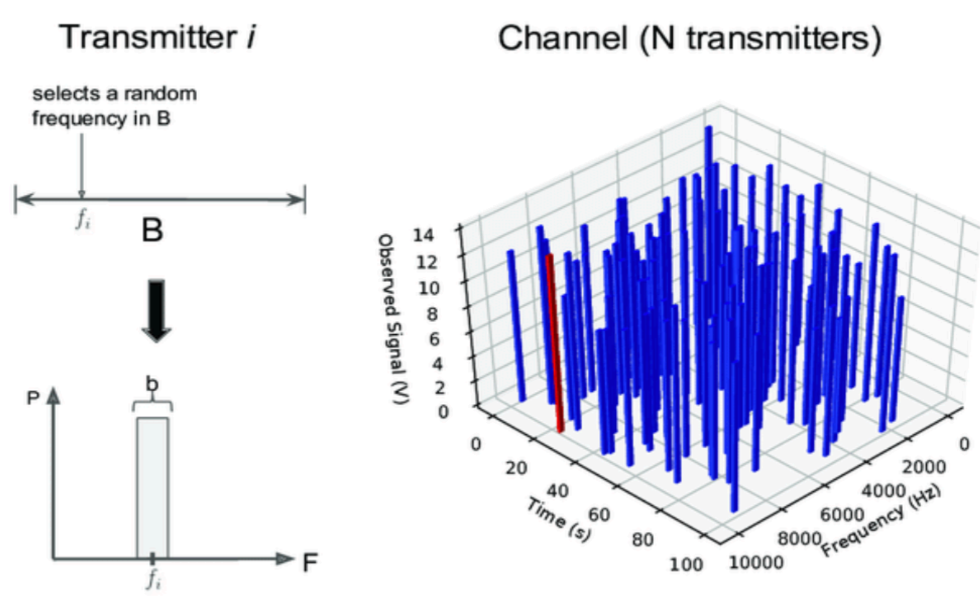

Fig 3 : Time & Frequency diversity

- **Spatial diversity** : radio planning is built in a way that 3 base stations receive the same message. This technique increases the chance to receive the messages in case of packet loss.

Sigfox radio range calculation

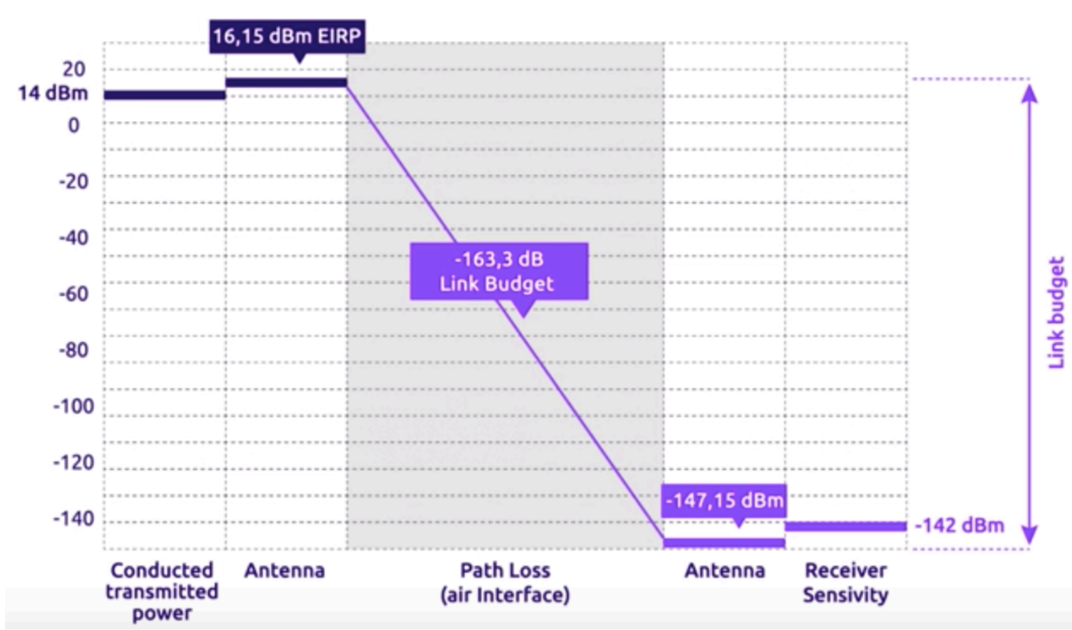

Fig 4 : Long range protocol

As seen before, in Europe, Sigfox uses a 192 kHz wide bandwidth, between 868 MHz and 868.2 MHz. ETSI EN 300 220 regulation refers to a maximum transmitted power of **25 mW** for this bandwidth.

As we can observe in the fig 4, from Sigfox documentation, the sensitivity of a Sigfox receiver is between **-142 dBm** at 100 bps and -134 dBm at 600 bps.

The **link budget** is a metric used by Sigfox to express the attenuation. It is the sum of the sensitivity of the base station, the antenna gains and the output power on the object's side. Supposing ideal conditions, such has no loss due to the antenna we can compute the link budget, which is of **-163.3 dB** as shown on fig 4.

Sigfox radio range depends on the localization. In a **rural** environment, Sigfox protocol covers **30 to 50 kilometers** while in an **urban** environment it covers **3 to 10 kilometers**.

Using **Friis formula**, we can calculate the radio range in free space environment with the link budget previously obtained.

$$L_p(dB) = 32.4 + 20\ log(d(km)) + 20\ log(d(km))$$

$$L_p(dB) = 32.4 + 20\ log(d(km)) + 20\ log(f(868M))$$

$$L_p(dB) = 32.4 + 58.77 + 20\ log(d(km))$$

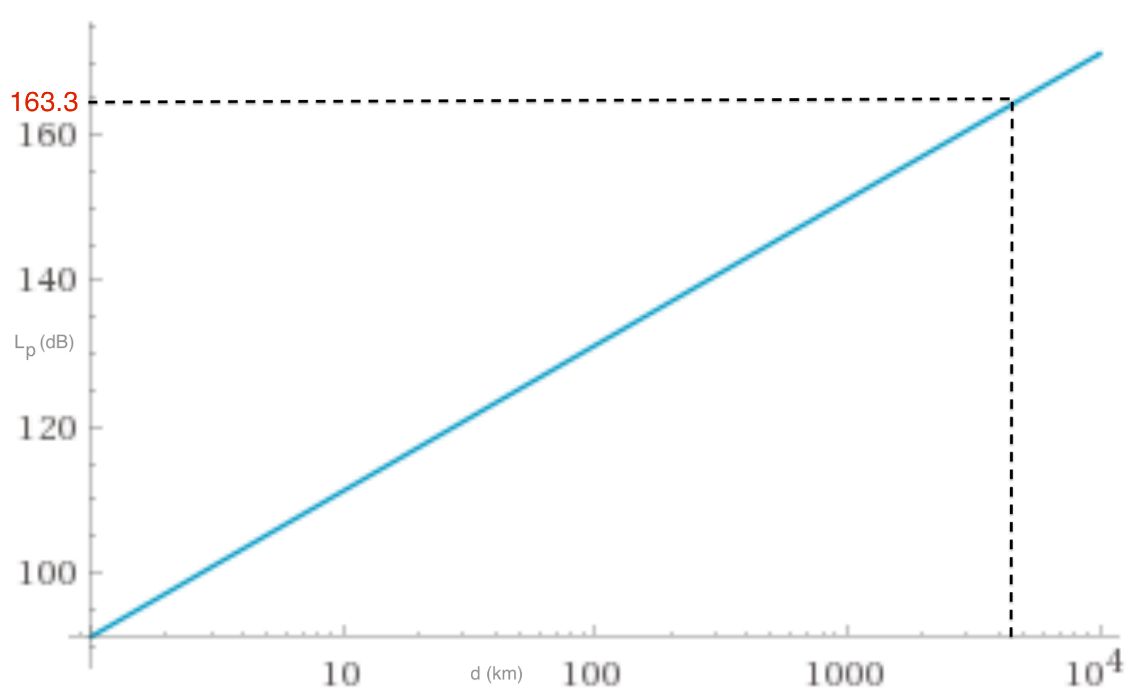

Fig 5 : Calculation of the radio rate in free space environment

$$\text{So, } 20\, log(d(km)) = 163.3 - 91,17 \quad dB$$

$$d = 10^{\frac{163.3-91,17}{20}} = 4041.1\ km$$

Resolving this equation we found a radio range of **4041.1 kilometers**. This value is quite optimistic because we consider a completely free space with the maximum power and ideal conditions of reception.

It is then interesting to study the influence of buildings on this radio range. To do so, we computed the necessary radio range for outdoor application. We have used the **model COST231-Hata** with the following estimation of the path loss :

$$L_u(dB) = 69.55 + 26.16\, log(f) - 13.82\, log(Hb) - A(H_m) + (44.9 - 6.55 log(Hb)) log(d) - B$$

This estimation is taking into account the two following correction factors :

$$A(H_m) = (1.1\, log(f) - 0.7) H_m - (1.56\, log(f) - 0.8)$$

$$B = 30 - 25\, log(BuildingArea\ \%)$$

H_m , the height to floor of the end-node antenna, is 1 meter and H_b , the height of the base station, is 15 meters. We computed the path loss with 3 different percentages of building area : **5%, 7,5%, and 10%.**

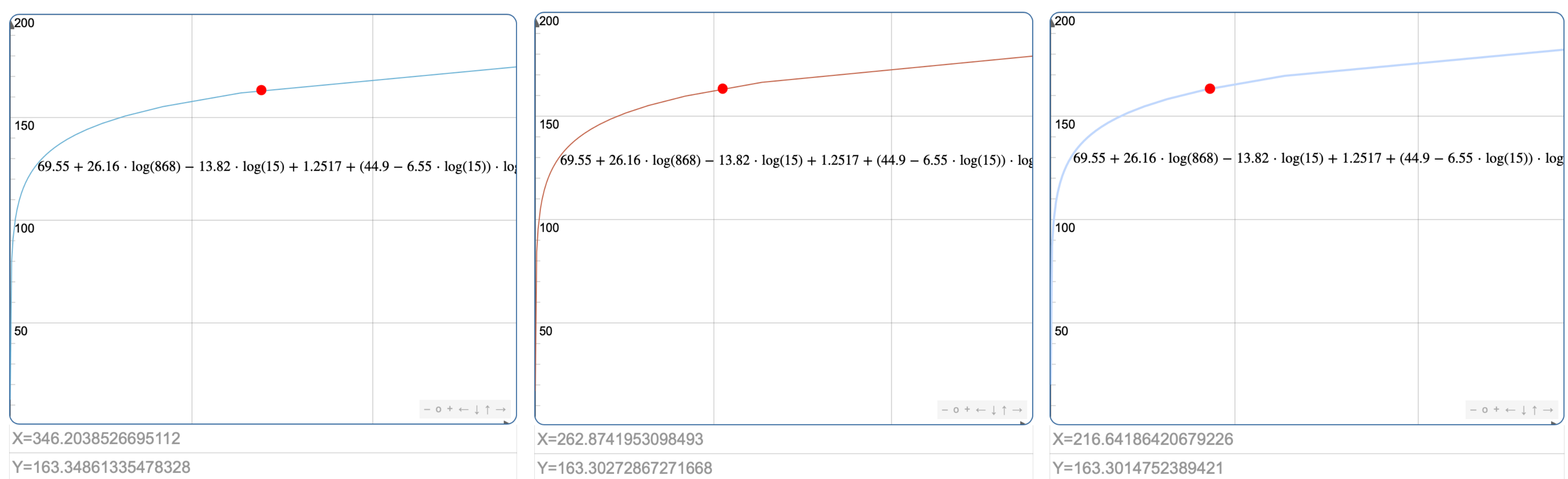

Fig 6 : Path loss with 5% building area, 7,5% building area and 10% building area, regarding the distance

On these three graphics, we can observe the evolution of the path loss regarding the distance between antennas. The first graph on the left represents this evolution with a percentage of 5% of the building area. We can observe, with the same method as

Conclusion

Through this study, we have learned a lot about SIgfox and some important aspects of wireless sensor network protocol. We have seen how the messages are modulated and how to deal with the occupation of bandwidth the transmit the maximum messages, using the less power possible. Sigfox is an ultra narrowband protocol, this characteristic allows long-range communications with low power consumption. However, we have seen with some calculations that the values given by Sigfox are very optimistic and will not be verified in real urban environments.

Sources

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