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LoRa & LoRaWAN
(**Lo**ng-**Ra**nge **W**ide **A**rea **N**etwork)

- Noël Jumin
- Clément Gauché
- Robin Marin-Muller
- Yohan Boujon

Introduction

Noël Jumin

- Long Range
- Long distance communication

- Low power consumption
- Created by a grenoble’s start up in 2009

History, Creation, Development, Evolution of LoRa

Clément Gauché

History & creation of LoRa

2009

Cycleo

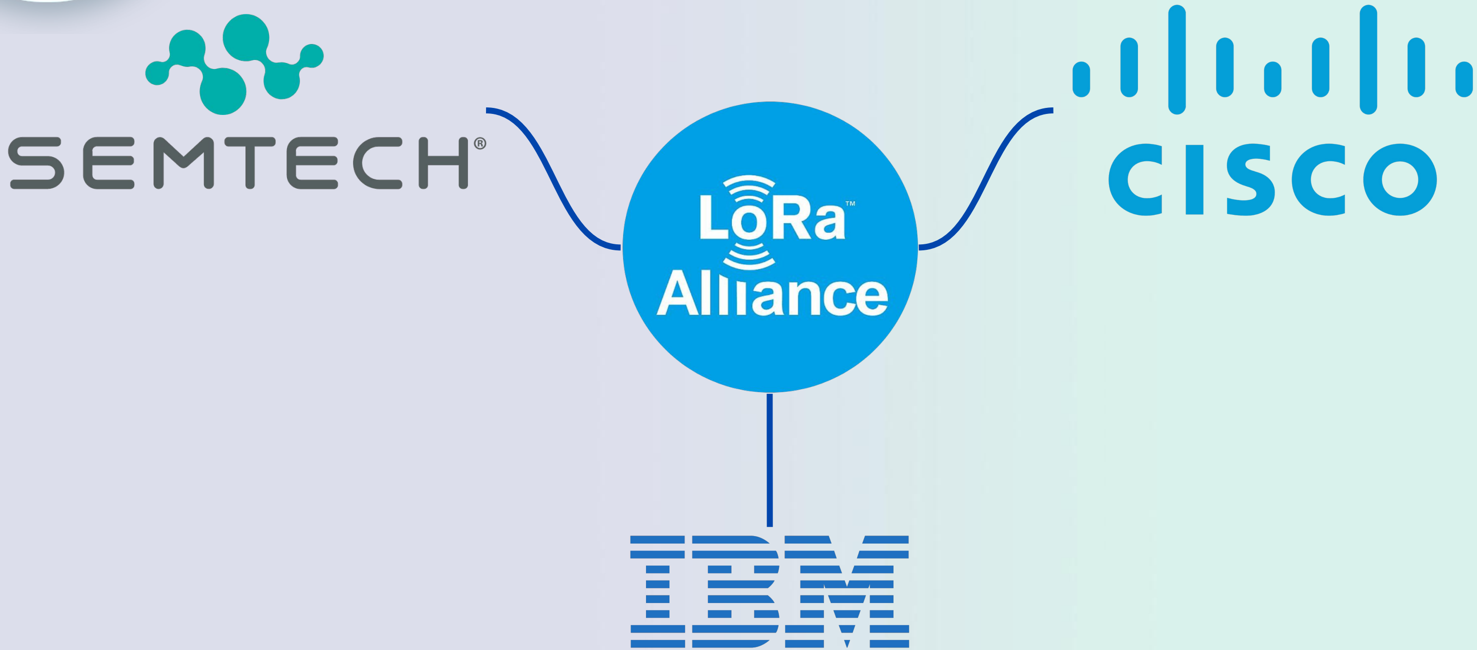
Cycleo, a French company, developed a long-range communication technology based on Chirp Spread Spectrum (CSS) modulation. This technology became the foundation for LoRa.

2012

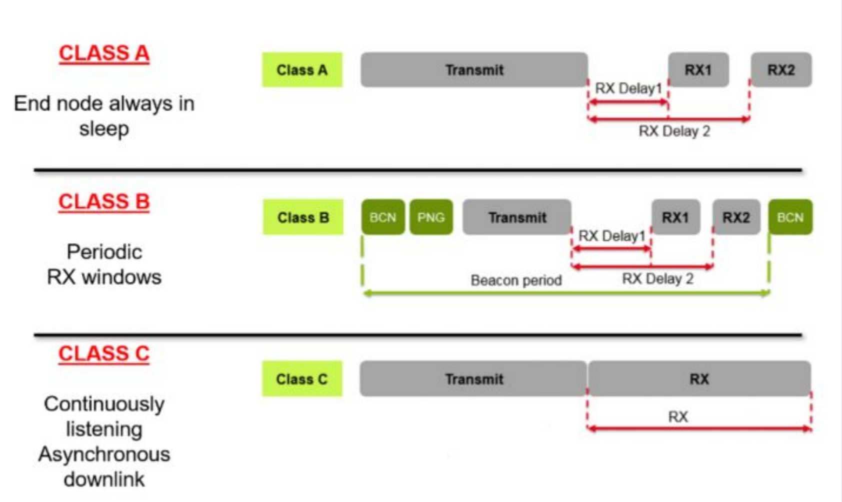
Semtech

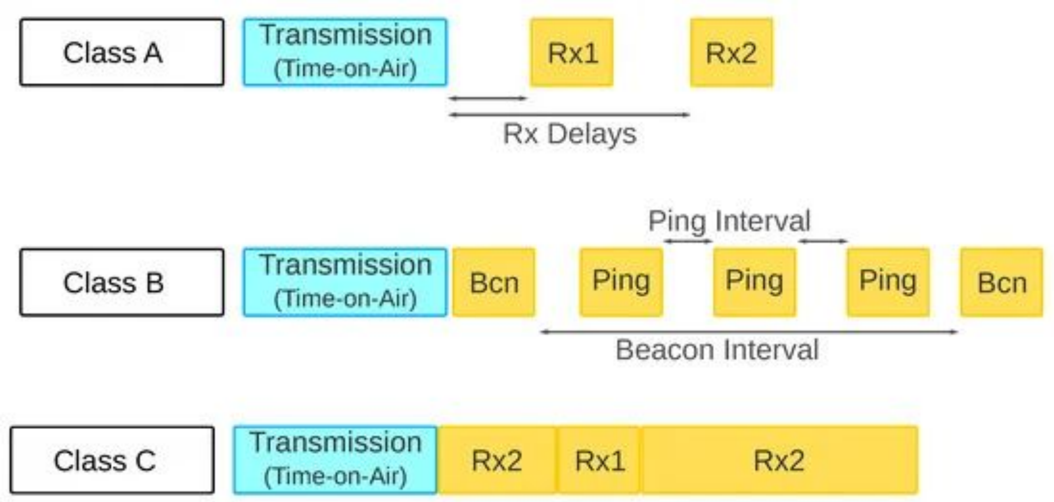
Semtech acquired Cycleo, gaining access to LoRa technology. Semtech began developing LoRa for IoT applications, laying the groundwork for its commercial expansion.

Formation of the LoRa Alliance



Evolution of LoRa Technology





Adoption and Industry Applications

Smart Cities

Agriculture

LoRa™

Environmental
Monitoring

Logistic

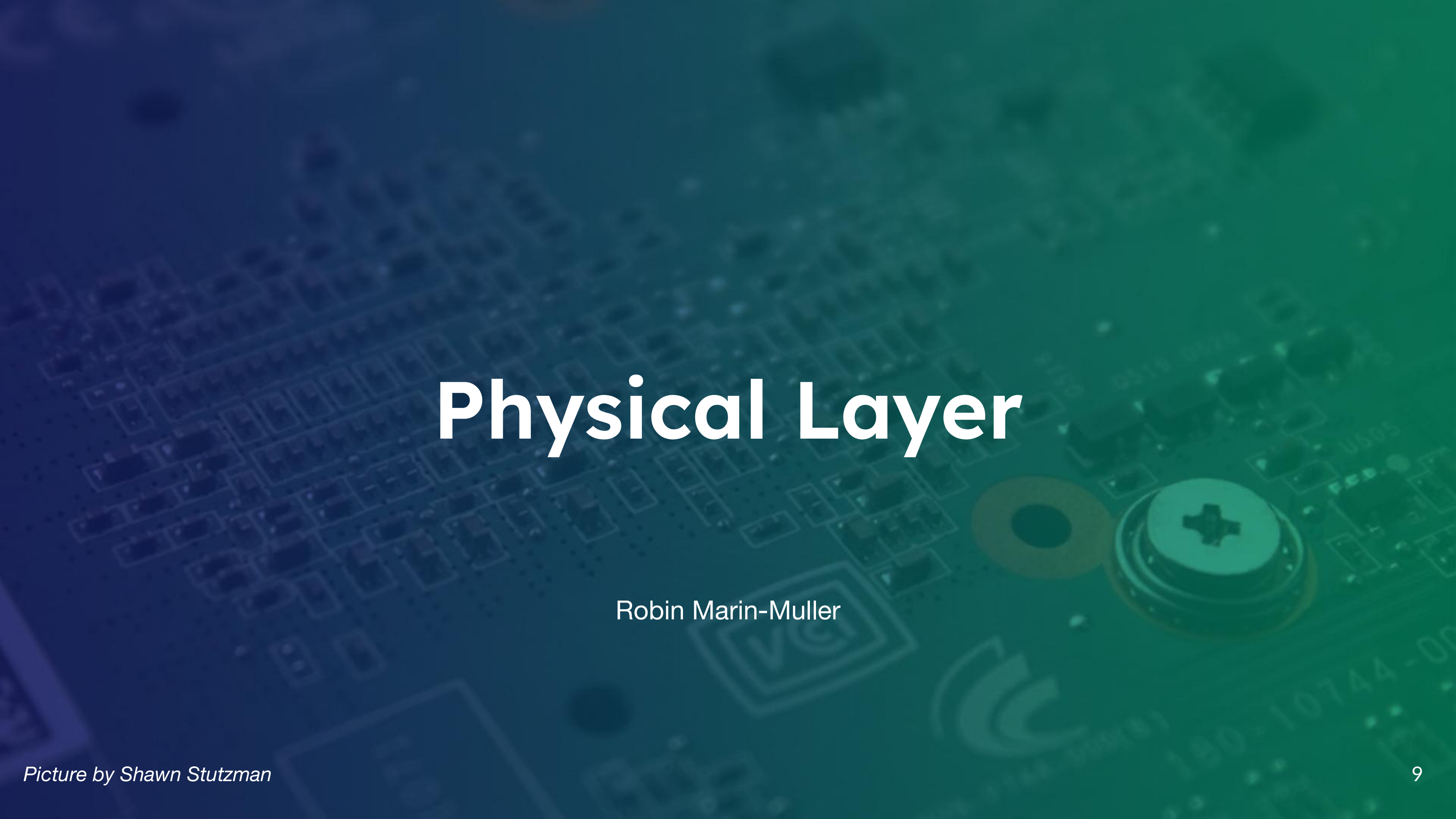
LoRa’s competitors

LPWA – the technical knockout

	NON-CELLULAR		CELLULAR	
	LoRaWAN	Sigfox	NB-IoT	LTE-M
Bandwidth	125kHz	100Hz	200kHz	1.08MHz
Coverage	165dB	165dB	164dB	156dB
Cell capacity	40,000	1 million	200,000	1 million
Payload capacity	243 bytes	12 / 8 bytes (UL / DL)	1600 bytes	-
Battery life	15+ yrs	15+ yrs	10+ yrs	10+ yrs
Throughput	50kbps	600bps	200kbps	1mbps
Two-way comms	Yes	Yes	Yes	Yes
Security	AES 128 bit	AES 128 bit	3GPP (128-256 bit)	3GPP (128-256 bit)
Localisation	Yes (TDOA)	Yes (RSSI)	Yes (3GPP Rel 14)	Yes (3GPP Rel 14)

Source: ABI Research

https://www.rcrwireless.com/20190829/carriers/lpwa-matchup-round-five

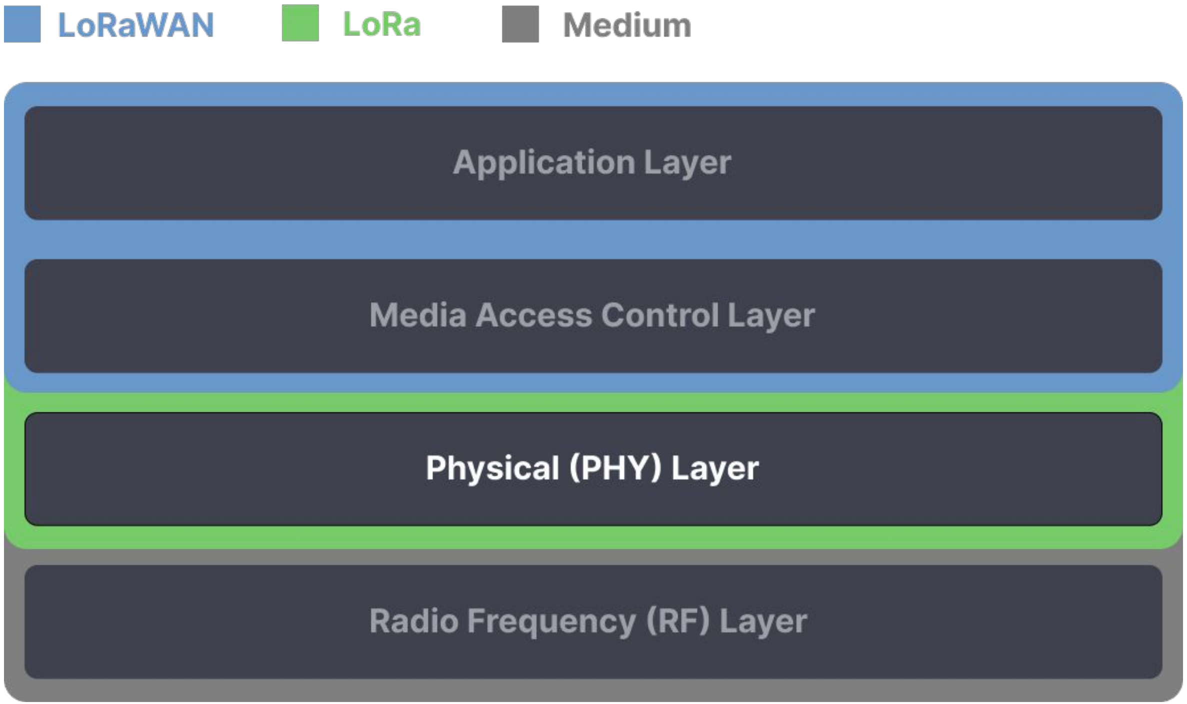


Physical Layer

Robin Marin-Muller

Picture by Shawn Stutzman

LoRa Physical Layer

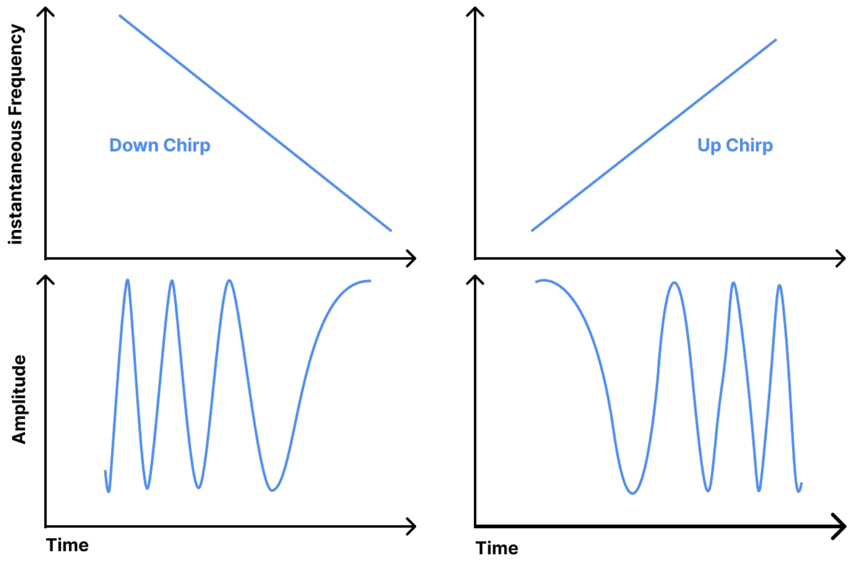


Role of the PHY Layer: Provide a robust, long-range radio communication link with low power consumption.

ISM Bands: 169 MHz, 433 MHz (Asia), 868 MHz (Europe), and 915 MHz (North America).

Modulation Chirp Spread Spectrum (CSS) : Basics

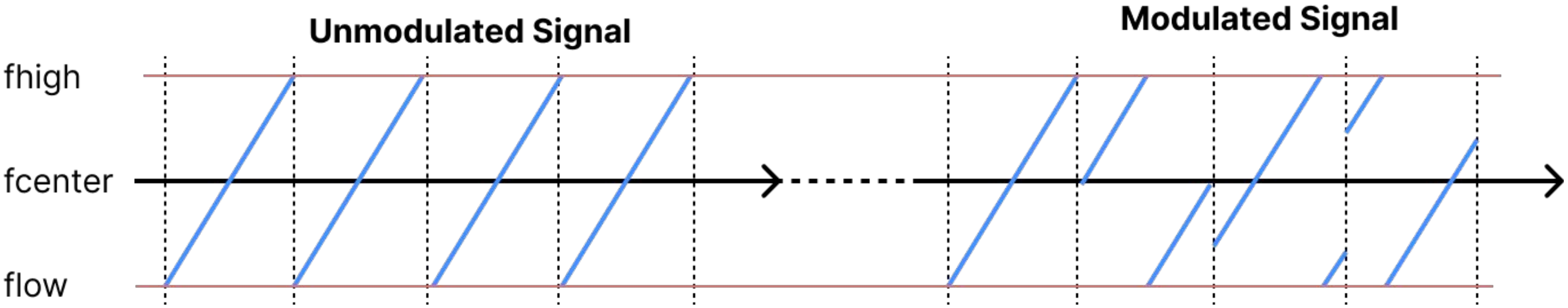
Modulation: LoRa uses a unique spread spectrum modulation type capable of transmitting information below the noise level.



Advantages:

- High immunity to noise and interference.
- Ability to transmit over long distances with low power levels.

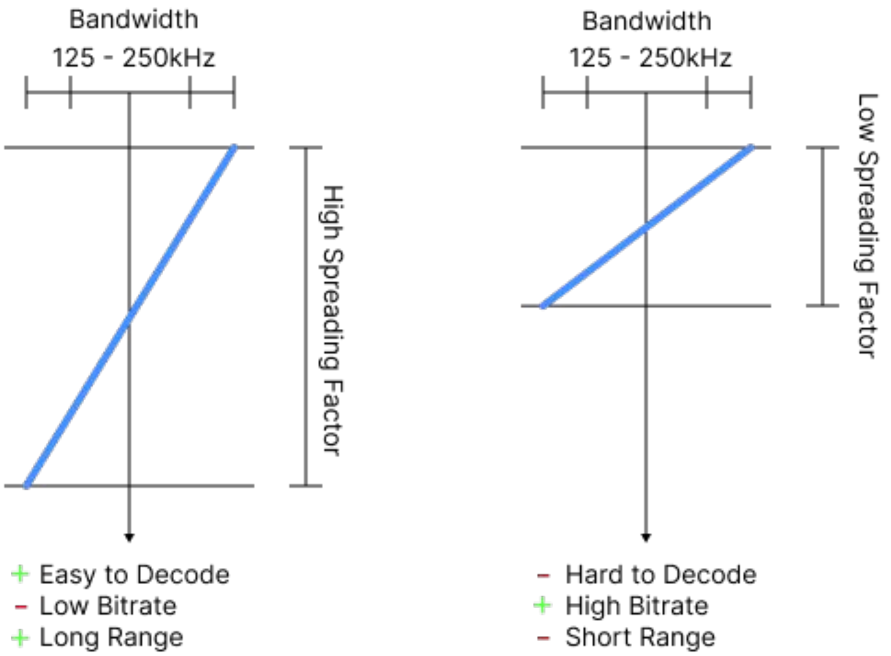
Modulation Chirp Spread Spectrum (CSS) : Basics



Chirp Signals: Uses chirp signals whose frequency varies linearly over time, enabling interference-resistant encoding.

Modulation Chirp Spread Spectrum (CSS) : Spreading Factor

Facteur d'étalement (Spreading Factor)

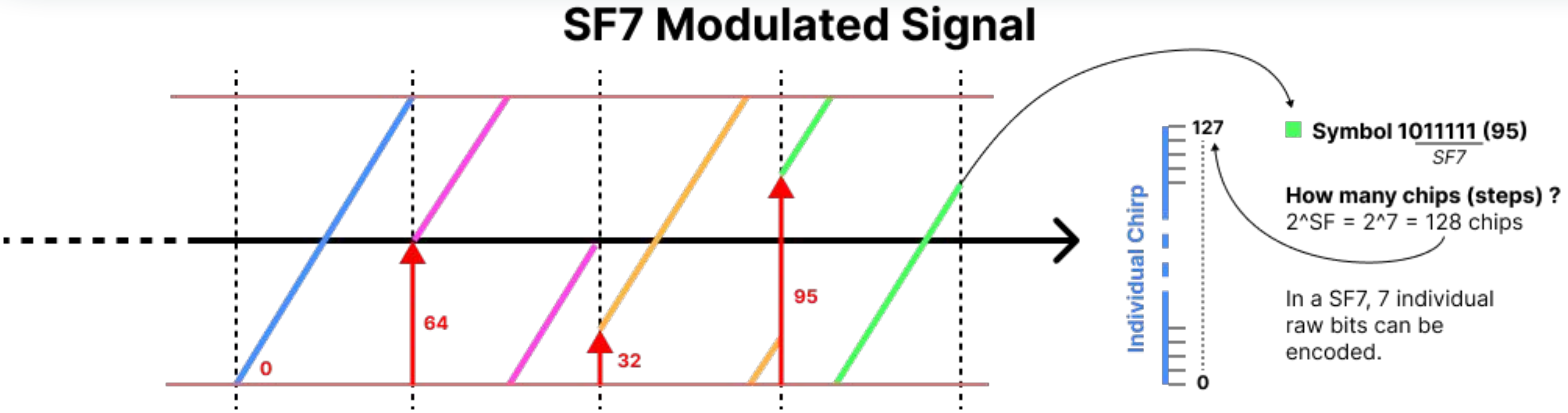


Orthogonalité des Spreading Factors : Les signaux LoRa utilisant différents SF peuvent coexister sur le même canal sans interférer entre eux : le récepteur différencie en fonction du SF.

NB: Orthogonal = Produit Scalaire Nul, les signaux ne se chevauchent pas ni n'interfèrent de manière constructive.

$$\int_0^T f(t) \cdot g(t)\, dt = 0$$

Modulation Chirp Spread Spectrum (CSS) : Symbols

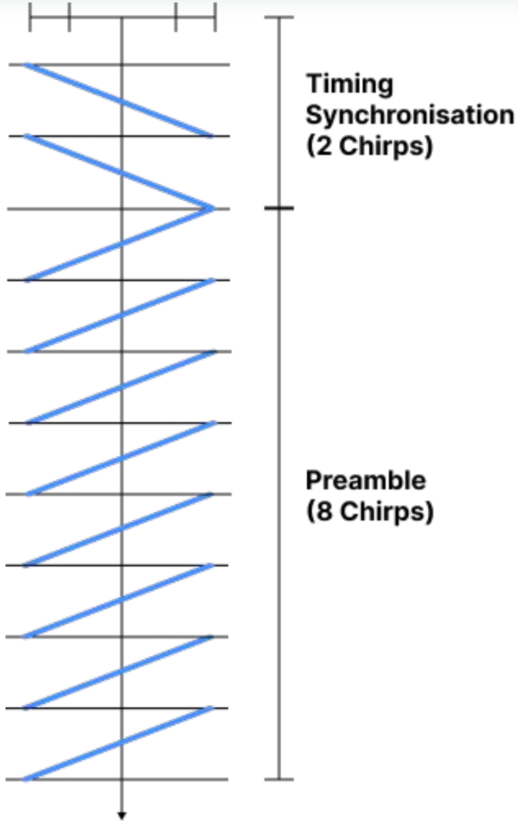


Symbol Representation: A symbol represents one or more data bits. A symbol has 2^SF possible values.

Direct Influence on Range and Data Rate: The higher the SF (SF6 to SF12), the greater the range but the lower the data rate.

Structure et composition d'une trame LoRa

Preamble	Synchronization	Payload	CRC



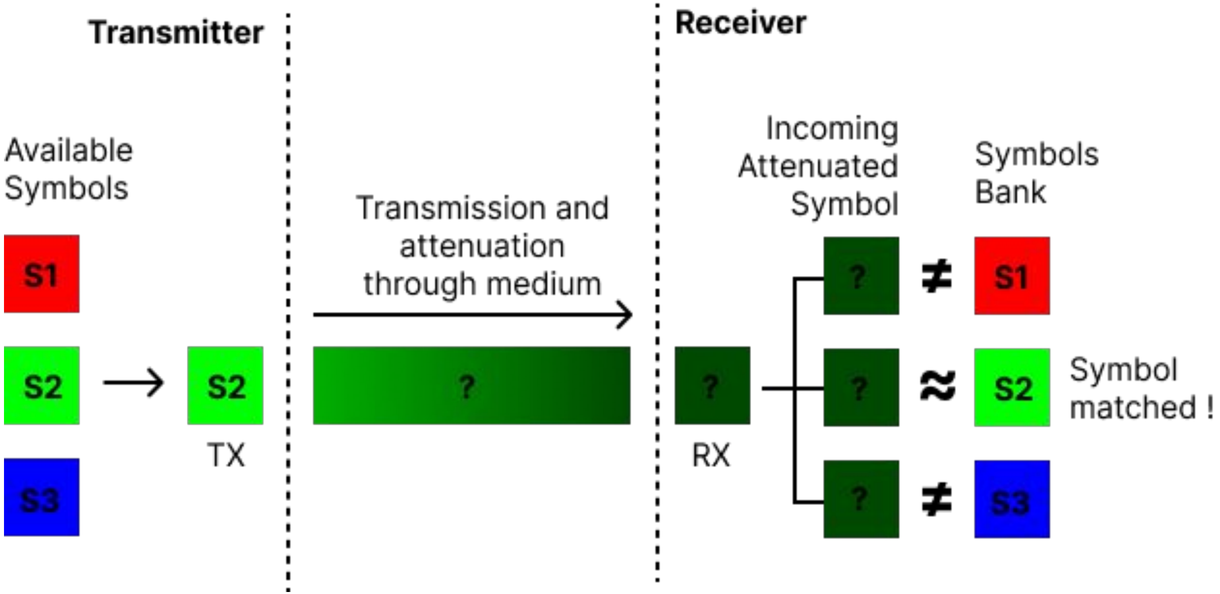
Preamble: Synchronization sequence used by the receiver to lock onto the signal.

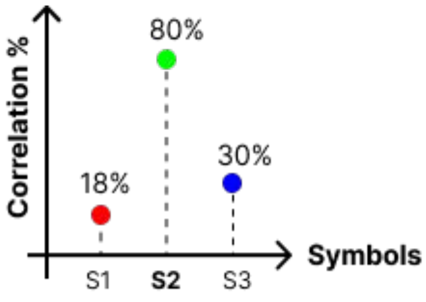
Synchronization

Payload: Contains the data transmitted by the node.

CRC (Cyclic Redundancy Check): Ensures data integrity.

LoRa Demodulation : Correlation





NB: Transmitter symbols must be the same as receiver symbols, in other words the Spreading Factor must match between RX and TX !

Temps de montée de la trame (ToA) et Sensibilité

$$\text{ToA} = \frac{\text{nombre de symboles} \times \text{durée d'un symbole}}{\text{fréquence de transmission}}$$

Factors Influencing ToA (Time on Air):

- High SF = increased ToA reduces energy consumption but increases latency.
- Bandwidth: A wider BW decreases ToA.

$$\text{Sensibilité} = -174 + 10\log(\text{BW}) + \text{NF} + \text{SNRmin}$$

-174dBm: Thermal noise level.
BW: Bandwidth in Hz.
NF: Noise Figure of the receiver (lower NF means better sensitivity).
SNR: Signal-to-noise ratio.

Receiver Sensitivity: The receiver's ability to detect a weak signal while maintaining sufficient reception quality.

Range and Limitations

ISM Band Concurrency: Shared bands can lead to collisions and interference.
Regulatory Duty Cycle: 1% in Europe.
Transmission Power: Limited to 14 dBm in Europe for 868 MHz.

Signal attenuation through different materials

Material attenuation	(dB)
Glass (6mm)	0.8
Glass (13mm)	2
Wood (76mm)	2.8
Brick (89mm)	3.5
Brick (178mm)	5
Brick (267mm)	7
Concrete (102mm)	12
Stone wall (203mm)	12
Brick concrete (192mm)	14
Stone wall (406mm)	17
Concrete (203mm)	23
Reinforced concrete (89mm)	27
Stone wall (610mm)	28
Concrete (305mm)	35

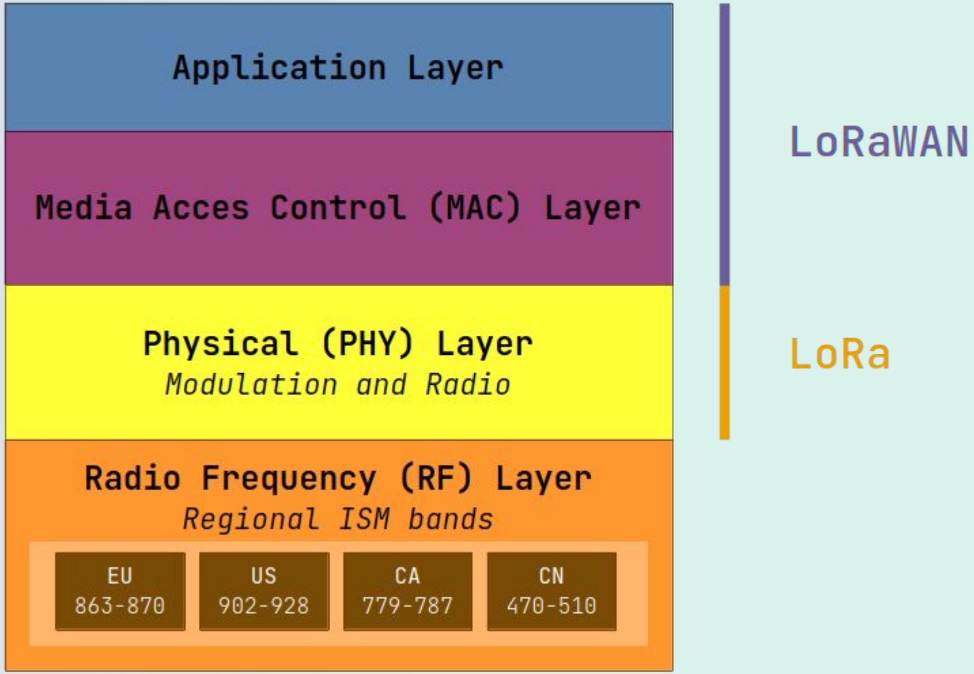
Media Access Control in LoRa

Yohan Boujon

Picture by Lucas Zimmermann

Differences between LoRa and LoRaWAN

- “LoRa” is only the physical layer
- LoRaWAN is an open protocol that can be used or not
- Using the LoRaWAN protocol stack can help greatly extend the distance between devices

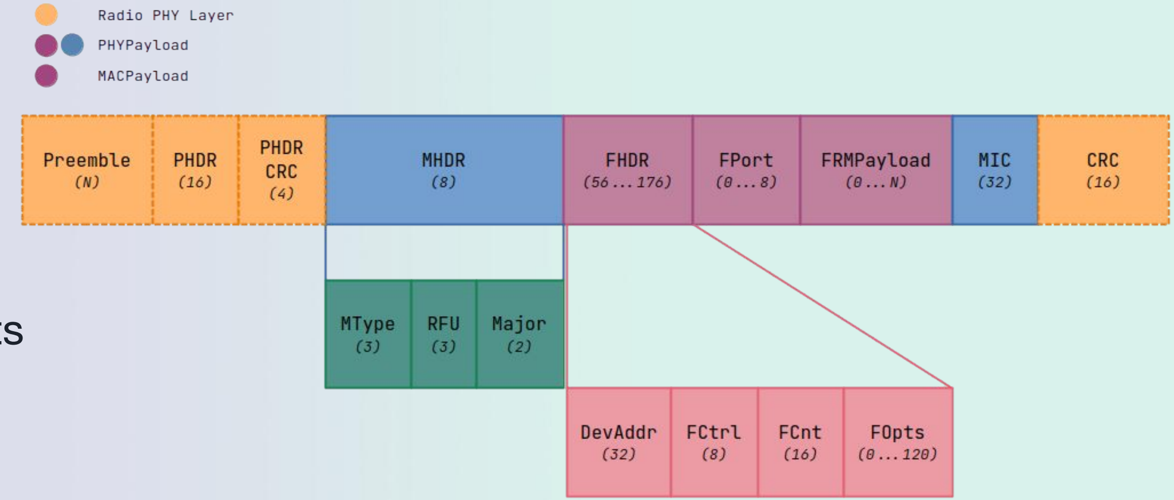


LoRaWAN protocol in depth

MacPayload

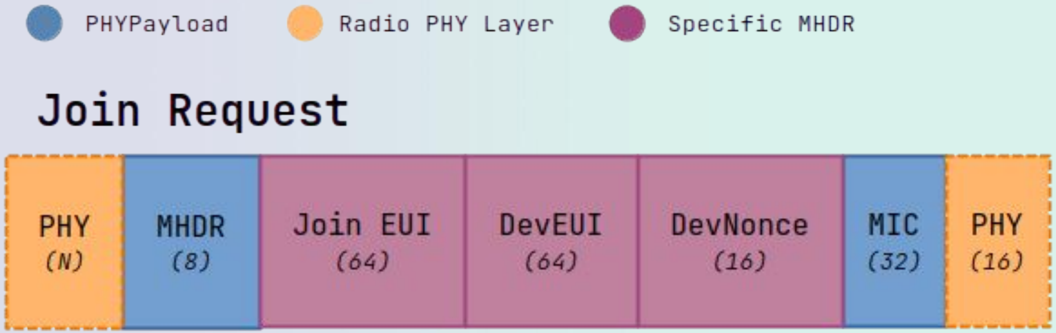
- **Class A**: Low power
- **Class B**: Periodic checking
- **Class C**: High power usage, constantly checking for packets

- **MType:** Indicates the type of the message, here only data



LoRaWAN protocol in depth

Join Request

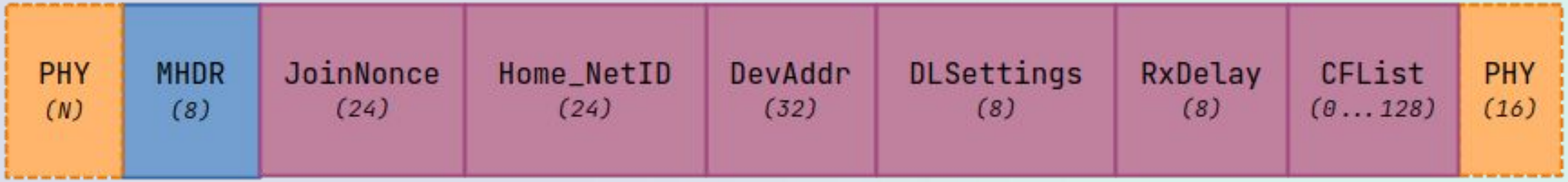


- **OTAA:** Over the Air Activation Protocol
- **JoinEUI**: Similar to an IP Address/DNS domain name
- **DevEUI**: Similar to a Mac address
- **DevNonce**: Random number generated by the device. Used later for security.

LoRaWAN protocol in depth

Join Accept

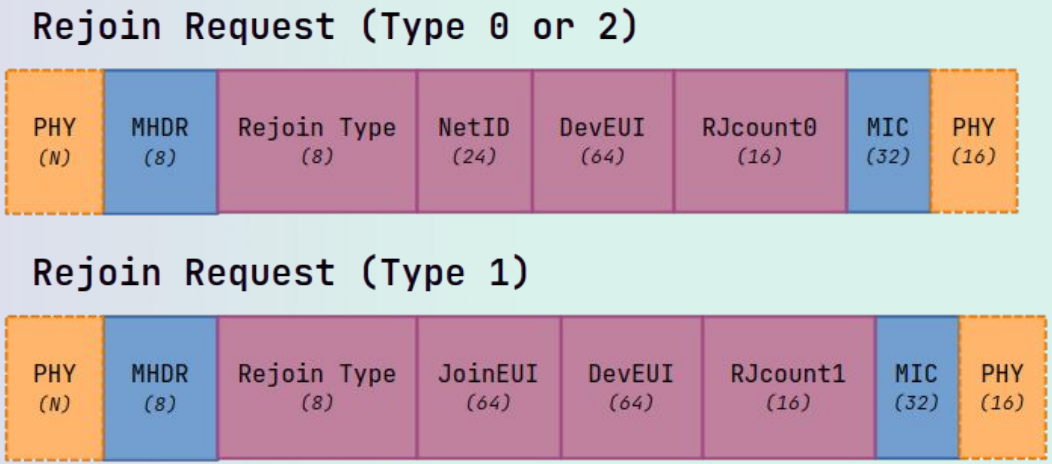
Join-Accept



- **JoinNonce**: Random number generated by the gateway. Used later for security.
- **NetID**: Multi-network ID given by the gateway.
- **DevAddr**: Non-unique ID, similar to a Virtual IP.
- **DLSettings** & **RxDelay**: Data rate and Delay.
- **CFList**: Optional field for the network.

LoRaWAN protocol in depth

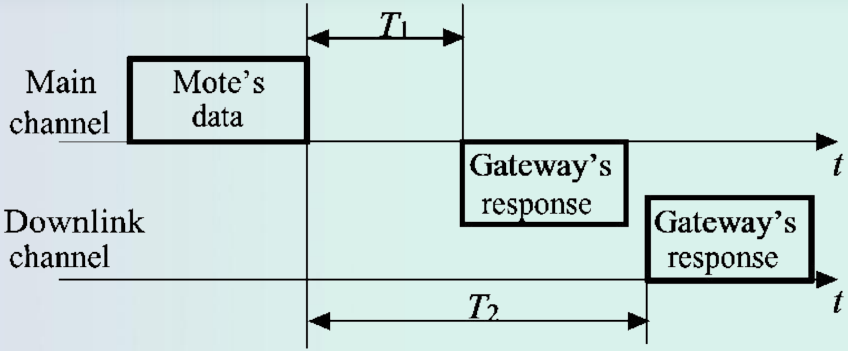
Rejoin Request (Type 0/2 & 1)

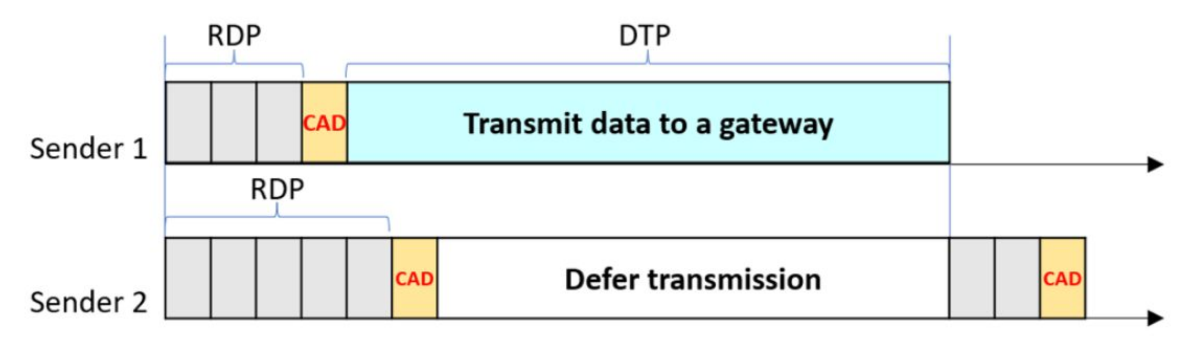


- **Type 0/2**: Reset any parameters of the network, asks for a new *DevAddr*.
- **Type 1**: Similar to a *Join-Request*.
- **RJ Count 0/1**: Number of time the device did a *Rejoin-Request*.

Channel access & Collision avoidance

- Multiple **channels** available
- **Software confirmation** (Confirm Data)
- **Delay Slot** with random number
- **Low bandwidth**
- **Short duty cycle**





Security Mechanisms

```
uint128_t NwkSKey = aes128_encrypt(AppKey, 0x01 | AppNonce | NetID | DevNonce | pad16 );
uint128_t AppSKey = aes128_encrypt(AppKey, 0x02 | AppNonce | NetID | DevNonce | pad16 );
uint128_t cmac = aes128_cmac(AppKey, MHDR | AppNonce | NetID | DevAddr | DLSettings | RxDelay | CFList);
uint3_t MIC = cmac[0..3];
uint128_t result = aes128_decrypt(AppKey
                                  ,AppNonce | NetID | DevAddr | DLSettings | RxDelay | CFList | MIC);
```

- **NwkSKey** *(Network)* & **AppSKey** *(Device)* calculated to encrypt data.
- **JoinNonce/AppNonce** & **DevNonce** gathered during *OTAA* process.
- **Message Integrity Control** uses these field.
- **AppKey** is stored inside the device and is a unique ID.

Power Consumption

Noël Jumin

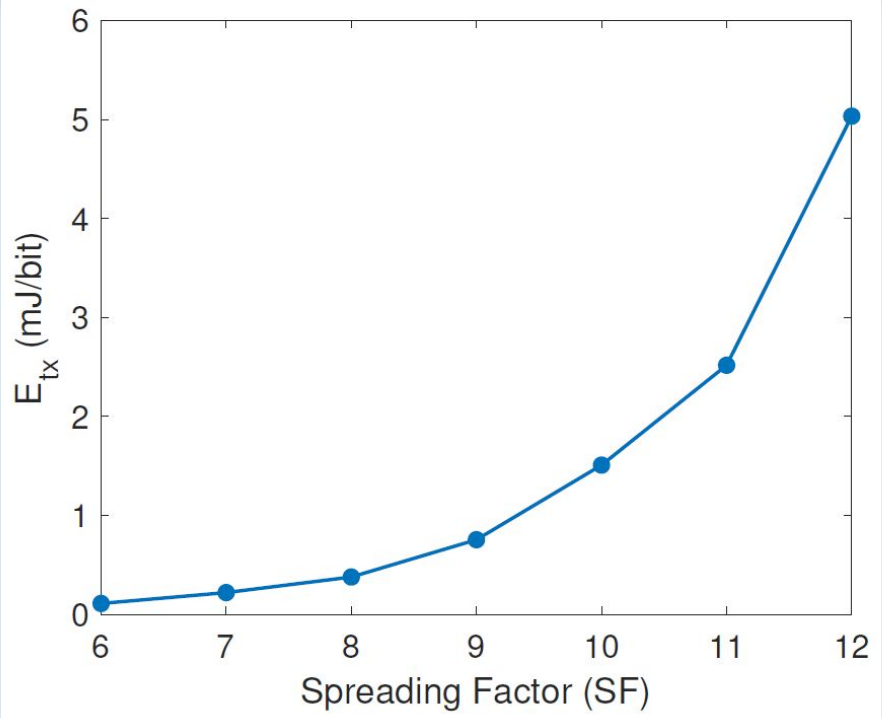
Image by Walid Beno

Power consumption

Compare to SIGFOX or NB-IOT, LoRA is the one that consume the less
The important parameters are:

- Transmission power
- Bandwidth
- Payload size
- Spreading factory

High SF = High range and improve noise resilience
Low SF = Shorter transmission time (high data rate) and low power consumption



LoRa Time-on-Air vs different SF with 8 bytes payload (CR = ⅘, BW = 125kHz and 8 preamble symbols)

Power consumption

Example:

We want a communication over a long range with theses parameters:

- **SF = 12**
- **Bandwidth = 125kHz**
- **TX power = 100mW**
- **Payload = 10 bytes**

Low consumption per bit for a communication of more than 1km

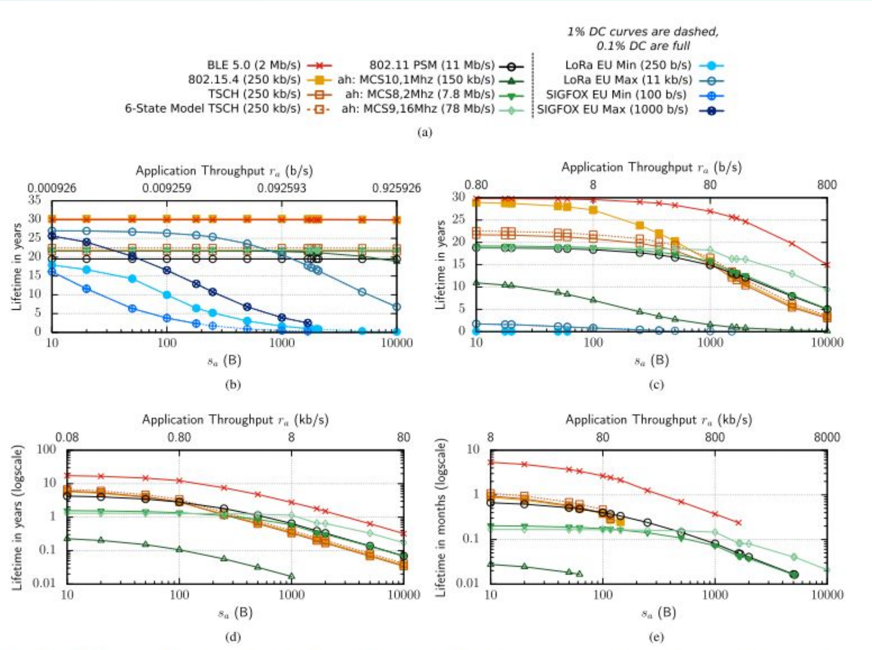
$$Symbol\ Duration = \frac{2^{SF}}{Bandwidth(Hz)} = 32.8\ ms$$

$$Transmission\ Duration = Symbol\ Duration(s) * Number\ of\ Bits = 2.624\ s$$

$$Energy\ per\ bit = \frac{Transmission\ Power(W) * Transmission\ Duration(s)}{Number\ of\ Bits} = 3.28\ mJ$$

Comparison with other protocols

- BLE is better one in energy saving BUT
- BLE cannot go further than ~15 meters
- LoRA can go further than 1 km
- Compare to SIGFOX or NB-IOT, LoRA is the one that consume the less



[Different t_a and data size s_a, in bytes, leading to varying r_a, impact lifetime for a starting energy E_0=13.5kJ, PER=0. The bottom x-axis is the data size in bytes per t_a while the top x-axis presents the corresponding data rate r_a in b/s. No packet loss or clock drift is assumed. (a) legend. (b) varying s_a, constant t_a=1 day. (c) varying s_a, constant t_a=100s. (d) varying s_a, constant t_a=1s. (e) varying s_a, constant t_a=10ms]

Conclusion

Clément Gauché

Sources

History of LoRa

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LoRa Physical Layer

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