PWD Specification

Document version

	Release date	Changes
V0.1	17/09/2019	Requirements added
V0.2	4/10/2019	LoRa specs, Link budget
V0.3	4/10/2019	PCB antenna specs added

Table of Contents

1 Technical Requirements for PWD wearable tracker

1.1 Sender requirements

The sender is embedded in the logo tag of the clothes so it has a very reduced size, is composed of:

GPS + GPS antenna + LORA chip + LORA antenna → SIP package

Battery – (possibly flexible), of long life (1 year) ???mA or allow induction charging - ???mA

Flexible PCB

Has to be waterproof (IP 68) with nano particle protection from nanoflowX -V3 solution

1.2 Receiver requirements

The receiver can be attached to the case of the cell phone or just put in a key chain it does not have same size restriction and is composed of:

- Bluetooth + Lora chip + Lora Antenna
- Bluetooth connectivity is so that mobile phone App can receive the Lora messages and provide users with location information
- Battery – induction charging - ???mA
- Display to indicate information on sender activation and reception

Be waterproof (IP 68) with nano particle protection from nanoflowX -V3 solution

2 Possible HW solutions

Two possible SIP solutions:

2.1 S76G/S78G from ACSIP

- Variants:
  - S76G: SX1276 (Lora chip) + STM32L073x (STM Arm cortex-M0 CPU)+ GNSS chip (SONY CXD5603GF)
  - S78G: SX1278 (Lora chip) + rest is identical

Note: difference between 76/78 chips is the Lora Semtech transceiver
https://www.semtech.com/products/wireless-rf/lora-transceivers/sx1276

SX1278 can operate in 137-525MHz while SX1276 supports frequency 137-1020 MHz so for our purposes (use of 868MHz band we should select SX1276 or similar variants)

- Form factor: 13mm X 11mm X 1.55 mm
- Datasheet on CPU STM32L073x: https://www.st.com/content/ccc/resource/technical/document/reference_manual/2f/b9/c6/34/28/29/42/d2/DM00095744.pdf/files/DM00095744.pdf/jcr:content/translations/en.DM00095744.pdf
- Product datasheet: http://www.acsip.com.tw/index.php?action=products-detail&fid1=19&fid2=&fid3=&id=41
- Product brief: http://www.acsip.com.tw/upload/product_attach/S76G_Brief_Rev.04.pdf

- Development board: http://www.acsip.com.tw/index.php?action=products-detail&fid1=21&fid2=&fid3=&id=103

2.2 ATSAMR35J16BT from Microchip

- Variants:
    - SAMR35 has several variants R35 has no USB (vs.R24) and J16 is the lowest memory variant with :LoRa SiP Transceiver 64K Flash 8K SRAM, 4KB LP SRAM, T&R
    - Need to add a GNSS SiP module. Example: https://www.u-blox.com/en/product/zoe-m8b-module (4.5 x 4.5 x 1.0mm) or https://www.u-blox.com/en/product/eva-m8-series
- Form factor: 6 mm x 6 mm
- Product datasheet: http://ww1.microchip.com/downloads/en/DeviceDoc/SAM-R34-R35-Low-Power-LoRa-Sub-GHz-SiP-Data-Sheet-DS70005356C.pdf
- Development board: https://www.microchip.com/DevelopmentTools/ProductDetails/dm320111

2.3 Component analysis

Component	Form factor	Costs	Links
SAMR35JXX	6 mm x 6 mm	5,22 eur (250 pcs)	https://pt.farnell.com/search?st=SAMR34
GPS ZOE-M8B	4.5 x 4.5 x 1.0 mm	12.99 eur (100-480 pcs)	https://www.u-blox.com/en/product/zoe-m8b-module
S76G	13mm X 11mm X 1.55 mm	Could only find prices for S76S with no GPS ($13.00)	https://techship.com/products/acsip-lorawan-module-s76s/
Battery (just a starting point)	20mmX20mm	0,433 eur per unit (consumer market)	Example for a 40mAh: https://bit.ly/2lVmXZR

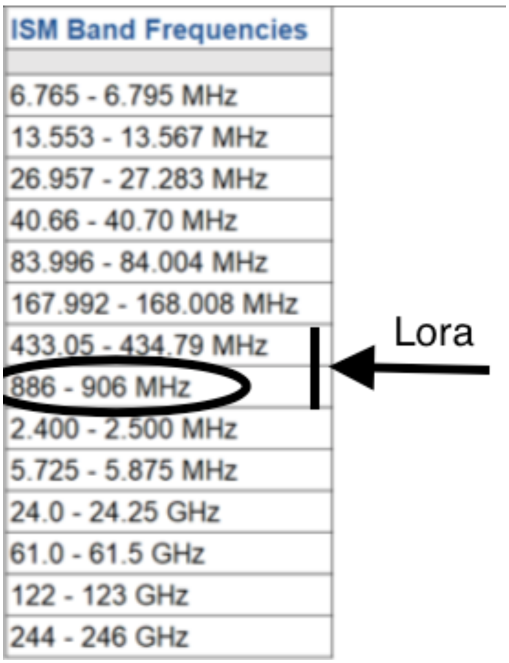
3 Lora Introduction

3.1 Introduction

LoRa is an acronym for **Lo**ng **Ra**nge and it is a wireless technology that operates in the ISM (Industrial, Scientific and Medical) radioband. LoRA is a technology that has several benefits:

- Very resistant to in-band and out-of-band interference
- High immunity to multipath and fading
- Doppler shift resistant (applies to moving devices and high clock tolerance)
- Good sensitivity
- Simple receptor

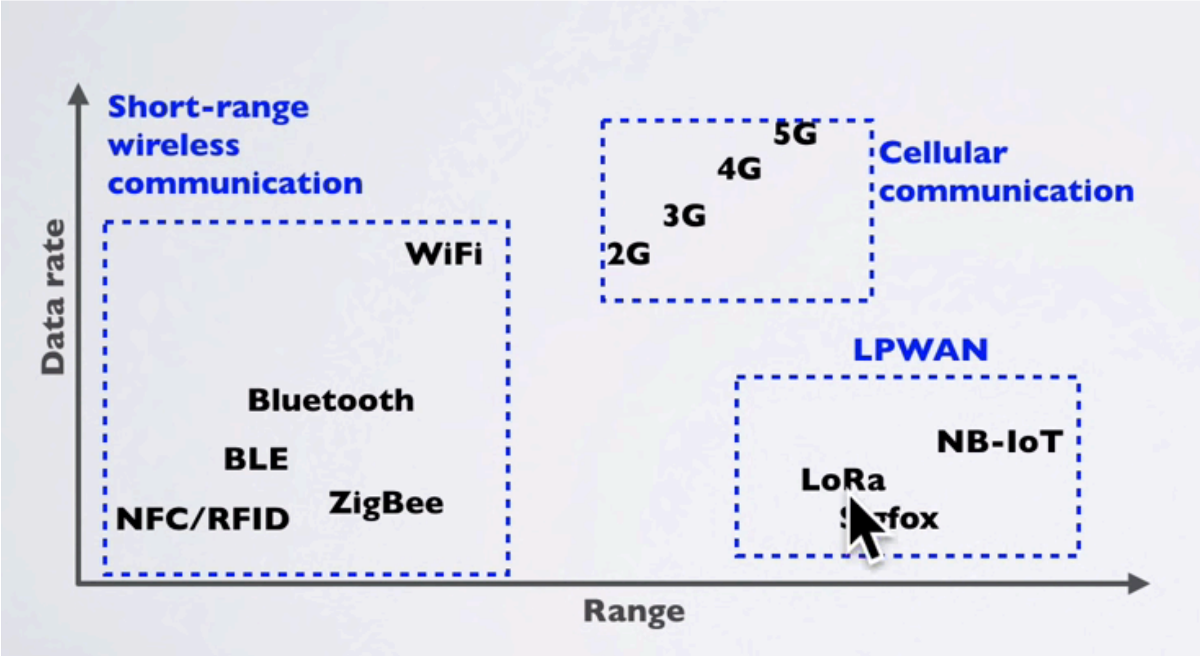
The ISM band frequencies are as follows:



ISM Band Frequencies
6.765 - 6.795 MHz
13.553 - 13.567 MHz
26.957 - 27.283 MHz
40.66 - 40.70 MHz
83.996 - 84.004 MHz
167.992 - 168.008 MHz
433.05 - 434.79 MHz
886 - 906 MHz
2.400 - 2.500 MHz
5.725 - 5.875 MHz
24.0 - 24.25 GHz
61.0 - 61.5 GHz
122 - 123 GHz
244 - 246 GHz

LoRa allows for low powered senders to transmit small data packages (0.3kbps to 5.5kbps) across long distances.

LoRa is part of a family of LPWAN – Low Power Wide Area Network technologies that compete in the same space (Like Sigfox and NB-IoT).



The diference between data LoRa and other technologies (e.g. 3G and 4G) is that LoRa has long range and low transmission power (compared with 3G/4G)

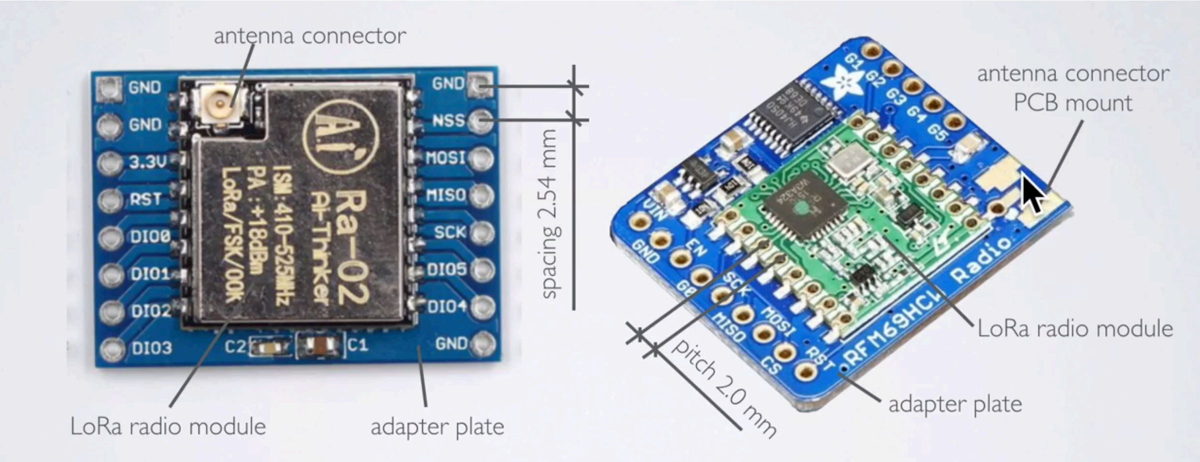
WIRELESS COMMUNICATION COMPARISON

Wireless Technology	Wireless Communication	Range (m)	Tx power (mW)
Bluetooth	Short range	~10	~2.5
WIFI	Short range	~50	~80
3G / 4G	Cellular	~5000	~500
LoRa*	LPWAN	2000-5000 (urban area) 5000-15000 (rural area) > 15000 (direct line of sight)	~20

* Data packages are very small

LoRa technology was developed by French startup Cycleo which developed the modulation technology (Chirp Spread Spectrum). In 2012 Semtech corp. acquired Cycleo. The LoRa radio and modulation Intellectual property (IP) is patented and the source is closed. The LoRa trademark is also patented. Semtech licenses the IP to chip manufacturers like Microchip, STMicroeletronics and HopeRF.

Following are examples of current boards in sale.



3.2 Expected Lora Range

Environment	Range (km)
Urban areas (towns & cities)	2-5
Rural areas (countrysides)	5-15
Direct Line Of Sight	>15

The main impediments to LoRa range is the environment:

- Buildings, mountains, trees
- Fresnel zone
- Jamming by other emitters

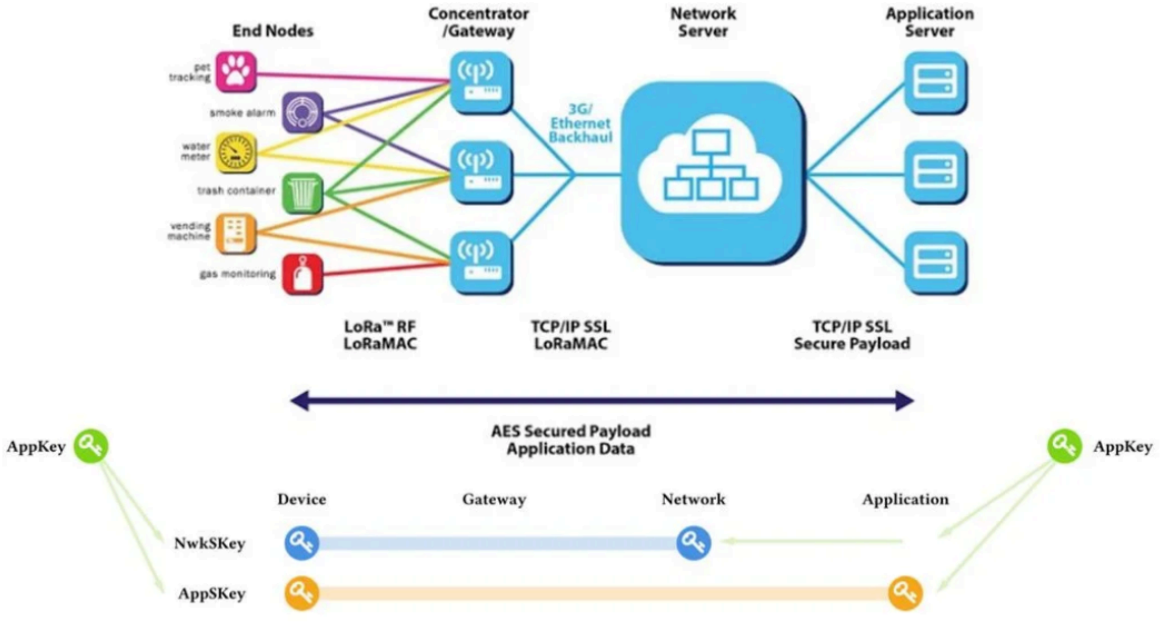
3.3 LoRa versus LoRaWAN

Lora differs from LoRaWAN as follows:

- 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.
- Both are based on the same modulation technology (the same PHY layer): LoRa™, developed by Semtech. The LoRa module implements a simple link

protocol. However, the LoRaWAN module runs the LoRaWAN protocol, a much richer and more advanced protocol, created by the LoRa Alliance.

So LoRaWAN is a complete network architecture that allows the nodes to connect to gateways and transmit to the internet.



Keys and Encryption in LoRaWAN

Figure 1 - What is LoRaWAN - https://lora-alliance.org/resource-hub/what-lorawanr

Here is a diagram that explain the stacks of LoRa and LoRaWAN

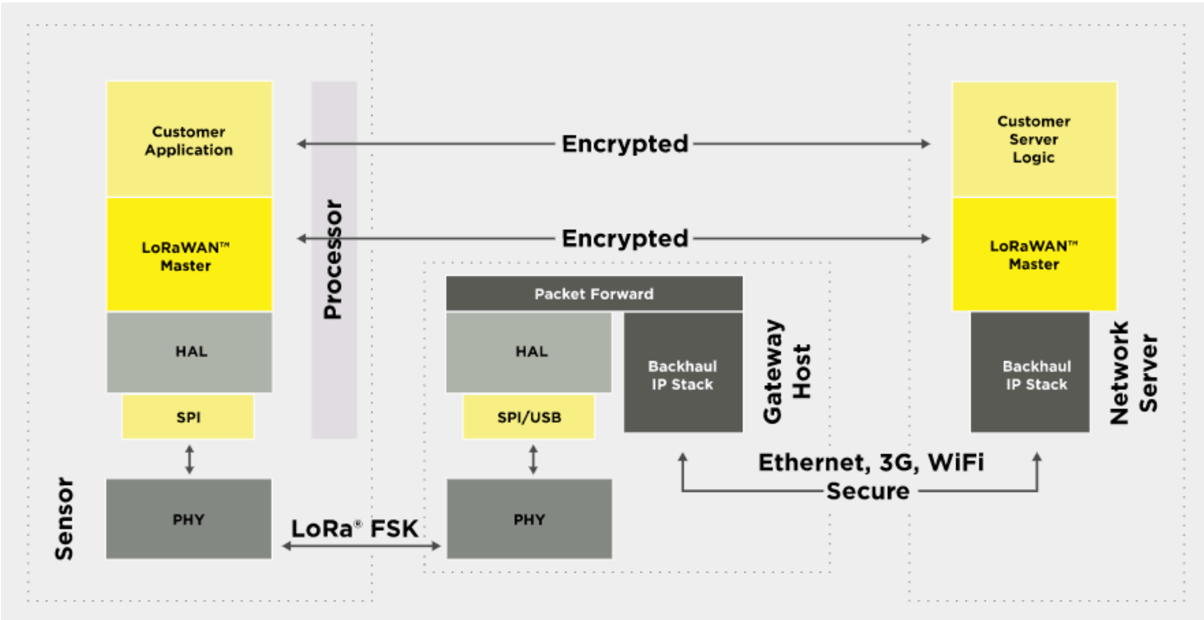


Figure 2 - LoraWAN Stack - https://lora-alliance.org/about-lorawan

However PWD is targeting mainly a point to point use case which only needs the LoRa technology and not the LoRaWan technology.

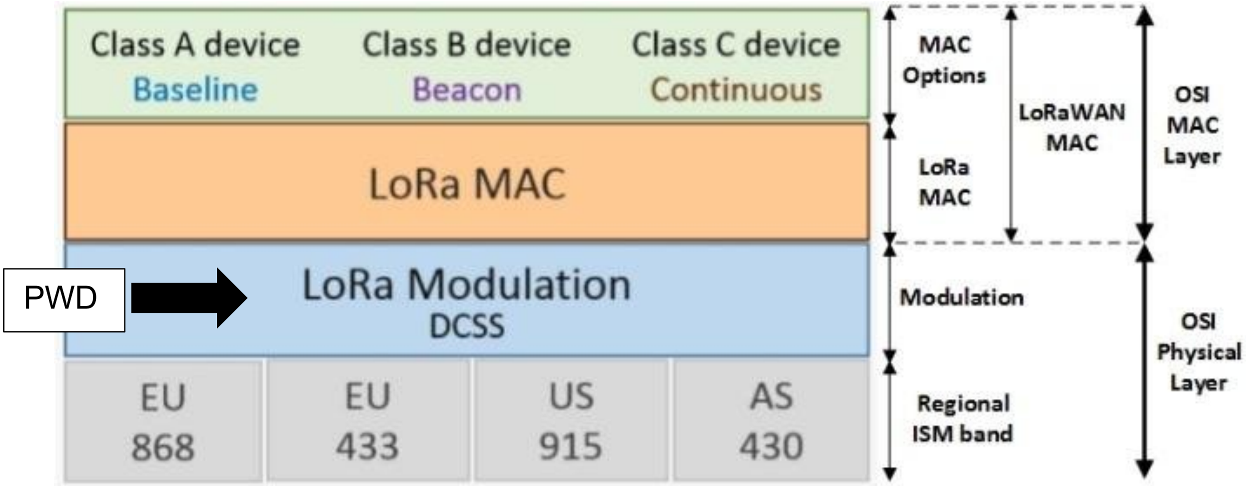


Figure 3 - Lora MAC - https://www.researchgate.net/figure/LoRa-and-LoRaWAN-protocol-stack-6_fig2_331790920

The Lora/LoraWAN packets and protocol stack are defined in the following way:

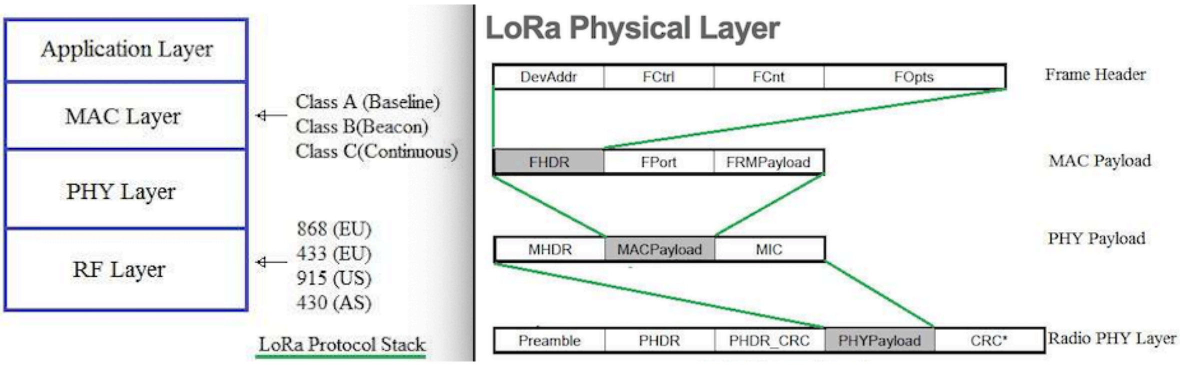


Figure 4 - https://www.rfwireless-world.com/Tutorials/LoRa-protocol-stack.html

3.4 LoRa Chip types

LORA CHIPS IN END NODES

Values taken from corresponding data sheets (Oct 10, 2018), see: https://www.semtech.com/lora/lora-products

Chip	Freq. range MHz	RF output power dBm	Max Link Budget dBm	Max Rx Sensitivity dBm	Remark
SX1261	150-960	15	170	-148	Support all major sub GHz ISM bands
SX1262	150-960	22	170	-148	Support all major sub GHz ISM bands
SX1268	410-810	22	170	-148	Chinese support of 490 & 780 MHz
SX1272	860-1020	20	157	-137	
SX1273	860-1020	20	157	-130	
SX1276	137-1020	20	168	-148	Support all major sub GHz ISM bands
SX1277	137-1020	20	168	-139	Support all major sub GHz ISM bands
SX1278	137-525	20	168	-148	
SX1279	137-960	20	168	-148	Support all major sub GHz ISM bands

3.5 LoRa Legal limits

3.6 Main issues affecting PWD use case

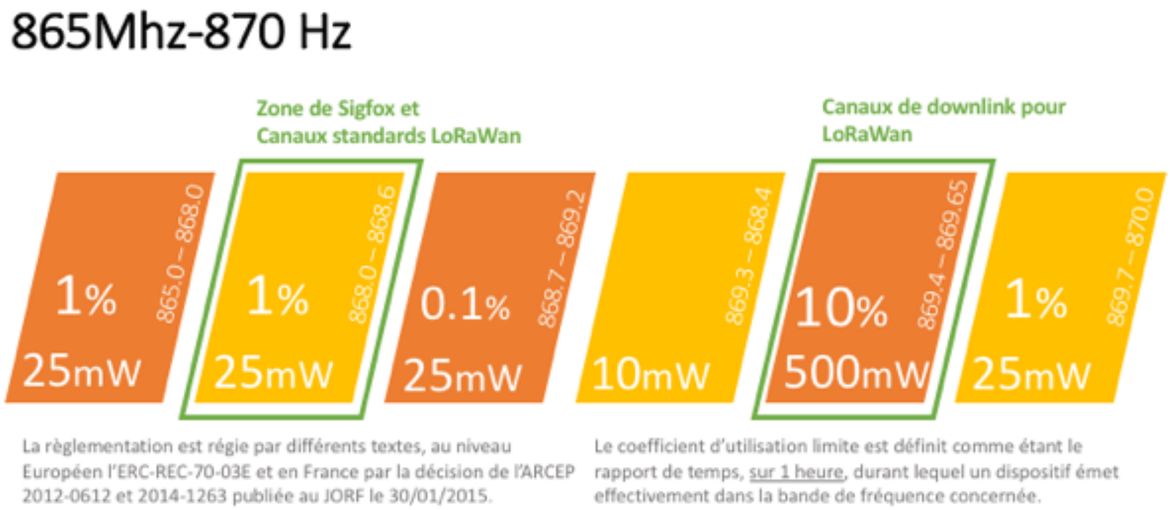
The main issues affecting PWD LoRa use case are:

- Power utilization
- Legal channel utilization that is to respect the duty cyle.
- Jamming problems that is avoid collisions with other emitters in the region.
- Antenna design and placement

4 Lora Radio Frequency

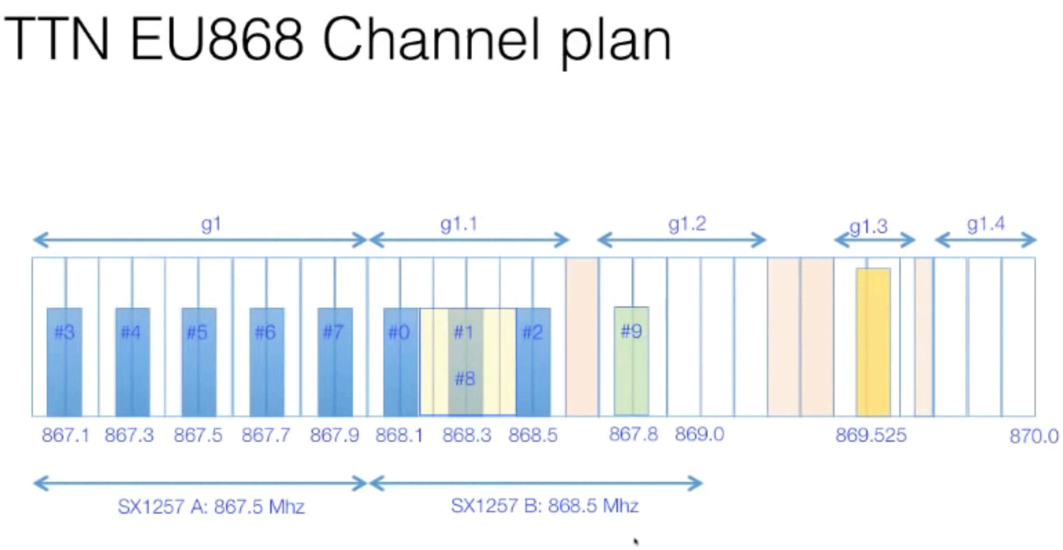
4.1 RF868 band

The RF868 band is split into 6 different sub-bands and each have different utilizations and legal limits.



The bands use cases are as follows:

- The first band: 865-688.0 MHz has 300kHz and is a 25mW / 1% duty cycle usage ruled band, it is used by RFIDs.
- The second band: 868.0 to 868.6MHz has 600kHz and is a 25mW and 1% duty cycle usage ruled band where the 2000x Sigfox channels and 8x TTN (The Things Network) channels and where the 3 standard LoRaWan channels are located.



- The third band: 868,7 to 869,2MHz has 50Khz and is a 25mW area but the duty cycle is 0.1%. This zone can be interesting to communicate when an objet is emitting once a day : the risk of collision is really lower and the number of time you will have to re-emit is, as a consequence, lower, so in this sub band you can expect to preserve your energy.
- The fourth band: 869,3 to 869,4MHz has 100KHz and is not usable for LPWAN as the maximum power is 10mW but there is no duty-cycle limit and so it can be a good area for local object communication
- The fifth band: The 869,4 to 869,65MHz has 250Khz is a 500mW with a 10% duty cycle. This band is more applicable for the central network access point (Gateway) and a good channel for downlink communications (as is used in LoRaWan). The gateway can communicate far away and be listen over the local noise of the object ; the larger duty cycle allows the gateway to communicate with many objects.
- The last band: 869,7 to 870MHz has 300KHz and is a 25mW / 1% duty cycle where you can deploy extra LoRaWan channels.

Table 9. Frequency Bands For Non-Specific Short Range Devices in Europe

Frequency Band	ERP	Duty Cycle	Channel Bandwidth	Remarks
433.05 – 434.79 MHz	+10 dBm	<10%	No limits	No audio and voice
433.05 – 434.79 MHz	0 dBm	No limits	No limits	≤– 13 dBm/10 kHz, no audio and voice
433.05 – 434.79 MHz	+10 dBm	No limits	<25 kHz	No audio and voice
868 – 868.6 MHz	+14 dBm	< 1%	No limits	
868.7 – 869.2 MHz	+14 dBm	< 0.1%	No limits	
869.3 – 869.4 MHz	+10 dBm	No limits	< 25 kHz	Appropriate access protocol required
869.4 – 869.65 MHz	+27 dBm	< 10%	< 25 kHz	Channels may be combined to one high speed channel
869.7 -870 MHz	+7 dBm	No limits	No limits	
2400 – 2483.5 MHz	+7.85 dBm	No limits	No limits	Transmit power limit is 10-dBm EIRP

Table 10. Frequency Band For License-Free Specific Applications in Europe

Frequency Band	Application	ERP	Duty Cycle	Channel Bandwidth
402 – 405 MHz	Ultra Low Power medical Implants	–16 dBm	No limits	25 kHz (1)
868.6 – 868.7 MHz	Alarms	+10 dBm	< 0.1%	25 kHz (1)
869.2 – 869.25 MHz	Social Alarms	+10 dBm	< 0.1%	25 kHz
869.25 – 869.3 MHz	Alarms	+10 dBm	< 0.1%	25 kHz
869.65 -869.7 MHz	Alarms	+14 dBm	< 10%	25 kHz
863 – 865 MHz	Radio Microphones	+10 dBm	No limits	200 kHz
863 -865 MHz	Wireless Audio Applications	+10 dBm	No limits	300 kHz
1785 – 1800 MHz	Radio Microphones	+7.85 dBm	No limits	200 kHz
2400 – 2483.5 MHz	Wideband data transmission	+17.85 dBm	No limits	No limits (2)
2446 – 2454 MHz	Railway applications	+24.85 dBm	No limits	No limits
2400 – 2483.5 MHz	Motion sensors	+11.85 dBm	No limits	No limits
2446 – 2454 MHz	RFID	+24.85 dBm	No limits	No limits
2446 – 2454 MHz	RFID	+33.85 dBm	< 15%	No limits

The transmission rules are based on 2 restrictions:

- Transmission power – it is the maximum power an emitter can use on the channel when it is communicating. 25mW (eq 14dB) is the usual power the LPWAN uses for communicating.
- The duty cycle – it is defined as the maximum ratio of time on the air per hour. Basically, 1% means you can speak 36s per hour, not more. Duty Cycle is applicable for the sub-band. So transmitting on several sub-bands it is possible to increase the duty cycle (e.g. transmit in 865.0Mhz band and 868Mhz band it is possible to reach 2%). However if several channels are used in the same band then the ratio of time is accordingly reduced (e.g. in LoraWAN the standard configuration is to have 3 channels in the same sub-band the duty-cycle of each of the channel is 0,33%)

5 Range analysis

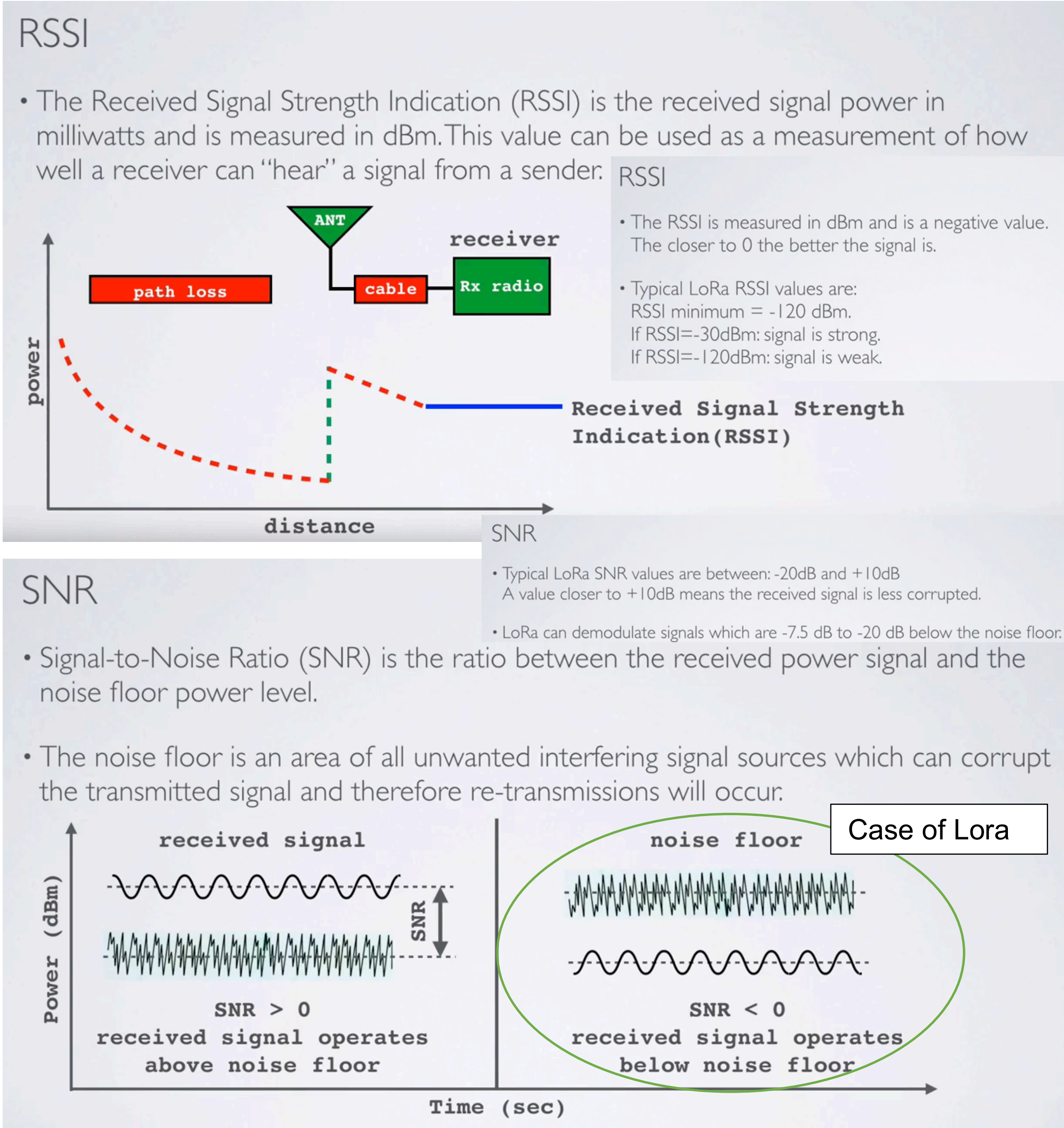
PWD wants to have the highest range with the lowest power consumption. There are 2 ways to get the longest range or maximize the link budget:

- **The hardware way** includes better and higher antennas and more power.
- **The software way** to get the longest range is using the Lora characteristics.

5.1 Maximizing the link budget

The Link Budget is how many dBs you can lose between the transmitter and the receiver. Higher link budgets directly translate to longer distances (6dB = twice distance).

5.1.1 RSSI and SNR



5.1.2 FSPL and other effects

In reality there are several effects that reduce the Free Space Path Loss and Fading further:

- Multipath (diffraction and reflection)
- Obstruction (structure attenuation)
- Fresnel zone (where the heights of the transmitter and receiver matter)

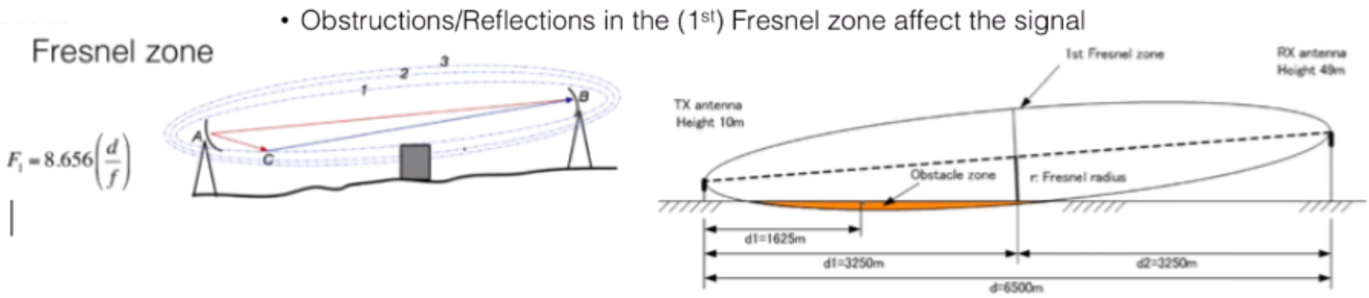
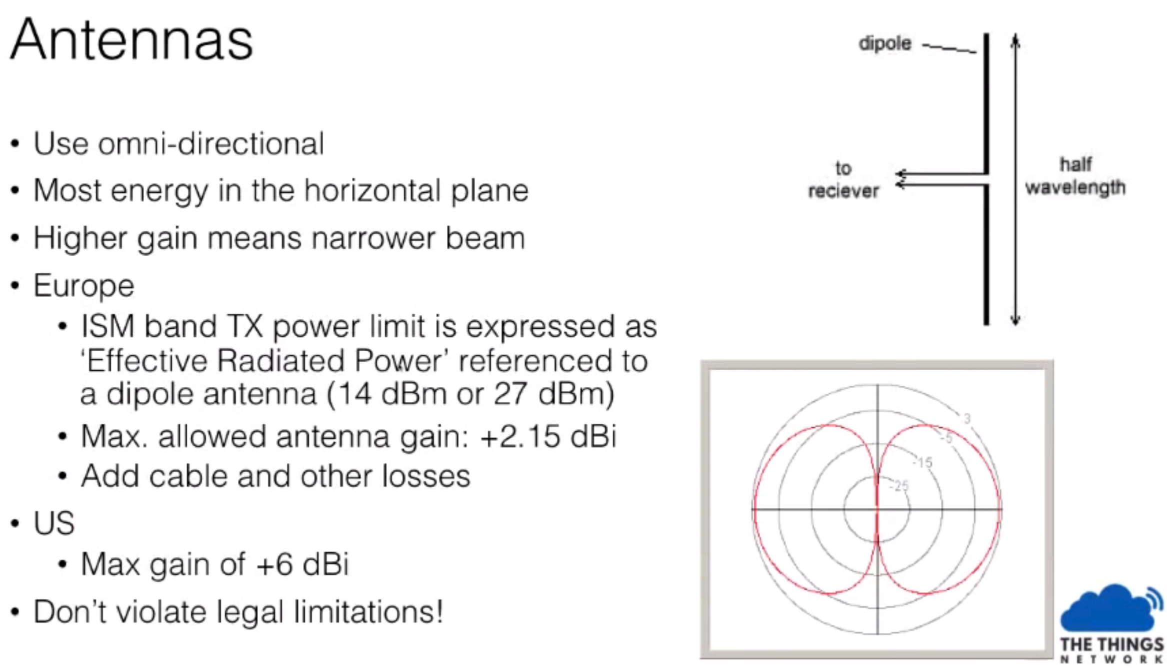


Figure 5 - The antenna height impacts link budget - https://www.youtube.com/watch?v=T3dGLqZrjIQ&feature=youtu.be

5.2 Optimizing Link Budget: the Hardware way

5.2.1 Antennas

In order to maximize the link budget the antenna also must follow some considerations



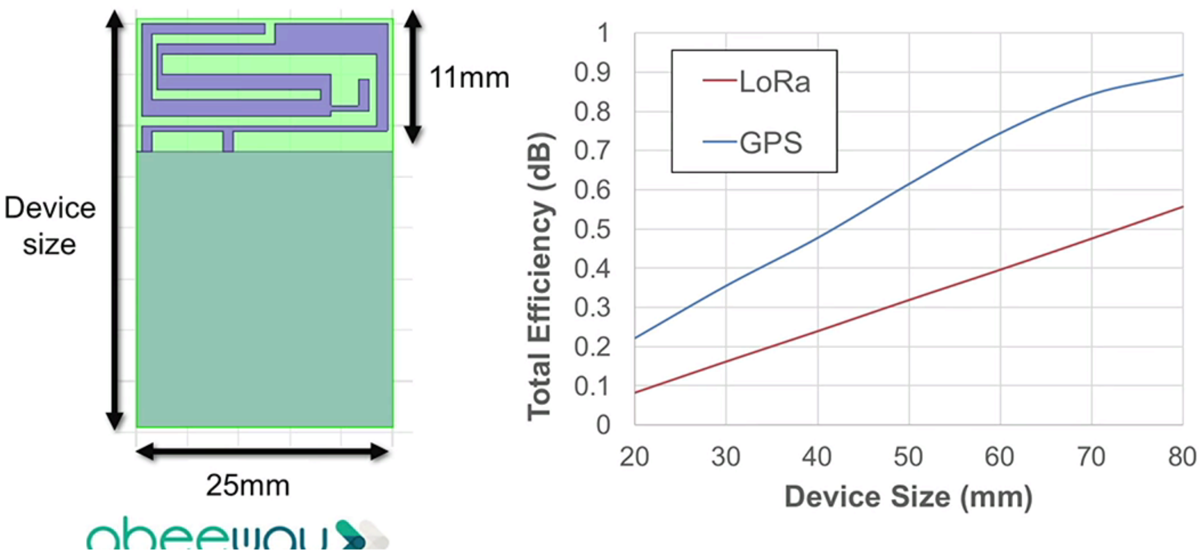
For antenna optimization see tutorials:

- Impedance: https://www.youtube.com/watch?v=tBrwqSYvjjs&list=PLmL13yqb6OxdeOi97EvI8QeO8o-PqeQ0g&index=34
- VSWR: https://www.youtube.com/watch?v=c7Hum0DuXEo&list=PLmL13yqb6OxdeOi97EvI8QeO8o-PqeQ0g&index=35
- Balun:https://www.youtube.com/watch?v=dIFUjNcQifM&list=PLmL13yqb6OxdeOi97EvI8QeO8o-PqeQ0g&index=39

5.2.2 PCB antennas

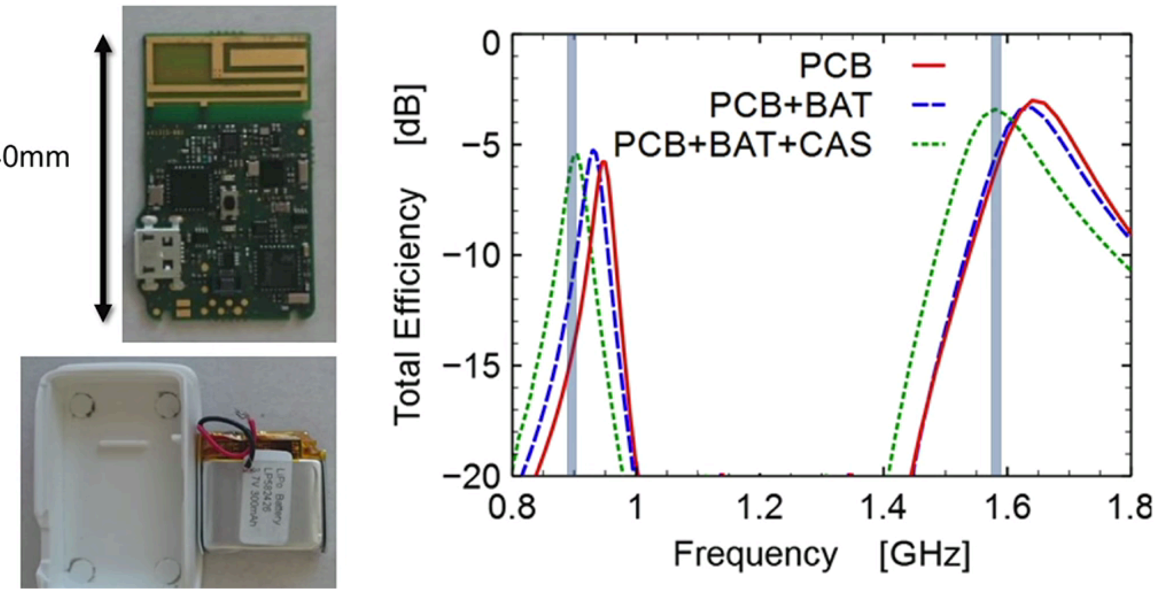
This is an example of an antenna that ressonates LoRa and GPS frequencies

- LoRa (868MHz) and GPS (1575MHz) antenna on small terminal

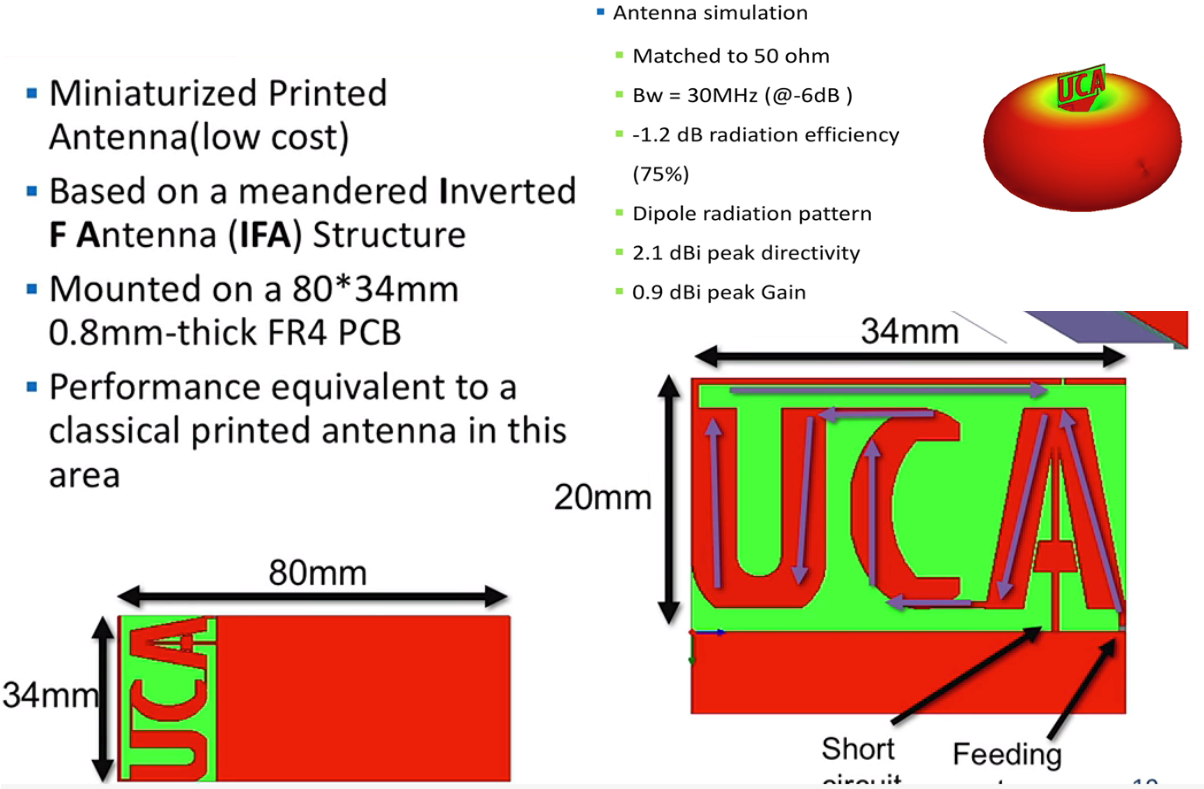


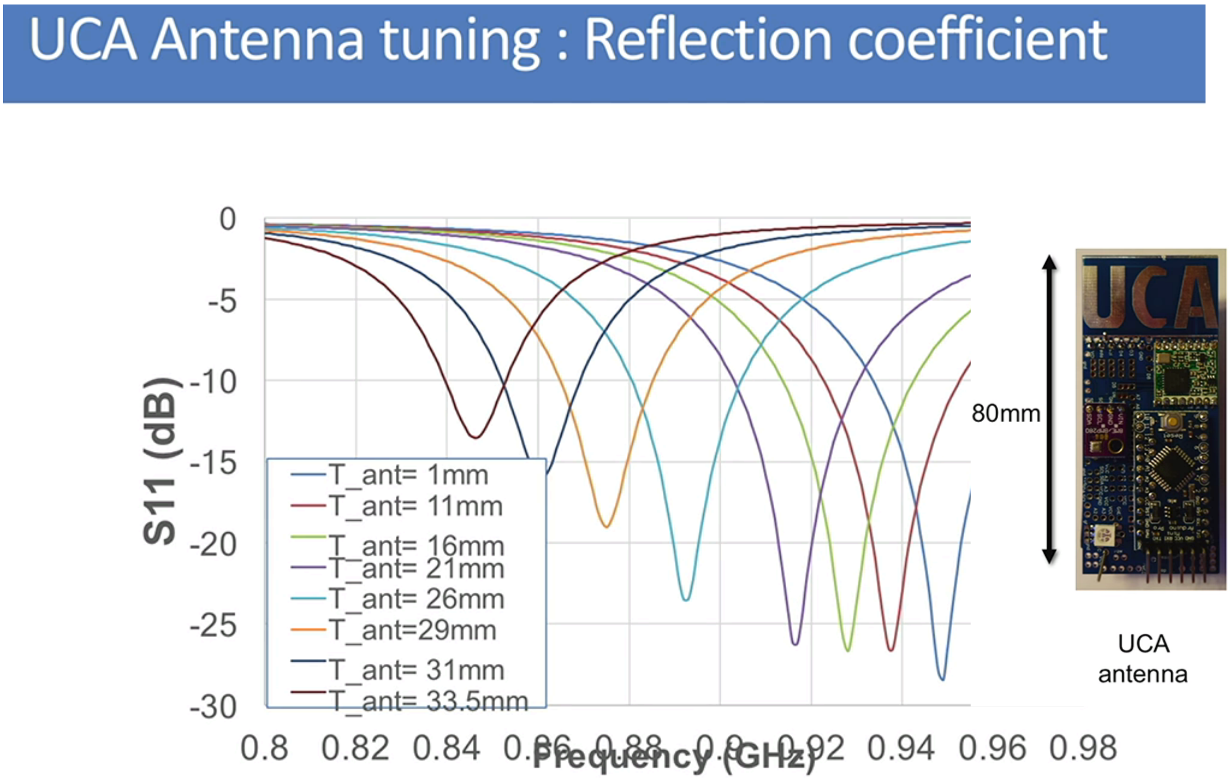
H owever even for this antenna there are influences to the antenna resonant frequency like the battery and the casing. Notice that the plastic casing can have a big impact.

Antenna are strongly influenced by the close environment like the battery or the terminal casing



- An example of a LoRa cheap PCB antenna. It has the limitation that it can only cover the EU or US or China device. Antenna must be tunned!



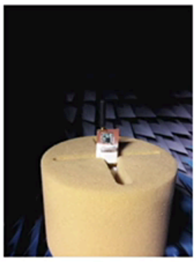


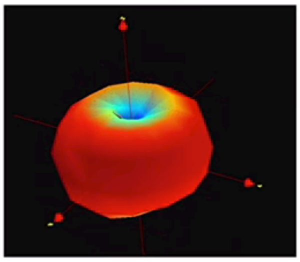
When compared with other antennas we can see that it has a comparable efficiency.

The antenna gerber files are available here:
https://github.com/FabienFerrero/UCA_Board/tree/master/Gerber

Comparison with on-the-shelf antenna

- Measurement on Satimo Starlab station
  - Continuous wave with 14 dBm power from RFM95W module
  - Efficiency calculated from the 3D antenna measurement





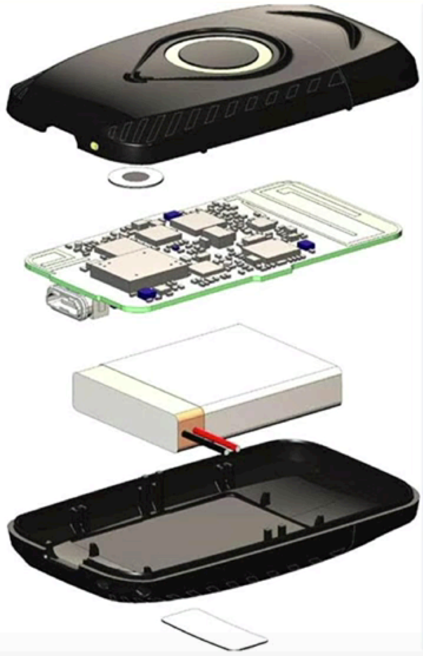
Antenna structure	TRP (dBm)	Total efficiency	Max Dimension
Small monopole	14.7	74%	105 mm
Quarter-wave monop.	15.7	94%	170 mm
Half-wave dipole	13.9	61%	280 mm
UCA untuned	13.8	60%	80mm
UCA after tuning	14.8	76%	80mm

https://github.com/FabienFerrero/UCA_Board

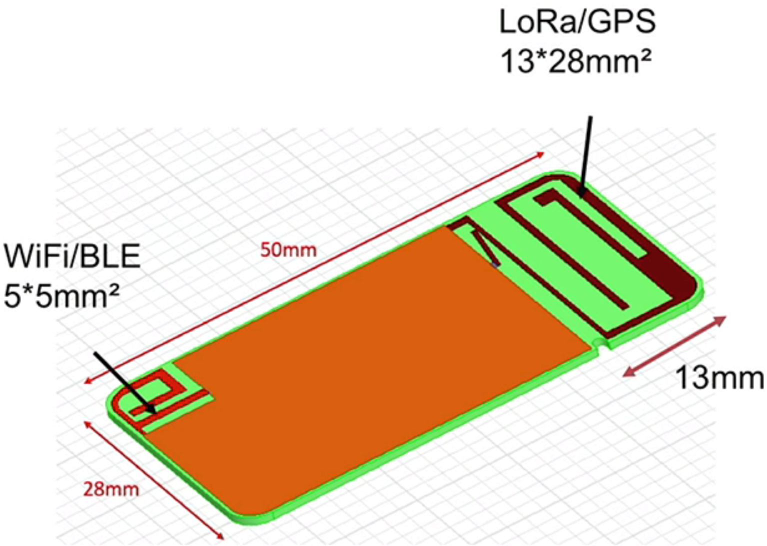
The layout of the antenna is open source and available at:
https://github.com/FabienFerrero/UCA_Board

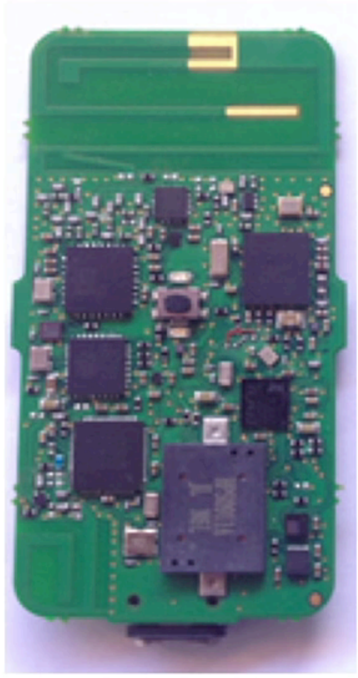
Micro-tracker Antenna Industrial project

- Specs
  - LoRa 868 or 915MHz
  - WiFi/BLE (2.4GHz)
  - GPS L1
  - Terminal size: 50*28mm²
- Proposed solution
  - Dual-band LoRa/GPS
  - SP4T to switch between LoRa Rx/Tx/Txboost and GPS.
  - WiFi/BLE antenna (2.4-2.48 GHz)

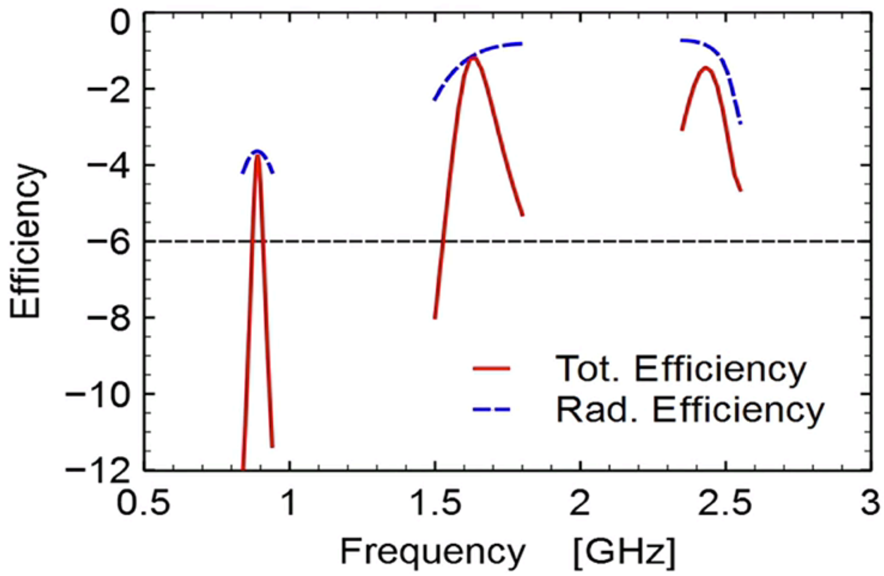


Another antenna is the Micro-tracker industrial project which is 50*28mm^2 and works for LoRa, Wifi and GPS L1.





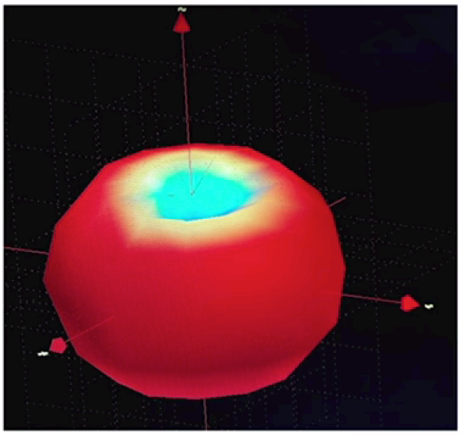
With efficiency of:



- Total Efficiency LoRa -4 dB (40%)
- Total Efficiency GPS -1.5 dB (70%)
- Total Efficiency WiFi/BLE -1.5 dB (70%)

Measurements :

- LoRa : Peak Gain -1.5dB
- BLE/WiFi : Peak Gain 0.5dB
- GPS : Estimated at 0dB from anechoic chamber measurement with GPS protocol tester.



So in this case we can use 17dBm of output power in this case.

It is possible of course to order the Antenna and PCB online via PCBWays.

- For Europe, shipping need usually 4-5 working days
- Think that DHL will ask for customs fees, usually in the range of the PCB cost (without shipping cost).
- You can start your board assembly

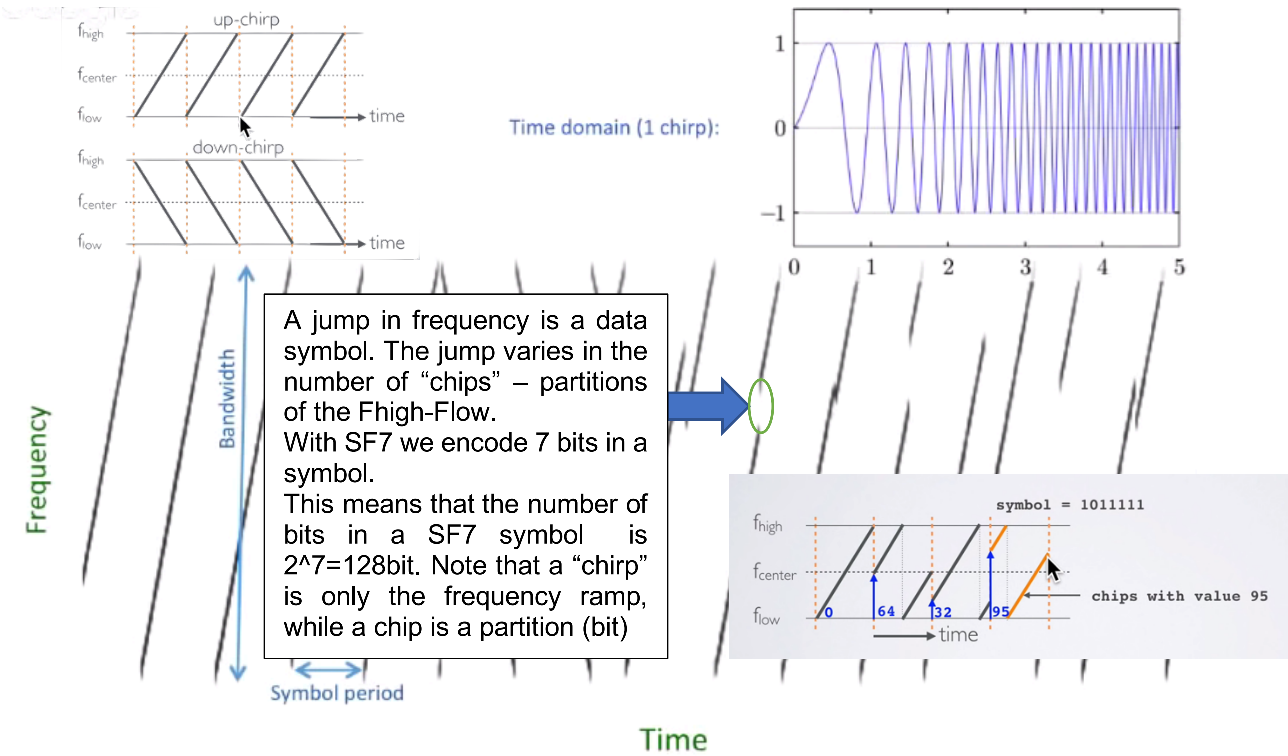
To test a miniature antenna a VNA is not required but a spectrum analyzer is useful.

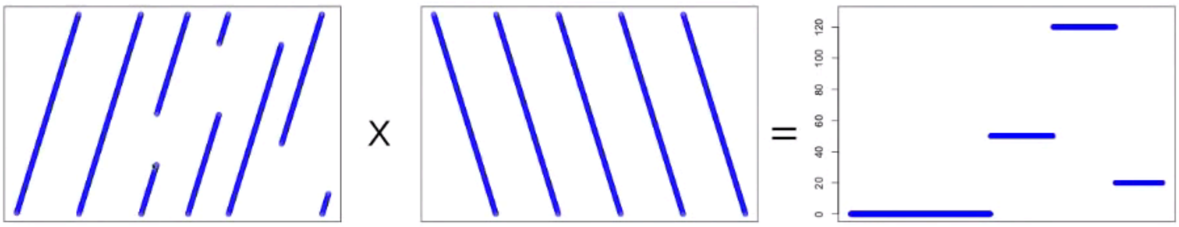
5.2.3 Receptor

It is possible to increase the receiver antenna sensitivity by limiting the amount of external noise coming into the LoRa receiver antenna input. This can be achieved by using a bandpass filter (also called a LNA – Low Noise Amplifier). From the tests in http://www.loratracker.uk/?p=591 it seems that if we operate at SF7 there is no advantage to the LNA. **However if we work at SF12 by applying a LNA we can get 7dB to the link margin (which would mean double the distance).**

5.3 Optimizing Link Budget: the software way

LoRa uses a spread-spectrum technique called CSS (Chirp Spread Spectrum). A chirp is a sinusoidal signal of frequency increase or decrease over time.





Received Lora signal X Inverse chirp = Decoded symbols

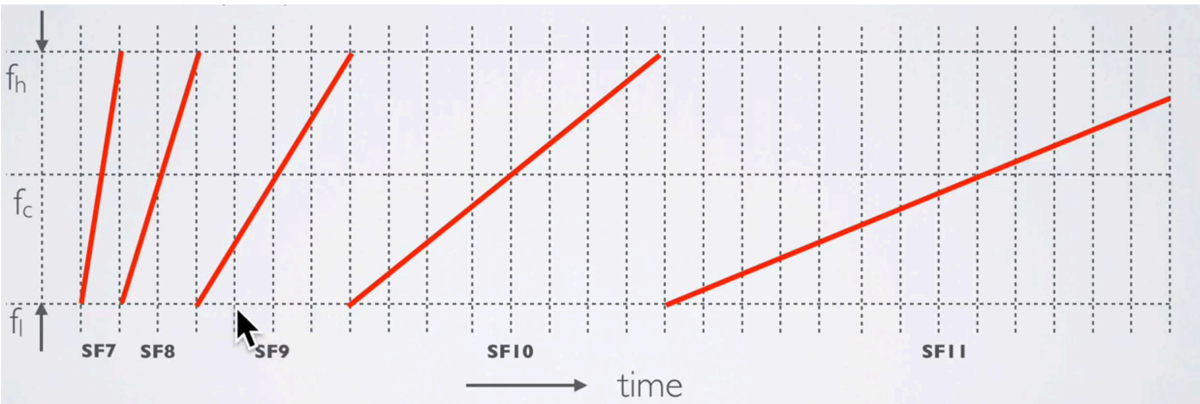
In LoRa we send chirp signals, that is the signal frequency moves up or down and these chirps are equivalent to set of symbols which when decoded give the information the sender sent. In LoRa we can change 2 factors: the bandwidth of the signal and the spreading factor. Each combination will bring a different sensitivity and also increase or decrease the data rate.

Bandwidth vs Spreading Factor – Sensitivity and Data Rate

		7800	10400	15600	20800	31200	41700	62500	125000	250000	500000
SF6	Sensitivity	-132	-131	-129	-128	-125	-124	-121	-118	-115	-112
	Data Rate	585	780	1170	1560	2344	3128	4688	9375	18750	37500
SF7	Sensitivity	-135	-134	-132	-131	-129	-128	-126	-123	-120	-117
	Data Rate	341	455	683	910	1367	1824	2734	5469	10938	21875
SF8	Sensitivity	-139	-138	-136	-135	-133	-131	-129	-126	-123	-120
	Data Rate	195	260	390	520	781	1367	1563	3125	6250	12500
SF9	Sensitivity	-142	-141	-139	-138	-136	-134	-132	-129	-126	-123
	Data Rate	110	146	219	292	439	586	879	1758	3516	7031
SF10	Sensitivity	-145	-143	-142	-140	-138	-137	-135	-132	-129	-126
	Data Rate	61	81	122	163	244	326	488	977	1953	3906
SF11	Sensitivity	-147	-145	-144	-142	-141	-139	-138	-135	-132	-129
	Data Rate	34	45	67	89	134	179	269	537	1074	2148
SF12	Sensitivity	-149	-148	-146	-145	-143	-142	-140	-137	-134	-131
	Data Rate	18	24	37	49	73	98	146	293	586	1172

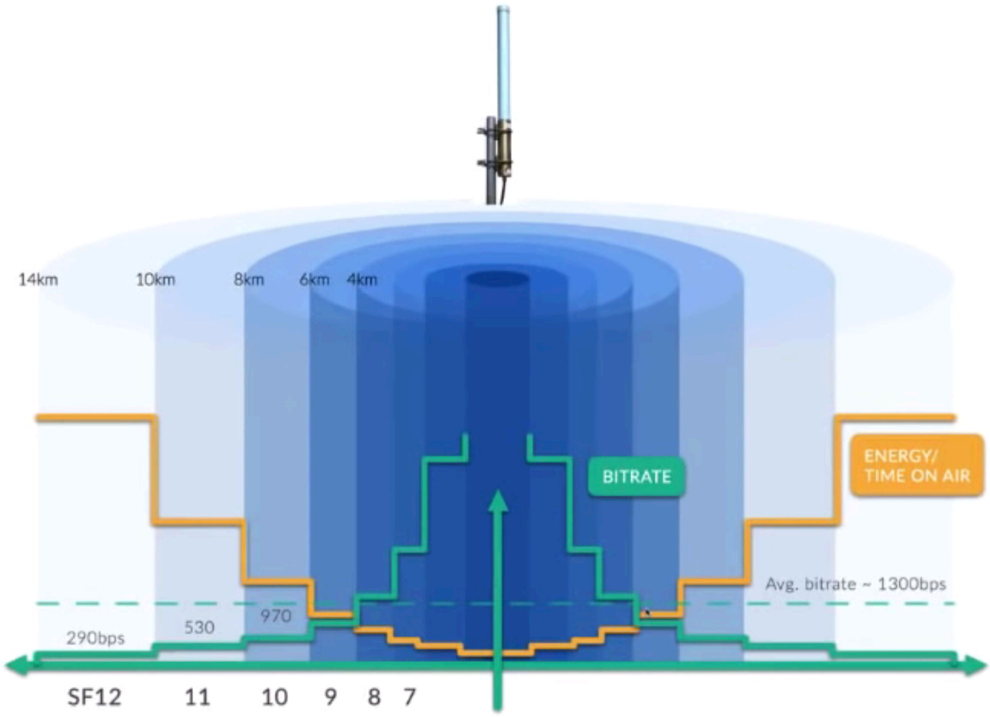
5.3.1 Spreading Factor

In LoRa when we change the spreading factor, we change the speed of the moving up or down of the chirp. The speed moved is roughly 2^spreading factor. Each step up in spreading factor doubles the time on air to transmit the same amount of data.



Higher spreading factors are more resistant to local noise effects and will be read more reliably at the cost of **lower data rate** and more congestion. **Each unit increase in SF correlates to about 2.5dB extra link budget**. This is because for each SF increase we increase the sensitivity at the receptor

Why is this gain in link budget? Because basically we put more energy to the air/more time the sender is active.



5.3.2 Bandwidth

The chirp will be sent over a bandwidth. Higher bandwidth has higher data rates but more congestion. Lower bandwidth will have lower data rates but less possibility of congestion (interference from other LoRA channels). However there is a problem with lowering the BW (see frequency variation) **Each doubling of the bandwidth correlates to almost 3dB less link budget.**

5.3.3 Frequency variation

So it would seem that to have the highest link budget we would only have to increase the SF (Spreading Factor) and decrease the BW (bandwidth). However there are some limitations to the BW. If let's say we reduce the BW to 7.8KHz the signal is much more susceptible to the Chip base crystal oscillator frequency deviation. According to Semtech the maximum frequency tolerance 25% of the LoRa modulation (better to use 20% in real case situations). So for 7.8KHz we would get 1.56KHz of accuracy. However in practice these cheap oscillators sometimes get maximum of +/- 5khz accuracy[1]. In these cases the maximum resolution would be 10Khz. This means that we would have to use a BW of >50KHz. In the case of the SandeepMistry LoRa library[2] the available bandwidths are: 7.8E3, 10.4E3, 15.6E3, 20.8E3, 31.25E3, 41.7E3,

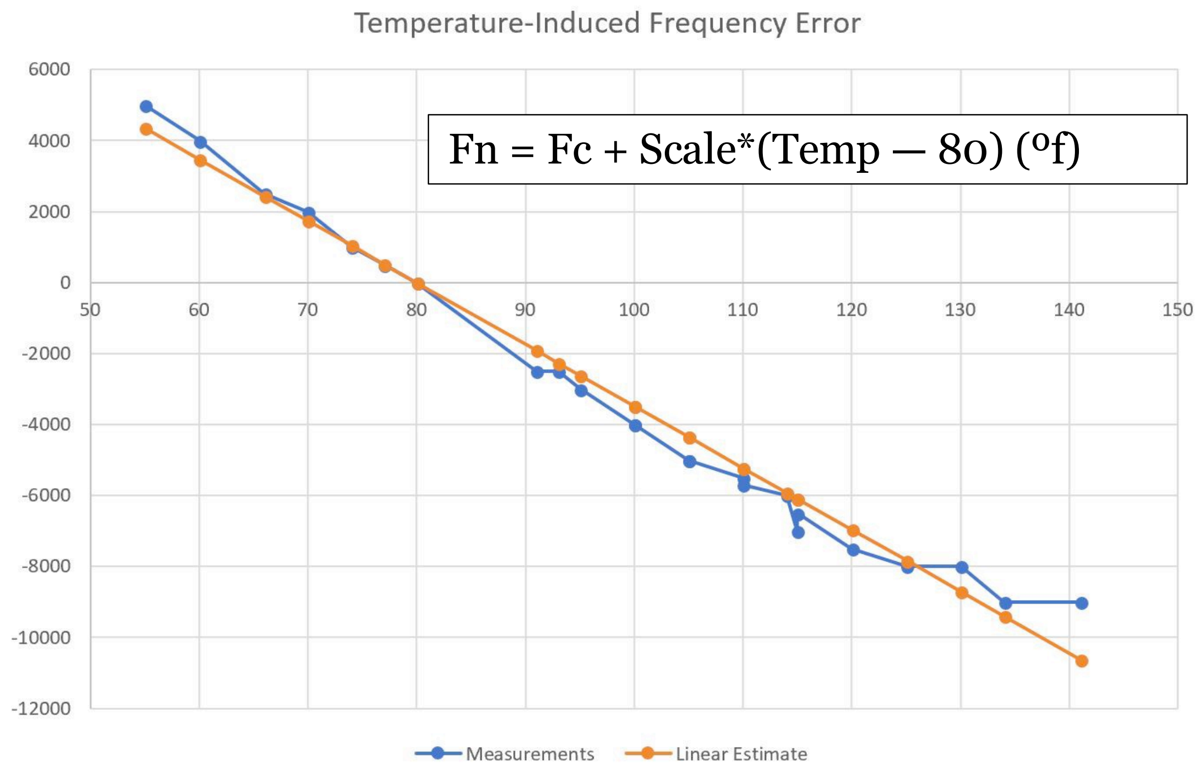
[1] As mentioned in: http://www.loratracker.uk/?m=201801
[2] https://github.com/sandeepmistry/arduino-LoRa/blob/master/API.md

62.5E3, 125E3, and 250E3 Hz. **So the next possible BW would be 62.5KHz**. In the TTN LoraWAN they use 125KHz BW to avoid this problem.

So in summary decreasing the bandwidth increases the risk of miscommunication due to frequency drift and inaccuracy. The Pycom and the Semtech Sx1272 only support 125KHz and above, for example. The Semtech Sx1262 and Sx1276 chipsets support bandwidths down to 8KHz.

5.3.4 Frequency and temperature compensation

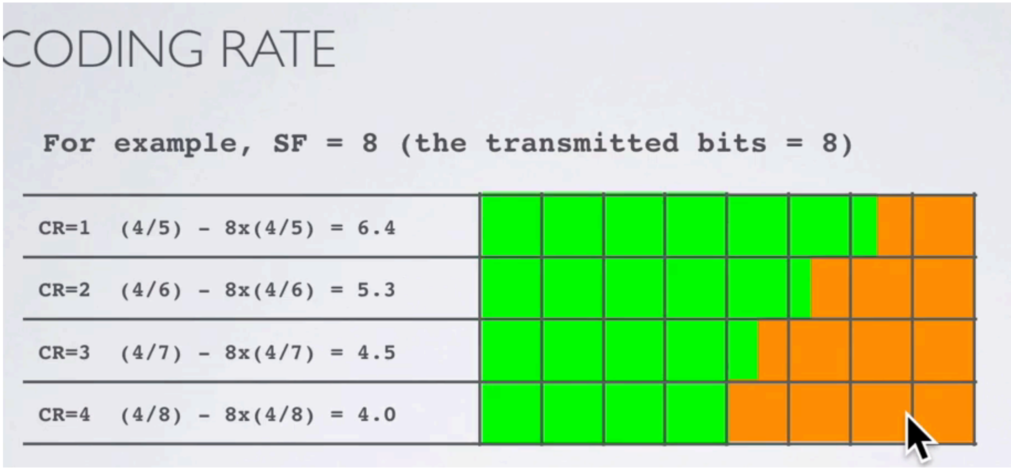
Frequency drift and inaccuracy are also dependent on temperature and this may be a problem for wearable technology. It is however possible to improve the temperature stability of the LoRa systems. We need to examine the temperature characteristics of the LoRa module and then alter the center frequency based on the known temperature drift. Note that the modules have a temperature sensor (albeit it's slow and clunky). Using a derived equation from that test **it is possible to program an algorithm and then correct the center frequency based on temperature changes to maintain a connection at the desired bandwidth.**



5.3.5 Coding rate

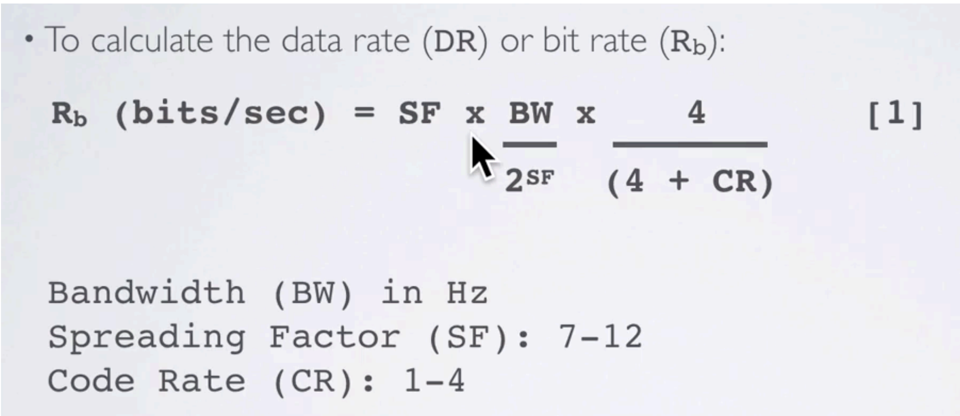
LoRa uses FEC (Forward Error Correction) which is the process where bits are added to the transmitted data. These redundant bits help restore the data when it gets corrupted by interference. In LoRa the FEC coding rate (CR) is the proportion of the transmitted bits that actually carry information versus the correction bits. That is CR=4/(4+correction bits) and the values can be CR=4/5,4/6,4/7.4/8.

The CR rate is multiplied by the SF to know the amount of actual bits are sent (SF=8 x CR=4/8 is 8x4/8=4 actual bits of payload.)



5.3.6 Bit rate

The bit rate is calculated as follows:



5.3.7 Maximize range Summary

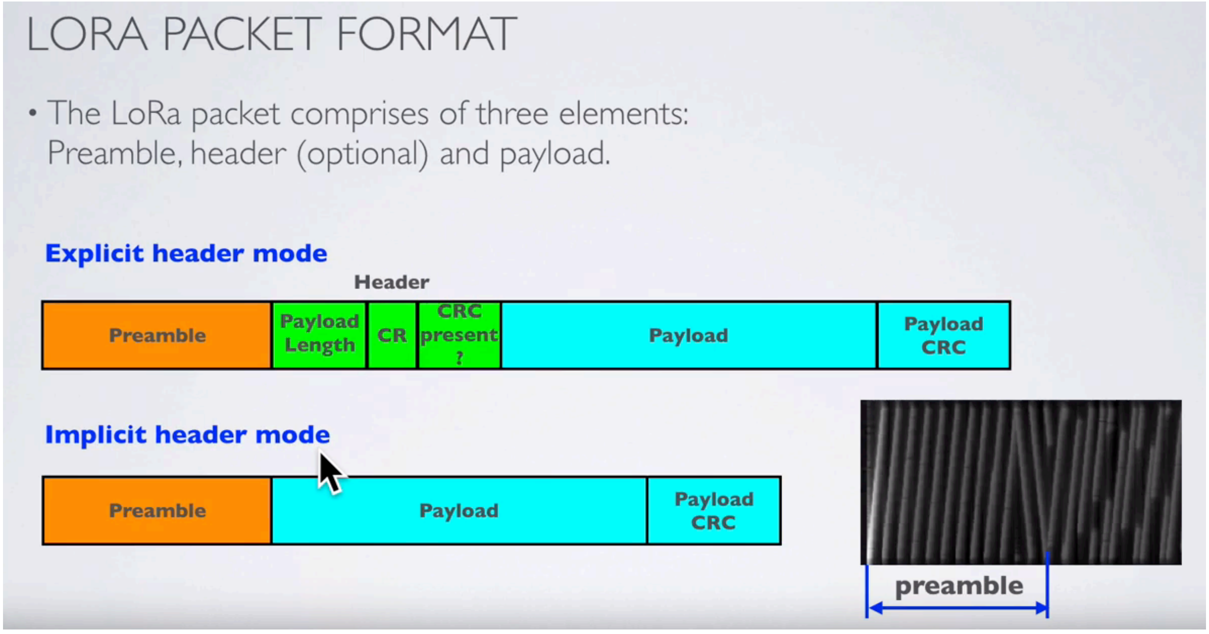
- Minimize bandwidth while still maintaining connection
- Maximize spreading factor to boost link budget.
- Maximize coding rate to boost reliability.

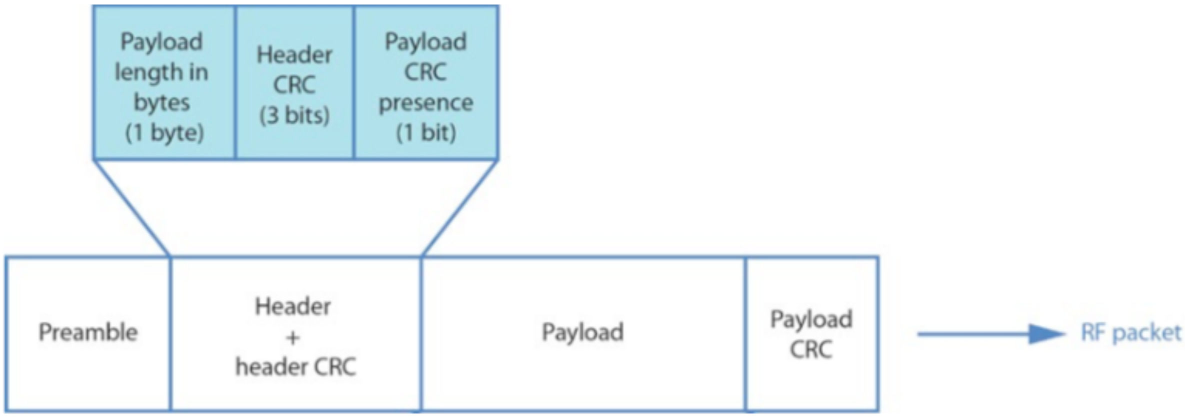
6 LoRa Data packet

The LoRa data packet is constituted by a preamble, payload and CRC.

There are 2 options of payload to choose from:

- Explicit header mode: includes the Payload length and indicates if an additional/optional 16 bits CRC is present.
- Implicit header mode: which includes the only the preamble (for the receiver to detect the signal and sync) and the payload CRC → **thus reducing the transmission time**





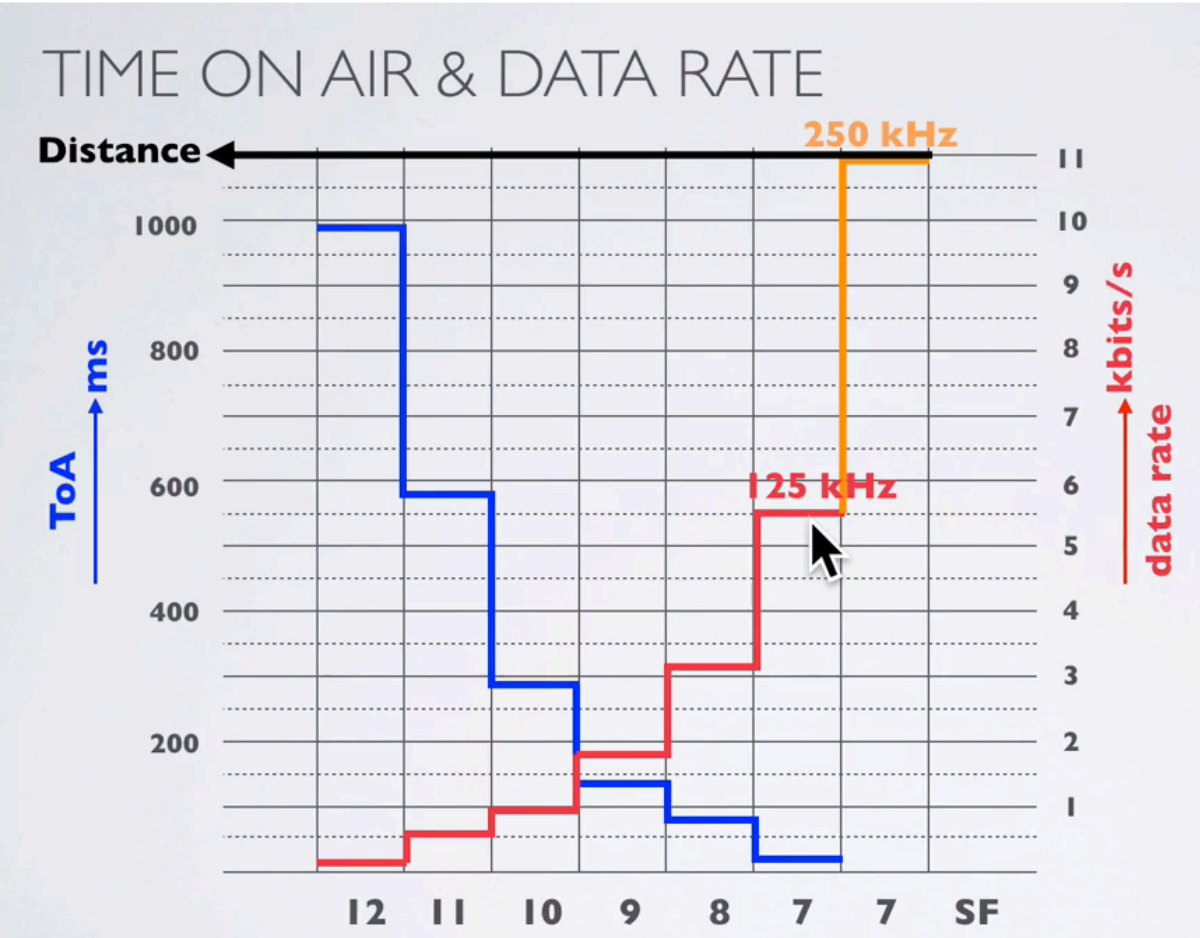
So from the previous considerations we know we want to reduce the size of the payload since the Preamble+Header+HeaderCRC+Payload CRC are not optional and already take some bytes.

6.1 Low data rate optimization

LOW DATA RATE OPTIMIZATION

- Given the potentially long duration of the packet at high spreading factors the Low Data Rate Optimization (LowDataRateOptimize) option can be set to improve the robustness of the transmission to variations in frequency over the duration of the packet transmission and reception.
- When the Low Data Rate Optimization is enabled it increases the robustness of the LoRa link at these low effective data rates. Its use is mandated when the symbol duration exceeds 16ms. Note that both the transmitter and the receiver must have the same setting for LowDataRateOptimize.
- The LowDataRateOptimize is enabled for bandwidth 125 kHz and Spreading Factor >= 11

6.2 Time on Air and Data Rate



6.3 Reducing the payload

Don't waste your time!

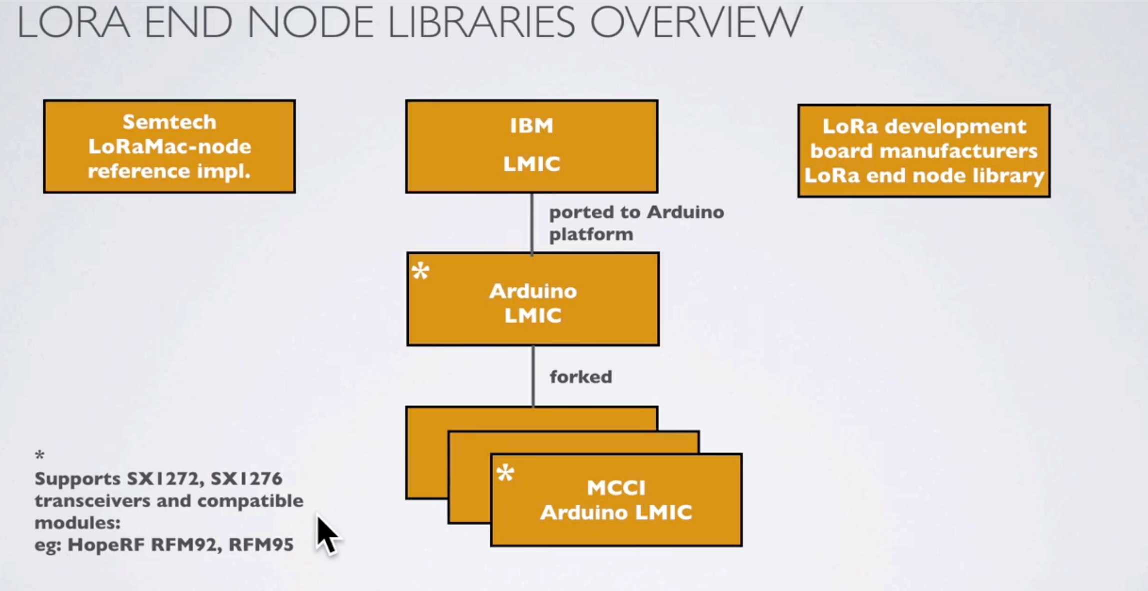
- Simple:
  - `{ "Count": 1234, "Temperature": 20.635 }`
  - 40 bytes: 292 messages per day (SF7)
- Remove counter (is already included in header), spaces, and compress names:
  - `{"t":20.63}`
  - 11 bytes: 486 messages per day
- No JSON:
  - `20.63`
  - 5 bytes: 582 messages per day
- Signed 16 bit integer
  - `0x080F`
  - 2 bytes: 648 messages per day

So we should aim to send as little data as possible. Possibly 32bits which would mean 4 bytes (instead of the 64 bytes we are currently using).

7 Software

7.1 LoRa end node libraries

There are several LoRa MAC end node libraries:



- Semtech LoRaMac-node library.
  - Available here: https://github.com/Lora-net/LoRaMac-node.
  - It is tested for NAMote72, NucleoLxxx, SKiM880B/980A/881AXL and SAML21 end nodes.
  - Porting to other platforms is available at: http://stackforce.github.io/LoRaMac-doc/_p_o_r_t_i_n_g__g_u_i_d_e.html
- IBM LMIC[3] library.
  - Available here: https://github.com/lmic-lib/lmic
  - No development since 2015, and not for Arduino.
- Arduino LMIC library connects to the transceiver via SPI low-level interface
  - This is a Arduino port of the IBM version maintained by Kooijman and Telkamp.
  - Available here: https://github.com/matthijskooijman/arduino-lmic .
  - It supports LoraWAN class A and B and for EU-868 and US-915 bands. This version is supported in SX1272, SX1276 tranceivers and compatible modules (such as some HopeRF RFM9x modules)

[3] LMIC is LoRa MAC in C

- This library cannot be used with full-stack devices like the Microchip RN2483 which contains a transceiver and microcontroller and exposes a high-level serial interface.

8 References

8.1 Radio theory basics

- RF 101 series (Bob Baxley): https://www.bastille.net/resources/education-radio-frequency-101
- LoRa video tutorial: https://www.youtube.com/playlist?list=PLmL13yqb6OxdeOi97EvI8QeO8o-PqeQ0g

8.2 Waterproofing

- IP68: No ingress of dust/ Immersion, 1 m up to 3m: https://en.wikipedia.org/wiki/IP_Code

8.3 LoRa Implementations/Competitors

- Libelium waspmote: http://www.libelium.com/development/waspmote/documentation/waspmote-lora-868mhz-915mhz-sx1272-networking-guide/
- Pycom: https://pycom.io/wp-content/uploads/2018/11/DETAILED-PYGO-SPECIFICATIONS-For-Developers-V1.2.pdf
- Pylife and PyGo: https://pycom.io/wp-content/uploads/2018/11/Pylife-and-PyGo-Kickstarter-FAQ-19Nov2018.pdf
- Abeeway microtracker: https://www.abeeway.com/products/

8.4 Power legal limits

- Limits on Lora radio power emitted to: https://stackoverflow.com/questions/50395087/lora-point-to-point-limitations
- RF regulations in Europe https://www.disk91.com/2017/technology/internet-of-things-technology/all-what-you-need-to-know-about-regulation-on-rf-868mhz-for-lpwan/ and ERC-REC-70-3E: https://www.ecodocdb.dk/download/25c41779-cd6e/Rec7003e.pdf and Texas Instruments analysis: http://www.ti.com/lit/an/swra048/swra048.pdf
- LoRa calculator: https://www.quora.com/How-much-data-at-a-time-can-be-transmitted-received-over-LoRaWAN-connections-Also-same-question-for-LoRa-point-to-point
- LoraWAN specification: https://lora-alliance.org/resource-hub/lorawanr-specification-v11

- Thesis on usage of randomness to avoid jamming: https://fenix.tecnico.ulisboa.pt/downloadFile/1126295043835530/Nuno%20Nico.pdf

8.5 LoRa Calculators

- Lora Alliand Duty Cycle: https://docs.google.com/spreadsheets/d/1QvcKsGeTTPpr9icj4XkKXq4r2zTc2j0gsHLrnplzM3I/edit#gid=0
- Semtech Lora Modem Calculator Tool: https://sx1272-lora-calculator.software.informer.com/download/ and https://www.elektroniknet.de/elektronik/kommunikation/nb-iot-nb-lte-oder-lte-cat-nb1-134629-Seite-3.html
- Lora AirTime calculator: https://www.loratools.nl/#/airtime
- Lora data rate calculator: https://www.rfwireless-world.com/calculators/LoRa-Data-Rate-Calculator.html and LoRa Link Budget calculator: https://www.rfwireless-world.com/calculators/LoRa-Link-Budget-Calculator.html
- Best LoRa settings for Range and Reliability: https://medium.com/home-wireless/testing-lora-radios-with-the-limesdr-mini-part-2-37fa481217ff

8.6 Microchip transceivers

- RN2483 LoRa wireless transceiver: https://www.rfwireless-world.com/ApplicationNotes/LoRa-transceiver.html

8.7 Antenna

- Antenna testing: https://github.com/LoRaTracker/AntennaTesting
- Fabien Ferrero on antenna design: https://www.youtube.com/watch?v=AhFy4-kForA
- UCA open source PCB antenna: https://github.com/FabienFerrero/UCA_Board

8.8 LoRa Packets

- https://hackmd.io/@hVCY-lCeTGeM0rEcouirxQ/S1kg6Ymo-?type=view