University of Piraeus

"LoRa protocol analysis and performance evaluation using PyCom equipment"

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October 22, 2019

Acknowledgement

I would first like to thank my thesis advisor Prof. Angelki Alexiou of the Departement of Digital Systems at University of Piraeus for her important role to my Master Thesis and Dr. Antonis Gotsis for his guidance, patience and aid.

As this master thesis was held in collaboration with Ms. Margarita Bitzi ,I would like to thank her for her work , her helpful suggestions and support. Without her the result would not be the same.

I would also like to acknowledge my family for their constant support.

Contents

Abstract

The purpose of this Master thesis is to present a thorough assessment of Lora Protocol, either for its Theoritical Backround or its Practical Applications to experiments that were held.

Firstly, we tried to place the Lora Technology to the IoT scenery as it is formed today, and compare it with its peer technologies. Afterwards, we examined the LoRa's technology technical anatomy. And finally we presented a set of experiments, which assessed the LoRa technology coverage.

Chapter 1

Introduction

1.1 Introduction

The fourth industrial revolution, as it is provisioned by the experts, bears many technological breakthroughs such as cyber-physical systems, robotics, AI implementations, biotechnology, 3D printing and fifth-generation wireless technologies (5G) . Among all these impressive innovations, we can not neglect the future form of Internet, the so called Internet of Things (IoT) which ,in the near future, is expected to be Internet of Everything (IoE).

If Internet of things(IoT) demands every object to be connected, then Internet of Everything (IoE) expects that objects will be connected even with human beings and other living species. Without doubt, this is a Technological evolution that revolutionizes not only the conventional Telecommunications System but brings a new era in our everyday life. Thus, IoT/IoE implementatios are expected to change the world.

Internet of Everything is a concept that describes a network of Internet of thing and Internet of Humans (IoH). (IoE) appears as a concept that contains both the IoT and the Internet of Humans (IoH), including the capability to share data between each other (IoT and IoH) or among themselves using machine to machine (M2M) or machine to human (M2H) communications. Following a similar approach, we could shape the IoT definition to include two different concepts: industrial IoT (iIoT) and consumer IoT (cIoT), exhibiting a new scenario that will dominate the world's communications in the near future, at least in terms of number of participating devices.

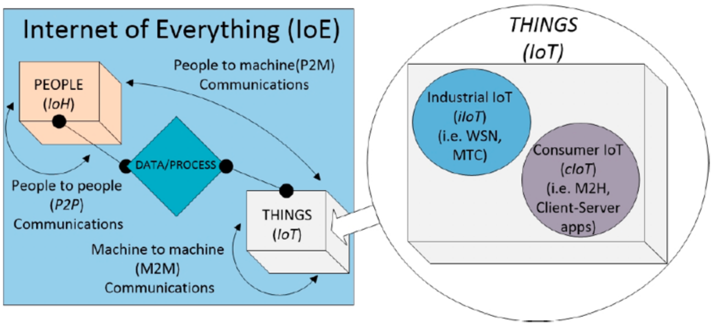


Figure 1. Internet of Everything concept.

Connection IoT and IoE [5]

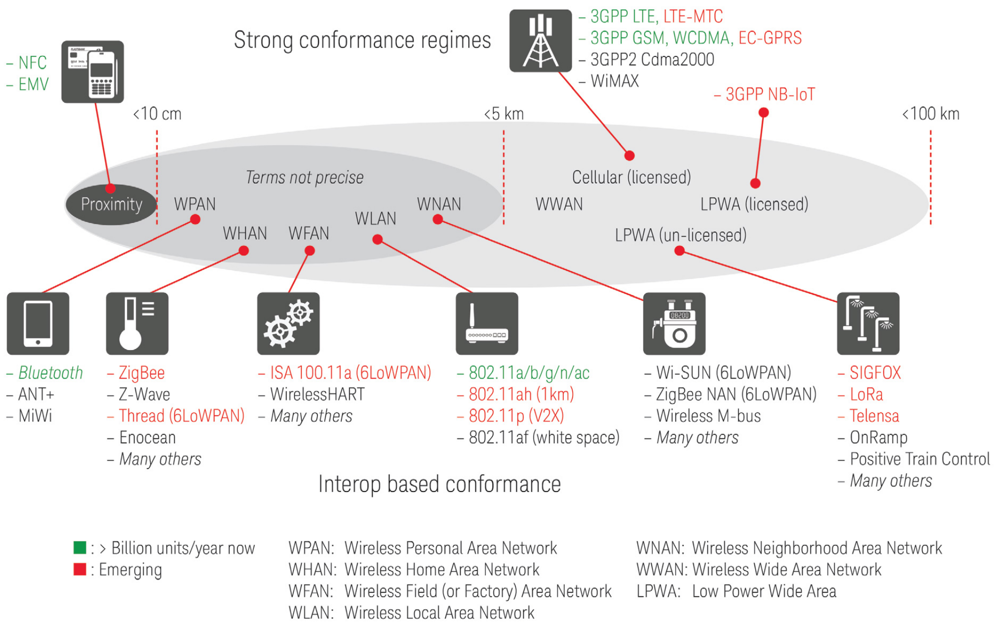
Thus, we can imagine the contribution of this upcoming technology to the already existing Iot Technology, as Smart cities, Smart Hospital , Smart Irrigation ,Smart Agriculture etc. A world fully connected it can't be but a safer world.

1.2 IoT Technologies

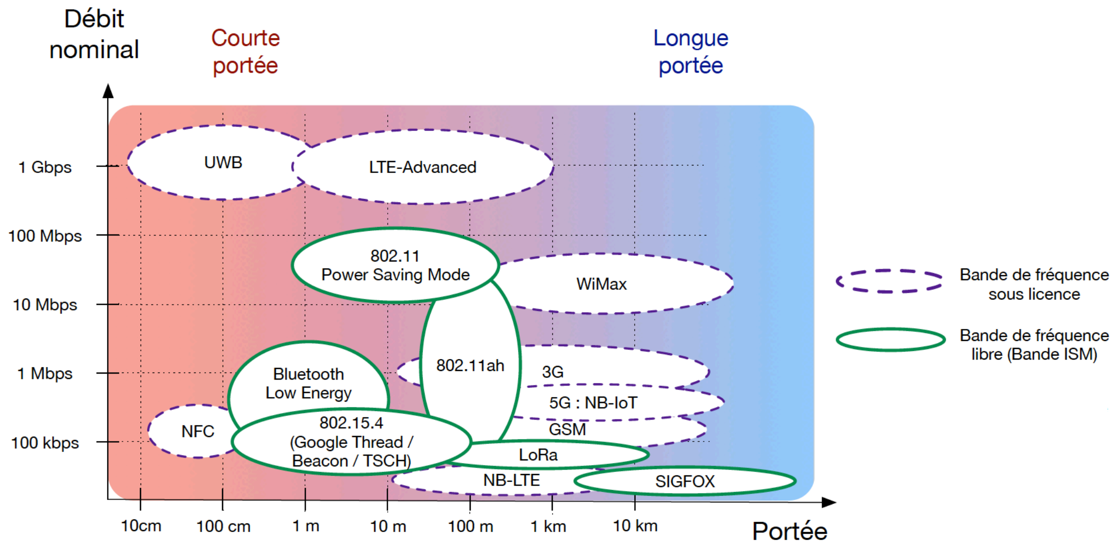
1.2.1 The Big Picture

The essential difference between conventional "Internet" and "Internet of Things" is that in the IoT, we need "less of everything" available in a given device or network device: less memory, less processing power, less bandwidth, less available energy. This is either because "things" are battery driven and maximizing lifetime is a priority or because their number is expected to be massive.[9]

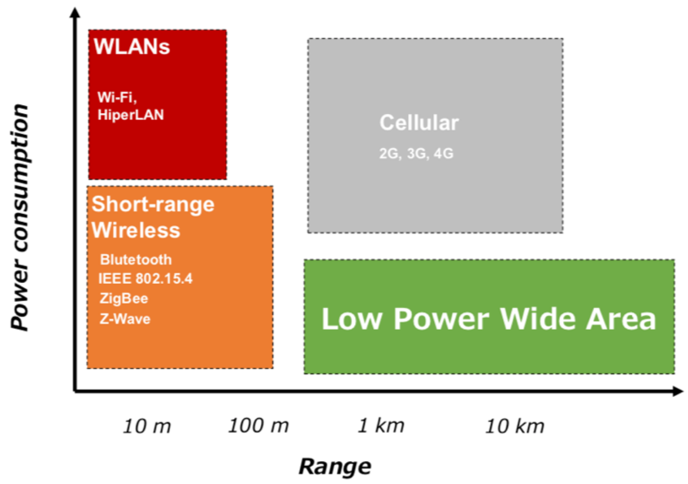
To visualise the scenery of Iot Technologies it would be useful for the reader to have a look to an IoT Technology map, which presents the differences between the existing technologies, regarding their Range-Coverage(Km), their Data Rates(Bps) and of course their Energy Consumptions:



A presentation of all the Iot technologies regarding their Coverage.[6]



A presentation of all the Iot technologies regarding their Data Rate.



A presentation of all the Iot technologies regarding their Power Consumption.[7]

So to the next section, we are going to examine the most popular technologies categorized by their Standardization Organization.

1.2.2 Most Popular IoT Technologies

There are many IoT Technologies proposed from different parties and we can distinguish three big groups:

1. 3GPP-based technology approach for IoT.
2. IEEE-based technology approach for IoT.
3. Protocols from Independant parties.

1. **3GPP-based technology approach for IoT.**

   3GPP stands for 3rd Generation Partnership Project and is a standards organization which develops protocols for mobile telephony. Its best known work is the developement and maintenance of GSM, UMTS and related 4G standards, including HSPA, LTE and related 4G standards (LTE Advanced and LTE Andvance Pro), 5G NR and relted 5G standards.

   3GPP had a determinant role regarding the establishment of IoT protocols and standards that are cellular based.

   Traditional cellular options such as 4G and LTE networks consume too much power and don't fit well with applications where only a small amount of data is transmitted infrequently (e.g. meters for reading water levels, gas consumption, or electricity use). Cellular IoT is meant to meet the requirements of low-power, long-range applications that Iot technology demands.

   3GPP has proposed 3 cellular based standards :

   (a) MTC LTE Cat-M (0,1).
   (b) EC-GSM-IoT.
   (c) NB-IoT.

   (a) **MTC LTE Cat-M (0,1).**
   Machine Type Communications is the term used in 3GPP to refer to Machine-to-Machine (M2M) communications, that is, machine devices talking to each other through mobile networks or locally.

   LTE-M (LTE-MTC [Machine Type Communication]), is a type of low power wide area network (LPWAN) radio technology standard developed by 3GPP to enable a wide range of cellular devices and services (specifically, for machine-to-machine and Internet of Things applications).[1][2] The specification for eMTC (LTE Cat-M1) was frozen in 3GPP Release 13 (LTE Advanced Pro), in June 2016

Cat-1 , Category 1 was included in the LTE specifications already in the beginning, Release 8. With a Cat-1 UE, it is possible to achieve 10 Mbps downlink and 5 Mbps uplink channel data rates.

Cat-0 , Category 0 is one of the newest standardized categories from Release 12. Cat-0 UEs are intended for IoT use cases, and provide 1 Mbps data rates for both up- and downlink.

Cat-M1, Category M1 (which has informally also been referred to as Category M), refers to Release 13, where further complexity reduction techniques on top of the ones for Cat-0 are standardized.

(b) **EC-GSM-IoT.**

EC-GSM-IoT, earlier referred to as EC-EGPRS, stands for Extended Coverage GSM for IoT. It includes the latest enhancements to the GSM and EGPRS standards to support better coverage and other IoT enhancements. EC-GSM-IoT supports 20 dB coverage improvements and can be deployed in the existing GSM networks.

(c) **NB-IoT.**

NB-IoT stands for Narrowband IoT and is a new narrowband radio technology being standardized in 3GPP. It covers all the components sought after: low complexity, low power consumption and long range. Some key characteristics include 180 kHz bandwidth and uplink and downlink data rates of about 200 kbps with half-duplex operation. Although this is a new radio interface, NB-IoT deployments can be made ”inband”, so that existing resource blocks in the LTE carrier are used. The term is not to be confused with LTE-M, which refers to more direct use of LTE evolution for MTC and IoT use cases. NB-IoT is subject to a lot of standardization activities at the moment. The complexity reduction compared to Cat-1 is up to 90 percent.

Summary for eMTC, NB-IOT and EC-GSM-IoT

	eMTC (LTE Cat M1)	NB-IOT	EC-GSM-IoT
Deployment	In-band LTE	In-band & Guard-band LTE, standalone	In-band GSM
Coverage*	155.7 dB	164 dB for standalone, FFS others	164 dB, with 33dBm power class 154 dB, with 23dBm power class
Downlink	OFDMA, 15 KHz tone spacing, Turbo Code, 16 QAM, 1 Rx	OFDMA, 15 KHz tone spacing, 1 Rx	TDMA/FDMA, GMSK and 8PSK (optional), 1 Rx
Uplink	SC-FDMA, 15 KHz tone spacing Turbo code, 16 QAM	Single tone, 15 KHz and 3.75 KHz spacing SC-FDMA, 15 KHz tone spacing, Turbo code	TDMA/FDMA, GMSK and 8PSK (optional)
Bandwidth	1.08 MHz	180 KHz	200kHz per channel. Typical system bandwidth of 2.4MHz [smaller bandwidth down to 600 kHz being studied within Rel-13]
Peak rate (DL/UL)	1 Mbps for DL and UL	DL: ~50 kbps UL: ~50 for multi-tone, ~20 kbps for single tone	For DL and UL (using 4 timeslots): ~70 kbps (GMSK), ~240kbps (8PSK)
Duplexing	FD & HD (type B), FDD & TDD	HD (type B), FDD	HD, FDD
Power saving	PSM, ext. I-DRX, C-DRX	PSM, ext. I-DRX, C-DRX	PSM, ext. I-DRX
Power class	23 dBm, 20 dBm	23 dBm, others TBD	33 dBm, 23 dBm

Comparison of 3GPPP standards. [4]

2. Protocols standarized from IEEE.

IEEE stands for ”Institute of Electrical and Electronics Engineers” and is a professional association of electrical engineers . It was formed in 1963 from the amalgamation of the American Institute of Electrical Engineers and the Institute of Radio Engineers. IEEE has a significant role in scientific research regarding technological issues and had determinant presence in the standardisation of many well known technologies such as Wi-Fi.

Thus, IEEE , as a pioneer institute ,was one of the organisations that paved the way for IoT standardisation protocols and their suggestions are the followings:

IEEE 802.11ah (Wi-FI)

This standard can use any industrial-scientific-medical (ISM) frequency spectrum below 1 GHz, but the primary targeted band is the 902- to 928-MHz license-free band in the U.S. Similar bands just below 1 GHz are found in other countries, such as 863-868 MHz in Europe, 717-723 MHz in Korea, 916-927 MHz in Japan, and 755-787 MHz in China. This is good news because low power can be used over these lower frequencies, enabling battery-operated equipment. While most Wi-Fi gear has a maximum range of 100 meters under ideal conditions, HaLow can reach up to a kilometer with the right antenna. The 902- to 928-MHz spectrum offers 26 MHz of bandwidth that's divided into 1-, 2-, 4-, 6-, or 16-MHz channels. The 11ah modulation scheme is orthogonal frequency-division multiplexing (OFDM) using 24 subcarriers in a 1-MHz channel and 52 data subcarriers in the larger bandwidths. Modulation can be BPSK, QPSK, or 16QAM, 64QAM, or 256QAM with multiple coding options, providing for a wide range of data rates. Rates of 100 kb/s in a 1-MHz channel and up to several hundred megabits per second in a 16-MHz channel are easily achieved. The real goal of 11ah is low power. The typical user station has a sleep mode to conserve battery charge. Short data packets and shortened contention access procedures minimize transmit time and power usage. The standard supports a massive number of possible network stations (8191). A special station type is the relay access point, which helps all other stations pass along messages over longer distances at low power. Support is also provided for up to four spatial data streams to further boost data rate. In addition, the antenna-sectorization feature partitions the coverage area. The 802.11ah standard is blessed by the Wi-Fi Alliance (WFA), which gave it the trade name HaLow. The WFA says that it will implement one of its testing and certification programs for HaLow by 2018. HaLow is a sophisticated technology that has yet to be widely adopted. Nevertheless, it's still worthy of consideration for new projects.[22]

IEEE 802.15.4

IEEE 802.15.4 is a standard that defines low rate wireless personal area networks (LR-WPANs). Created by IEEE 802.15 TG4 in 2003 when the goup was chartered to investigate a low data rate solution with multi-month to multi-year battery life and very low complexity. It is operating in an unlicensed, international frequency band. Potential applications would be sensors, interactive toys, smart badges, remote controls, and home automation.

It is the basis for the Zigbee, ISA100.11a, WirelessHART, MiWi, 6LoWPAN, Thread and SNAP specifications, each of which further extends the standard by developing the upper layers which are not defined in IEEE 802.15.4. In particular, 6LoWPAN defines a binding for the IPv6 version of the Internet Protocol (IP) over WPANs, and is itself used by upper layers like Thread.

Technically it supports a transfer rate of 250 kbit/s, real-time suitability by reservation of Guaranteed Time Slots (GTS), collision avoidance through CSMA/CA and integrated support for secure communications. Devices also include power management functions such as link quality and energy detection.

IEEE 802.15.1 (Bluetooth)

Bluetooth technology was invented in 1994 by engineers at Ericsson. In 1998, a group of companies agreed to work together using Bluetooth technology as a way to connect their products. These companies formed the Bluetooth Special Interest Group (SIG), an organization devoted to maintaining the technology. This means that no single company "owns" Bluetooth technology, but that many members of the Bluetooth SIG work together to develop Bluetooth technology. Bluetooth SIG developed Bluetooth specification. Afterwards this specification became a part of IEEE 802.15.1 standard.

In 2011, the Bluetooth SIG announced the Bluetooth Smart logo so as to clarify compatibility between the new low energy devices and other Bluetooth devices. In contrast with previous Bluetooth flavors, BLE has been designed as a low-power solution for control and monitoring applications. BLE is the distinctive feature of the Bluetooth 4.0 specification. BLE operates in the 2.4 GHz Industrial Scientific Medical (ISM) band and defines 40 Radio Frequency (RF) channels with 2 MHz channel spacing.

	Wi-Fi IEEE 802.11b	Bluetooth IEEE 802.15.1	ZigBee IEEE 802.15.4
Radio	Direct Sequence Spread Spectrum DSSS	Frequency Hopping Spread Spectrum FHSS	Direct Sequence Spread Spectrum DSSS
Data rate	11 Mbps	1 Mbps	250 kbps
Nodes per master	32	7	64,000
Slave enumeration latency	up to 3 s	up to 10 s	30 ms
Data type	video, audio, graphics, pictures, files	audio, graphics, pictures, files	small data packet
Range [m]	100	10	10 - 100
Extendibility	roaming possible	no	yes
Complexity	Complex	very complex	simple
Positioning technology	CoO, (tri)lateration, fingerprinting	CoO	(tri)lateration, fingerprinting

Comparison of Ieee standards. [3]

3. **Protocols from other parties.**

Sigfox

Sigfox is a standard created by a French Enterprise. It uses the ISM band and an Ultra-Narrow Band (UNB) modulation with Differential Binary Phase-Shift Keying (DBPSK). It operates in the 200 KHz of the publicly available band to exchange radio messages over the air. Each message is 100 Hz wide and transferred at 100 or 600 bits per second, depending on the region. As a result, long distances can be achieved while being very robust against noise.

WeightLess

Weightless is a set of LPWAN open wireless technology standards for exchanging data between a base station and thousands of machines around it. These technologies allow developers to build Low-Power Wide-Area Networks.Originally, there was three published Weightless connectivity standards Weightless-P, Weightless-N and Weightless-W. Weightless-N was an uplink only LPWAN technology. Weightless W was designed to operate in the TV whitespace. Weightless (Weightless-P) was the true winner with its true bi-directional, narrowband technology designed to be operated in global licensed and unlicensed ISM frequencies.

LoRa

LoRa (short for long range) is a spread spectrum modulation technique derived from chirp spread spectrum (CSS) technology. Semtech?s LoRa devices and wireless radio frequency technology (LoRa Technology) is a long range, low power wireless platform that has become the de facto technology for Internet of Things (IoT) networks worldwide. LoRa Technology and the open LoRaWAN.

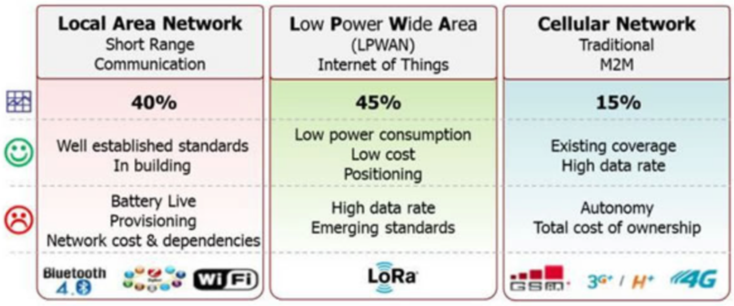
The LoRaWAN open specification is a low power, wide area networking (LPWAN) protocol based on LoRa Technology. Designed to wirelessly connect battery operated things to the Internet in regional, national or global networks, the LoRaWAN protocol leverages the unlicensed radio spectrum in the Industrial, Scientific and Medical (ISM) band. The specification defines the device-to-infrastructure of LoRa physical layer parameters and the LoRaWAN protocol, and provides seamless interoperability between devices. While Semtech provides the radio chips featuring LoRa Technology, the LoRa Alliance®, a non-profit association and the fastest growing technology alliance, drives the standardization and global harmonization of the LoRaWAN protocol.

	Sigfox	Lora	Weightless-P
Total Bandwidth(kHz)	200	1000	100
Typical Data Rate(bps)	100	2466	3200
Simultaneous Demod	0.016	0.08	1
Number of Channels	2000	8	8
PHY Throughput(bps)	3200	1536	25600
Repetition Rate	1	1	1
Up Dn Ratio	1	1	2
Protocol Overhead	2	2	2
Multi-Cell Interference	1.14	1.5	1.3

A LWAN protocol Comparison.[**?**]

1.2.3 Why LoRa

Lora is an upcoming IoT Protocol that gains ground in comparison to its peers standards because of its low power consumption and low cost. Despite, its lower data rate , for certain application (as Agricultural applications) can be the best choice , and this is because some IoT applications, demand a simple connection that data rate is not a critical factor.



In this Thesis we are going to conduct a set of experiments that utilize LoRa PHY in order to transmit basic messages.

Under examination, is considered to be LoRa Radio Coverage related to different Spreading Factors and and different Transmit Powers.

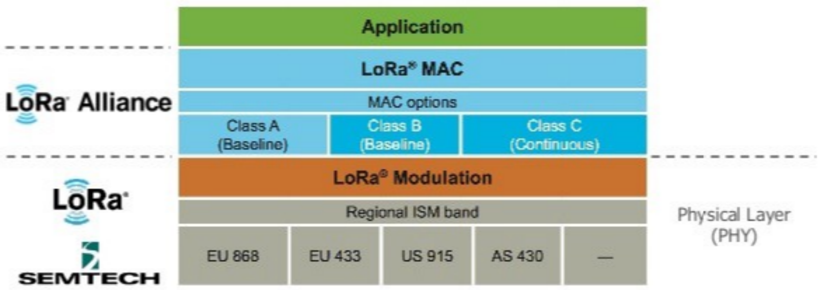
Chapter 2

Lora's Technical Anatomy

LoRa stands for "Long Range" and is a long-range wireless communications system, promoted by the LoRa Alliance. This system aims at being usable in long-lived battery-powered devices, where the energy consumption is very importance. LoRa consists of two layers :

1. A physical layer using the Chirp Spread Spectrum (CSS) radio modulation techniqueand

2. A MAC layer protocol (LoRaWAN), although the LoRa communications system also implies a specific access network architecture



The radio and modulation part of the LPWAN technology is specified and patented by the company Semtech. The LoRa Alliance is in charge of standardizing the LoRaWAN part of the stack(Mac Layer).

2.1 Lora Physical Layer-Modulation

The radio wave modulation technology behind LoRa was developed by engineers at French company Cycleo which was founded in 2009 and acquired by Semtech, a supplier of analog and mixed-signal semiconductors, in 2012 to "complement" the latter's long-range low power radio frequency technology portfolio.

The LoRa physical layer, developed by Semtech, allows for long-range, low-power and low-throughput communications. It operates on the 433-, 868- or 915-MHz ISM bands, depending on the region in which it is deployed. The payload of each transmission can range from 2–255 octets, and the data rate can reach up to 50 Kbps when channel aggregation is employed. The modulation technique is a proprietary technology from Semtech.[8].

	Europe	North America	China	Korea	Japan	India
Frequency band	867-869MHz	902-928MHz	470-510MHz	920-925MHz	920-925MHz	865-867MHz
Channels	10	64 + 8 +8	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee
Channel BW Up	125/250kHz	125/500kHz				
Channel BW Dn	125kHz	500kHz				
TX Power Up	+14dBm	+20dBm typ (+30dBm allowed)				
TX Power Dn	+14dBm	+27dBm				
SF Up	7-12	7-10				
Data rate	250bps- 50kbps	980bps-21.9kpbs				
Link Budget Up	155dB	154dB				
Link Budget Dn	155dB	157dB				

Chirp Spread Spectrum (CSS)

Spread spectrum technique, uses wideband, noise-like signals that are hard to detect, intercept, or demodulate. Additionally, spread-spectrum signals are harder to jam (interfere with) than narrow band signals. These low probability of intercept (LPI) and anti-jam (AJ) features are why the military has used spread spectrum for so many years. Spread-spectrum signals are intentionally made to be a much wider band than the information they are carrying to make them more noise-like. There many spread spectrum techniques and Lora modulation uses The Chirp Spread Spectrum.

In digital communications, chirp spread spectrum (CSS) is a spread spectrum technique that uses wideband linear frequency modulated chirp pulses to encode information.

CHIRP stands for Compressed High Intensity Radar Pulse and

A chirp waveform is a Sinusoidal waveform whose frequency varies in time either linearly , or geometrically :

In a linear-frequency chirp or simply linear chirp, the instantaneous frequency f(t) varies exactly linearly with time. The waveform can be written as [17]

$$s(t) = a(t)cos[\Theta(t)]$$

where $\Theta(t)$ is the phase, and $a(t)$ is the envelope of the chirp signal which is zero outside a time interval of lenght T. The instantanous frequency is defined as :

$$f_M(t) = \frac{1}{2\pi}\frac{d\Theta}{dt}.$$

The chirp rate is defined by

$$\mu(t) = \frac{df_M}{dt} = \frac{1}{2\pi}\frac{d^2\Theta}{dt^2}$$

and represents the rate of change of the instantanous frequency.
Waveforms with $\mu(t) > 0$ are the up-chirps. and those with $\mu(t) < 0$ are the down-chirps.

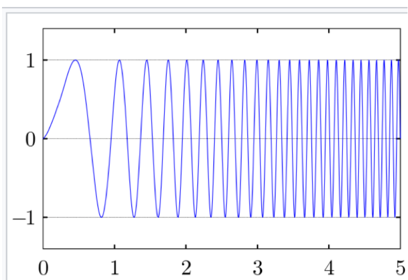
for a linear chirp $\mu(t)$ is constant, and hence $f_M(t)$ is a linear function of t, and $\Theta(t)$ is a quadratic function. If we take the waveform to be centered at t=0 it can written as:

$$s(t) = a(t)cos[2\pi f_c t + \pi\mu t^2 + \varphi_0]$$

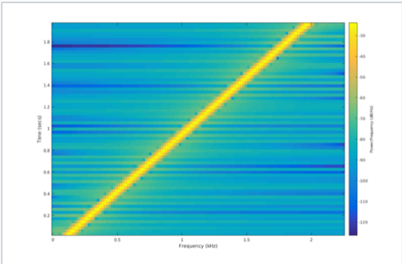
where f_c is the center frequency and a(t)=0 for $|t| > \frac{T}{2}$. It is convenient to defi

ne the bandwidth B as the range of the instantanous frequency, so that:

$$B = |\mu|T.$$

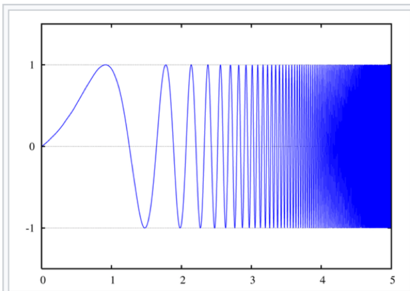


A linear chirp waveform; a sinusoidal wave that increases in frequency linearly over time

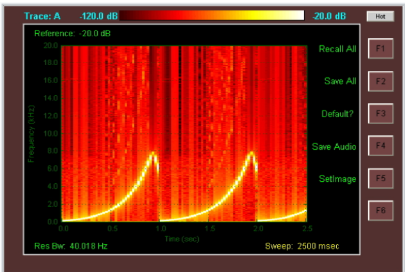


Spectrogram of a linear chirp. The spectrogram plot demonstrates the linear rate of change in frequency as a function of time, in this case from 0 to 7 kHz, repeating every 2.3 seconds. The intensity of the plot is proportional to the energy content in the signal at the indicated frequency and time.

In a geometric chirp, also called an exponential chirp, the frequency of the signal varies with a geometric (exponential)relationship over time.

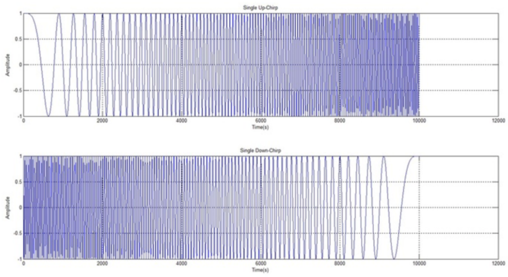


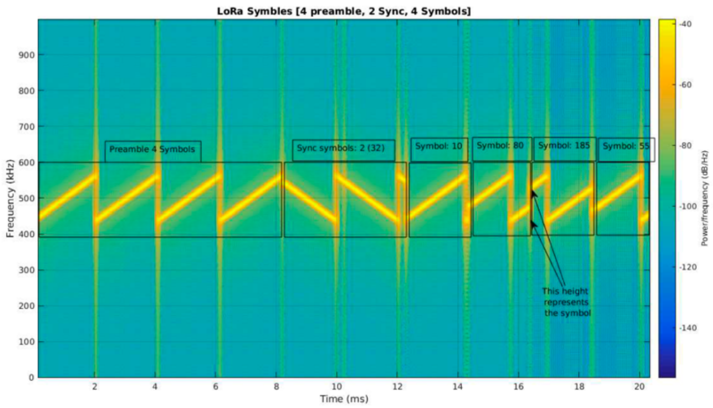
An exponential chirp waveform; a sinusoidal wave that increases in frequency exponentially over time



Spectrogram of an exponential chirp.

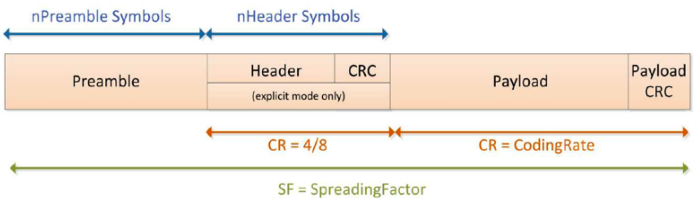
LoRa Symbols consists from upchirps and downchirps. Upchirps : Increases frequency in time. Downchirps: Decreases frequency in time.





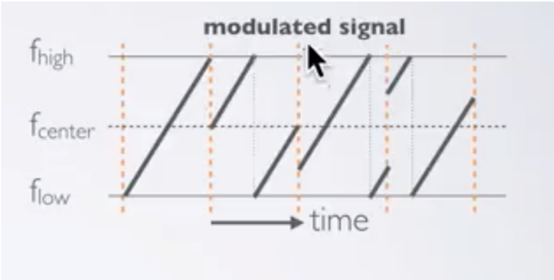
Lora's packet frame[14]:

- Physical Frame (explicit mode)
  - In the following picture, the preamble includes the synchronization word.
  - Explicit mode includes the explicit header + CRC



Chirp signals are used as carrier signals where message is encoded on. Chirps are cyclically-sifted in time and it is the frequency jumps that determines how the data is encoded onto the chirps. To an unmodulated signal corresponds the below spectrogram:

To a modulated signal corresponds the following spectrogram:



Frequency Hopping with LoRa

Frequency hopping spread spectrum (FHSS) is a wireless technology that spreads a signal over rapidly changing frequencies. The frequency hopping mode of the LoRa modem can be enabled by setting FreqHoppingPeriod to a non-zero value in register RegHopPeriod of the semtech's chip.

The principle behind the FHSS scheme is that a portion of each LoRa® packet is transmitted on each hopping channel from a look up table of frequencies managed by the host microcontroller(semtech's chip). After a predetermined hopping period the transmitter and receiver change to the next channel in a predefined list of hopping frequencies to continue transmission and reception of the next portion of the packet. The time which the transmission will dwell in any given channel is determined by FreqHoppingPeriod which is an integer multiple of symbol periods:

$$HoppingPeriod = T_s x FreqHoppingPeriod[21]$$

2.1.1 Other Modulations supported by LoRa

There are also others modulation supported by LoRa. More specifically, Lora modulator supports FSK(Frequency Sift Keying) modulation and OOk modulation.

Frequency-shift keying (FSK) is a frequency modulation scheme in which digital information is transmitted through discrete frequency changes of a carrier signal(the chirp).

On-Off Keying (OOK) is an amplitude-shift keying (ASK) modulation that represents digital data at the presence or absence of a carrier wave and it is simply deploed by switching on and off the power amplifier.

LoRa's demodulator from the other hand, can also demodulate FSK, GFSK, MSK and GMSK modulated signals.

GFSK (Gaussian frequency-shift keying modulation) filters the data pulses with a Gaussian filter to make the transitions smoother. This filter has the advantage of reducing sideband power, reducing interference with neighboring channels, at the cost of increasing intersymbol interference.

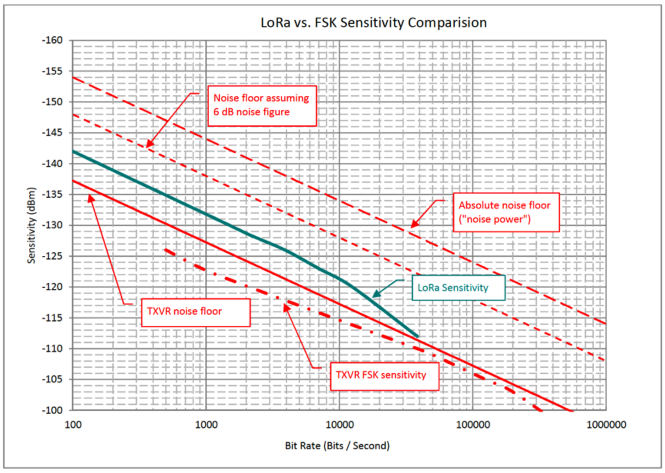
MSK (Minimum frequency-shift keying or minimum-shift keying) is a particular spectrally efficient form of coherent FSK. In MSK, the difference between the higher and lower frequency is identical to half the bit rate. Consequently, the waveforms that represent a 0 and a 1 bit differ by exactly half a carrier period.

GMSK (Gaussian Minimum Shift Keying) is a form of modulation based on frequency shift keying that has no phase discontinuities and provides efficient use of spectrum as well as enabling high efficiency radio power amplifiers.

2.1.2 Lora's Sensitivity :

$NoiseFloor = 10 * log_{10}(k * T * B * 1000)$ (dBm)
Where:
Noise Floor = equivalent noise power (dBm)
K = Boltzmann's Constant (1.38 *10-23)
T = 293 kelvin ("room temperature")
B = channel bandwidth (Hz)
1000 = scaling factor from Watts to milli-Watts
This can be simplified as:
$NoiseFloor = -174 + 10 * log_{10}(B)$ (dBm)

Where:
-174 = 10 * log10 (k * T * 1000) as defined above
B = channel bandwidth (Hz) as before
Lora Protocol Descrption[12]



2.1.3 Lora's Link Budget :

The link budget of a wireless system or network is a measure of all the gains and losses from the transmitter, through the propagation channel, to the target receiver. These gains and losses include system gains and losses associated with the antenna, matching networks, etc. as well as losses associated propagation channel itself (either though modelling or measured data). Typically randomly varying channel mechanisms such as multipath and Doppler fading are taken into account by factoring additional margin depending on the anticipated severity. The link budget of a network wireless link can be expressed as:

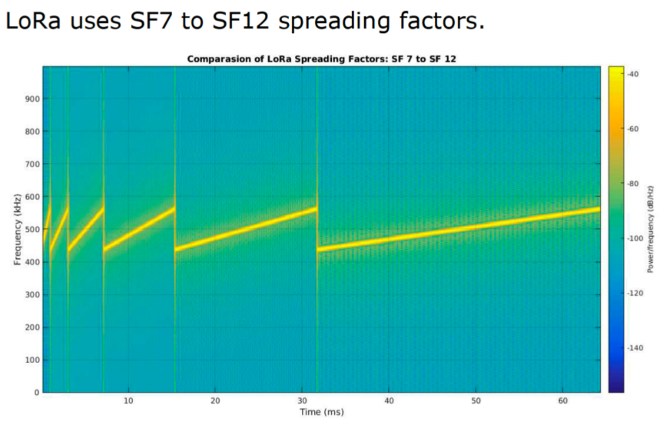
$$P_{RX}(dBm) = P_{TX}(dBm) + G_{SYSTEM}(dB) - L_{SYSTEM}(dB) + l_{CHANNEL}(dB) + M(dB)$$

Where:
P_{RX}= the expected power incident at the receiver
P_{TX} = the transmitted power
G_{SYSTEM} = system gains such as those associated with directional antennas, etc.
L_{SYSTEM} = losses associated with the system such as feed-lines, antennas (in the case of electrical short antennas associated with many remote devices),

etc.
$l_{CHANNEL}$ = losses due to the propagation channel, either calculated via a wide range of channel models or from empirical data.
M = fading margin, again either calculated.

2.1.4 LoRa Wireless Transmission Principals.

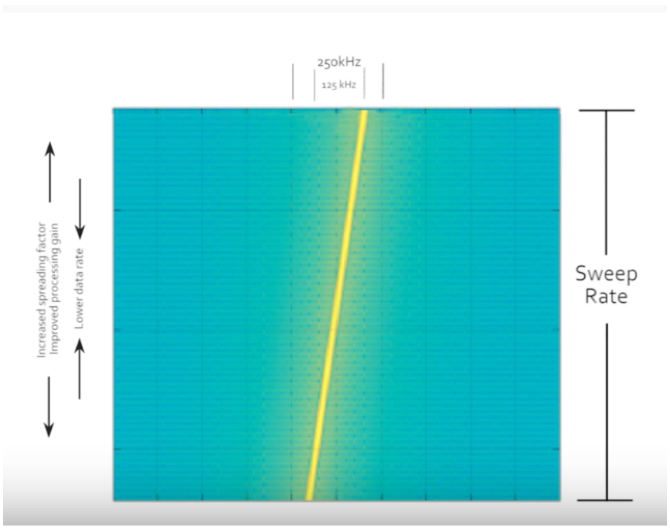
As mentioned before, LoRa is a spread Spectrum technology, which use chirps to transmit data. The spreading factor expresses the number of bits that is carried by a symbol. As LoRa is basically an FSK modulation, the bits to be transmitted are expressed by the jumping of the signal between two frequencies, and the chirp pulse plays the role of the carrier signal. The spreading factor of LoRa protocol is, essentially, the sweep rate between the frequencies. Six different SF are supported by the LoRa modulation.



Bandwidth expresses the range of frequencies via the signal can be transmitted. As shown to the below spectrogram.

(a) Transmitter (b) Receiver

Figure 2.1: LoRa Transmission

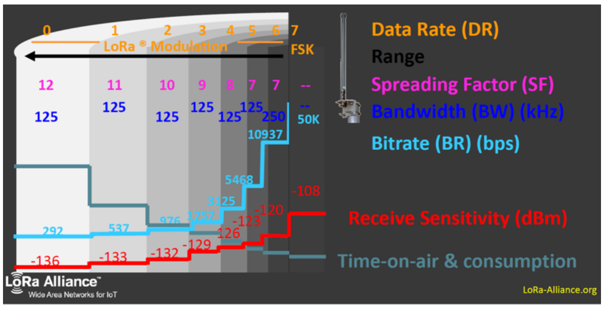


As The SF increases, the the symbol duration increases, the packet and consequently the Time on air of the packet (ToA), the message transmission time in other words.

In the contrary the as the Spreading Factor increases the data rate decreases, because as the SF increases, the same data bits are transferred with more chips.

$$DataRate(bits/sec) = SF * \frac{BW}{2^{SF}} * \frac{4}{4+CR}$$

CR:Coding Rate



DataRate	Configuration	Indicative physical bit rate [bit/s]
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa: SF7 / 125 kHz	5470
6	LoRa: SF7 / 250 kHz	11000
7	FSK: 50 kbps	50000
8..15	RFU	

TXPower	Configuration
0	20 dBm (if supported)
1	14 dBm
2	11 dBm
3	8 dBm
4	5 dBm
5	2 dBm
6..15	RFU

LoRa Spreading Factors (125kHz bw)

Spreading Factor	Chips/symbol	SNR limit	Time-on-air (10 byte packet)	Bitrate
7	128	-7.5	56 ms	5469 bps
8	256	-10	103 ms	3125 bps
9	512	-12.5	205 ms	1758 bps
10	1024	-15	371 ms	977 bps
11	2048	-17.5	741 ms	537 bps
12	4096	-20	1483 ms	293 bps

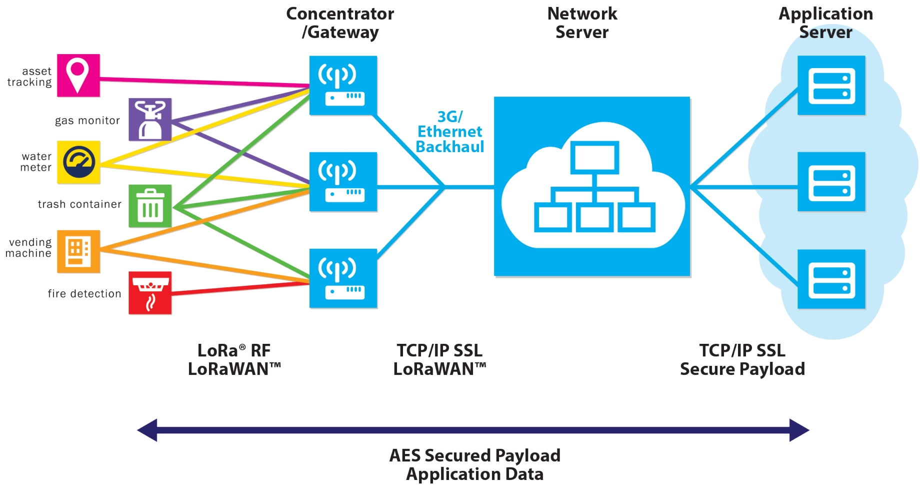
2.2 Lora Mac Layer-LoRaWAN

LoRaWAN is a media access control (MAC) protocol for wide area networks. It is designed to allow low-powered devices to communicate with Internet-connected applications over long range wireless connections. LoRaWAN can be mapped to the second and third layer of the OSI model. It describes star-shaped networks and it is implemented on top of LoRa or FSK modulation in industrial, scientific and medical (ISM) radio bands. The LoRaWAN protocols are defined by the LoRa Alliance and formalized in the LoRaWAN Specification which can be downloaded on the LoRa Alliance website[10]. Unlike Lora Physical Layer which is proprietary and is owned by semtech, LoRaWAN is an open source protocol.

The LPWAN typically has star topology and consists of BSs relaying data messages between the End Devices and an Application Server. The

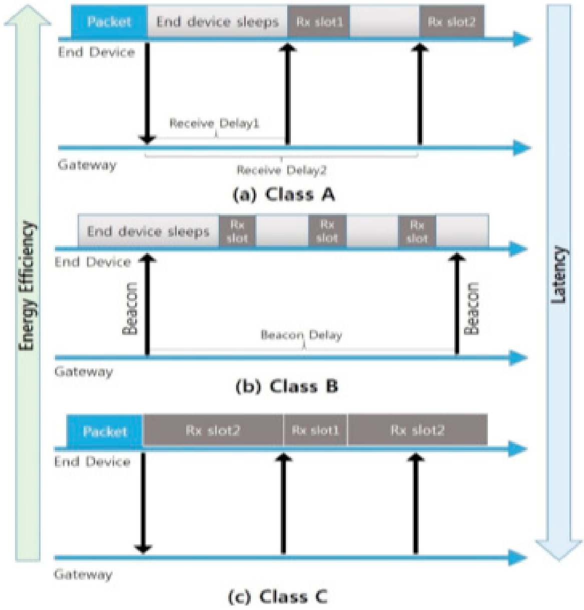
Network Server implements the MAC layer and network management functions.The BSs can be connected to the central server via backbone internet protocol (IP) based link, and the wireless communication based on LoRa or GFSK modulation is used to move the data between EDs and the BSs.

LoRaWAN Architecture:



LoRaWAN Architecture.[10]

LoRaWAN end Devices:



End Devices Classification .[14]

End Devices Classification:
Bi-directional end-devices (Class A):

End-devices of Class A allow for bi-directional communications whereby each end-device's uplink transmission is followed by two short downlink receive windows. The transmission slot scheduled by the end-device is based on its own communication needs with a small variation based on a random time basis (ALOHA-type of protocol). This Class A operation is the lowest power end-device system for applications that only require downlink communication from the server shortly after the end-device has sent an uplink transmission. Downlink communications from the server at any other time will have to wait until the next scheduled uplink.

Bi-directional end-devices with scheduled receive slots (Class B)

This class of end devices use extra receive windows during downlink period in addition to two time slots specified in class-A. Class B devices will get extra receive windows at specified duration. The duration is specified by the gateway using beacon frame. Hence this way LoRa system indicates to the server when end device can listen.

Bi-directional end-devices (Class C)

This class of end devices can listen all the time except in transmit mode. Hence it is ideal for applications requiring more downlink transmissions. Class C LoRa end device will utilize more power compare to Class A and Class B counterparts. It has lowest latency among all the LoRa class end devices for data communication between server and end device.

LoRa Class A	LoRa Class B	LoRa Class C
Battery Powered	Low Latency	No Latency
Bidirectional communications	Bidirectional with scheduled receive slots	Bidirectional communications
Unicast messages	Unicast and Multicast messages	Unicast and Multicast messages
Small payloads, long intervals	Small payloads, long intervals, Periodic beacon from gateway	Small payloads
End-device initiates communication (uplink)	Extra receive window (ping slot)	Server can initiate transmission at any time
Server communicates with end-device (downlink) during predetermined response windows	Server can initiate transmission at fixed intervals	End-device is constantly receiving

End Devices Comparison. [23]

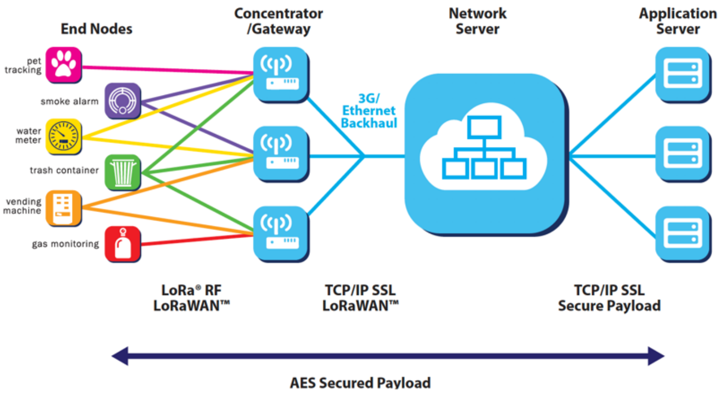
2.3 Difference between Lora and LoRaWan

LoRa is the modulation technique used in the physical layer of LoRaWAN network. It is basically CSS (Chirp Spread Spectrum) modulation used to provide different data rates using different spreading factors. Used as robust modulation in LORaWAN system. It helps in achieving different data rates. It has specific function in physical layer of the system. LoRaWAN is wireless network used as WAN (Wide Area Network) due to its wide coverage capabilities. Used as low power, low data rate and long range wireless system. It is popular in IoT/M2M based systems. It has four layers viz. RF, PHY, MAC and Application layer.

Chapter 3

Lora's Market Applications

LoRa Technology according to semtech[11], has registered over 600 known uses cases for smart cities, smart homes and buildings, smart agriculture, smart metering, smart supply chain and logistics, across the world. With 97 million devices connected to networks in 100 countries and growing, LoRa Technology is the DNA of IoT, creating a Smarter Planet.



A few implementations of Lora standard to left side.[12]

Lora's Use Case's concerns, mainly, the following sectors:[13]

1. **Smart Agriculture**

   From measuring environmental conditions that influence crop production to tracking livestock health indicators, Internet of Things (IoT) technology for agriculture enables efficiencies which reduce environmental impact, maximize yield and minimize expenses. Smart agriculture use cases based on Semtech's LoRa® devices and the LoRaWAN®

protocol have demonstrated significant improvements, such as a 50 per cent water reduction for commercial farms. LoRa Technology's long-range, low-power wireless qualities enable the use of low cost sensors to send data from the farm to the Cloud where it can be analyzed to improve operations.

2. **Smart Cities**

   Everyday municipal operations are made more efficient with LoRa Technology's long range, low power, secure, and GPS-free geolocation features. By connecting city services such as lighting, parking, waste removal, and more, cities can optimize the use of utilities and personnel to save time and money.

3. **Smart Environment**

   By implementing a network of sensors and gateways embedded with LoRa Technology across a region, environmental indicators can be measured and reported for data analysis in real-time, detecting issues before they become crises. From air quality monitoring to radiation leak detection, LoRa®-based IoT solutions for the environment help protect citizens from environmental dangers.

4. **Smart Healthcare**

   LoRa Technology's low power, low cost and reliable performance make it suitable for critical smart healthcare applications. IoT solutions comprised of LoRa®-based sensors and gateways can monitor high-risk patients or systems around the clock, ensuring health and medical safety are never overlooked.

5. **Smart Homes and Buildings**

   LoRa Technology's low power qualities and ability to penetrate dense building materials make it an ideal platform for IoT-connected smart home and building devices. In addition, the long range capabilities make it possible for LoRa®-enabled sensors and the LoRaWAN® protocol to track assets that stray from home. Sensors in smart home and building applications can detect danger, optimize utility usage and more to improve the safety and convenience of everyday living.

6. **Smart Industrial Control**

   Industrial operations can benefit from the deployment of IoT-connected sensors for various aays-on monitoring functions. Due to the long range, low power, and long battery life of LoRa®-based devices, sensors in manufacturing plants or mobile industries can relay critical data to a LoRaWAN® network where it can be analyzed and businesses operations can be optimized.

7. **Smart Metering**

   Traditional utility operations are labor intensive and utilize subjective measurement by field personnel. Additionally, meters are often located in dense urban environments, indoors or even underground, which can be difficult or impossible to reach by many wireless technologies. By implementing a smart utilities infrastructure comprised of sensors and gateways utilizing LoRa® devices and the LoRaWAN® protocol, utility and metering companies can collect data remotely and use personnel more efficiently to streamline operations.

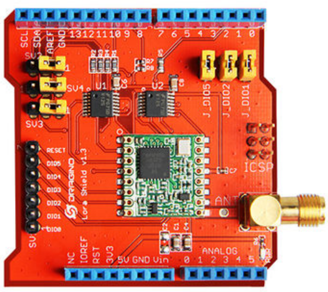
8. **Smart Supply Chain and Logistics**

   LoRa Technology makes it easy and affordable for smart supply chain and logistics to track highly valued assets that are in transit. Due to LoRa Technology's long range and low power consumption qualities and GPS-free geolocation abilities, cargo, vehicles and other assets can be easily monitored over large geographic regions and within harsh environments.

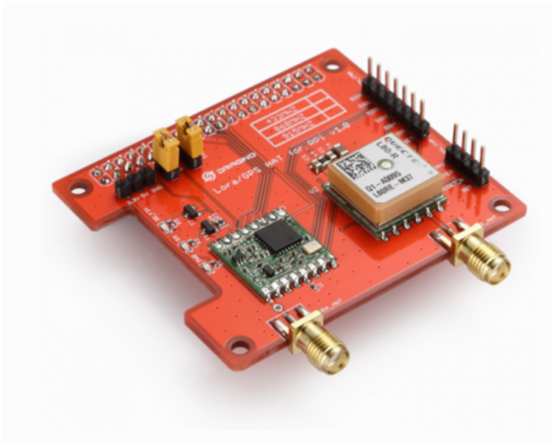
Chapter 4

Commercial Hardware for LoRa Protocol

As it was expected ,the advent of Lora technology, attracted the interest of many hardware manufacturers. At the moment, we can find many modules , that offers communication under Lora's rules. The most popular are modules that can be connected to Arduino and Raspberry pi, and convert them into nodes. Also, well known are the Lopy-pycom nodes. Some of them are shown below:



Arduino Lora shield from Dragino[18]



Raspberry pi Lora shield from Dragino[19]

Pycom Modules from Pycom[20]

These are the most popular Lora modules, there are also other hardware manufacturers that creates similar modules. But, all modules, regardless the manufacturer, shares one thing in common, and this is the Semtech's Lora chip.

4.1 Semtech's LoRa Chip

As LoRa modulation is a proprietary protocol, it is expected that all the hardware regarding lora would wear semetch's chips. This chip,in fact, is a transceiver.

More precisely, The SX1276/77/78/79 transceivers feature the LoRalong range modem that provides ultra-long range spread spectrum communication and high interference immunity whilst minimising current consumption.

For the sake of this thesis, SX1276 transceiver was used for Pycom's Lopy4.

Table 1 SX1276/77/78/79 Device Variants and Key Parameters

Part Number	Frequency Range	Spreading Factor	Bandwidth	Effective Bitrate	Est. Sensitivity
SX1276	137 - 1020 MHz	6 - 12	7.8 - 500 kHz	.018 - 37.5 kbps	-111 to -148 dBm
SX1277	137 - 1020 MHz	6 - 9	7.8 - 500 kHz	0.11 - 37.5 kbps	-111 to -139 dBm
SX1278	137 - 525 MHz	6- 12	7.8 - 500 kHz	.018 - 37.5 kbps	-111 to -148 dBm
SX1279	137 - 960MHz	6- 12	7.8 - 500 kHz	.018 - 37.5 kbps	-111 to -148 dBm

[21]

For our experiments we used the SX1276 transceiver.

1.1. Simplified Block Diagram

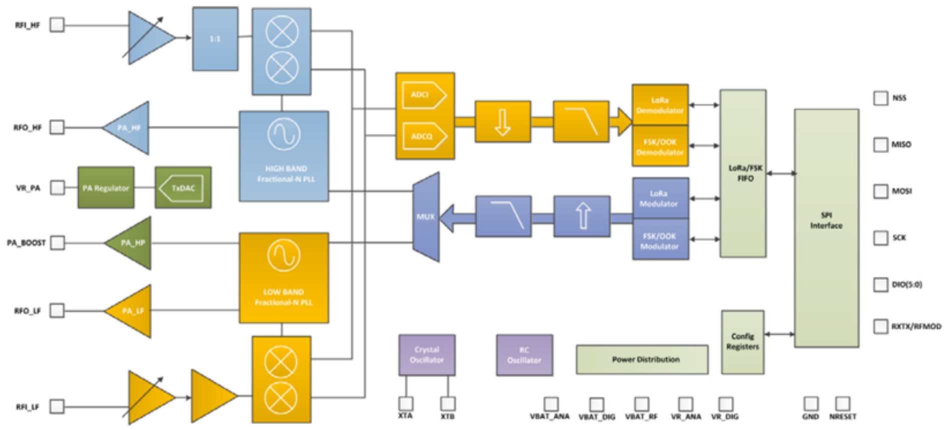


Figure 1. Block Diagram

Simplified Block Diagram of the chip[21]

In fact, SX1276/77/78/79 is a half-duplex, low-IF transceiver.

LNA : LNA is an electronic amplifier that amplifies a very low-power signal without significantly degrading its signal-to-noise ratio. A typical amplifier increases the power of both the signal and the noise present at its input, whereas LNAs are designed to amplify a signal while minimizing additional noise. So at first the received RF signal is first amplified by the

LNA. The LNA inputs of owr tranceivers are single ended to minimize the external BoM and for ease of design.

Mixer Stage : Mixer is responsible the conversion to differential is made to improve the second order linearity and harmonic rejection. The signal is then down-converted to in-phase and quadrature components at the intermediate frequency (IF) .

ADCs : A pair of sigma delta ADCs perform data conversion, with all subsequent signal processing and demodulation performed in the digital domain. The digital state machine also controls the automatic frequency correction (AFC), received signal strength indicator (RSSI) and automatic gain control (AGC). It also features the higher-level packet and protocol level functionality of the top level sequencer (TLS), only available with traditional FSK and OOK modulation schemes.

Frequency synthesizers: generate the local oscillator (LO) frequency for both receiver and transmitter, one covering the lower UHF bands (up to 525 MHz), and the other one covering the upper UHF bands (from 779 MHz). The PLLs are optimized for user-transparent low lock time and fast auto-calibrating operation. In transmission, frequency modulation is performed digitally within the PLL bandwidth. The PLL also features optional pre-filtering of the bit stream to improve spectral purity.

Modems : The SX1276/77/78/79 are equipped with both standard FSK and long range spread spectrum (LoRa®) modems. Depending upon the mode selected either conventional OOK or FSK modulation may be employed or the LoRa® spread spectrum modem.

SX1276/77/78/79 also include two timing references, an RC oscillator and a 32 MHz crystal oscillator.

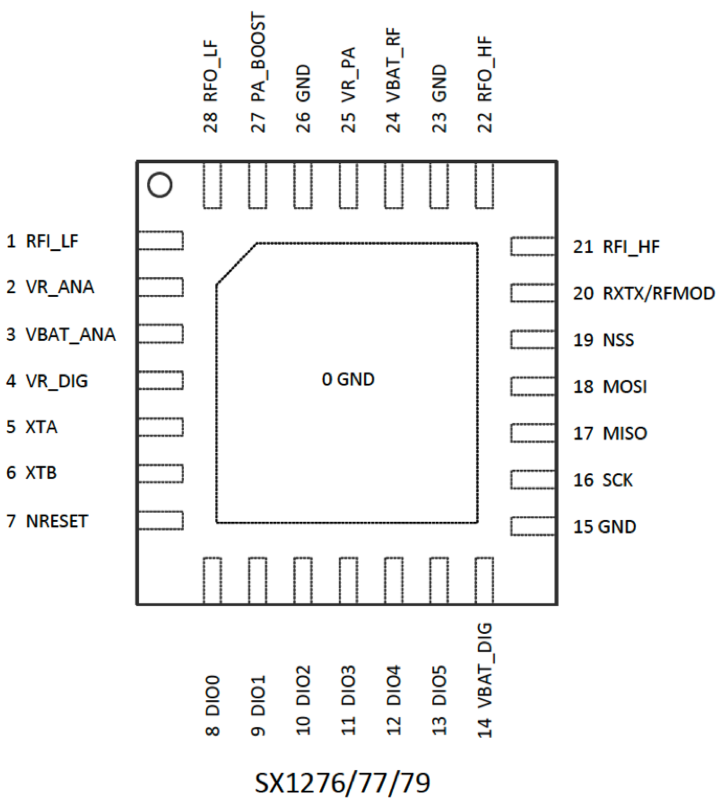
SPI interface : All major parameters of the RF front end and digital state machine are fully configurable via an SPI interface which gives access to SX1276/77/78/79's configuration registers. This includes a mode auto sequencer that oversees the transition and calibration of the SX1276/77/78/79 between intermediate modes of operation in the fastest time possible.

FIFO data buffer : A 256 byte RAM data buffer which is uniquely accessible in LoRa mode. This RAM area, herein referred to as the FIFO Data buffer, is fully customizable by the user and allows access to the received, or to be transmitted, data. All access to the LoRa® FIFO data buffer is done via the SPI interface.

Pins (General purpose IO)

General purpose IO pins are available used in LoRa® mode. Their mapping is shown below and depends upon the configuration of registers RegDioMapping1 and RegDioMapping2.

The Pin equivalent of the chip:



[21]

Pins description:

1.4. Pin Description

Table 2 Pin Description

Number	Name	Type	Description
	SX1276/77/79/(78)	SX1276/77/79/(78)	SX1276/77/79/(78)
0	GROUND	-	Exposed ground pad
1	RFI_LF	I	RF input for bands 2&3
2	VR_ANA	-	Regulated supply voltage for analogue circuitry
3	VBAT_ANA	-	Supply voltage for analogue circuitry
4	VR_DIG	-	Regulated supply voltage for digital blocks
5	XTA	I/O	XTAL connection or TCXO input
6	XTB	I/O	XTAL connection
7	NRESET	I/O	Reset trigger input
8	DIO0	I/O	Digital I/O, software configured
9	DIO1/DCLK	I/O	Digital I/O, software configured
10	DIO2/DATA	I/O	Digital I/O, software configured
11	DIO3	I/O	Digital I/O, software configured
12	DIO4	I/O	Digital I/O, software configured
13	DIO5	I/O	Digital I/O, software configured
14	VBAT_DIG	-	Supply voltage for digital blocks
15	GND	-	Ground
16	SCK	I	SPI Clock input
17	MISO	O	SPI Data output
18	MOSI	I	SPI Data input
19	NSS	I	SPI Chip select input
20	RXTX/RF_MOD	O	Rx/Tx switch control: high in Tx
21	RFI_HF (GND)	I (-)	RF input for band 1 (Ground)
22	RFO_HF (GND)	O (-)	RF output for band 1 (Ground)
23	GND	-	Ground
24	VBAT_RF	-	Supply voltage for RF blocks
25	VR_PA	-	Regulated supply for the PA
26	GND	-	Ground
27	PA_BOOST	O	Optional high-power PA output, all frequency bands
28	RFO_LF	O	RF output for bands 2&3

[21]

Chapter 5

Experiments

In this chapter we will present a set of a experiments that took place in several places, indoor and outdoor, with purpose to examine the protocol coverage, in different places and ambiances. We used two different hardware modules (pycoms and raspberries), in order to achieve this goal.

The signal strength indicators that we used were RSSI and SNR.

Received Signal Strength Indicator (RSSI)

RSSI or this signal value is measured in decibels from 0 (zero) to -120 (minus 120). The closer the value to 0 (zero), the stronger the signal will be.

$P_{RX} = P_{TX} x G_{TX} x G_{RX} \lambda 4$

Friis's free space transimission equation.

$$RSSI = 10xlog P_{RX} P_{Ref}$$

Signal to Noise Ratio (SNR)

Signal-to-noise ratio is defined as the ratio of the power of a signal (meaningful information) to the power of background noise (unwanted signal):

$$SNR = P_{signal} P_{noise}$$

5.1 Pycom's Modules

With this equipment, 4 experiments were performed, 3 indoor and 1 outdoor. The coverage was assessed with different Spreading Factor(SF) and Transmit Powers(TXPWR) in different distances and different circumstances(indoor and outdoor).

(a) Transmitter (b) Receiver

Figure 5.1: LoRa Transmission

5.1.1 Code Used

To pass code files to pycoms, FileZilla was used. The code was used with the PuTTy program. There are two nodes, com 7 and com 6, one is the transmitter and the other is the receiver respectively. In the code we observe that when parameters are changed to the transmitter (eg Spreading Factor), the receiver must do the same for the experiments procedure to work properly.

```
#Network_connection
>>> from network import WLAN
>>> import machine
>>> import time
>>> wlan = WLAN(mode=WLAN.STA)
>>> wlan.ifconfig(id=0, config='dhcp')
>>> wlan.connect(ssid='name of the network',
  auth=(WLAN.WPA2, 'password'), timeout=5000)

#Transmitter_COM7
#IP_addresses
>>> wlan.ifconfig()
('192.168.1.111', '255.255.255.0',
  '192.168.1.254', '192.168.1.254')
#versions_of_pycoms
>>> import os
>>> os.uname()
(sysname='LoPy4', nodename='LoPy4', release='1.18.2.r7',
version='v1.8.6-849-df9   f237 on 2019-05-14',
machine='LoPy4 with ESP32', lorawan='1.0.2', sigfox='1.0.1'
)

#Receiver_COM6
#IP_addresses
>>> wlan.ifconfig()
('192.168.1.217', '255.255.255.0',
  '192.168.1.254', '192.168.1.254')
#versions_of_pycoms
>>> import os
>>> os.uname()
(sysname='LoPy4', nodename='LoPy4', release='1.18.2.r7',
version='v1.8.6-849-df9 f237 on 2019-05-14',
machine='LoPy4 with ESP32', lorawan='1.0.2', sigfox='1.0.1' )

#Example_of_samples
```

```
#height 8 meters

#The following code is an
imported python file named loranode.py

from network import LoRa
import socket
import utime
import ubinascii
import machine
import struct
import sys
import gc

# PARAMETERS
_MSG_CODE = 200 # dummy code
_ACK_CODE = 201 # dummy code
_FREQ = 863000000 # LoRa frequency
_SF=7
# Accepts values between 7 and 12 (assume bw 125 kHz only)
_TXPWR=2
# Accepts values between 2 and 14 for the 868 band
_LISTEN_FOR_ACK = 10
# max waiting time for listening for ack msg

# INITIALIZATIONS
gc.enable()
# setup pytrack
'''
from pytrack import Pytrack
py = Pytrack()
# setup gps
from L76GNSV4 import L76GNSS
l76 = L76GNSS(py, timeout=180, debug=True)
'''

def tx(tx_msg_id=0, ack=False, gps=False):
# create lora interface
lora = LoRa(mode=LoRa.LORA,
region=LoRa.EU868, tx_iq=True,
frequency=_FREQ, tx_power=_TXPWR,
coding_rate=LoRa.CODING_4_5,
 bandwidth=LoRa.BW_125KHZ, sf=_SF)
```

```
lora_sock = socket.socket(socket.AF_LORA, socket.SOCK_RAW)
lora_sock.setblocking(False)

#get gps fix
if gps:
print("Getting fix...")
while not(l76.get_fix()):
machine.idle()
print("Fix ok...")
# get location
loc=l76.get_location()

# format packet
pkg = machine.unique_id()+
struct.pack("BB", tx_msg_id, _MSG_CODE)
#6 bytes id + 1byte msg_id + 1byte msg_code
if gps:
pkg=pkg+struct.pack("ii", int(loc['latitude']*1000000),
int(loc['longitude']*1000000)) # 4 bytes lat + 4 bytes lon
# send packet
        try:
lora_sock.send(pkg)
s=lora.stats()
print("Packet {} ({} bytes)
Sent by Node [sf={}, tx_power={}, tx_time_on_air={}]".
format(tx_msg_id, len(pkg), s[4],s[6],s[7]))
if gps:
print("Coords sent: Lat: {}, Lon: {}".format(loc['latitude'],
loc['longitude']))
# listen for acks for some time
if ack:
start_time=utime.time()
while (utime.time()-start_time < _LISTEN_FOR_ACK):
recv_pkg = lora_sock.recv(64)
# check if proper length
if len(recv_pkg) >0:
print("Received ACK with length {}".format(len(recv_pkg)))
devID = ubinascii.hexlify(recv_pkg[0:6]).decode('utf-8')
msg_id, msg_code = struct.unpack("BB", recv_pkg[6:8])
# check if proper msg code
if msg_code == _ACK_CODE:
s=lora.stats()
print("Packet ({} bytes) Recovered by Node: DeviceID: {},
```

```
Msg_Id: {}, Msg_Code: {} [rssi={}, snr={}]"
.format(len(recv_pkg),devID,
msg_id, msg_code, s[1],s[2]))
if gps and len(recv_pkg)>8:
print("Coords received: Lat:{},Lon:{}"
.format(0.000001*struct.
unpack("i", recv_pkg[8:12])[0],
0.000001*struct.unpack("i", recv_pkg[12:16])[0]))
break
utime.sleep_ms(10)
gc.collect()
        except Exception as e:
print("Exception in Lora Tx: {}".format(e))
        # close socket
        lora_sock.close()
        gc.collect()

def rx(ack=False, gps=False):
# create lora interface
lora =
LoRa(mode=LoRa.LORA,   region=LoRa.EU868, rx_iq=True,
frequency=_FREQ, tx_power=_TXPWR, coding_rate=
LoRa.CODING_4_5, bandwidth=LoRa.BW_125KHZ, sf=_SF)
lora_sock = socket.socket(socket.AF_LORA, socket.SOCK_RAW)
lora_sock.setblocking(False)

#get gps fix
if gps:
print("Getting fix...")
while not(l76.get_fix()):
machine.idle()
print("Fix ok...")
# get location
loc=l76.get_location()

print("Start listening lora iface")
while (True):
# Since the maximum
 body size in the protocol is X
 the request is limited to Y bytes
recv_pkg = lora_sock.recv(64)
# check if proper length
if len(recv_pkg) >= 8:
```

```
#print("Packet received: ", len(recv_pkg))
devID = ubinascii.hexlify(recv_pkg[0:6]).decode('utf-8')
msg_id, msg_code = struct.unpack("BB", recv_pkg[6:8])
# check if proper msg code
if msg_code == _MSG_CODE:
s=lora.stats()
print("Packet ({} bytes)
 Recovered by Node: DeviceID: {}, Msg_Id: {},
Msg_Code: {} [rssi={}, snr={}]"
.format(len(recv_pkg),devID, msg_id, msg_code, s[1],s[2]))
if gps:
print("Coords received: Lat:{},Lon:{}".
format(0.000001*struct.
unpack("i", recv_pkg[8:12])[0],0.000001*struct.unpack
("i", recv_pkg[12:16])[0]))
if ack:
# prepare and send back an ack packet
ack_pkg = machine.unique_id()
+struct.pack("BB", msg_id, _ACK_CODE)
if gps:

ack_pkg = ack_pkg +
 struct.pack("ii", int(loc['latitude']*1000000),
 int(loc['longitude']*1000000))
 # 4 bytes lat + 4 bytes lon
try:
lora_sock.send(ack_pkg)
print("For Packet {} Sent Ack [length: {} bytes]".
format(msg_id, len(ack_pkg)))
if gps:
print("Send Coords in ACK msg: Lat:{}, Lon:{}".
format(loc['latitude'],loc['longitude']))
s=lora.stats()

except Exception as e:
print("Exception in Lora Tx: {}".format(e))
gc.collect()
utime.sleep_ms(10)

#Transmitter
>>> import loranode
>>> loranode.tx(tx_msg_id=0, ack=True, gps=False)
>>> loranode._SF=7
```

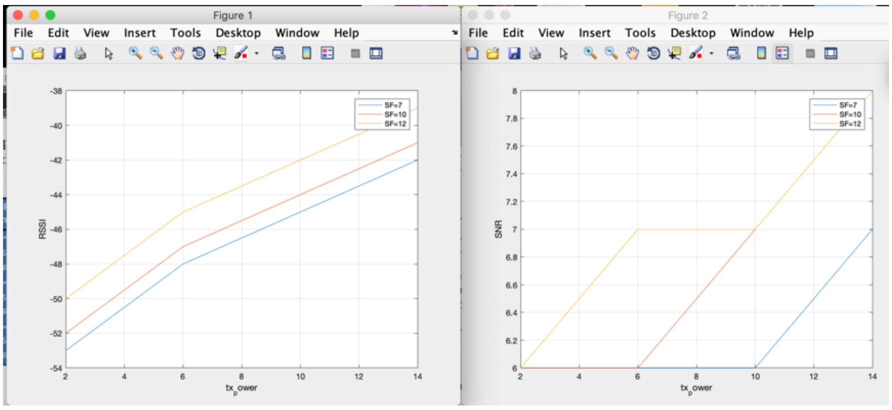
```
>>> loranode._TXPWR=6
Packet 0 (8 bytes) Sent by Node [sf=7,
 tx_power=6, tx_time_on_air=37]

#Receiver
>>> import loranode
>>> loranode.rx(ack=False, gps=False)
Start listening lora iface
Packet (8 bytes) Recovered by Node:
 DeviceID: 30aea4ec8bf0,
Msg_Id: 0, Msg_Code: 200 [rssi=-92, snr=5.0]

#Hard_reset
>>> import machine
>>> machine.reset()

#Soft_reset
ctrl-D
```

5.1.2 Indoor in a 4 storey apartment building

In 4 storey apartment building the Indoor assessment was held with the Transmitter placed in the ground floor. The receiver was moved thoughtout the floors and presented the following results:

2m

TXPWR (2m.)	2	6	10	14
SF = 7				
RSSI	-53 dBm	-48 dBm	-45 dBm	-42 dBm
SNR	6.0	6.0	6.0	7.0
SF = 10				
RSSI	-52 dBm	-47 dBm	-44 dBm	-41 dBm
SNR	6.0	6.0	7.0	8.0
SF = 12				
RSSI	-50 dBm	-45 dBm	-42 dBm	-39 dBm
SNR	6.0	7.0	7.0	8.0



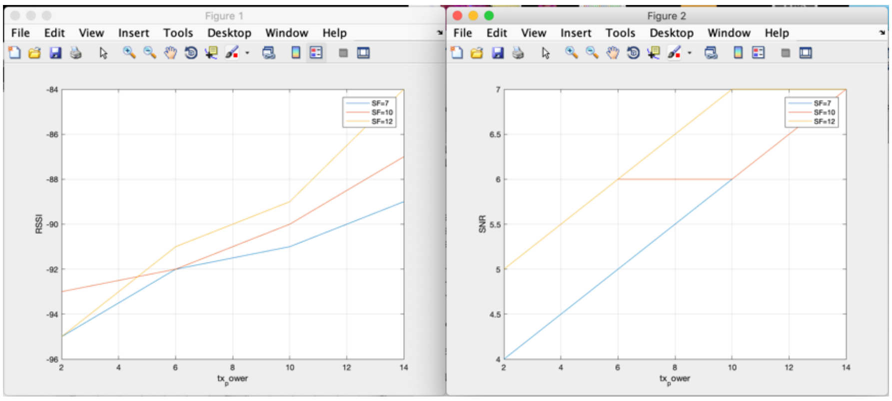
From stairs and 2 meters high
Transmitter Point: On the ground floor of the apartment building.
Receiving Point: On the 1st floor

Comments

During the indoor experiment, at 2 meters height and in particular a block of flats, the dependence of the signal with the TXPWR and SF was different. Specifically, when we lowered TXPWR and SF, RSSI and SNR was reduced, while with increase of TXPWR and SF, RSSI and SNR increased, respectively.

8m

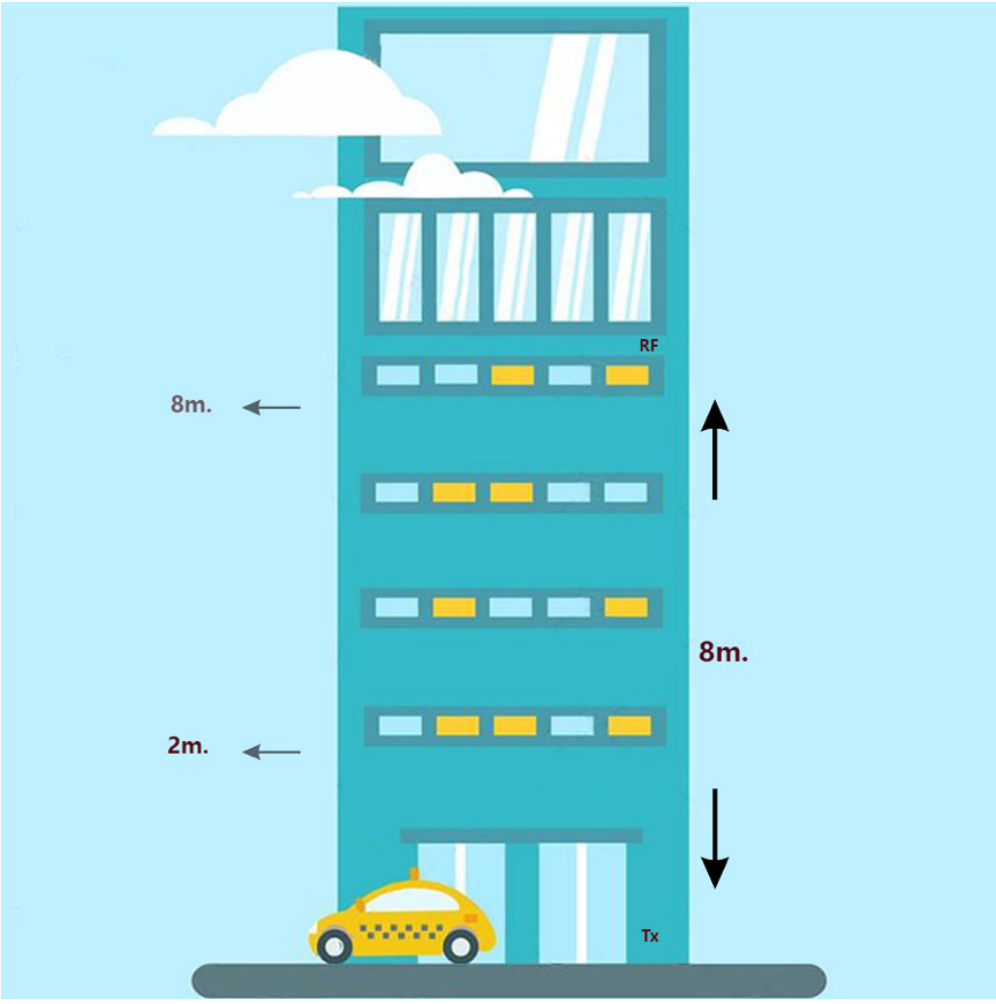
TXPWR (8m.)	2	6	10	14
SF = 7				
RSSI	-95 dBm	-92 dBm	-91 dBm	-89 dBm
SNR	4.0	5.0	6.0	7.0
SF = 10				
RSSI	-93 dBm	-92 dBm	-90 dBm	-87 dBm
SNR	5.0	6.0	6.0	7.0
SF = 12				
RSSI	-95 dBm	-91 dBm	-89 dBm	-84 dBm
SNR	5.0	6.0	7.0	7.0



Measurement procedure
From stairs and 8 meters high
Transmitter Point: On the ground floor of the apartment building.
Receiving Point: On the 4th floor.

Comments

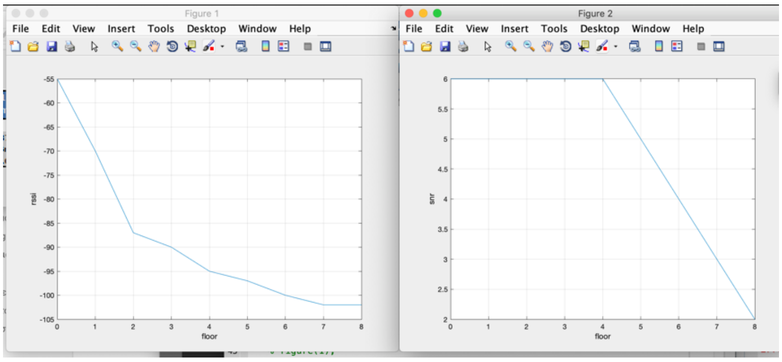
During the indoor experiment, at 8 meters height and in particular a block of flats, the dependence of the signal with the TXPWR and SF was different. Specifically, when we lowered TXPWR and SF, RSSI and SNR was reduced, while with increase of TXPWR and SF, RSSI and SNR increased, respectively.


RF
8m.
8m.
2m.
Tx

5.1.3 Indoor Measurements in the building of University of Piraeus (Androutsou)

Measurement procedure From stairs
Transmitter Point: Fixed point. Ground floor start with SF = 7 and TX-PWR = 14. At this point RSSI is -55 dBm and SNR 6.0.

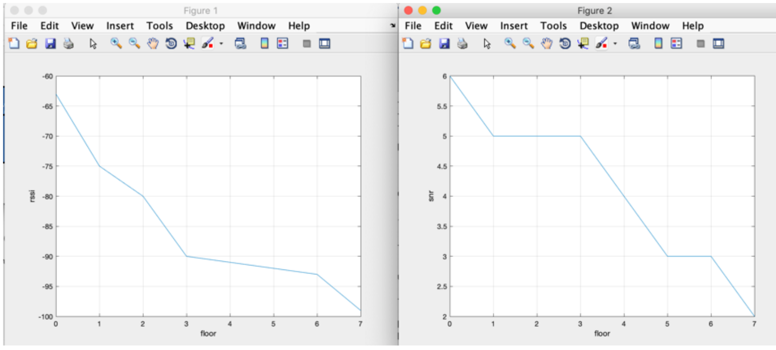
Floor (stairs)	0	ME	1 (2m.)	2 (4m.)	3 (6m.)	4 (8m.)	5 (10m.)	6 (12m.)	7 (14m.)
SF = 7									
RSSI	-55 dBm	-70 dBm	-87 dBm	-90 dBm	-95 dBm	-97 dBm	-100 dBm	-102 dBm	-102 dBm
SNR	6.0	6.0	6.0	6.0	6.0	5.0	4.0	3.0	2.0



Comments

During the measurement, which took place indoor and specifically in the building of the University of Piraeus, it is worth noting that the signal was in all 7 floors, i.e. at least 14 meters high. In this building there are various things, such as computers, tables, chairs, etc., which have a strong influence on the signal strength as long as the signal permeates all surfaces.

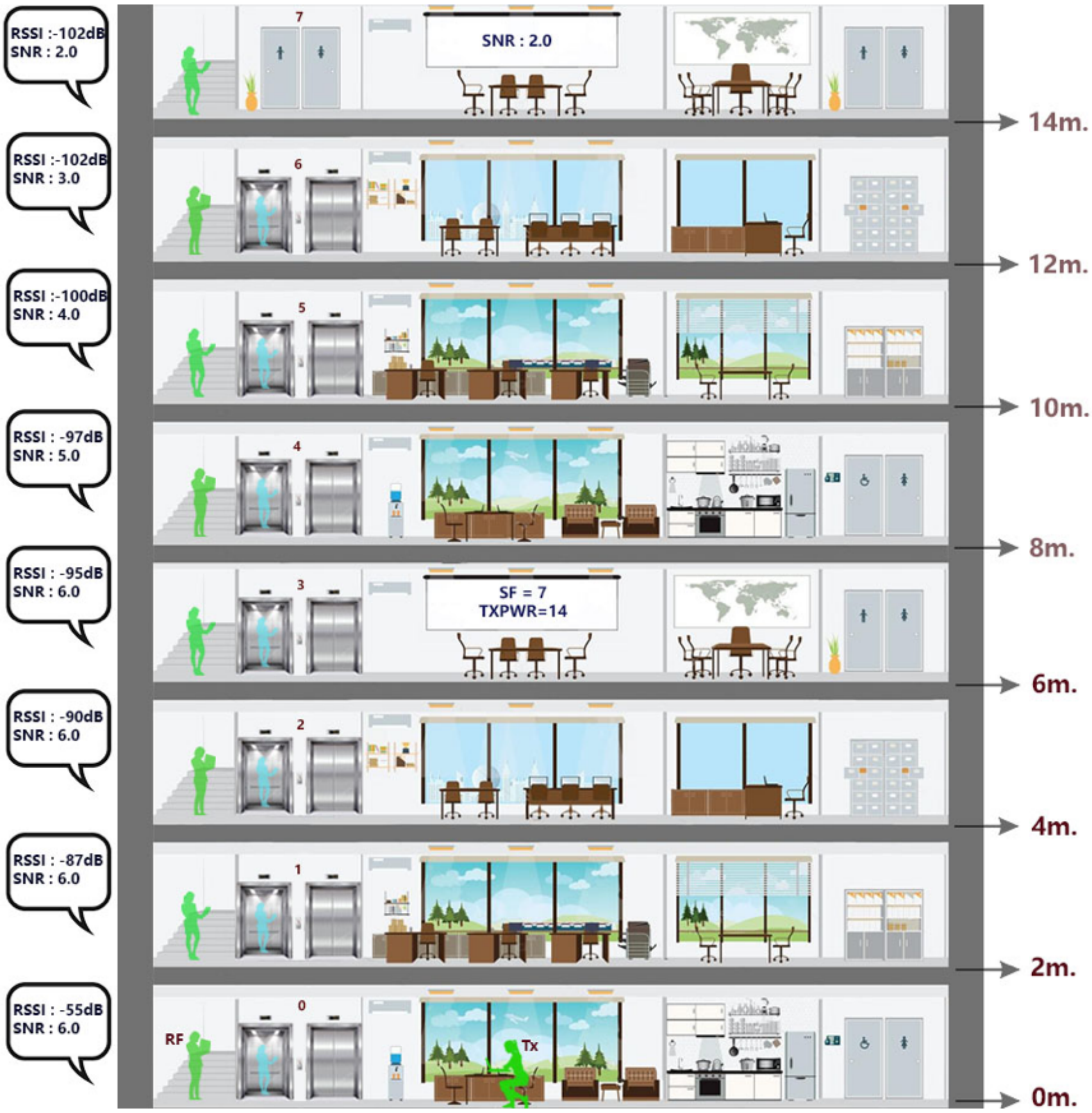
Floor (elevator)	0	ME	1 (2m.)	2 (4m.)	3 (6m.)	4 (8m.)	5 (10m.)	6 (12m.)
SF = 7								
RSSI	-63 dBm	-75 dBm	-80 dBm	-90 dBm	-91 dBm	-92 dBm	-93 dBm	-99 dBm
SNR	6.0	5.0	5.0	5.0	4.0	3.0	3.0	2.0



Measurement procedure
In the elevator
Transmitter Point: Fixed point. Starting from the ground floor of the University of Piraeus.

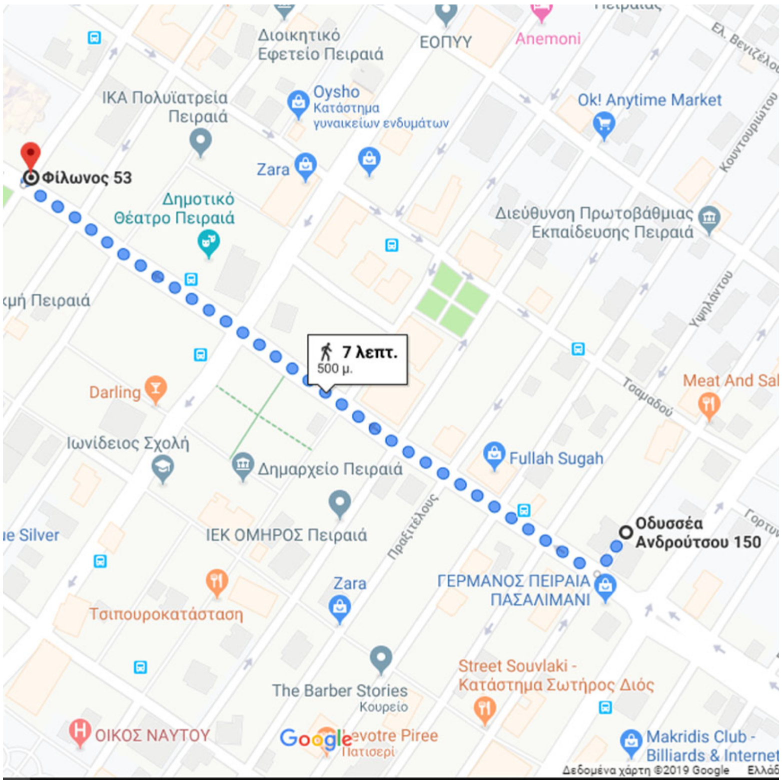
Comments

During the measurement, which was carried out indoors and specifically on the lift of the University of Piraeus, it is worth noting that the signal level was valid on all 6 floors, i.e. at least 12 meters high. There are various things in this building, such as computers, tables, chairs, etc. and in addition the lift is metallic, so there is considerable influence on signal strength as long as the signal crosses all surfaces. When comparing the two tables the main difference is the SNR, that is, the signal strength.


RSSI :-102dB
SNR : 2.0
RSSI :-102dB
SNR : 3.0
RSSI :-100dB
SNR : 4.0
RSSI : -97dB
SNR : 5.0
RSSI : -95dB
SNR : 6.0
RSSI : -90dB
SNR : 6.0
RSSI : -87dB
SNR : 6.0
RSSI : -55dB
SNR : 6.0
7
SNR : 2.0
6
5
4
3
SF = 7
TXPWR=14
2
1
0
RF
Tx
14m.
12m.
10m.
8m.
6m.
4m.
2m.
0m.

5.1.4 Outdoor Experiment in Piraeus

Measurement procedure
Transmitter Point: Fixed point. University of Piraeus, Androutsou 150.
Receiver Point: Transition point. Starting from Androutsou 150 with SF = 7 and TXPWR = 14. At this point RSSI is -45 dBm and SNR 6.0.



First stop: Androutsou and Vasileos Georgiou. At this point RSSI is -69 dBm and SNR 5.0.
Second stop: Ipsilantou. At this point RSSI is -85 dBm and SNR 5.0.
Third stop: Kountouriotou. At this point RSSI is -100 dBm and SNR 4.0.
Fourth stop: Praxitelous. At this point RSSI is -105 dBm and SNR 1.0.
Fifth stop: Alkiviadou. At this point the RSSI is -111 dBm and SNR -3.0.
Sixth stop: Karaiskou. At this point the RSSI is -119 dBm and the SNR is -8.0. Missing packages are displayed.
Seventh Stop: Municipal Theatre. At this point the signal coverage was lost. So the spreading factor changed to
SF = 12. Results with the new SF were RSSI -125 dBm and SNR -12.0. There were many lost packets observed

Eighth stop: Dēmotiko bus stop. At this point RSSI is -127 dBm and SNR is -14.0. The number of lost packets has increased significantly.
Ninth stop: Kolokotroni. At this point RSSI is -132 dBm and SNR is -17.0. There is a continuation of lost packets.
Tenth stop: Notara. At this point RSSI is -134 dBm and SNR is -18.0. Lost packets are too many.
Eleventh stop: Filonos. At this point the signal coverage was lost.

Comments Throughout the measurement, which took place on the road, it is worth noting that the signal was valid for a distance of 500 meters. In this part there are various buildings, apartment buildings, vehicles and subway projects are done so some parts are fenced off with a metal fence. Even the altitude changes, mainly from the Municipal Theater, and then downhill is visible. All of this has a considerable influence on the signal strength, since the signal crosses all surfaces.

Street			Street		
Androutsou 150	-45 dBm	6.0	Mun. Theatre of Piraeus	-125 dBm	-12.0
Androutsou & Vasileos Georgiou	-69 dBm	5.0	Bus stop Dēmotiko	-127 dBm	-14.0
Ipsilantou	-85 dBm	5.0	Kolokotroni	-132 dBm	-17.0
Kountouriotou	-100 dBm	4.0	Notara	-134 dBm	-18.0
Praxitelous	-105 dBm	1.0	Filonos	-	-
Alkiviadou	-111 dBm	-3.0			
Karaiskou	-119 dBm	-8.0			
Municipal Theatre of Piraeus	-	-			

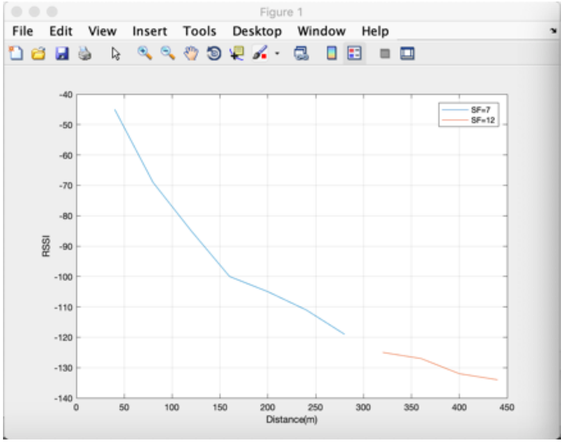


Figure 1
File Edit View Insert Tools Desktop Window Help
SF=7
SF=12
RSSI
Distance(m)

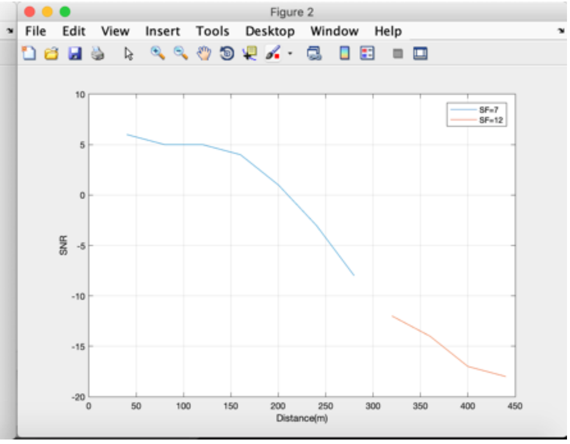
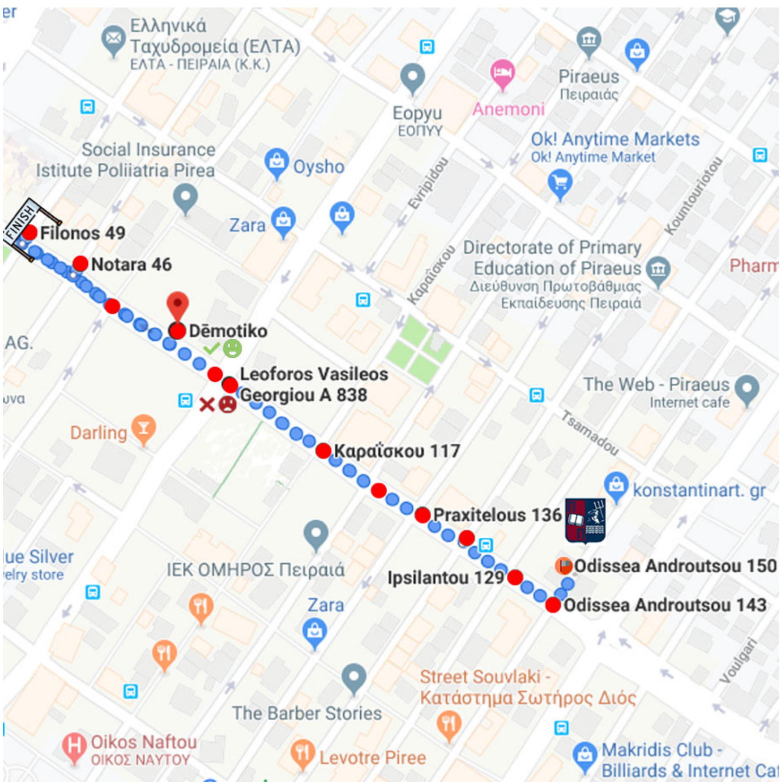


Figure 2
File Edit View Insert Tools Desktop Window Help
SF=7
SF=12
SNR
Distance(m)

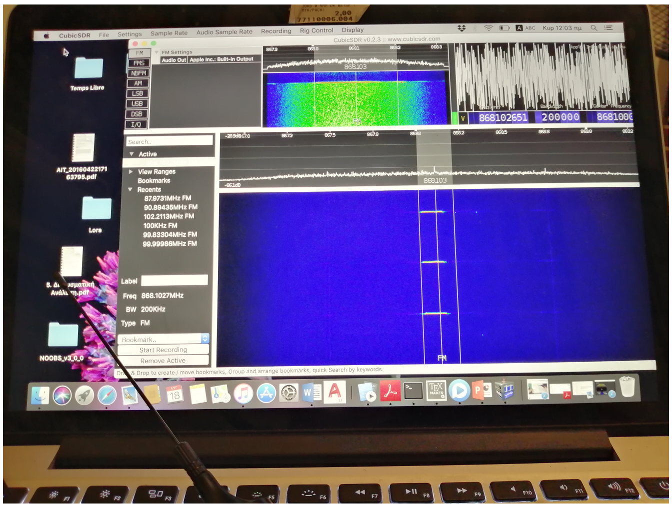

FINISH
Filonos 49
Notara 46
Dēmotiko
Leoforos Vasileos Georgiou A 838
Καραϊσκου 117
Praxitelous 136
Ipsilantou 129
Odissea Androutsou 150
Odissea Androutsou 143
Piraeus
Πειραιάς
Zara
Oysho
Darling
The Web - Piraeus
Internet cafe
IEK ΟΜΗΡΟΣ Πειραιά
The Barber Stories
Street Souvlaki -
Κατάστημα Σωτήρος Διός
Levotre Piree
Oikos Naftou
ΟΙΚΟΣ ΝΑΥΤΟΥ
Directorate of Primary
Education of Piraeus
Ok! Anytime Markets

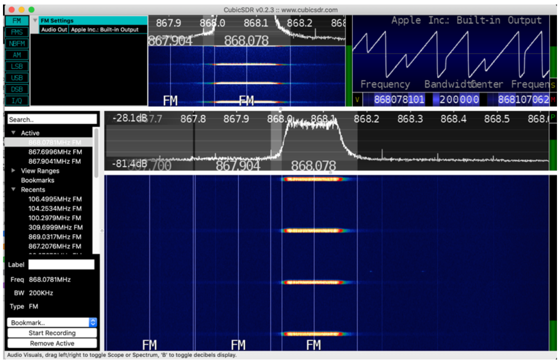
5.2 SDR

Software-defined radio (SDR) is a technique for turning a computer into a radio. But not just an AM/FM radio - by using the computing power on your desktop you can listen and decode a wide variety of broadcasts. SDR can turn your computer into a weather-band receiver, a police/fire report scanner, a music listening station, and more! Instead of manually tuning inductors, its all done in software by chips fast enough to pick up and decode radio waves on the fly.[?]

For this experiment, the equipment that was used was an adafruit sdr the RTL-SDR and the CubicSDR software.

Then as seen in CubicSDR is the appearance of the packet at the appropriate Frequency. So, in 868 MHz we can see a lora packet, in an abstract form. In the black box at right side of the console we can see the chirps form.





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