Development and Implementation of LoRa radio links for rural areas without coverage and Study of Harmful Effects on radio links

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I. Abstract

The following paper will consist of the design and implementation of LoRa radio links for the control of industrial and mechanical machinery in areas without coverage and actual impossibility of data transmission.
Moreover, the study will be carried out in different scenarios for the analysis of losses and harmful effects in radio links in order to conclude and identify factors that can constructive and destructively affect to radio signal transmission to optimize the link performance in terms of received power.

II. Introduction

Nowadays, wireless communications are the ideal transmission medium of information, since they facilitate infinite connections of agile communication, in addition to assuming a great saving of materials such as wiring and physical mediums. In the last years, this medium has been developed exponentially obtaining extraordinary speeds and capabilities with 802.11 protocols, and most lately, 5G. However, this growth in services has led to an increase of expenses and energy consumption in certain cases.
Under this context, and as a solution to the enormous consumption, certain wireless communications models are presented for low energy consumption.

Furthermore, there is a great demand at the moment for technologies capable of implementing mechanisms of control over long-distance devices in different environments, both rural and urban, as industrial.
Faced with this scenario, it is necessary to establish communications systems capable of supplying the needs with reduced budgets due to low information load and bandwidth required in standard control systems.
For these reasons, and trying to put a solution to this problem, LoRa transmission technology for long scope is an open-source, low-cost that could solve our problem. And in conclusion, due to its simplicity, low cost and good match for long distances and low information load scenarios compared to other alternatives, we will use it for this research project.

III. Objectives

The objective of the project will be to develop and implement a long-distance point-to-point radio link via LoRa communication module, for future applications in control of devices in remote locations. Moreover, the study will be carried out in different scenarios for the analysis of losses and harmful effects in radio links.
To implement this general objective we will go through different phases:

- The most optimal hardware radio link system will be designed, defining the protocol to be used.
- A prototype will be developed from low-cost tools (ESP32 microcontroller, boards, LoRa transceivers…).
- The communication system will be implemented and analyzed with the aim of characterizing the radio link.
- The behavior of the prototype will be analyzed in different scenarios to study the impact of obstacles in terms of losses and the effect of diffraction in transmission.

IV. Hardware and technology

As it is explained in the introduction, the great need of technologies capable of implementing mechanisms of control over long-distance devices in different environments, is making the pursuit of the best alternative mandatory. Here it is where LoRa technology enters to scene.
Various authors define LoRa (Long Range) as a new wireless transmission module that has recently evolved and is gaining popularity in low powered battery operated embedded systems that need to

transfer small amount of data at short intervals over long range [1].
Since we are looking for data transmission for a non-coverage area, we could think of Wi-Fi technology. And it is true that Wi-Fi is the most popular technology that has recently evolved and is used in long distance communications. However, LoRa enables bi-directional communication, lower cost and mobile communication for IoT, smart city, machine to machine (M2M) and industrial applications [2]. Moreover, we can see LoRa technology as a more secure bi-directional communication system compared to Wi-Fi due to implementing customer's Wi-Fi infrastructures comes with several security risks, unlike LoRaWAN, which has very tight security concepts [3] [4].
LoRa is rapidly gaining high popularity and is a preferred technology for IoT and control embedded systems because of its long range, high capacity of nodes in networking, long battery life, bi-directional functionability, secured and efficient networks and its interference immunity [2].
For all these reasons, we choose LoRa technology as the most optimal hardware radio link system for our main scenario, due to its good functionality and its low cost.

The hardware used to implement the LoRa radio link will be a ESP32 microcontroller connected to a LoRa transceptor isotropic antenna. Moreover, for the power measurement we will transmit temperature and pressure data obtained from sensors. And finally, we will use a power battery to maintain the microcontroller operative. To implement the system we will finally need:

- The complete microcontroller and antenna device is a “MakerFocus ESP32 Development Board WIFI Bluetooth LoRa Dual Core 240MHz CP2102 with 0.96inch OLED Display and 433/470MHz Antenna (868/915MHz)”.
- “BMP280” sensor.
- ADATA PowerBank P10000QDC.

V. Radio transmission basis

Once the technology and hardware used to the control system is defined, we are ready for the implementation of the said transmission system.
In order to assemble this wireless transmission system and to pursue its optimal functionality, we have to take into account several basic concepts of free space and terrestrial environment propagation, such as signal reflection and diffraction.
The electrical characteristics of the Earth and its orography, influence the propagation of electromagnetic waves.
On the one hand, when an electromagnetic wave impinges on the Earth surface, a reflection signal is generated. On the other hand, when an electromagnetic wave hits an obstacle, a diffraction phenomenon occurs whereby the obstacle re-radiates part of the intercepted energy. Both new signals join the original signal's way, and both can be constructive or destructive depending on the phases between the direct and reflected or diffracted waves [5].

Moreover, diffraction phenomenon in radio transmission is highly interesting since it makes possible the reception of the radiated waves even in the case there is no visibility between transmitter and receiver, and we will take advantage of it.

Now clarified the existence of these phenomenons, we can define the Fresnel zones in order to be taken into account later on.
The Fresnel zones are the finite volumes between transmitter and receiver that divide the complete free zone of the radiolink according to the diffraction by obstacles and reflected signals impact on the radiolink viability. There are infinite Fresnel zones, but for the study we will only focus on the first ones because they are more important for radiolink viability. Theoretically, if about 55% of the first Fresnel zone is clear, we can avoid the 6dB loss associated with grazing incidence, so this is one of the many reasons we will be looking to clear the first zones [6].

VI. Methodology

In order to cover all the proposed rural area for industrial control systems, we will have to implement three transmission radio links to complete control of the area. However, before these tests we will first try the radio link and check its functionality in lighter scenarios, and therefore, we will obtain more evidence for our diffraction exploitation conclusions.

This is why we will divide all the research in four different measurement phases.

- **First phase:** in the first measurement scenario, we will try the LoRa radio link in a free obstacle space road just to check it works correctly, and therefore, we can characterize the LoRa radio link.
- **Second phase:** in the second measurement scenario we will try the LoRa radio link

in the UANL rooftop, first in free obstacle space and later in a non-free obstacle space to start checking the diffraction signals contribution to the received power of our radio link.

• **Third phase:** in the third measurement scenario we will try the LoRa radio link in a football stadium with a free obstacle space, in order to check the impact of different heights with respect to the transmitter and receiver.

• **Fourth phase:** finally we will implement the LoRa radio link in the non-coverage proposed area in order to implement the control systems. Moreover, this scenario is located in a forest and mountainous zone so we will obtain the final results to conclude completely the diffraction impact to radio links viability.

VII. Results

For the complete study of the LoRa radio link, we tried the radio link in different situations for every phase and we took 100 received power values each.

• **First phase:** during the first phase, we tried the radio link twice. The first point to point link was divided by a distance of 34m, it had no obstacles and both transmitter and receiver were at the same height, and the second one, was divided by 110m, it had no obstacles and they were at the same height.

• **Second phase:** for the second phase, we tried the radio link six times. The first point to point link was divided with a distance of 62m, it had no obstacles and and both transmitter and receiver were at the same height, the second one was divided by 97m, it had no obstacles and they were at the same height, the third one was divided by a distance of 40m, they were at the same height but this time there were obstacles. And for the last part of the phase, the previous measures were repeated but this time the origin had a height of 10m above to their respectives receiver points.

• **Third phase:** for the third phase we tried the LoRa radio link five times. The first point to point link was divided with a distance of 56m and transmitter and receiver were at the same height, the second one was divided by 124m and they were at the same height, the third one was divided by a distance of 89m and they were at the same height, the fourth one was divided by 150m and they were at the same height, and the final one was divided by 150m but with a difference of height between transmitter and receiver of 30m.

• **Fourth phase: f**inally, for the fourth phase we tried the Lora radio link seven times. The first try was a point to point link divided by 84m, with no obstacles between transmitter and receiver, the second try was divided by 90m, and has no obstacle between points, the third one was divided by 105m and it was placed in the edge of the main forest of the area, with a slight level of obstacles, the fourth try was divided by a distance of 117m, and although the transmitter was placed in a free obstacles space plain, the receiver was inside the woods, with a medium-high level of obstacles, the fifth try was divided by 198m, and this time the transmitter was placed in the forest with a medium-high level of obstacles and the receiver in a clear plain, the sixth try was divided by 173m and both transmitter and receiver were placed in the forest and the area between them was highly obstacle with no clear view, and finally for the last try transmitter and receiver were divided by 227m and both were placed in the forest with a high obstacles level but this time with slightly clear views.

We entered the power received data in *Table 1*, and although we obtained 100 values for each try, we show in *Table 1* 15 tries in order to summarize due to there being a homogeneous response. However, we show in *Figures 1, 2, 3 and 4* graphically the 100 values in dBm for every try in each phase respectively.

Phase 1		Phase 2						Phase 3					Phase 4						
T1	T2	T1	T 2	T 3	T 4	T5	T 6	T 1	T 2	T3	T 4	T 5	T 1	T 2	T 3	T 4	T 5	T 6	T 7
-110	-120	-106	-101	-109	-68	-88	-97	-103	-103	-108	-111	-98	-113	-93	-105	-106	-113	-126	-118
-114	-122	-105	-102	-104	-74	-100	-98	-100	-101	-94	-106	-93	-108	–93	-106	-110	-110	-134	-120
-109	-127	-101	-107	-109	-83	-86	-93	-100	-109	-99	-106	-99	-113	-93	-105	-112	-116	-130	-122
-110	-123	-105	-99	-110	-75	-96	-94	-106	-99	-83	-109	-94	-119	-94	-103	-121	-116	-132	-124
-113	-120	-105	-96	-104	-78	-94	-97	-97	-99	-102	-105	-103	-108	-93	-105	-117	-116	-134	-118
-110	-119	-105	-103	-111	-78	-88	-107	-105	-103	-91	-112	-96	-110	-91	-104	-119	-110	-122	-117
-111	-117	-99	-103	-107	-73	-92	-93	-104	-102	-107	-119	-97	-111	-92	-105	-113	-119	-131	-120
-105	-118	-103	-105	-105	-78	-90	-97	-107	-106	-100	-103	-100	-104	-92	-106	-118	-121	-134	-119
-108	-121	-102	-111	-116	-90	-104	-92	-105	-106	-100	-111	-93	-98	-91	-104	-113	-119	-125	-118
-108	-130	-105	-108	-98	-80	-95	-97	-101	-105	-98	-112	-102	-101	-92	-106	–118	-118	-129	-119
-110	-119	-99	-103	-103	-77	-95	-103	-107	-107	-97	-109	-97	-93	-88	-108	-121	-122	-134	-118
-109	-121	-100	-108	-109	-81	-91	-93	-94	-103	-101	-112	-100	-94	-90	-96	-120	-120	-130	-119
-106	-119	-101	-108	-112	-76	-93	-96	-98	-107	-90	-112	-108	-92	-90	-109	-124	-120	-123	-119
-111	-119	-103	-106	-114	-73	-87	-102	-110	-107	-96	-107	-98	-91	-90	-106	-121	-118	-123	-119
-109	-116	-103	-103	-113	-84	-95	-94	-103	-103	-93	-111	-99	-93	-89	-102	-113	-119	-128	-118

Table 1: Power received data in dBm

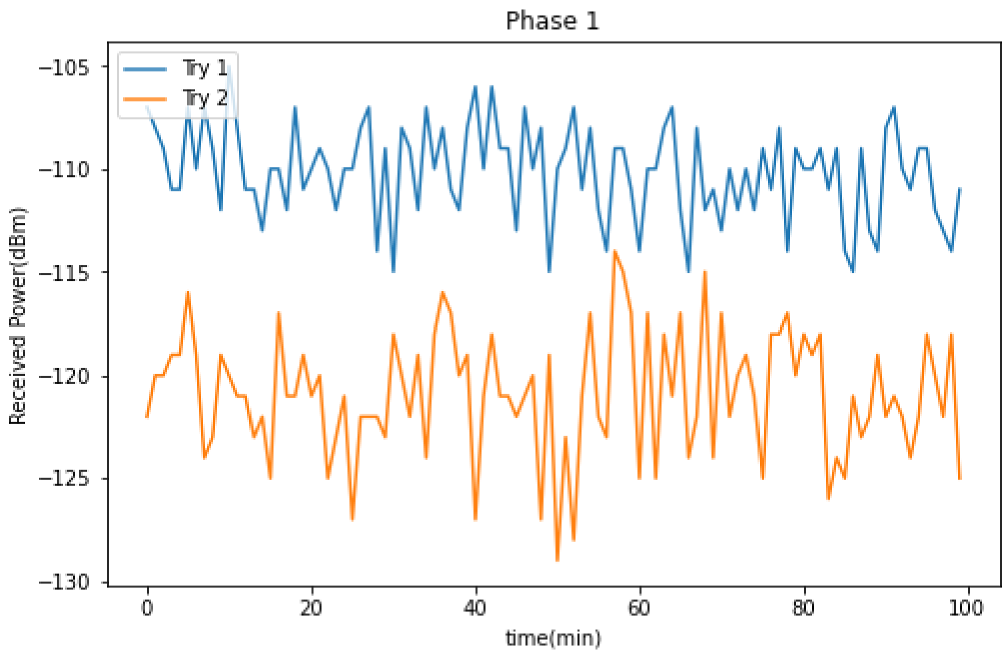

Figure 1: Phase 1 power received values

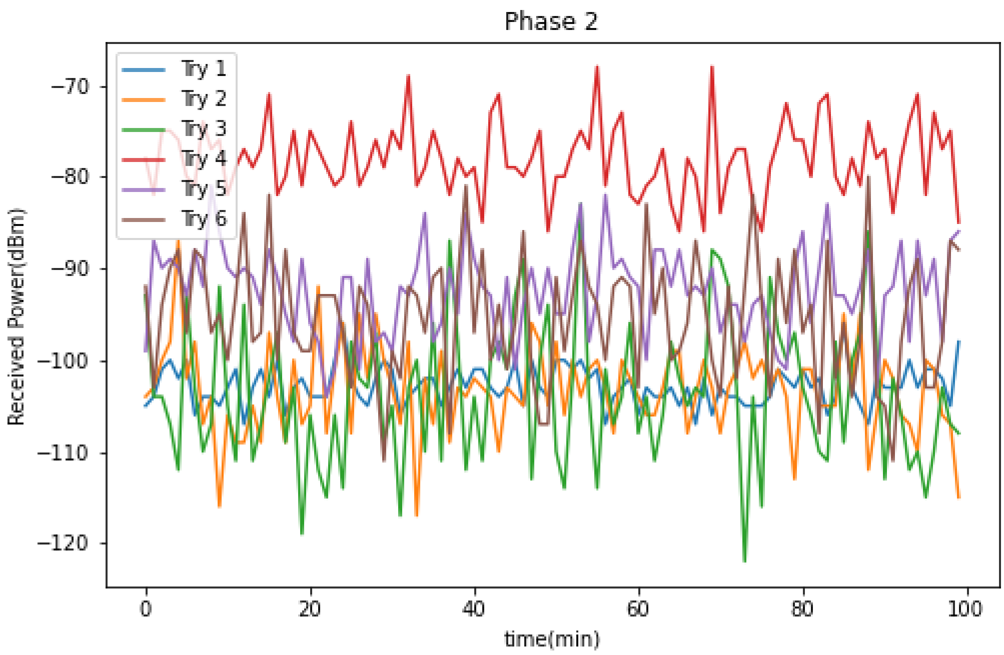

Figure 2: Phase 2 power received values

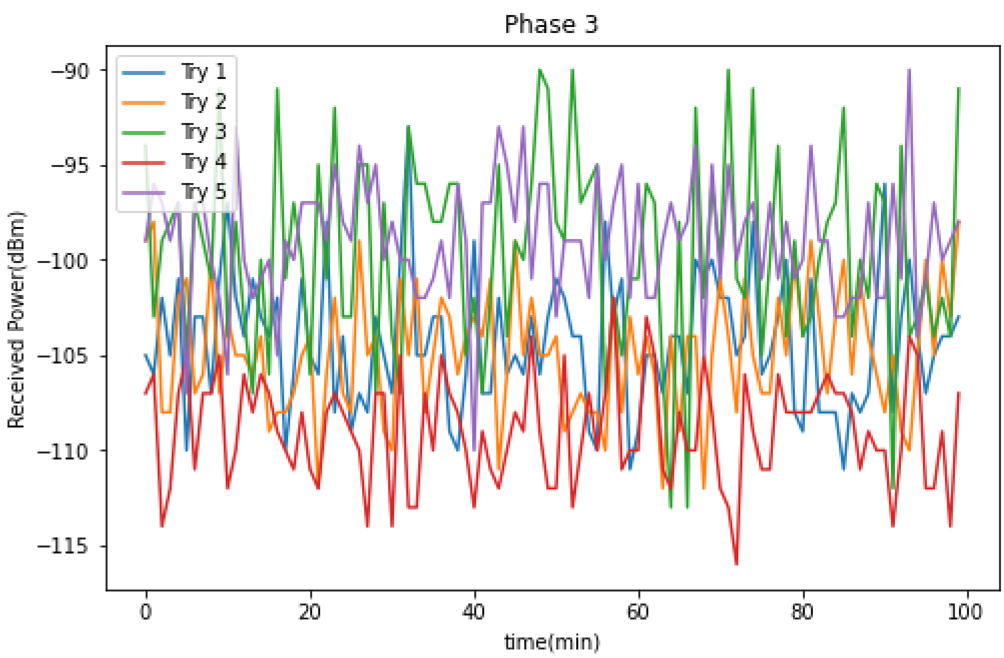

Figure 3: Phase 3 power received values

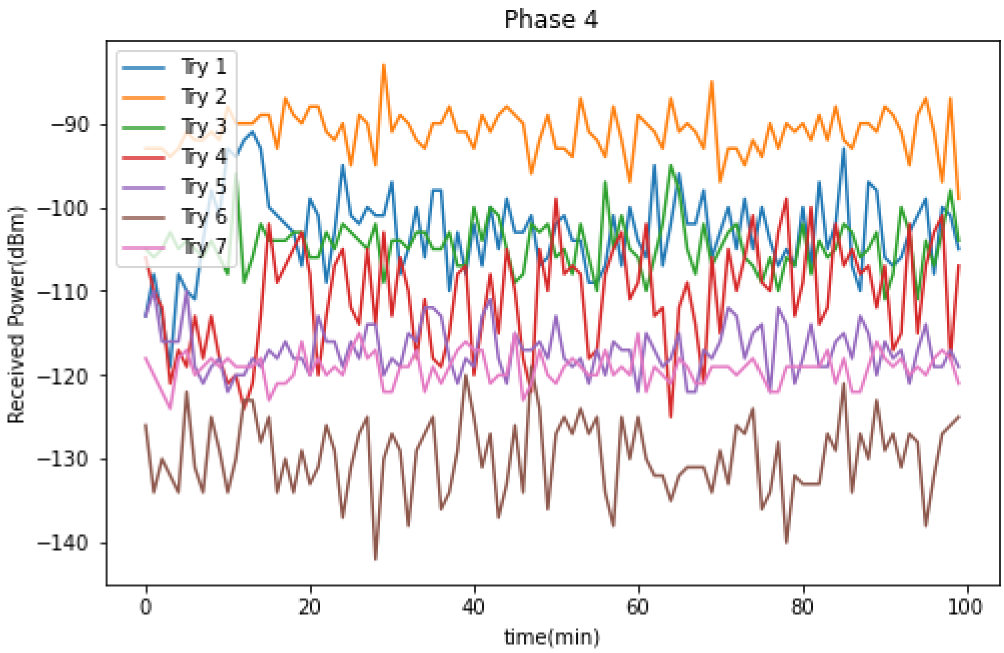

Figure 4: Phase 4 power received values

VIII. Conclusions

Once all the data is obtained, we can start checking the success of this research project.

The principal aim of the project was to establish control systems to monitorize machinery in the non-coverage proposed area. And secondly, identify how diffraction phenomenons can be used for radio link viability improvements.

Several things can be concluded in each phase of measurements. And therefore, we will analyze each one separately.

For the functionality of LoRa transmission and reception, we can check from phases 1 and 3, represented in *Figures 1* and *3*, that this technology is fully viable for any low bandwidth data transmission system, where powers of -100 dBm are received for distances of 100m, and powers of -120 dBm for distances over 200m. These powers exceed the minimum need for IoT transmissions. Moreover, we checked the perfect functionality of control applications over LoRa for long distances, since we did not get errors of transmission between microcontrollers or any kind of package losses.

Regarding phase 2, highly interesting conclusions can be obtained about diffraction.

For these measures, we check that in free space scenarios, for distances under 200m we will never need tall towers to assure a functionable LoRa radio link, since they only suppose an unnecessary lengthening of the distance, and therefore a decrease in power received. However, we check that for free space radio links under 200m distances, obstacles creating diffraction phenomenons can contribute to the received signal, due to the obstacle re-radiates part of the intercepted energy, obtaining a stronger signal in reception because of the addition of constructive contributions. In *Figure 2* we can check this very effect in tries 3 and 6, where removing the obstacles from the radio link trajectory by increasing the transmitting antenna height, does not improve the received signal.

Finally, for the fourth phase, we can reinforce previous concepts by checking different results.

During the radio link third try, we check how even having a bigger distance than the first free space try, we obtained similar received powers. From this, we can observe how we take advantage of the tangent edge of the obstacles, where the received energy is re-radiated and we improve the original signal by constructively adding this diffracted one. Moreover, in tries 5 and 7, although we have a highly obstacle radio link over distances of 200m between transmitter and receiver, we obtained similar values to phases 1 and 3. This is because of the advantage of diffracted signal contribution. Finally, regarding this last phase, we must consider why we obtained in try 6 the lowest power received of all radio links in all the research. This scenario was different from the previous ones, because although it has a high level of obstacles as tries 5 and 7, this one has a complete non visibility between points, not giving way to the contribution by diffracted signal to the main one, unlike those mentioned above, where small visibility gaps in the middle of the trajectory facilitated the passage of the diffracted signal to the receiver.

After analyzing all scenarios and checking the total radio link functionality, we concluded that LoRa is a perfect control transmission system technology, that gives us the ability to establish the proposed control systems, ensuring the perfect functioning of this.
In addition, we conclude that the diffraction phenomena can be used in our favor for the correct transmission we are looking for and the optimization of any radio link in terms of received power.

IX. Future lines

Once we assure the success of this research project by checking the perfect LoRa transmission functionability, and correctly implementing the control systems for machinery for long distances, we proposed possible future lines of this research.

In terms of microcontroller knowledge, we can establish cloud applications to give orders to the transmitter microcontroller in order to control it from our mobile phone, by FireBase libraries, and this way, optimize the control of machinery not being necessary to program physically the ESP32 to change orders.

In terms of radio link systems, for this research project we only work on direct wave transmission (the one transmitted directly from the transmitter antenna) and secondary wave transmission (those generated by reflection and diffraction effects). The contribution to this research could be the use of space waves to improve transmission radios.

X. References

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