Article

Range Evaluation of a Point-to-point Link using Software Defined Radio

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Abstract: A software defined radio (SDR) is a communication system that makes use of components that can be configured through software, in contrast to traditional systems where these components are variable through hardware, these radio devices are much more versatile, this article describes the factors that must be considered when implementing a communication system based on Software Defined Radios (SDR), to reduce the attenuation factors and thus obtain the maximum distance for transmission of data effectively in the UHF band. The calculations made for the first Fresnel zone and the design of the Ground Plane type antennas used in the transmission/reception stages of the x40 bladeRF platforms are also presented. The tests were carried out at the facilities of the Huarangal Nuclear Center of the Peruvian Institute of Nuclear Energy, obtaining favorable results that allow ratifying the versatility and performance of the SDRs.

Keywords: software defined radio; radio link; ground plane antenna; wireless communication; internet of things

1. Introduction

In recent years, wireless technologies have gained great importance due to their application in various fields such as the Internet of Things (IoT) [1], telemetry [2], radio astronomy [3], and automation [4], which are advancing rapidly thanks to the appearance of new software tools, algorithms, and hardware that allow their implementation and development, some examples are Cognitive Radio (CR), GNU radio Companion (GRC), Orthogonal Frequency Division Multiplexing (OFDM) and Software Defined Radio (SDR). In particular, there is a greater interest in the use of the so-called television white spaces (TVWS) of the RF spectrum, which are bands originally assigned to transmit television, but due to greater use of Internet technologies by radio stations, TV, some of these channels are no longer being used and therefore being enabled for other uses that include telemetry systems and other local and regional area networks [5].

Traditional RF systems use only a transmitter and receiver, commonly called a transceiver, along with a transmitting and receiving antenna. Advances in signal processing have enabled the use of multiple transmitters and antennas, a technology called MIMO (multiple input multiple outputs) which means that multiple transceivers and antennas are used on the transmit (output) side as well as on the other side. the receiving (input) side [6].

Telemetry in rural areas has made great progress since its early days when isolated sensors were equipped with ISM (Industrial, Scientific, and Medical) band radios to send measured data on the 900 MHz ISM band to a central location. Today's telemetry systems are very different, they are capable of handling many sensors and typically use wide frequency bands and Radio Frequency (RF) technology through sophisticated communication systems or network-based systems. Furthermore, the collection, pre-processing, and post-processing of sensor data is usually automated, using sophisticated signal and data processing equipment [7]. Currently, there are advanced telemetry systems such as SDR in which most of the signal processing of both the baseband and the carrier is done by software, leaving only the power stage or signal output to the hardware.

The possibility of carrying out these operations by software makes these design tools very powerful and a very versatile possibility of implementation to remotely monitor environmental variables, which by their nature often require a great capacity for monitoring. adaptation and versatility [8]. In this sense, these advanced SDR systems provide low-cost technological solutions since their dependence on hardware is quite low. However, as a disadvantage derived from their versatility, these systems are relatively complex in software or firmware design, since advanced knowledge of communication techniques, current regulations about the band to be used, and intensive use of advanced devices such as FPGA is required. [9].

Currently, wireless sensor networks have a great boom in various applications, since they provide an excellent response to the current needs of having low-cost networks, in some works it has been shown that monitoring data can be obtained from inaccessible environments so that these are sent to a base station where it can process said information [10]. With the growth of wireless applications, there is inherently a scarcity of frequency spectrum, in this context CR technology has been proposed as a potential means of overcoming this problem by introducing opportunistic use into less congested portions of the licensed spectrum, in some work using this technology in networks consisting of several nodes with or without a secondary base station [11].

In the context of our country Peru, SDR technology has applications in the study of satellite images using double cross antennas with four dipoles [12], these applications are increasing since the Earth observation satellite PeruSat-1 is available. In other works, a network has been trained using artificial neural networks to select routing paths taking into account the monitoring period, making comparisons between various metrics to demonstrate that the network can learn from past experiences [13].

2. Materials and Methods

A. Frequency selection

The advanced telemetry system has been designed in such a way that it can transmit and receive data in the UHF band, where there are unlicensed frequencies (commonly used by radio amateurs) and television broadcasting frequencies [14], called in other countries TV White Spaces after the analog blackout [15]. The specific frequency used for the tests was that corresponding to channel 14 (470-476 MHz) shown in Table 1, which is expected to remain as an unlicensed frequency once analog TV transmission ceases [16].

Table 1. Channel 14 frequencies.

Channel	Lower Limit	Video Carrier
14	470.0	471.25

B. RF Antenna design

For the tests, a ¼ wave Ground Plane type antenna was chosen, due to its omnidirectional nature and relatively simple construction [17]. To calculate the dimensions of the antennas, an application was developed with Python and the Qt framework, which calculates and displays the measurements that the central radial and the radials that make up the ground plane must have. The calculation was made using the following formulas:

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$$X = \frac{C}{4f} \tag{1}$$

$$Y = 0.95\, x \frac{C}{4f} \tag{2}$$

Where:
C: Speed of light
f: Frequency
X: Center radial
Y: Ground plane radials

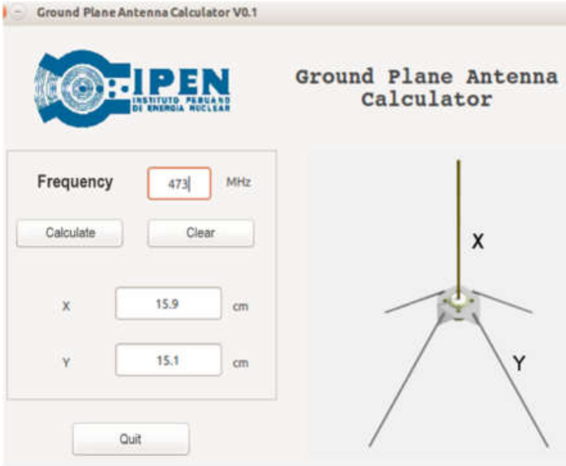

Figure 1. Software for calculating radial dimensions.

As can be seen in Figure 1, after entering the frequency, the values obtained for the radials are as follows:

$$X = 15.9cm, Y = 15.1cm$$

Having the appropriate dimensions, the antenna was elaborated as we can see in **Figure 2**.

Figure 2. A ground plane antenna was built for testing.

C. The theoretical calculation for the radio link distance and the Fresnel zone

For the theoretical radio link calculations, a Python program was developed with the GTK framework, using the following equations:

$$P_{Tx}(dBm) - Lf_{Tx}(dB) + G_{Tx}(dBi) - L(dB) + G_{Rx}(dBi) - Lf_{Rx} = M - S_{Rx} \tag{3}$$

Where:
P_{Tx}= Transmitter power.
Lf_{Tx}= Losses in the Tx wire.
G_{Tx}= Antenna Gain Tx.
L = Free space losses.
G_{Rx}= Antenna Gain Rx.
Lf_{Rx}= Losses in the Rx wire.
M = Margin.
S_{Rx}= Receiver Sensitivity.

$$L = 32.4 + 20Log(d(Km)) + 20Log(F(MHz)) \quad (4)$$

Where:
d = Distance.
F = Frecuencia.

The radius of the first Fresnel zone was calculated to know the height at which the antennas should be located and thus avoid obstructions that hinder data transmission, for which the following formula was used:

$$r = 17.32\ x \sqrt{\frac{d}{4f}} \quad (5)$$

Where:
d = Distance between transmitter and receiver (km).
f = Frequency (GHz).
r = Radius (m).

The calculations showed that the system has a maximum range distance of 720 meters, for which the antennas must be positioned with a difference of 7.75 meters, concerning height.

D. Test System Design

D.1 Design criteria

The main requirements for evaluating the range of a point-to-point link are:

- Autonomous transmitting nodes constantly send data while the receiving node moves and the distance is calculated.
- Receiver node with the ability to view the power and data received.
- Large area with a line of sight.
- Adequate environmental conditions for carrying out the test.

D.2 Basic engineering of the test system

The evaluation system developed consists of two main systems called the Transmitter node and Receiver node; both nodes are constituted by an RF communication subsystem that allows the sending and receiving of data, respectively. In the case of the Transmitter node, it also has a power supply subsystem that allows a long working time, due to its low power consumption.

D.3. RF communication subsystem selection

Cognitive Radio and other hardware developments such as SDR (Software Defined Radio) are allowing the implementation of communication systems and networks using

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TVWS, among some of the hardware platforms that allow the use of this are: Ettus USRP N210, Fairwaves UmTRX, BladeRF, Myriad RF, and the EVB7 kit.

Most of these hardware platforms are based on Lime Microsystems' highly successful LMS6002D chip due to its open-source nature, flexibility, and low cost. The latest development in this area is the LMS7002M chipset (a second generation of the LMS6002D) which includes 2 sets of transmitters/receivers thus allowing MIMO (multiple input multiple outputs) processing.

A comparison of all these modules was made by analyzing the following parameters:

- Low energy consumption.
- Software in real-time.
- Low cost.
- No need for an interface for packetized networks

As a result of this comparison, the BladeRF card was chosen, which is an open-source SDR with USB 3.0 (Figure 3). It contains a microprocessor, an FPGA for configurable logic, and the LMS6002D transceiver, it also has SMA-type connectors on the RF front end and can be used on Linux, Windows, and Mac.

Figure 3. BladeRF board.

Therefore, the system is made up of the SDR BladeRF x40 platform and the Ground Plane antennas. The bladeRF x40 as a receiver is in charge of receiving the radiofrequency signals to adapt them and convert them into Intermediate Frequency (IF). As a transmitter, it is in charge of amplifying and modulating the IF signals, converting digital signals into analog ones.

D.4. Transmitter Node

It is built by the RF communication subsystem and a Raspberry Pi 2 model B, a reduced board computer to which the GNU radio software tools and the necessary drivers to manipulate the BladeRF x40 were previously installed. The transmitting node also has an application developed in GRC (Figure 4), in charge of generating, packaging, and modulating digital data that is generated randomly and which is then sent through the BladeRF to the receiving node for subsequent processing and visualization.

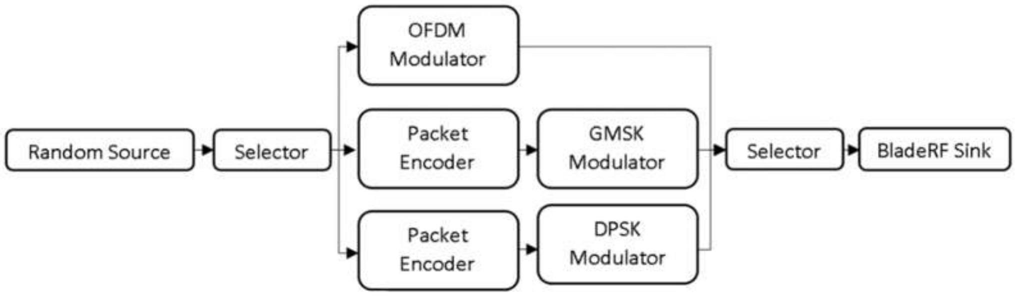
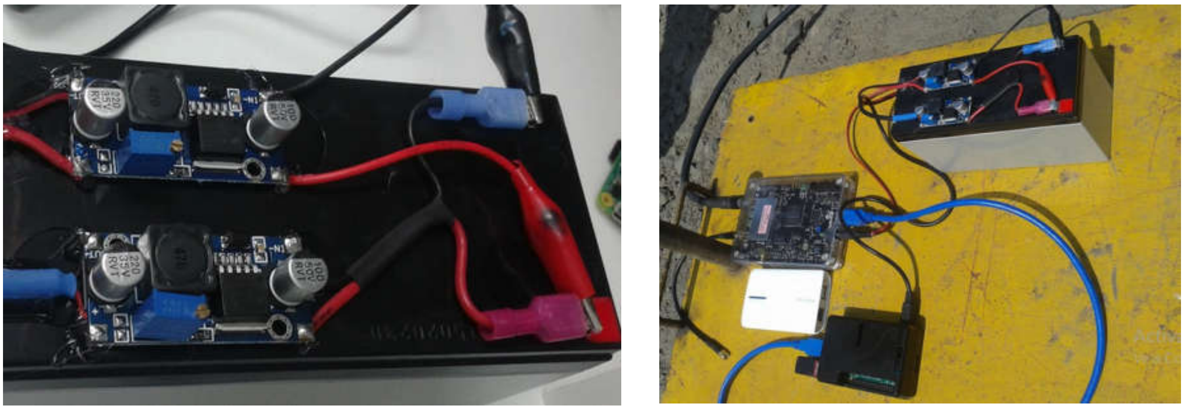


Figure 4. Block diagram of the application for the transmission of digital data.



(**a**) (**b**)

Figure 5. a) Power supply subsystem for the Transmitter Node. b) Transmitter Node installed.

The switching on and control of the program is done through a smartphone that is associated with the WiFi network generated by a TP-LINK portable modem (Figure 5B). The aFreeRDP application installed on the smartphone allows the manipulation of the Raspberry Pi through the Microsoft Remote Desktop Protocol, in order not to have to use a monitor or touch screen, which is not suitable for a system that is going to be in a rural zone.

The system is powered by a 12V 7.0 Ah lead acid battery and DC-DC circuits that are responsible for converting the 12V to 5V (Figure 5A), which is the voltage required for the SDR and the Raspberry Pi.

D.5. Receiver Node

The receiver node is constituted by the RF subsystem and a laptop, to which the GNU radio software tool and the necessary drivers to manipulate the BladeRF x40 were also installed (Figure 6).

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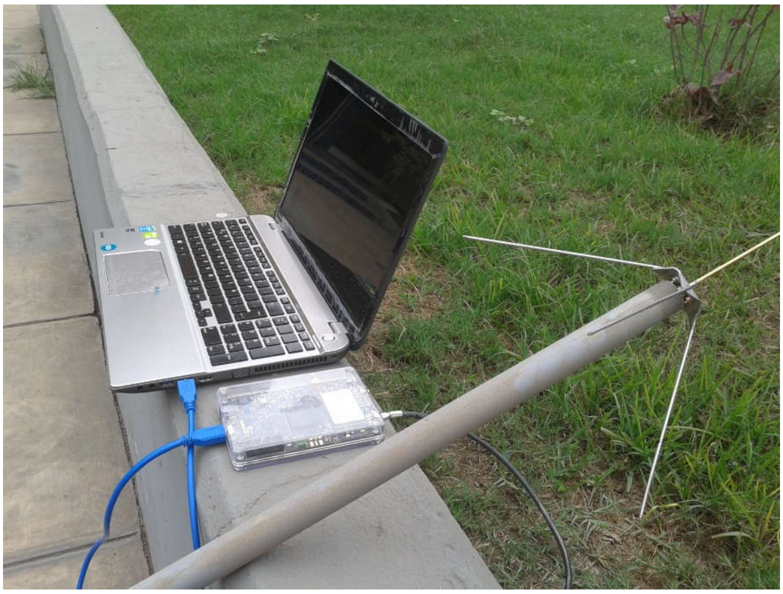

Figure 6. Receiver Node.

As in the case of the Transmitter node, the Receiver node has a GRC application (Figure 7), in charge of demodulating, unpacking, and visualizing the data sent by the Transmitter node.

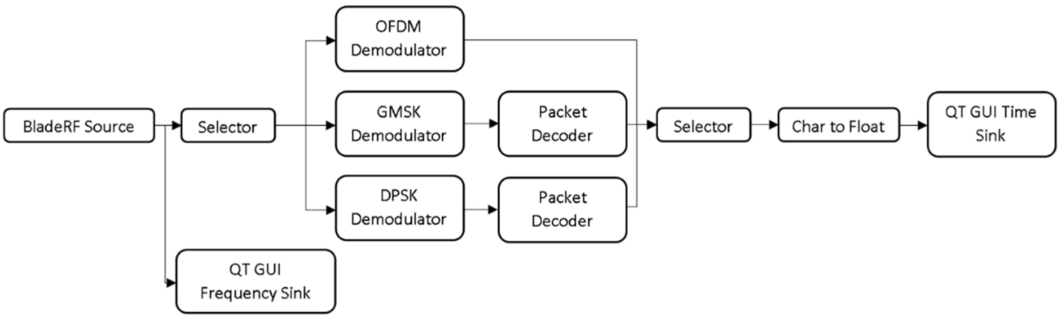

Figure 7. Block diagram of the application for receiving and displaying the data sent by the Transmitter Node.

3. Results and Discussion

The nominal output power of the bladeRF x40 card is 6 dBm (4mW), the same as in ideal conditions according to the calculations made in 2.2, based on [17] it would be enough to reach a maximum distance of 720 m. To verify this, two points were chosen as far apart as possible, the same ones that for practical and logistical reasons had to be located within the perimeter of the 16 hectares of the Nuclear Center. Both points should also have an unobstructed line of sight between them.

The chosen points were the ends located to the northwest (Figure 8) with an approximate separation of 533 meters. The Transmitter Node was located at point A and the Receiver Node at point B, each of them was placed on a pole that measured 4 meters high.

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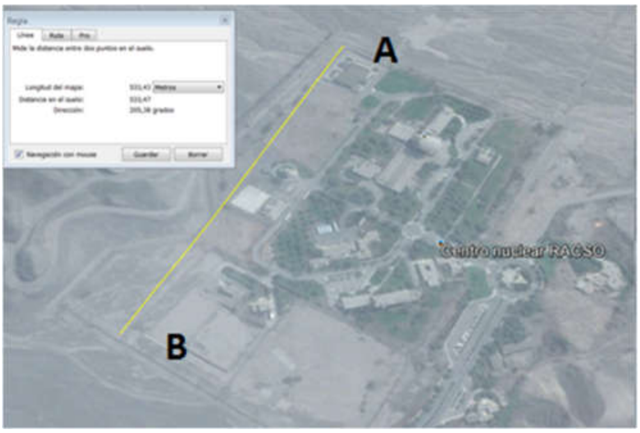

Figure 8. Distance calculated with the Google Earth program.

Two criteria were used to verify the radio link: the coincidence between the data frame transmitted and the one received after demodulation and the relative gain observed at the reception point before demodulation. In both cases, Gaussian minimum shift keying (GMSK) was used due to its high spectral efficiency.

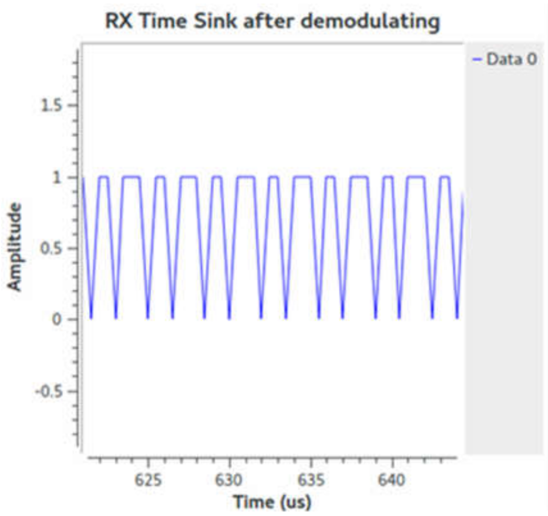

Figure 9. Digital data is received at the Receiver node.

For the first case, a binary frame consisting of 0110111 (Figure 9) was used, the same one that after successive transmissions was compared with the information received, verifying that no errors or inconsistencies were identified between them.

For the second case, the relative gain of the receiver at the frequency used was measured, obtaining a value of -40 dBm (Figure 10), which is well above the -115 dBm value specified as the sensitivity of the receiving stage of the card. bladeRF x40 [18].

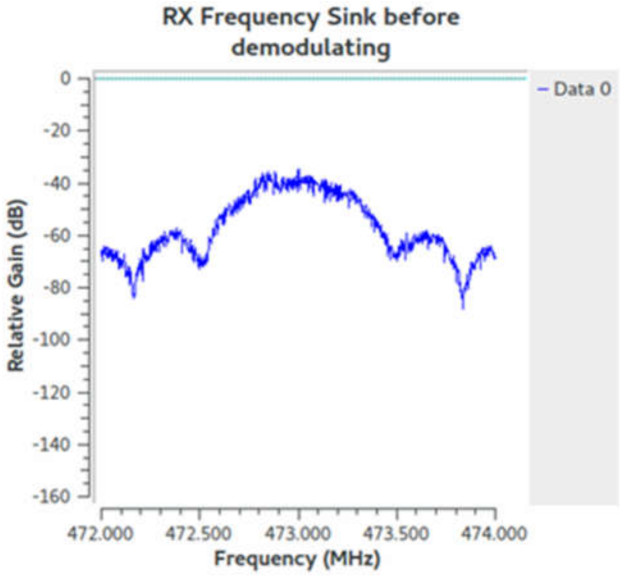

Figure 10. Frequency spectrum acquired at the Receiver node.

With the previous results, it has been possible to establish that under such conditions, the point-to-point link is reliable, however, it is necessary to extend the tests by configuring the nodes in a full duplex link in which both nodes operate as receiver and transmitter simultaneously.

4. Conclusions

A system for calculating the range of a point-to-point system using SDR BladeRF x40 platforms has been developed and built. The system was based on GMSK modulation and demodulation to transmit and receive data respectively. It was verified that the system works correctly and that it manages to transmit at a much greater distance than that required by the application for which it will be used.

According to the calculations obtained, to achieve a greater range, having the gain values and transmit/receive powers fixed, the losses caused by the cable must be minimized. Therefore, in our system, we use RG8/u type cable, which has lower loss than the RG58 cable commonly used in other applications

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Conflicts of Interest: The authors declare no conflict of interest.

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