

Teaching Workbench for Channel Emulation Attenuation

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Abstract — With the increasing use of the Internet of Things, wireless solutions like Low Power Wide Area Networks will be in demand. The behavior of the radio link constitutes a major challenge for these solutions. It dictates the quality of the service and is dependent on the communication channel that in turn is correlated to the environmental conditions where the network is to be installed. Professionals in this area need to understand the propagation mechanisms to plan, implement and manage these networks. The learning of these principles can be arduous if using real radio links in open areas, due to the impossibility to control the propagation mechanisms. This paper presents the first results of a low-cost channel emulation workbench to be used in classrooms for the learning of propagation principles in different scenarios. The proposal is to emulate flat fading channel behaviors and thus facilitating the learning of propagation principles and the effects in link quality with different channel models, like Friis and Log-Distance. The testing and benchmarking of the workbench was done with the use of an open source wireless sensor network to measure the radio signal intensity and thus verify the reproduction of the flat fading model by the workbench. The initial results demonstrate the usefulness of this workbench as it incorporates an automatic setup that permits the execution of different propagation experiments in the classroom.

Keywords – LPWAN; IoT; Network; WSN; channel emulation.

I. INTRODUCTION

The number of devices connected to the Internet is growing with the perspective of yearly increases [1]. This will generate a large amount of data that will need to be processed in order to control industrial processes or simply assure more comfort or safety, such as residential automation and applications in smart cities.

The Low Power Wide Area Networks (LPWAN) technologies are a solution. Several technologies have been proposed to meet different Internet of Things (IoT) scenarios such as Lora [2] and SigFox [3]. The knowledge of how LPWAN works is fundamental for the effective implementation of IoT, especially the communication channel since there is no point in focusing on the storage of data if there is no guarantee of communication between nodes.

To assure connectivity, it is necessary to invest in the operation of LPWAN, monitoring the behavior of the channel.

There are many studies about channel effects focusing on the higher layers of the protocol as in [4], where there is a concern regarding the teaching of LPWAN, focusing on network configuration, data set and software engineering. In [5] solutions are proposed only for routing and medium access through a simulation model.

There is also some use of LPWAN to teach other subjects [6] and [7] despite IoT and data communication and there are some authors who use simulation to explain the communication channel, as in [8] and [9].

The teaching of wireless networks stumble on the complexity of assembling experiments that allow the reproduction of the phenomena found in radio frequency (RF) connections. In laboratory it would be difficult, for example, to create free space attenuation scenarios or environment effects by varying the loss with physical obstacles. There are some commercial channel emulators like PropSim Channel Emulator from Keysight [10], however these are quite complex to operate and expensive to acquire, rendering them unsuitable for use in undergraduate classes.

This article presents a low-cost strategy for teaching the particularities of wireless communications, simulating the disturbances suffered by the RF signal, as it is essential to understand how the system reacts to the channel. To create the conditions for the learning and understanding of these processes, a radio channel emulator is proposed. With this strategy, it is possible to imprint, on the radio signal, the characteristic signal fluctuations while generating statistical representations. The emulator reproduces propagation phenomena, such as free space attenuation, log-normal, Rayleigh, etc. With this capability, it is possible to present communication concepts in real conditions, with experiments that can be evaluated in laboratory.

The emulation is accomplished using software-controlled attenuators, connected to real wired networks using a shielded camera, so that it is possible to evaluate the channel effect in the communication with regard to the wireless network physical layer [11]. Parameters, such as modulation, data rate, power, frequency offset, etc. can then be controlled and explored.

Section II presents a review of the literature on propagation in Free Space and Log Distance models. Section III presents the emulation table, while Section IV presents the materials used. Section V shows the test methods and emulations with the results in Section VI and conclusions in Section VII.

II. FREE SPACE AND LOG DISTANCE MODELS

The Received Signal Strength Indication (RSSI) decreases over the distance on any transmission medium. In wireless systems this attenuation can be quite strong due to large distances and types of environment in which the system is operating.

Considering a simple network with two nodes, for the monitoring of IoT devices, as shown in Figure 1. It is necessary to think about the channel effect over the system to appropriately ensure the communication's quality between the nodes.

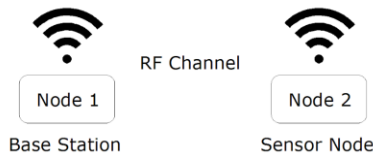


Fig 1: Nodes connectivity

The models used to plan the communication channels, which are still the subject of research, are usually deterministic or statistical [12]. Regarding the deterministic models, it is important to consider the exact physical characteristics of the propagation medium. In this paper we will consider the Free Space and the Log Distance models.

The Free Space model considers the transmission power (P_{TX}), the gains on the transmission (G_{TX}) and the reception (G_{RX}) antennas, the distance between nodes and the operating frequency [3]:

$$P_{RX} = P_{TX} + G_{TX} + G_{RX} - 10 \log\left(\frac{4\pi d}{\lambda}\right)^2 \quad (1)$$

This expression considers as attenuation only the distance between nodes and the frequency of operation, which can be observed in Figure 2:

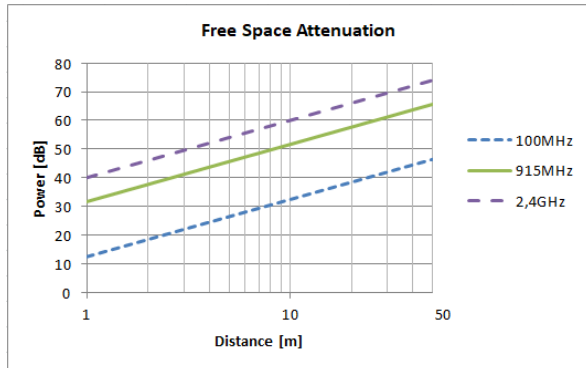


Fig. 2: Free Space Attenuation Calculated for Three Different Frequencies

The Log Distance model considers the Path Loss Attenuation factor (β) that characterizes the different types of environments, according to Table 1:

TABLE I: Path loss β [12]

Environment	Path Loss β
Free Space	2
Rural (plane)	3
Suburban (plane)	4
Urban (high buildings)	4.5

This model assumes that the P_{RX(d)}, at a distance d, can be calculated by considering β and a reference P_{RX(d₀)} at a point close to the transmitter (with Free Space attenuation), according to Figure 3 [13].

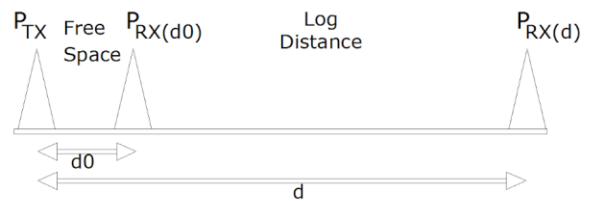


Fig. 3: Log Distance Model

$$P_{RX}(d) = P_{RX}(d_0) - 10\beta \log\left(\frac{d}{d_0}\right) \quad (2)$$

The calculations based on the Log Distance model, for 3 different values of β (Figure 4), consider that to know the total attenuation of the system, it is necessary to add the attenuation of the Free Space, according to (2):

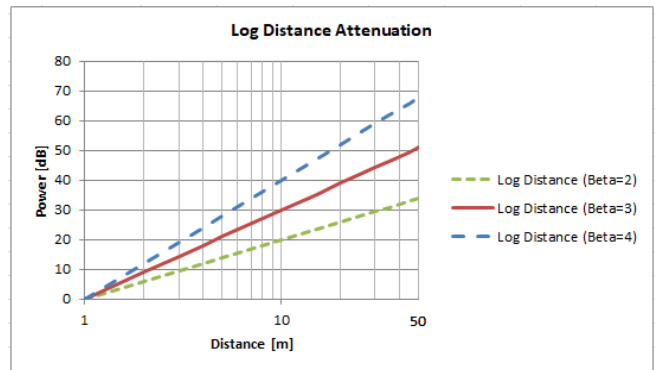


Fig. 4: Log Distance Attenuation Calculated

The Free Space Model predicts that the received power decays as the negative square root of the distance and the Log Distance increases the decay according to the propagation environment. Although they are simple and deterministic models, they are the base for the characterization of the workbench and the development of other statistical models.

III. EMULATION WORKBENCH

According to [14], both simulated experiments (virtual laboratories) and real remotely operated plants (remote laboratories), have recently been used more often. The advantage of remote laboratories resides in the fact that students can use real equipment that exist in several areas of engineering [15] [16].

The emulating workbench replicates a two-node LPWAN, showing what would happen to the propagation signal if those nodes were transmitting information through a RF channel (Figure 5), where the nodes are interconnected by an emulated RF channel.

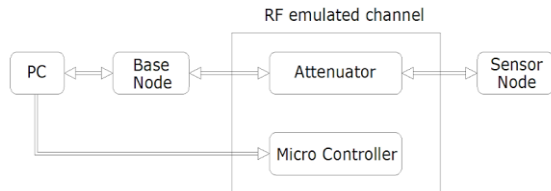


Fig. 5: Emulation Workbench Diagram

Only two nodes were used to demonstrate the workbench in this work, but the system allows the use of several nodes to emulate characteristics like routing techniques, for example.

IV. MATERIALS

Currently, there are many LPWAN technologies. Among these technologies, Radiuino [17] was chosen mainly because it is an open platform created specifically for LPWAN. It is based on the Arduino development environment (IDE).

i. Hardware

For the RF channel emulation, the base and the sensor were interconnected through a Mini-Circuits digital variable attenuator (ZSAT -31R5+) operated by a microcontroller as shown in Figure 6:

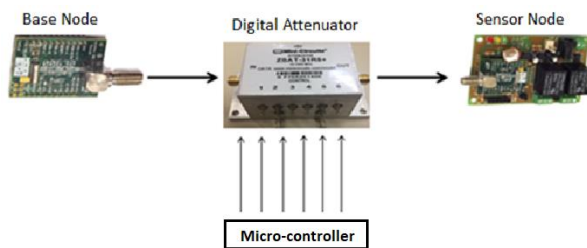


Fig. 6: Emulation Workbench Materials

ii. Firmware

The base and sensor node programming was done with the Arduino's Integrated Development Environment (IDE), the firmware was developed in C ++ and Radiuino-specific libraries [17].

iii. Software

The programs used to control the base node, as well as the sensor node and the digital attenuator were developed in Python.

V. METHODS AND RESULTS

The final test configuration included a PC-Base and a PC-Microcontroller connection made via a USB cable. The Base-Attenuator-Sensor connection was made through a coaxial cable, eliminating the antennas. The digital attenuator created the attenuation effect on the channel.

The computer sent the Arduino's 52-byte packet to the base via the USB, the base incremented the address identification (ID) and transmitted via emulated RF with the power previously programmed into the base firmware. For each packet sent, the attenuation value was changed. The sensor node received the packet from the base, measured the RSSI, verified the instructions regarding what should be done and returned the information to the base to be processed by the computer.

The digital variable attenuator of 31.5 dB was controlled by an Arduino. For each received packet, the attenuation was incremented to represent the attenuation in Free Space and Log Normal models with several values of β .

Figure 7 shows the graph for the RSSI on the primary vertical axis against the attenuation on the secondary vertical axis.

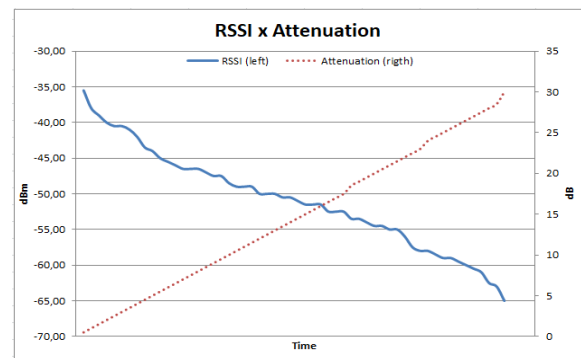


Fig. 7: Emulation Results

The attenuation ranged from 0 to 31.5dB, while the RSSI went from -35 dBm to nearly -67dBm. The time was also emulated to vary. The graphs confirm the usefulness of this setup to carry out experiments. It is possible to observe the expected inverse correlation between attenuation and intensity of the emulated signal, representing the attenuation in free space.

Figure 8 shows the emulated of path loss attenuation for different values of β according to the attenuation in the Log Distance model.

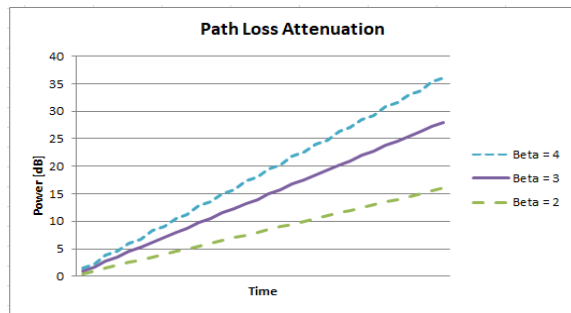


Fig. 8: Log Distance Emulation Results

The graph highlights the versatility the workbench lends to the task of varying the attenuation curve to reflect different environments.

Figure 9 presents the comparison between the emulated workbench and the calculated Free Space model, with the power on the primary vertical axis against the attenuation on the secondary vertical axis.

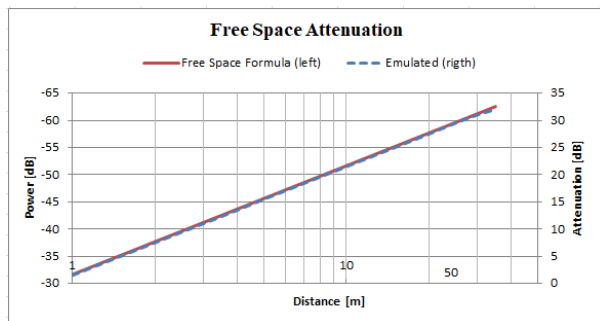


Fig 9: Emulated x Calculated Comparison

It is possible to verify that as the attenuation of the emulated system (continuous line) grows, the RSSI proportionally degrades, coinciding with the calculated values (dashed line), demonstrating the efficiency and accuracy of the workbench.

VI. CONCLUSION AND FUTURE WORKS

This paper presented an emulation workbench that can be used for testing LPWAN technologies and for the demonstration of how these technologies behave in an unstable and non-repeatable environment such as RF communication, using the Free Space and Log Distance models as examples.

Results from the workbench using RADIUINO LPWAN technology demonstrate that a set up consisting of two interconnected nodes and a digital attenuator can emulate the characteristics of a real environment.

Teaching RF channel becomes much more effective with an emulated system that uses real IoT components. The workbench also allows the testing and comparison of other technologies for predetermined scenarios, making it easier to define the technologies to be used, since IoT technologies must be customized per application.

The great advantage of this type of emulation is the control over the attenuation imprinted on the channel. It can be used for the emulation of models like the propagation in free space, Log Distance or any other type of probabilistic distribution. As a future work, we propose to extend the emulation bench to cater for probabilistic models of channel propagation, such as Log Normal, Rayleigh and Rice. In addition, we also intend to use other LPWAN technologies to compare performance and efficiency, as well as to enable the emulation bench to be accessible remotely.

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