# Performance Evaluation of ZigBee Transmissions on the Grass Environment

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***Abstract*—This article proposes a prototype to measure the Received Signal Strength Indicator (RSSI) value in devices of ZigBee-based networks. The developed device was employed in two outdoor experiments, to verify how far transmitter and receiver can be separated to still maintain a connection. The proposed system utilizes a XBee module Series 1, an Arduino Uno R3 microcontroller board, a XBee Arduino Shield and a LCD. The measurements were accomplished on and over a grass environment. The RSSI meter demonstrated efficiency for good quality connections, but at certain environmental conditions, the connection was lost at a short distance of 9 m.**

***Keywords–Arduino; RSSI; Prototype; ZigBee.***

## I. Introduction

Wireless Sensor Networks (WSN) became a trend in the last years due to advances in wireless communications, such as new information technologies and electronic attributes developed for these technologies [1]. WSNs are one of the most promising technologies from this generation, as they have great usability due to their implementation on industrial control systems. Moreover, the low cost multi-functional sensors that accomplish surveillance control reinforce the strong importance of these networks.

With a great versatility for being used in several application fields, WSNs have joined an increasingly interest in the last years [2]. Particularly, extensive researches have induced to the definition of a new wireless systems generation, capable of extending even more the WSN application fields. It is relevant to characterize how the radio signal range varies over indoor and outdoor environments, because some ambient conditions can cause impairments to any transmissions [3].

The ZigBee technology promotes communication between devices and manages big WSN size. This standard provides a license-free and low-power, two-way wireless communications with high reliability and more extensive reliable range at an affordable cost. It is deployed in wireless control and monitoring applications with low data rate, low power consumption, allows longer life with smaller batteries [4].

In wireless networks, an important project aspect is to consider the fading effect, as shown in several articles, such as [5]–[7]. There are various electromagnetic wave's fading processes, for example fading caused by signal reflections on objects, and they all quite affect the transmission between nodes. The waves travel through different ways, that not necessarily have the same length, and interactions between them and the objects and barriers during their travel are responsible for great part of the fading phenomenon on transmission and reception processes. Fading during electromagnetic waves propagation is also caused by reflection, diffraction and scattering [7].

RSSI is a measurement of the power in a received radio signal. Several works have been proposed to investigate radio signals' propagation effects at ZigBee devices. Ben Hamida and Chelius [8] have studied the effects of human movement on the RSSI, in an indoor environment. The sensors were deployed in different floors of a building, and the researchers analyzed their data by observing the impact from human presence, and showed that it causes a degrading effect on the system's performance. In [9], the impacts from antenna orientation in WSNs were empirically determined, by tilting TelosB modules in several directions. When these modules are in contrary orientations, there are great variations on the RSSI. Ben Graham et al. [10], they monitor the effects by installing the sensors on the ceiling, where the antenna stays inverted and pointing to the ground. All these works focused in different factors that have influence on the RSSI, such as antenna orientation and human presence.

In this paper, we propose the development of a RSSI meter, which was utilized to collect data on sport fields, on the grass environment. The data collected during tests were used as a case study, and the relevant factors on several RSSI measurements were identified. Environment effects related to the considered physical scenario were taken into account, as such as wind, temperature and humidity, which were determining factors on the RSSI variation.

The remaining of the paper is organized as follows: in Section II, the ZigBee technology and the XBee modules characteristics are presented. Section III describes the hardware used during the RSSI meter assembly, and the concepts about the RSSI meter prototype. Section IV brings the methodology used for the experiments and Section V presents the measurement results. At last, the conclusions are devoted to Section VI.

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## II. ZigBee Technology

ZigBee technology is an option to fill a gap in WSN's network architecture, being an appropriate communication protocol for this application. The differential of this technology is its advantage in face of other communications protocols, such as Wi-Fi [11] and Bluetooth [12]. ZigBee technology has a protocol that supports mesh, star and tree networks, creating more than one path possible between a transmitter and a receiver.

This technology has been gaining great notoriety due to simplified code and protocol, and also its reduced development cost. The modularization allowed by ZigBee during development also attracts attention to this technology. The IEEE (Institute of Electrical and Electronics Engineers) has regularized its functioning in the IEEE 802.15.4 protocol [13]. However, Zigbee is not part of IEEE 802.15.4 standard, being Zigbee and IEEE 802.15.4 related but different things. IEEE 802.15.4 is a IEEE communication standard that specifies the medium access control (MAC) sublayer and physical (PHY) layer for low rate and low power wireless communication devices.

XBee is the brand name from Digi International for a family of ZigBee-compatible radio modules, that take part during hardware implementation necessary on a ZigBee network's assembly. The device controls radio wave's propagation by the transmission/reception antenna. This antenna, usually, works at a maximum power of $60\,\mathrm{mW}$, and its frequencies are usually between $2.40\,\mathrm{GHz}$ and $2.48\,\mathrm{GHz}$.

## III. Hardware Description

### A. Arduino

Arduino is a small microcontroller board, connected to a PC through an USB connection, allowing so a connection between the board and the PC. Moreover, an Arduino board contains several other terminals that allow connection with external devices such as motors, relays, light sensors, LEDs, speakers and so on. This board's project is open-source, that means that any user could construct Arduino-compatible boards. A board's cost reduction was accomplished by the opening of the Arduino's source code.

The Arduino's development platform was the base-device during the assembly of the prototypes. The model used was an Arduino Uno R3, chosen due to its great application field and its easy integration with the XBee module's platform, and shown in Figure 1.

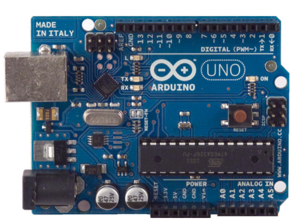


Figure 1. *Arduino Uno R3* microcontroller board

### B. XBee Shield for Arduino and XBee Module

The basic Arduino boards can be complemented some boards, called *shields*, that can be coupled over the basic Arduino board. These shields are circuit boards containing other devices (GPS receivers, LCD displays, Ethernet modules, etc.) that are connected to the Arduino in order to obtain additional functionalities. Thus, a shield is a Printed Circuit Board (PCB) coupled over an Arduino board allowing communication between these boards, through an connection fed by connector-pins.

In order to correctly couple the XBee modules to the Arduino board, it was also used a shield whose function is to convert the socket's format from the Arduino board to the one from the *XBee S1 MaxStream* module. This shield is shown in Figure 2.

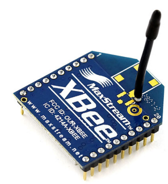


Figure 2. *XBee MaxStream* Module

All this connection procedure is made aiming the surveillance at the received signal's state during transmissions between the two modules. Their communication is very simply configured, as the signal forwarded to the transmitter device is directly sent to the receiver device. Such a configuration is possible because the XBee modules can directly communicate, without any need for addressing, while at AT (transparent) mode.

### C. RSSI

RSSI is a measure from the received radio signal's power. Such a metric used to estimate the transmission quality between two nodes as the distance between them is varied. It works by using the distance between transmitter and receiver to designate the quality from the received signal, even considering variations on signal strength by comparing the received signal level with probability distributions and localization measures based on statistic analysis [14].

## IV. Methodology

The methodology adopted during the assembly of the prototype and subsequent measurements with it were made under the following schedule.

1st: The used device allowed the RSSI measurement on a specific pin. On this pin, there was a PWM (Pulse Width Modulation) modulated signal, where the RSSI value is codified in how long the pin's output stands on a certain digital level. This output was treated as analogic, but actually is a digital output that generates an alternating signal (*low* and *high* digital levels).

2nd: Compatibility tests were made between the used Arduino Uno R3 platform and the XBee modules, for the purpose of test basic trigger circuits with the modules, and verify whether there was communication establishment between the devices. On this stage, the prototypes were assembled in assembly boards. Other electronic components


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were also added to project, such as a $16 \times 2$ LCD display for showing RSSI values, and components responsible for maintain and feed this display.

3rd: The programming language used to create the source code executed by the prototype is called *Wiring*, that stands as the standard development language for Arduino projects. The RSSI value was obtained from the $A1$ pin, through `pulseIn()` function. This function measures the length of the PWM pulse. The code executed by the microcontroller responsible for the reading function follows.

```
int dur = pulseIn(A1,LOW,200);
int rssi=(dur+50)*(-1);
```

4th: The measurements were made on an outdoor sports field. The transmitter was fixed and the receiver was taken to increasingly distances to the transmitter. Two tests were made: on the first, both devices were on ground level. A photo was taken showing how the receiving device was put during this test, and this photo is shown in Figure 3. At first, distancing them by one meter, the RSSI was measured by the receiving device. The distance was increased up to one in which there weren't connection. This test was made on a sunny day, in the afternoon, low wind, temperatures between $28\,°\mathrm{C}$ and $31\,°\mathrm{C}$, and air humidity at $65\%$. The second test was made similarly to the first, but the devices were $45\,\mathrm{cm}$ over the ground.

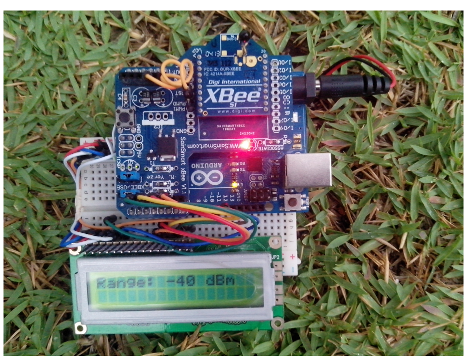


Figure 3. Prototype standing on the ground, during first measurement.

5th: On the tests, every measure took 45 RSSI samples. As the tests ended, the samples were processed. For every measure point in every test, it was calculated the average, the standard deviation of the mean (through formula shown in (1)), and the highest and lowest received signal strength. Equation (1) shows how the standard deviation of the mean was calculated.

$$\sigma_{\text{mean}} = \sqrt{\frac{1}{N \cdot (N-1)} \sum_{i=1}^{N} (x_i - \overline{x})^2}, \qquad (1)$$

in which $N$ is the number of samples, $x_i$ is the value of the $i$-th sample, and $\overline{x}$ is the arithmetical mean.

## V. Performance Evaluation

Figure 4 shows the measurement's data for the experiment in which the devices were on ground level.

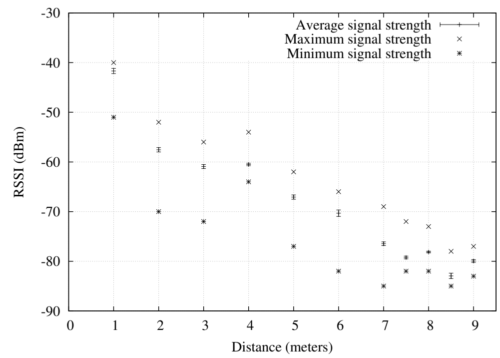


Figure 4. Received signal's power versus distance between transmitter and receiver at first measurement.

As shown in Figure 4, as the receiver device was taken farther, lower RSSI values were measured, reaching minimum levels of -85 dBm. When the receiver was at a distance of $9\,\mathrm{m}$ far, there was not anymore connection between the devices. Before that, the last average signal strength (measured at $8.5\,\mathrm{m}$) was -75.95 dBm. The RSSI values did not fluctuated too much around the mean, as shown by the small standard deviations.

A similar measurement was made, but this time the devices were $45\,\mathrm{cm}$ over the ground. The results can be seen in Figure 5.

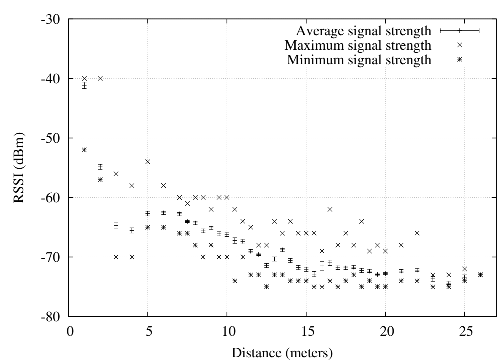


Figure 5. Received signal's strength versus distance between transmitter and receiver at second measurement.

As the environmental parameters on both measurements were almost the same, the difference between how far the transmission went can be explained by the device's height. In the second experiment, the connection was broken when the devices were distanced by $26\,\mathrm{m}$. Overall, the RSSI during the second experiment was higher than the one of the first, in which the lowest strength was about $-76\,\mathrm{dBm}$. On the second experiment, just before connection loss, the last average signal strength was $-73.00\,\mathrm{dBm}$.

Apparently, in such environmental conditions there is no useful connection between the devices if the RSSI is under $-70\,\mathrm{dBm}$. Based on this statement, it was analyzed how long the signal strength stood under this level, from now on called of percentage of idle time. It is shown in Figure 6 the analysis' result for the first experiment. From $8\,\mathrm{m}$ and beyond it's difficult to hold an connection between the two devices, as the signal has a very low RSSI on such a distance.

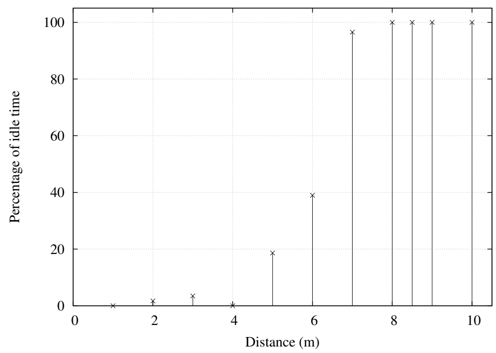


Figure 6. Percentage of idle time versus distance in the first measurement.

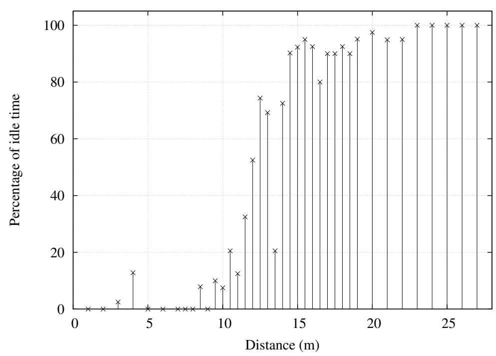


Figure 7. Percentage of idle time versus distance in the second measurement.

The results for the second measurement can be found in Figure 7. Despite the fact the connections is maintained up to a distance between transmitter and receiver of $26\,\mathrm{m}$, distances greater than $15\,\mathrm{m}$ would have a bad quality of service, as the connection would have to be constantly reestablished.

## VI. Conclusion and Future Work

We successfully built a functional prototype and analyzed some data extracted from the experiments. Reading the RSSI value seems to be a positive indicator for good quality connections, but at certain environmental conditions (devices at ground level) the connection was lost at a small distance of $9\,\mathrm{m}$.

One important result achieved through this article was the determination of how far can two sensors be and still maintain connection. At ground level, this distance is about $7\,\mathrm{m}$, and to a $45\,\mathrm{cm}$ height, this distance goes up to $15\,\mathrm{m}$, showing how great is the influence of the environmental conditions.

We aim at improving the measurements quality, by changing other environmental parameters. Experiments in cloudy or rainy days, with or without human presence, with more samples, and at different times shall be done in order to allow a more complete efficiency analysis of the experiments data.

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