Received strength signal intensity performance analysis in wireless sensor network using Arduino platform and XBee wireless modules

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Abstract
Today, through the monitoring of agronomic variables, the wireless sensor networks are playing an increasingly important role in precision agriculture. Among the emerging technologies used to develop prototypes related to wireless sensor network, we find the Arduino platform and XBee radio modules from the DIGI Company. In this article, based on field tests, we conducted a comparative analysis of received strength signal intensity levels, calculation of path loss with “log-normal shadowing” and free-space path loss models. In addition, we measure packet loss for different transmission, distances and environments with respect to an “Arduino Mega” board, and radio modules XBee PRO S1 and XBee Pro S2. The tests for the packet loss and received strength signal intensity level show the best performance for the XBee Pro S2 in the indoor, outdoor, and rural scenarios.

Keywords
XBee, wireless sensor network, radio propagation model, packet loss, received strength signal intensity level

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Introduction
In precision agriculture, tools from different disciplines of science are applied to agriculture, including the use of remote sensing, that has helped improve production efficiency levels, decrease production costs, and minimize environmental impact. All these, thanks to its ability to obtain information from the environmental variables, affect the crop, whether in small farms or large tracts of land.¹⁻³ Therefore, technologies based on WSN (wireless sensor networks) offer a good option of distributed monitoring through sensors that cooperatively operate in a given area and in different physical and geographical conditions. This contributes to real-time information collection (such as temperature, solar radiation, atmospheric humidity, and soil pH) which can be analyzed by producers to take the necessary measures regarding their crops.⁴,⁵

In the Colombian case, some regions have made efforts in precision agriculture by WSN in the field of sugar cane, coffee, palm, and rice,⁶ and in other

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countries like the United States of America, Brazil, and Argentina, these agricultural techniques are causing a positive impact on economic matters.

Thus, modernizing agriculture means farmers and their crops can survive climate change and free trade agreements (FTA) which in the future will be a priority to maintain competitiveness in the domestic and international markets. In the case of the Atlantic Coast region of Colombia, the implementation of WSN technology represents an opportunity for precision agriculture in its representative crops such as cassava, pepper, and mango, whose agro-production processes are nowadays widely performed with rudimentary mechanisms.

In this sense, the main contribution of this document is to validate the use of XBee modules on agricultural scenarios, through tests with metrics that affect wireless transmission, such as reception signal strength levels, packet loss in transmission, and attenuation per propagation models that are suitable for scenarios on the WSN. Our tests indicate that the XBee Pro S2 platform shows a better performance in the metrics evaluated, especially in terms of packet losses. For the metric of received strength signal intensity (RSSI) level, the results were similar in the different scenarios evaluated. Regarding attenuation, the Log-Normal Shadowing Model (LNSM) shows better behavior for each of the tests performed in the two modules. Besides, this article establishes limits of reliability for the use of the XBee Pro S1 and XBee Pro S2 platforms in the recreated scenarios in the tests carried out in the context of precision agriculture.

The rest of this article is organized as follows. In the next subsection, the revision of the propagation models for WSN is realized. In the following sections, the methodology used for the tests in the different scenarios are described and later the main results and its analyses. Finally, we offer our conclusions in the last section.

**Propagation of the wireless signal in a WSN**

In our case study, the analysis of signal propagation in a WSN free space is essential to determine efficiency between transmitter and receiver within the deployed network in a crop field. In this regard, among the phenomena that attenuate the signal in an unguided medium of propagation are diffraction, refraction, reflection, and dispersion depending on the type of environment where the communication is deployed. It can lead to problems like multipath signal fading and inter symbol interference, among others.

The aim of this study is to evaluate the deployment of a WSN in two types of environments using the Arduino platform, widely known and used in the context of environmental monitoring.

In this work, we present the analysis of wireless transmission between two nodes using the Arduino platform with the radio Digi XBee Pro modules in its versions S1 and S2 to evaluate the following:

- The levels of RSSI;
- Packet loss;
- Models for levels of indoor/outdoor attenuations.

**Description of propagation models in urban and rural environments**

Among the most usual models for WSN, we have the classic model of propagation in free space. Widely used in environments with LOS (line of sight), this model describes optimal signal behavior. However, in urban environments, the signal could be affected by the presence of different kinds of obstacles. To address this issue, there are models like the Shadow Log-Normal Model (LSNM) that includes prevailing conditions, such as barriers, absorption by walls, and considers the presence of non-LOS. With this in mind, we used the following two models.

**Free-space path loss model.** Its use is of importance to rural environments.

\[
PL_{FSPL}(d) = 20 \log_{10}(d) + 20 \log_{10}(f) + 20 \log_{10}\left(\frac{4\pi}{c}\right)
\]

where \(PL_{FSPL}(d)\) is the path loss at \(d\) meters from the transmitter in dB, \(d\) is the distance between the transmitting and receiving antenna in meters, \(f\) is the frequency in Hertz, and \(c\) is the speed light in m/s.

**LNSM.** Also called “One Slope” model, it is a generic model to estimate the average of path loss in indoor or outdoor environments. The concept of log-normal is a statistical measurement of power fluctuations received from the blockages suffered by the signal (diffraction) also called “shadowing.” In the case where many blockages occur, there are different paths to the receiver. These paths are multiplicative, meaning that the effects can be treated as additives if dB are used. If there is enough points of diffraction and/or multi-reflection paths to the receiver, the central limit theorem can be used to justify the use of a Gaussian random variable to represent path loss.

A description of this model is found in equation (2)

\[
PL(dB) = PL(d0) + 10 \times n \times \log(d/d0) + X\sigma
\]

where \(PL(dB)\) is the ratio between transmitted and received power expressed in dB; \(PL(d0)\) is path loss to
a referential distance $d_0$, usually taken as free-space loss (theoretical) to 1 m; $X\sigma$ is the Gaussian random variable with a zero mean and standard deviation zero in dB; and $X\sigma = z \times \sigma$, where $z$ is the probability percentage of coverage and $\sigma$ the deviation. $n$ is the exponent of path loss and indicates the increase in path loss as a function of the distance with LOS. In turn, $10 \times n$ is the so-called slope factor.

**Similar works**

Measurements of RSSI and packet loss are important communication aspects of the WSN. We observed this in the research of Mahalin et al.\textsuperscript{18} It shows a system based on measurements of RSSI in order to find out the communication coexistence between devices operating in 802.15.4 and 802.11 b/g. For this purpose, a network was used composed of TelosB sensors and a multi-hop topology. In the literature,\textsuperscript{19,20} similar experiments were carried out using an analysis of propagation behavior of the RF signal (ZigBee for the second case) modules in a real environment through RSSI measurements at different distances. There are also studies on the use of WSN in the environment to improve the production of mixed crops with precision farming variables,\textsuperscript{21,22} or systems for measuring climate variables such as temperature, humidity, rainfall, solar radiation, wind speed, and direction.\textsuperscript{22,23}

**Materials and methods**

**Description of the sensor and sink nodes, and software testing**

For the test, we used a sensor node device composed of an Arduino, open-source platform, which is used for the development of electronic prototypes including those focused on creating interactive environments.\textsuperscript{24} It is based on the ATMEGA168, ATMEGA1280, and ATMEGA328 microcontrollers, which are open source with Creative Commons license. On the other hand, we used radio modules XBee Pro S1 and S2 (manufactured by the DIGI Company). In this case, the S1 version works with layer 2 of IEEE 802.15.4 standard, and S2 meanwhile implements layer 3 supported by the Zigbee protocol; also, the term “Pro” means that it offers longer distance range.\textsuperscript{25} For better comprehension, Figure 1 details the main features of XBee Pro modules S1 and S2.

The characteristics in terms of power and range of each of these modules are summarized in Table 1.

Table 1 shows that, given the constraints of existing transmission in Europe and Japan, the Digi company radio module XBee Pro S1, identified with the CE logo on it (“international version”), uses less power output (Figure 1(b)).

The sink node connected via USB to a laptop uses the XBee Pro S1/S2 modules. These modules are configured using the software tool X-CTU to monitor RSSI levels and packet loss.

Arduino and XBee were chosen as hardware testing tools due to their diffusion related to agricultural and environmental applications. For example, the Libelium Company uses Arduino in Spain as the core of its work, and the “Waspmote” board, offered commercially by Libelium, was adapted and improved to control specific variables. It has a development and integration of communication technologies.\textsuperscript{26} It is also compatible with software for network management which makes it very commercially attractive.\textsuperscript{27}
Assessment of connectivity in wireless XBee modules

To assess the performance in terms of connectivity for the modules XBee Pro S1 and XBee Pro S2, we measured their coverage in urban and rural locations, changing distances to the receiver. RSSI levels and packet loss were measured to estimate the operational performance of the radio modules.

For the testing stage, we used an “Arduino Mega ADK” with a shield for coupling the XBee Pro S1 and XBee Pro S2 modules.28 As a receiver, we used a USB programmer module of XBee, connected to a laptop. The devices are shown in Figure 2.

We made four tests in different environments, as described below:

- **TEST 1**—Indoor: packets are received as far as 40 m distances. In this case, the signal is sent from the end device to the module that operates as a gateway and must overcome interferences produced when going through walls for each test. Measurements were taken at 1, 10, 20, 30, and 40 m.

- **TEST 2**—Urban Outdoor (Plaza): data packets are received as far as 40 m distances. In this case, the signal sent to the gateway was produced outdoors but with walking people, and vegetation and trees obstructing the LOS. Measurements were taken at 1, 10, 20, 30, and 40 m. The term “Plaza” refers to the plaza environment inside the campus where we did the tests.

- **TEST 3**—Rural: packets of data are received as far as 500 m distances. In this test, data packets are sent with a free LOS between the modules. The measurements were taken with distances of 100, 200, 300, 400, and 500 m and a height of 2 m from the ground. This was done in a straight segment of 1 km of a road, located outside the city of Barranquilla (see Figure 3).

- **TEST 4**—Rural Grassland: packets of data are received as far as 40 m distances. In this test, data packets are sent with a LOS get blocked by foliage between the modules. The measurements were taken with distances of 1, 10, 20, 30, and 40 m and a height of 1 m from the ground.

For the four tests, 100 data packets are sent from the coordinator (sink) node (connected with a PC) to the remote host. The remote host receives the packets and returns them again to the local host. RSSI parameter and packet loss were measured through the X-CTU tool owned by the DIGI Company commonly used in other studies for similar purposes.29

With both modules, transmission is made to a maximum allowable power, which is 10 dBm for XBee Pro S1 and 17 dBm for XBee Pro S2.

Table 2 shows the values obtained using the X-CTU software for different tests. These were tabulated for an easier comparison of the modules XBee Pro S1 (XBPS1) and XBee Pro S2 (XBPS2).

### Results and discussion

#### Indoor tests in urban environments

For each case, the values obtained in the measurements for packet loss and RSSI in modules XBee Pro S1 and XBee Pro S2 were plotted. Figures 4 and 5 show a comparison for each respective analysis. We confirmed that packet loss and RSSI levels increase in proportion to the distance in which the end-device is located. The two modules obtained similar levels of RSSI at distances of 30 m without relevant differences. But, at distances greater than 30 m, the module XBPS1 tends to be less efficient than the XBPS2. This is partly due to the differences in the power of the two transmitters. The XBPS1 module is the international version. We also
Table 2. Samples for each test using modules XBee Pro S1 and XBee Pro S2.

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>RSSI level (dBm)</th>
<th>% Packet loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>63</td>
<td>2</td>
</tr>
<tr>
<td>20</td>
<td>82</td>
<td>5</td>
</tr>
<tr>
<td>30</td>
<td>84</td>
<td>4</td>
</tr>
<tr>
<td>40</td>
<td>No signal</td>
<td>73</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distance (m)</th>
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<th>% Packet loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>39</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>77</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>83</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>91</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>88</td>
<td>1</td>
</tr>
</tbody>
</table>

RSSI: received strength signal intensity; LOS: line of sight.

Figure 4. Comparison of packet loss between modules XBee Pro S1 and XBee Pro S2: (a) indoor, (b) outdoor (Plaza), (c) outdoor (Grassland), and (d) rural.
observed the aforementioned lower efficiency in packet loss, a higher rate for the XBPS1 module at 30 m. Before that, at 10 m, both modules presented no significant differences regarding packet loss.

**Tests in urban outdoor environments (Plaza)**

Figures 4 and 5 show RSSI levels with many similarities in the two modules and without any relevant difference. However, in regard to packet loss, we observed that from 30 m the XBPS1 module presents a significant increase in packet loss compared to module XBPS2, which maintains a negligible rate of packet loss.

**Test in rural environment (LOS)**

The results obtained for RSSI and packet loss are similar in different distances ranging up to 500 m. However, beyond the 500 m, XBPS2 module provides an acceptable performance for packet transmission, similar to the results obtained by Harun et al., where an XBee Pro module is compared to other technologies and obtained the best performance. This clearly reflects the greater transmission power provided by this module.

It is noteworthy that the XBPS1 module offers slightly better performance in terms of RSSI levels at 500 m.

**Test in rural grassland environment (LOS)**

The loss packet loss in XBPS2 is despicable; meanwhile, XBPS1 module from the begin had losses of 30% until 45% increase with the distance until 40 m. However, both RSSI values are similar and acceptable in XBPS1 and XBPS2.

Likewise, we observed that the levels of RSSI in the WSN have a better performance when it comes to outdoor environments since the indoor obstacles influence the transmission.

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those in the field test for rural environments, being the closest in this case when the XBPS1 module is used.

Conclusion

The XBPI modules show lesser performance in indoor environments without LOS because it works with 7 dBm less than the XBPS2 modules. However, the performance in packet loss is similar to XBPS2 over short distances (up to 30 m) in outdoor environments.

Is important to note that the XBPS1 module has better RSSI level for external environments over long distances (up to 400 m). On the other hand, to model the losses for path attenuation on the urban environments, it is better to use the LNSM because the values are close to the ones obtained in field tests compared to the free-space model.

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