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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.[7,8] 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.[9]

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.[10–12]

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.[13]

Free-space path loss model. Its use is of importance to rural environments[14]

$$PL_{FSPL}(d) = 20\ \mathrm{Log}_{10}(d) + 20\ \mathrm{Log}_{10}(f) + 20\ \mathrm{Log}_{10}\left(\frac{4\pi}{c}\right) \quad (1)$$

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.[15] 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 multireflection paths to the receiver, the central limit theorem can be used to justify the use of a Gaussian random variable to represent path loss.[16,17]

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

$$PL(\mathrm{dB}) = PL(d0) + 10 \times n \times \log(d/d0) + X\sigma \quad (2)$$

where PL (dB) is the ratio between transmitted and received power expressed in dB; PL ($d0$) is path loss to a referential distance $d0$, 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 σ 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.[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,[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,[21,22] or systems for measuring climate variables such as temperature, humidity, rainfall, solar radiation, wind speed, and direction.[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.[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.[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)).

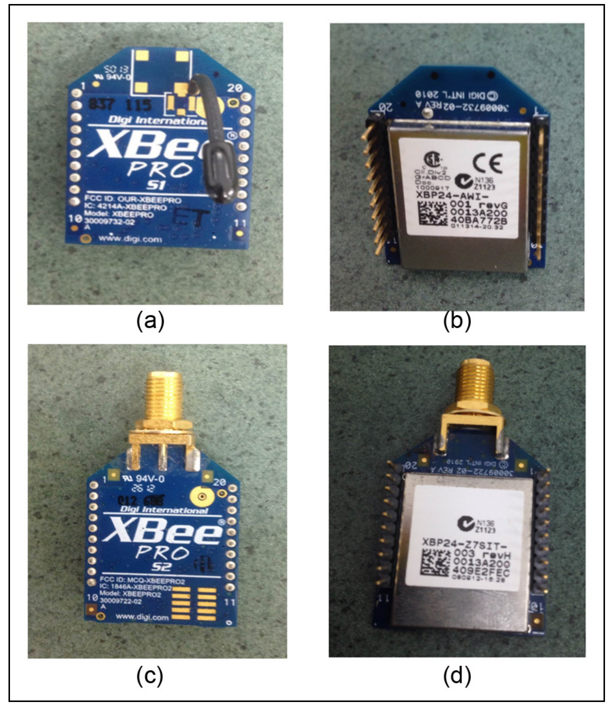

Figure 1. Tested radio modules: (a) front and (b) rear side of the XBee module S1 Pro; (c) front and (d) rear side of the module XBee Pro S2.

Table 1. Specifications of RF modules XBee Pro S1 and XBee Pro S2.

Module	XBee Pro S1	XBee Pro S2
TX Power	10 dBm	17 dBm
RX sensitivity	−100 dBm	−102 dBm
Indoor range	60 m	90 m
Outdoor range	750 m	1500–2000 m
Operation frequency	2.4 GHz	2.4 GHz
Antenna gain	1.5 dBi	5 dBi

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.[26] It is also compatible with software for network management which makes it very commercially attractive.[27]

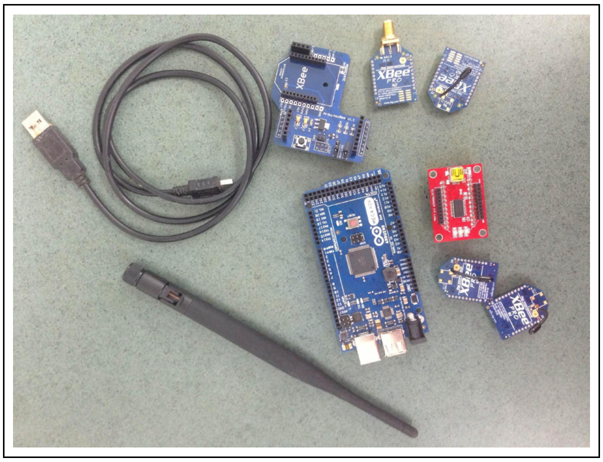

Figure 2. Radio modules used in the tests.

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).

Figure 3. Measuring equipment in outdoor tests with the geographic coordinates: 10.6187499, −74.7636483.

- 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.

Indoor test XBee Pro S1			Outdoor test (Grassland) XBee Pro S1		
Distance (m)	RSSI level (dBm)	% Packet loss	Distance (m)	RSSI level (dBm)	% Packet loss
1	48	0	1	36	32
10	63	2	10	62	32
20	82	5	20	72	38
30	84	4	30	75	36
40	No signal	73	40	72	46
Indoor Test XBee Pro S2			**Outdoor Test (Grassland) XBee Pro S2**		
Distance (m)	RSSI level (dBm)	% Packet loss	Distance (m)	RSSI level (dBm)	% Packet loss
1	39	0	1	39	0
10	77	0	10	50	0
20	83	1	20	64	1
30	91	0	30	65	1
40	88	1	40	80	0
Outdoor test (Plaza) XBee Pro S1			**Rural test (LOS) XBee Pro S1**		
Distance (m)	RSSI level (dBm)	% Packet loss	Distance (m)	RSSI level (dBm)	% Packet loss
1	36	0	100	65	0
10	51	1	200	72	0
20	60	85	300	79	1
30	60	98	400	78	1
40	65	No signal	500	82	10
Outdoor test (Plaza) XBee Pro S2			**Rural test (LOS) XBee Pro S2**		
Distance (m)	RSSI level (-dBm)	% Packet loss	Distance (m)	RSSI level (dBm)	% Packet loss
1	39	0	100	65	0
10	48	2	200	76	1
20	57	34	300	90	9
30	53	49	400	95	1
40	60	61	500	No signal	No signal

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

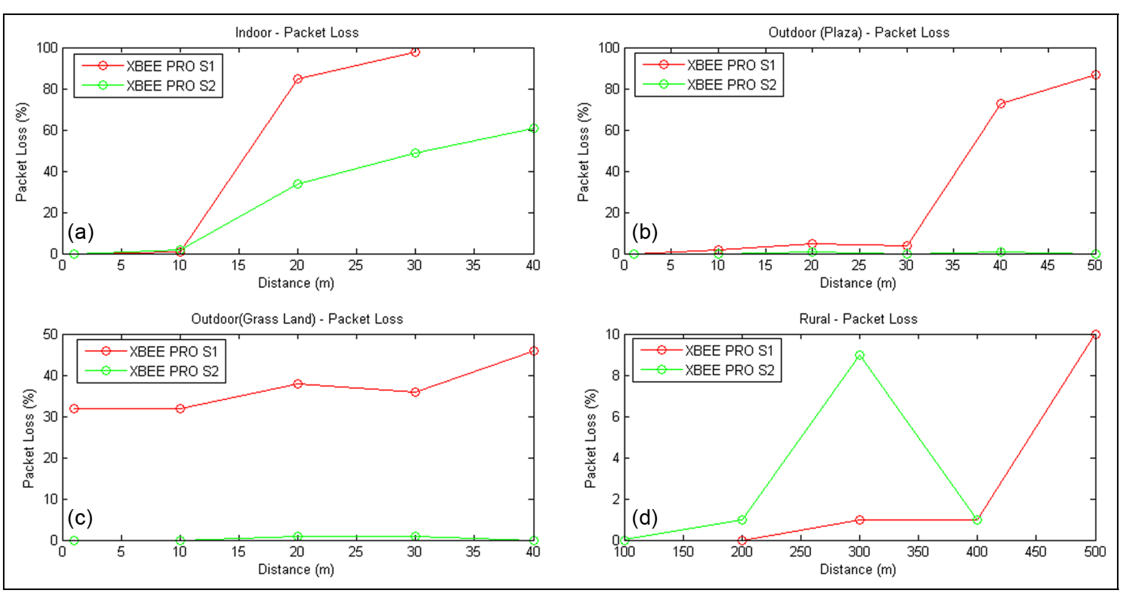

Figure 4. Comparison of packet loss between modules XBee Pro S1 and XBee Pro S2: (a) indoor, (b) outdoor (Plaza), (c) outdoor (Grassland), and (d) rural.

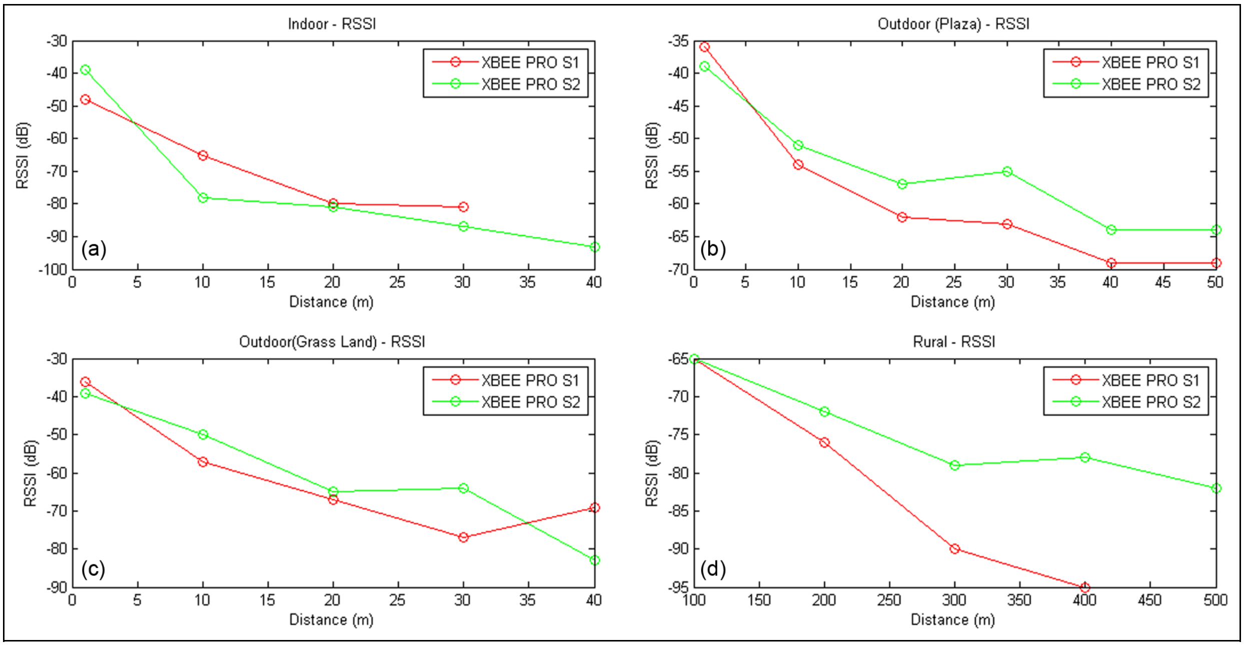

Figure 5. Comparison of RSSI between modules XBee Pro S1 and XBee Pro S2: (a) indoor, (b) outdoor (Plaza), (c) outdoor (Grassland), and (d) rural.

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.[21] 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 XBP1 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.[30]

Figures 6 and 7 exhibit the values of path attenuation measured with XBPS1 and XBPS2 indoors and outdoors, as compared to the Log-Normal Shadowing (LNSM) and the free-space path loss (FSPL).

We obtained the attenuation value of XBPS1 and XBPS2 after subtracting the value of the transmitter power, and gain of transmitting and receiving antennas to the value of RSSI taken in the field tests.

The values are as follows:

$\sigma = 10.95$, which are in the same floor;[31]
$\sigma = 3.02$, for grassland environment;[32]
$\sigma = 3.25$, for urban outdoor (plaza) environment;[32]
$PL(d_0) = 40.51$, for grassland environment;[32]
$PL(d_0) = 42.86$, for grassland environment;[32]
$z = 1.645$ to a coverage probability of 95%;[17]
$n = 2$, indoors without LOS[33] using XBPS1;
$n = 2.7$, indoors without LOS[33] using XBPS2;
$n = 1.86$, urban outdoor (plaza) environment;[32]
$n = 1.90$, for grassland environment.[32]

Finally, we corroborated that the values of LNSM are very close to those obtained in field tests (Figure 6(a)–(f)). Moreover, analyzing Figures 6 and 7, we notice that the values for FSPL model are closer to

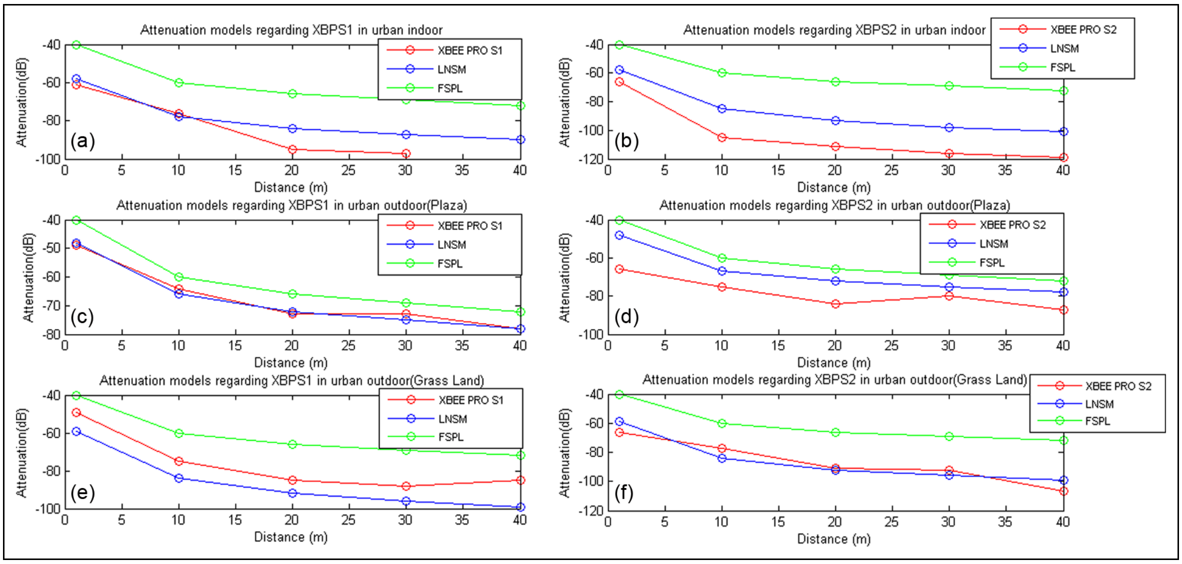

Figure 6. Comparison of the attenuation between LNSM models and free space: (a) XBPS1 indoor, (b) XBPS2 indoor, (c) XBPS1 outdoor (Plaza), (d) XBPS2 outdoor (Plaza), (e) XBPS1 outdoor (Grassland), and (f) XBPS2 outdoor (Grassland).

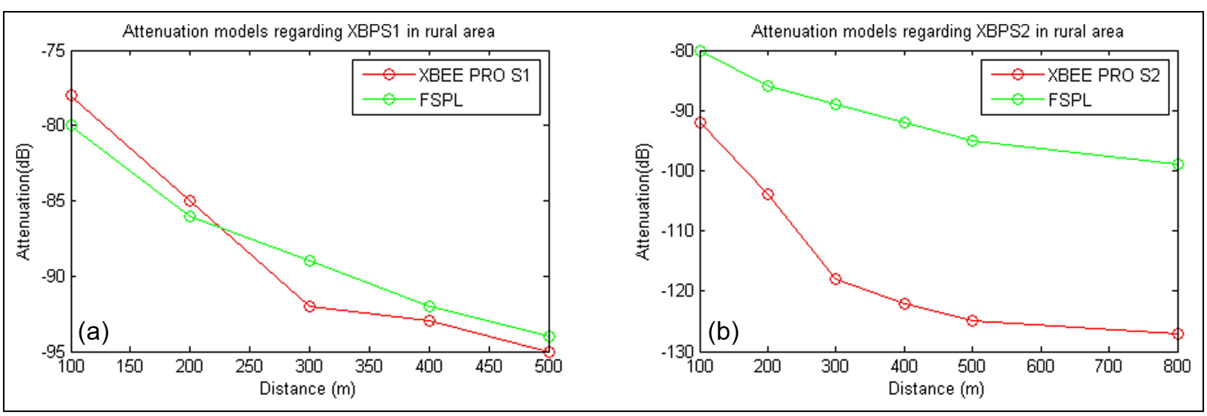

Figure 7. Comparison of the attenuation between the models of free-space path loss and the one registered in rural environment of (a) XBPS1 and (b) XBPS2.

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

Conclusion

The XBP1 modules shows 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.

Declaration of conflicting interests

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References

1. Srbinovska M, Gavrovski C, Dimcev V, et al. Environmental parameters monitoring in precision agriculture using wireless sensor networks. *J Clean Prod* 2015; 88: 297–307.

2. Montoya FG, Gómez J, Cama A, et al. A monitoring system for intensive agriculture based on mesh networks and the android system. *Comput Electron Agr* 2013; 99: 14–20.
3. Cama-Pinto A, Gil-Montoya F, Gómez-López J, et al. Wireless surveillance system for greenhouse crops (Dyna. 81,184,164.), Revista DYNA, 2014, http://www.scielo.org.co/pdf/dyna/v81n184/v81n184a22.pdf
4. Urbano-molano Aparicio F. Redes de Sensores Inalámbricos Aplicadas a Optimización en Agricultura de Precisión para Cultivos de Café en Colombia. *J Cienc Ing* 2012; 5(1): 46–52.
5. Xiao L and Guo L. The realization of precision agriculture monitoring system based on wireless sensor network. In: *Proceedings of the international conference on computer and communication technologies in agriculture engineering (CCTAE'10)*, Chengdu, China, 12–13 June 2010, pp.89–92. New York: IEEE.
6. Ministerio de Educación, 2009, http://www.mineducacion.gov.co/cvn/1665/w3-article-200749.html (accessed 28 August 2016).
7. Cirstea C, Cernaianu M and Gontean A. Packet loss analysis in wireless sensor networks routing protocols. In: *Proceedings of the 2012 35th international conference on telecommunications and signal processing (TSP)*, Prague, 3–4 July 2012, pp.37–41. New York: IEEE.
8. Bas CU and Ergen SC. Spatio-temporal characteristics of link quality in wireless sensor networks. In: *Proceedings of the 2010 IEEE wireless communications and networking conference (WCNC)*, Shanghai, China, 1–4 April 2012, pp.1152–1157. New York: IEEE.
9. Goldsmith A. *Wireless communications*. New York: Cambridge University Press, 2005.
10. Al-Busaidi AM. Development of an educational environment for online control of a biped robot using MATLAB and Arduino. In: *Proceedings of the 2012 9th France-Japan & 7th Europe-Asia congress on mechatronics (MECATRONICS)/13th int'l workshop on research and education in mechatronics (REM)*, Paris, France, 21–23 November 2012, pp.337–344. New York: IEEE.
11. Al-kadi T, Al-tuwaijri Z and Al-omran A. Arduino Wi-Fi network analyzer. *Proced Comput Sci* 2013; 21: 522–529.
12. Kornuta JA, Nipper ME and Dixon JB. Low-cost microcontroller platform for studying lymphatic biomechanics in vitro. *J Biom* 2013; 46(1): 183–186.
13. Xu J, Liu W, Lang F, et al. Distance measurement model based on RSSI in WSN. *Wirel Sens Netw* 2010; 2(8): 606–611.
14. Lee J-H, Choi J, Lee W-H, et al. Measurement and analysis on land-to-ship offshore wireless channel in 2.4 GHz. *IEEE Wirel Commun Lett* 2017; 6(2): 222–225.
15. Biaou U, Sadoudi L, Bocquet M, et al. Modeling of ZigBee (IEEE 802.15.4) channel in rail environment for intelligent transport. In: *Proceedings of the 2015 4th IEEE international conference on advanced logistics and transport, IEEE ICALT 2015, art. no. 7136637*, 2015, pp.293–298.
16. Seybold J. *Introduction to RF propagation*. Hoboken, NJ: Wiley Interscience, 2005.
17. Chrysikos T, Georgopoulos G and Kotsopoulos S. Wireless channel characterization for a home indoor propagation topology at 2.4 GHz. *Proceedings of the wireless telecommunications symposium*, New York, 13–15 April 2011, article no. 5960879. New York: IEEE.
18. Mahalin NH, Sharifah HS, Syed Yusof SK, et al. RSSI measurements for enabling IEEE 802.15.4 coexistence with IEEE 802.11b/g. In: *Proceedings of the IEEE region 10 annual international conference on TENCON*, Singapore, 23–26 January 2009, pp.1–4. New York: IEEE.
19. Hamida E, Ben Lyon I, Chelius G, et al. Investigating the impact of human activity on the performance of wireless networks—an experimental approach. In: *Proceedings of the 2010 IEEE international symposium on a world of wireless mobile and multimedia networks (WoWMoM)*, Montreal, QC, Canada, 14–17 June 2010. New York: IEEE.
20. Pellegrini RM, Persia S, Volponi D, et al. 2011; RF propagation analysis for ZigBee Sensor Network using RSSI measurements. In: *Proceedings of the 2011 2nd international conference on wireless communication, vehicular technology, information theory and aerospace & electronic systems technology (Wireless VITAE)*, Chennai, India, 28 Febraury–3 March 2011, pp.1–5. New York: IEEE.
21. Harun A, Ramli MF, Kamarudin LM, et al. Comparative performance analysis of wireless RSSI in wireless sensor networks motes in tropical mixed-crop precision farm. In: *Proceedings of the 2012 third international conference on intelligent systems modelling and simulation*, Kota Kinabalu, Malaysia, 8–10 February 2012, pp.606–610. New York: IEEE.
22. Kodali RK, Rawat N and Boppana L. WSN sensors for precision agriculture. In: *Proceedings of the region 10 symposium*, Kuala Lumpur, Malaysia, 14–16 April 2014, pp.643–648. New York: IEEE.
23. Howell B, Anderson E and Flores A. A low cost wireless sensor network for landslide hazard monitoring. In *Proceedings of the geoscience and remote sensing symposium (IGARSS)*, Munich, 22–27 July 2012, pp.4793–4796. New York: IEEE.
24. Zamora R. *Análisis de requerimiento para la implementación de Laboratorios Remotos*. Barranquilla, Colombia: Educosta, 2011.
25. Mahmoud KH. *Data collection and processing from distributed system of wireless sensors*. Master Thesis, Masaryk University, Brno, 2013.
26. Caicedo-Ortiz J, Coll MAA and Cama-Pinto A. Modelo de despliegue de una WSN para la medición de las variables climáticas que causan fuertes precipitaciones. WSN deployment model for measuring climate variables that cause strong precipitation, pp.106–115, http://www.scielo.org.co/pdf/prosp/v13n1/v13n1a11.pdf
27. Libelium, http://www.libelium.com/products/waspmote
28. Faludi R. *Building wireless sensor networks*. 4th ed. USA: Brian Jepson, 2012, p.32.
29. Arnil J, Punsawad Y and Wongsawat Y. Wireless sensor network-based smart room system for healthcare monitoring. In: *Proceedings of the 2011 IEEE international conference on robotics and biomimetics (ROBIO)*, Karon Beach, Phuket, Thailand, 7–11 December 2011, pp.2073–2076. New York: IEEE.
30. Benkic K, Malajner M, Planinsic P, et al. Using RSSI value for distance estimation in wireless sensor networks based on ZigBee. In: *Proceedings of the 15th international*

conference on systems, signals and image processing, Bratislava, 25–28 June 2008, pp.303–306. New York: IEEE.

31. Chrysikos T and Kotsopoulos S. Characterization of large-scale fading for the 2.4 GHz channel in obstacle-dense indoor propagation topologies. *Proceedings of the 2012 IEEE vehicular technology conference*, Quebec City, QC, Canada, 3–6 September 2012, article no. 6399239. New York: IEEE.
32. Kurt S and Tavli B. Path-loss modeling for wireless sensor networks: a review of models and comparative evaluations. *IEEE Antenn Propag M* 2016; 59(1): 18–37.
33. Farahani S. *ZigBee wireless networks and transceivers*. 1st ed. Oxford: Elsevier Ltd., 2008, p.173.