Modelamiento del canal de propagación con Zigbee para escenarios outdoors

On Modelling Channel propagation with Zigbee technology in outdoors scenarios

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Resumen

En el presente trabajo se presenta un modelo semi-empírico del canal de propagación para enlaces punto a punto en la banda de 2.4 GHz, empleando tecnología *ZigBee*, capaz de contribuir a la mejora de la planificación y dimensionamiento de una red para sectores con baja densidad poblacional. Este modelo es estimado a partir del indicador de la fuerza de la señal recibida con base en los datos registrados en escenarios con características rurales y suburbanas, en un rango de 2 a 200 metros. A diferencia de varios artículos de la literatura, en nuestra propuesta se detecta una discontinuidad en 60 metros. En el método planteado se realiza una regresión lineal para obtener las características del medio de propagación y conseguir un solo modelo de pérdidas en función del punto de discontinuidad.

Palabras clave: modelamiento matemático, punto a punto, Waspmote, XBee, ZigBee.

Abstract

In this work we present a model semi empirical of channel propagation for links to band of 2.4 GHz, using ZigBee technology, able to contribute to the improvement of planning and sizing of a network to areas with low population density. This model is estimated from the indicator of the strength of the signal received based on data captured in scenarios with features rural and suburban, in a range from 2 to 200 meters. Contrary to several articles of literature, in our motion is detected a discontinuity in 60 meters. In the proposed method is a linear regression to obtain the means of propagation characteristics and get only one model of losses depending on the point of discontinuity.

Key words: mathematical modeling, point to point, Waspmote, XBee, ZigBee.

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Introduction

Wireless communications have become an essential part of the daily activities of human beings, providing users a network connectivity without being tethered to a cable, with lower cost of installation and at the same time lower cost of maintenance compared to wired networks (Wang, Yongle, Feng, & Yu-Han, September 2011). An example of these wireless networks that have generated great interest are those that use the Zigbee technology, created with the aim to interconnect various mobile devices through a transceiver (Baronti, Pillai, Chook, Chessa & Gotta, May 2007); these devices have a range of typical coverage from 10 to 75 meters, which may vary according to the transmitting and receiving antennas power. ZigBee operates in non-licensed bands of: 868 MHz, 915 MHz and 2.4 GHz. In addition, ZigBee has a lower power consumption than Bluetooth. Specifically, ZigBee consumes 30 mA transmitting and 3 uA resting against the 40 mA transmitting and 0.2 mA at rest of the Bluetooth (Salgado, 2012).

To perform this type of wireless network planning, it is important to know the power of the signal that is received at a particular distance (de Sales Bezerra, Rodrigues de Sousa, da Silva Eleuterio, & Silva Rocha, August 2015), the same suffering variations in the receiver due to signals unwanted as noise, distortion, interference and other effects characteristic of the communication channel. For this reason, it is necessary to model the transmission medium, obtaining what is commonly referred to as propagation model. Usually, propagation models can be classified as: empirical models, i.e., those in which there are several measurements over an environment in particular so that it resembles more to the reality; semi-empirical models are those that perform a purchase of several measures which are then adjusted to a model set of theoretical way (García Fernández, March 2006); and finally, they are theoretical models, which are based on fundamental principles of wave propagation phenomena.

In this context, there are several models of propagation that have been generated for different wireless networks, whether it is in accordance with IEEE 802.16, IEEE 802.15 IEEE 802.11 standards, mobile networks, etc. That is why, according to the literature, over similar technologies (Sujak, Ghodgaonkar, Mohd, & Khatun, December 2005) the authors made a model of the propagation channel for indoors environments with IEEE 802.11b, where point access (AP, access point English) it was 1.5 m above the ground and at every point measurements were recorded up to 2.5 m, obtaining a propagation model for the interior of an office and taking into account different obstacles. On the other hand. (De Souza & Lins, October 2008) A channel modeling was performed on a WiFi network in accordance with IEEE 802.11g band industrial, scientific and medical areas (ISM, the English Industrial, Scientific and Medical) 2.4 GHz, where two indoors environments for model creation and two outdoors environments were used to validate it. Specifically, with respect to IEEE 802.15.4 (Zigbee) (Pellegrini, Persia, Volponi, & Marcone, October 2011), an analysis of the spread with a ZigBee sensor network is performed using measurements of the indicator of signal intensity received (RSSI, English received Signal Strength Indicator) in three different environments, with a display of more than 10 meters. On the other hand, (Moschitta, Macii, Trentino, Dalpez, & Bozzoli, May 2012) A modeling of the propagation channel is performed using IEEE 802.15.4 in an anechoic chamber with a maximum distance of 4 meters, in which you get a free interference pattern, that is, under ideal conditions. Thus (Hoon Yoo, Hyoung Lee, & Ho Cho, October 2011) propagation model is made in the 2.4 GHz ISM band using IEEE 802.15.4, with two scenarios, obtaining a model for an indoor environment and a model for one outdoor environment up to 200 meters. However, in previous studies it is not considered a comparison of various scenarios outdoors to establish a general propagation model resembles a real behavior for suburban and rural areas, using IEEE 802.15.4.

The main objective of this work is to identify a semi-empirical model of the propagation channel in point-to-point links (PtP, English Point to Point) in the 2.4 GHz band using ZigBee technology; because of the need for planning a network for outdoors environments, suburban and rural scenarios were considered, obtaining the RSSI values main metrics for modeling the propagation loss. Subsequently adjustment data to a logarithmic curve type is performed and finally a correction factor in order to obtain a general model for the two scenarios is obtained. This model will help improve the accuracy in planning and dimensioning a network with such technology to areas with low population density.

The paper is organized as follows. Section II methodology, where the materials used for the deployment of the PtP network and description of suburban and rural scenarios proposed research is done is explained. Section III provides an analysis of the statistical values of RSSI parameter, the curve fit with the values obtained and modeling for each of the scenarios is performed. While in Section IV of the modeling results shown on stage at each interval. Finally, Section V discussion is made with the results of related work, as well as the conclusions and future work.

Materials and methods

To obtain the RSSI parameter, various stages of research are proposed:

First, wireless sensors are available Waspmote Waspmote Gateway V1.1 and manufacturer Libelium and XBee modules (S2 XBee PRO) Manufacturer Digi International. RPSMA 2.4 GHz antenna is used, with a gain of 2.2 dBi and vertical polarization. The Waspmote

Gateway serves as a bridge to access data between the network and the receiving device and is also used to configure the XBee modules. a computer under the Windows 7 operating system was used with a 32-bit processor operating at 1.8 GHz. For programming Waspmote v1.1 wireless sensor installation Waspmote ID software version 0.2 is required, while to configure XBee modules X-CTU software is used. So that there is interaction between the computer module and the Waspmote Gateway.

Then, to establish the wireless network PtP Waspmote XBee sensor module configured as end device, while the other XBee Gateway Waspmote Coordinator module configured placed standing, this is shown in Figure 1. Additionally, the tool was used Matlab for modeling and process adjustment.

Figura 1. Escenario de la Red Inalámbrica PtP

Secondly, the deployment of a network PtP two similar to those presented in rural and suburban environments scenarios are performed outdoors. For this reason, the first stage was deployed in the College Football League Valley Chillos "FODERJ" located in the city of Sangolquí-Ecuador (0 ° 18'12.7 "S 78 ° 26'52.2" W) with a temperature ranging from 19 ° C to 23 ° C, and a height of 2477 meters, without the presence of rain and winds moderate speed. This scenario was chosen because it has features that resemble a rural setting, no nearby buildings around it, has low population density, scarcity of cars, possesses no obstacles and the area is grass. Figure 2 shows a front view of one stage.

Figura 2. Escenario 1 (rural), Escuela de Fútbol Liga Valle de los Chillos "FODERJ".

The second scenario was deployed in Eloy Alfaro-ESMIL Military College, located in the city of Quito-Ecuador (0 ° 05'09.7 "S 78 ° 29'11.3" W) with a variable temperature of 16 ° C to 21 ° C, up to 2654 meters, without the presence of rain and winds moderate speed. this place was chosen because it has similar characteristics to a suburban setting, has few nearby buildings around it, has low population density, low presence of cars, possesses no obstacles and is cement surface. Figure 3 shows a front view of the stage two.

Figura 3.Vista panorámica del Escenario 2 (suburbano), Escuela Superior Militar Eloy Alfaro-ESMIL.

In tests in both scenarios the RSSI parameter is recorded in 49 different locations, with varying distance of 2 200 meters long, with line of sight between the Coordinator and the End Device; Data were acquired in two different ranges: the first phase measurement was conducted between 2-30 meters to 2 meters, whereas the RSSI parameter tends to have large variations in this range. While the second measurement phase was between 30-200 meters at intervals of 5 meters, since in those distances the RSSI parameter tends to stabilize.

However, it is possible that the measurements obtained vary among themselves according to the proposed scenarios, so in August RSSI data records were made at each point (49 points) to reduce measurement uncertainty because the percentage of dispersion 6.66% (Villasuso, 2003).

Modeling of the propagation channel for ZigBee technology

For the two scenarios the RSSI parameter was obtained and analysis of statistical values of the same was carried out. Figure 4 shows the variations at each point where it can be seen that as the receiver moves away from the transmitter, measurements have shown a greater variation.

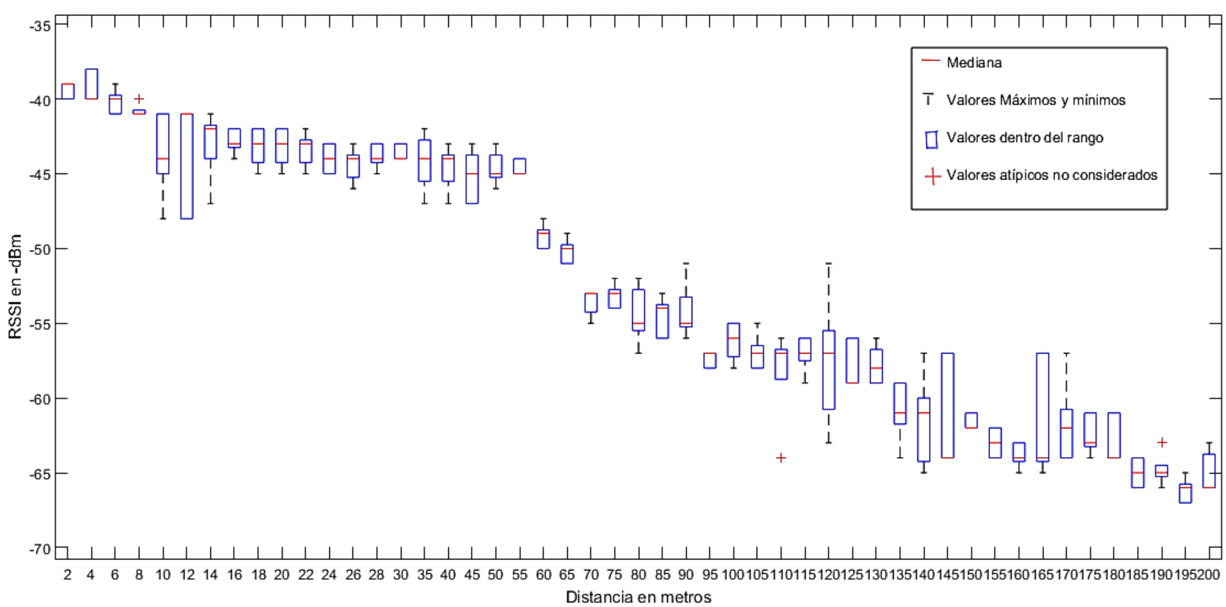

Figura 4. Estadística del parámetro RSSI en función de la distancia (escenario rural).

Subsequently they considered the values in the range of mean ± 1 standard deviation. Values outside this range were discarded because they increase the mean square error; with the values obtained the calculation of the mean at each point away where you can see that there is a discontinuity at 60 meters, which can be attributed to multipath fading causing interference when subsequently reach the receiving antenna is made , or shading that affects wave propagation (Soo Yong Cho, Jaekwon Kim, Won Young Yang, & Chung G. Kang, 2010).

several tests with different types of equations become and to determine the adjustment error equation 1 is used.

$$EMC = \frac{1}{n}\sum_{i=1}^{n}\left(\widehat{Y_i} - Y_i\right)^2. \quad (1)$$

Where:

$\widehat{Y_i} =$ RSSI values registered.

$Y_i =$ Values of the equation to be like.

$n =$ Number of measurements.

This way you get:

TABLE I. Error adjustment equations in rural setting.

ESCENARIO RURAL (2 a 200 metros)		
Tipo de Ecuación	**Constantes**	**Porcentaje de error [%]**
Ecuación logarítmica $a + 10 \times b \times log(x)$	$a = -23.1931$ $b = -1.6698$	30.1429
Ecuación lineal $a + bx$	$a = -40.0546$ $b = -0.1418$	5.0483
Ecuación cuadrática $a^2 + bx + c$	$a = 3.1982e - 4$ $b = -0.2024$ $c = -38.446$	5.6014

TABLE II. Setting error equations in the suburban setting.

ESCENARIO SUBURBANO (2 a 200 metros)		
Tipo de Ecuación	**Constantes**	**Porcentaje de error [%]**
Ecuación logarítmica $a + 10 \times b \times log(x)$	$a = -24.1442$ $b = -1.6295$	32.6238
Ecuación lineal $a + bx$	$a = -40.3858$ $b = -0.1409$	4.4421
Ecuación cuadrática $a^2 + bx + c$	$a = 1.87e - 4$ $b = -0.1763$ $c = -39.4467$	4.006

After this analysis it is determined that the error rate is set high. For this reason and the aforementioned discontinuity at 60 m, setting the analysis is divided into two intervals, yielding:

TABLE III. Setting error equations in the rural scenario from 2 to 60 meters.

ESCENARIO RURAL (2 a 60 metros)		
Tipo de Ecuación	**Constantes**	**Porcentaje de error [%]**
Ecuación logarítmica $a + 10 \times b \times log(x)$	$a = -36.425$ $b = -0.5055$	1.8281
Ecuación lineal $a + bx$	$a = -40.0197$ $b = -0.1128$	2.1528
Ecuación cuadrática $a^2 + bx + c$	$a = 0{,}0011$ $b = -0.1762$ $c = -39.3915$	1.9429

TABLE IV. Setting error equations in the rural scenario from 60 to 200 meters.

ESCENARIO RURAL (60 a 200 metros)		
Tipo de Ecuación	**Constantes**	**Porcentaje de error [%]**
Ecuación logarítmica $a + 10 \times b \times log(x)$	$a = 6.1147$ $b = -3.1193$	1.6782
Ecuación lineal $a + bx$	$a = -44.4912$ $b = -0.112$	2.486
Ecuación cuadrática $a^2 + bx + c$	$a = 4.2321e - 4$ $b = -0.222$ $c = -38.0796$	1.7224

TABLE V. Setting error equations in the suburban setting 2 to 60 meters.

ESCENARIO SUBURBANO (2 a 60 metros)		
Tipo de Ecuación	**Constantes**	**Porcentaje de error [%]**
Ecuación logarítmica $a + 10 \times b \times log(x)$	$a = -37.791$ $b = -0.4416$	1.3338
Ecuación lineal $a + bx$	$a = -41.1415$ $b = -0.0901$	2.6301
Ecuación cuadrática $a^2 + bx + c$	$a = 0.0019$ $b = -0.2063$ $c = -39.9897$	1.9488

TABLE VI. Setting error equations in the suburban setting 60 to 200 meters.

ESCENARIO SUBURBANO (60 a 200 metros)		
Tipo de Ecuación	**Constantes**	**Porcentaje de error [%]**
Ecuación logarítmica $a + 10 \times b \times log(x)$	$a = 15.5508$ $b = -3.5692$	1.7306
Ecuación lineal $a + bx$	$a = -42.5087$ $b = -0.1269$	3.7558
Ecuación cuadrática $a^2 + bx + c$	$a = 6.6177e - 4$ $b = -0.299$ $c = -32.4828$	1.8378

After setting the various tests we decided to use a logarithmic equation type, confirming that the data were consistent with the curve. Therefore, Equation 2 is used.

$$\mathrm{L} = \mathrm{a} + 10 \times \mathrm{b} \times \log(\mathrm{x}) \qquad (2)$$

Where a and b are characteristics of the propagation medium and x is the distance.

In the curve fitting equation 2, in Figure 5 and Figure 6 it can be clearly seen how the data have a logarithmic trend in both intervals.

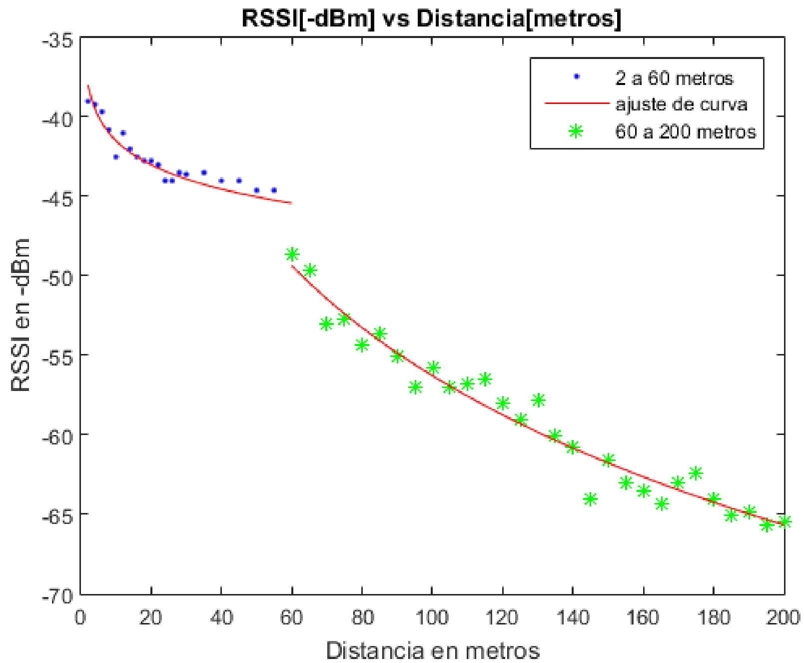

Figure 5. Scenario 1 (rural): RSSI vs Distance with logarithmic trend from 2-60 meters and from 60 to 200 meters.

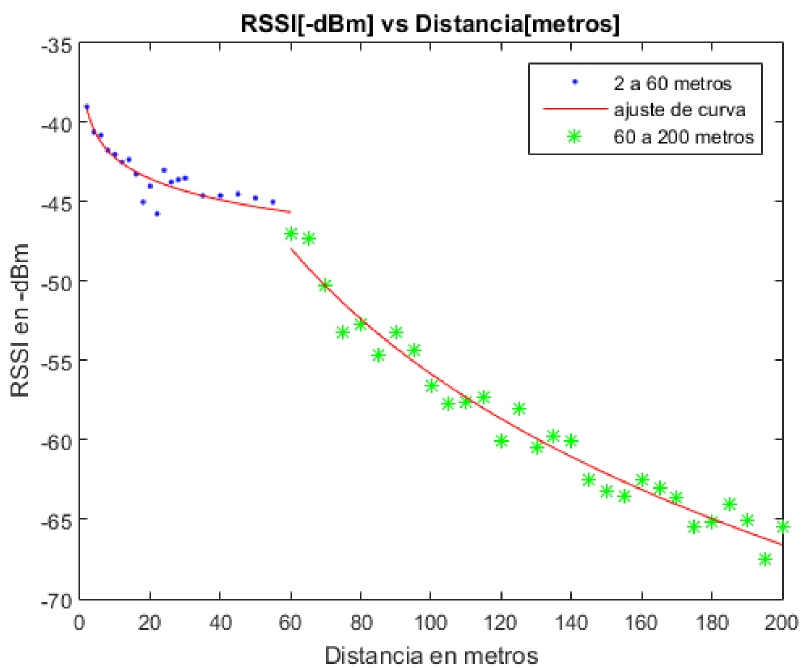

Figure 6. Scenario 2 (city): RSSI vs Distance with logarithmic trend from 2-60 meters and 60 200 meters.

To obtain the loss model is considered the link budget as shown in Figure 7, whereby the equation 3 is obtained by considering the balance between gains and losses in the transmitter and receiver.

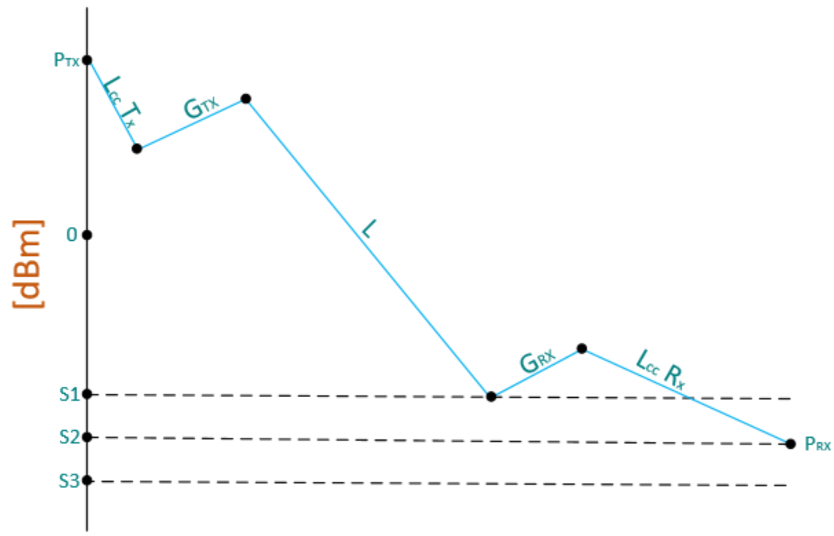

Figura 5. Balance del enlace

$$P_{rx} = P_{tx} - L + G_{tx} + G_{rx} - L_{cc}. \quad (3)$$

Where:

P_{rx} = Reception power in dBm.

P_{tx} = Power transmission dBm.

L = It represents the path loss from transmitter to receiver in dB.

G_{tx} = Gain of transmitting antenna dBi.

G_{rx} = Gain of the receiving antenna dBi.

L_{cc} = Attenuation cables and connectors, these values are negligible transmitter and receiver.

Equation 2 is replaced in Equation 3, obtaining the equation 4:

$$P_{rx} = P_{tx} - a + 10 \times b \times \log(x) + G_{tx} + G_{rx} - L_{cc} \quad (4)$$

I.A. Analysis of scenarios in the range of 2 60m.

A linear regression in which the constant values for the adjustment are obtained, as shown in Table VII runs.

TABLE VII. Constants obtained for the stage 1 and 2 in the range of 2 60m.

ESCENARIO 1 (Rural)	
$a_1 = -36.425$	$b_1 = -0.5055$
ESCENARIO 2 (Suburbano)	
$a_2 = -37.791$	$b_2 = -0.4416$

For scenario 1, the value is replaced a_1 y b_1, obtained in Table VII, the value of P_{tx} for two intervals it is equal to 20 dBm and antenna gains G_{tx} , G_{rx} for the two intervals are 2.2 dBi; to replace these equation is obtained 5.

$$\mathrm{P_{rx1}}(\text{rural de 2 a 60 metros}) = 60.825 + 5.055 \times \log(x) \quad (5)$$

The same is done in stage two, obtaining the equation 6.

$$P_{rx2}(\text{suburbano de 2 a 60 metros}) = 62.191 + 4.416 \times \log(x) \quad (6)$$

To adjust the graphs in the two scenarios, in the range of 2 to 60 meters, the equation is used 7.

$$\mathrm{P_{rx1}} - \mathrm{P_{rx2}} = \mathrm{K}, \quad (7)$$

donde K: Representa el factor de corrección

Substituting equation 5 and 6 in equation 7, equation is obtained 8.

$$K = -1.366 + 5.055 \times \log(x) - 4.416 \times \log(x) \quad (8)$$

Where different values are obtained for K, varying the value of x representing the distance (from 2 to 60 meters). Finally, the average is calculated to obtain a K total.

Which results in a correction factor $K_1(2\ a\ 60\ metros) = -0.5548$

At the end it should be expressed Equation 7 in terms of path loss from the transmitter to the receiver, so equation 9 is obtained.

$$K_1 = (P_{tx1} - L_{rural} + G_t + G_r) - (P_{tx2} - L_{suburbano} + G_t + G_r) \quad (9)$$

By simplifying equation 9 Equation 10 is obtained.

$$L_{suburbano} - L_{\mathrm{rural}} = K_1 \qquad (10)$$

From Equation 10 we can deduce the equation 11.

$$L_{suburbano} = K_1 + L_{\mathrm{rural}} \qquad (11)$$

To confirm that the correction factor is appropriate, in Figure 8 the setting without the correction factor is shown, while in Figure 9 setting the correction factor shown.

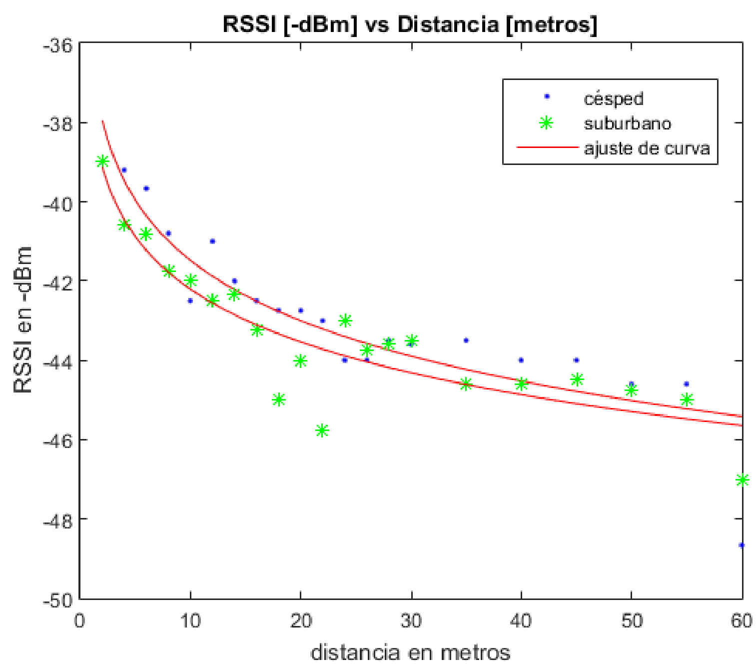

Figure 8. Curves adjusted to a logarithmic equation 2 to 60 meters.

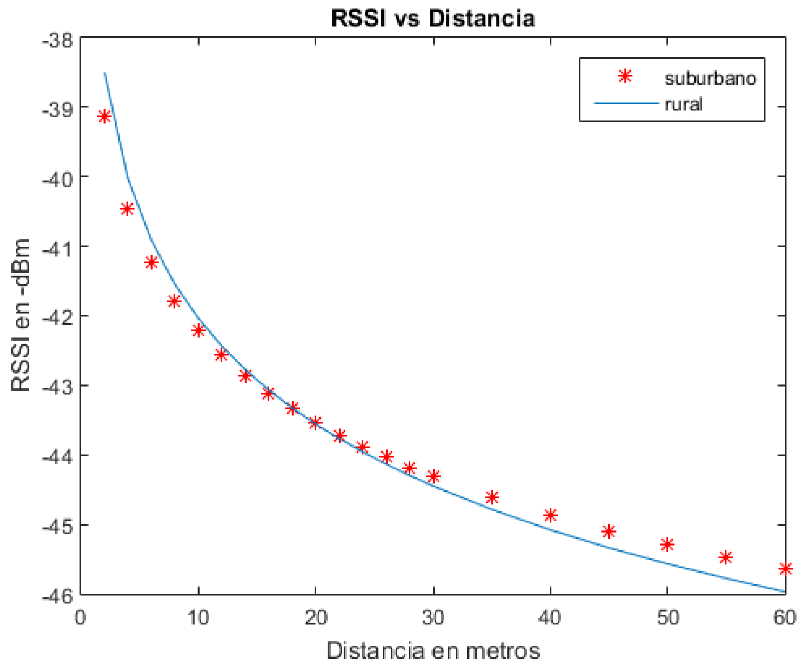

Figure 9. Curves with the correction factor K_1.

II.B. Scenario Analysis in the range of 60 200 meters

As in the above range, a linear regression in which the constant values for the adjustment are obtained, as shown in Table VIII runs.

TABLE VIII. Constants obtained for the stage 1 and 2 in the range of 60 200 meters.

ESCENARIO 1 (Rural)	
$a_1 = 6.1147$	$b_1 = -3.1193$
ESCENARIO 2 (Suburbano)	
$a_2 = 15.5508$	$b_2 = -3.5692$

The same procedure is in the range of 2 to 60 meters. Equation 2 is replaced in Equation 3, but now for this interval. For scenario 1, the value is replaced a_1' y b_1', obtained in Table VIII. Substituting these values in equation 12 is obtained.

$$P'_{rx1}(\text{rural de 60 a 200 metros}) = 18.2853 + 31.193 \times \log(x) \quad (12)$$

The same is done with scenario 2, yielding the equation 13.

$$\mathrm{P}'_{\mathrm{rx2}}(\mathrm{suburbano\ de\ 60\ a\ 200\ metros}) = 12.89 + 35.692 \times \log(\mathrm{x}) \quad (13)$$

For adjusting the graphic in the two scenarios in the range of 60 200 meters Equation 7 is used

And the result is Equation 14.

$$K_2(60\ a\ 200\ metros) = 5.3953 + 31.193 \times \log(x) - 35.692 \times \log(x) \quad (14)$$

Obtaining a correction factor $K_2(60\ a\ 200\ metros) = 0.0379$.

In the end it should express the equation 7 in terms of path loss from transmitter to receiver, so you get to the equation 15.

$$K_2 = (P'_{tx1} - L'_{rural} + G'_t + G'_r) - (P'_{tx2} - L'_{suburbano} + G'_t + G'_r) \quad (15)$$

Using Equation 15 can derive the equation 16.

$$\mathrm{L}'_{suburbano} = \mathrm{K}_2 + \mathrm{L}'_{\mathrm{rural}} \quad (16)$$

To verify that the appropriate correction factor is the result shown in Figure 10 without the correction factor, while in Figure 11 the result with the correction factor shown.

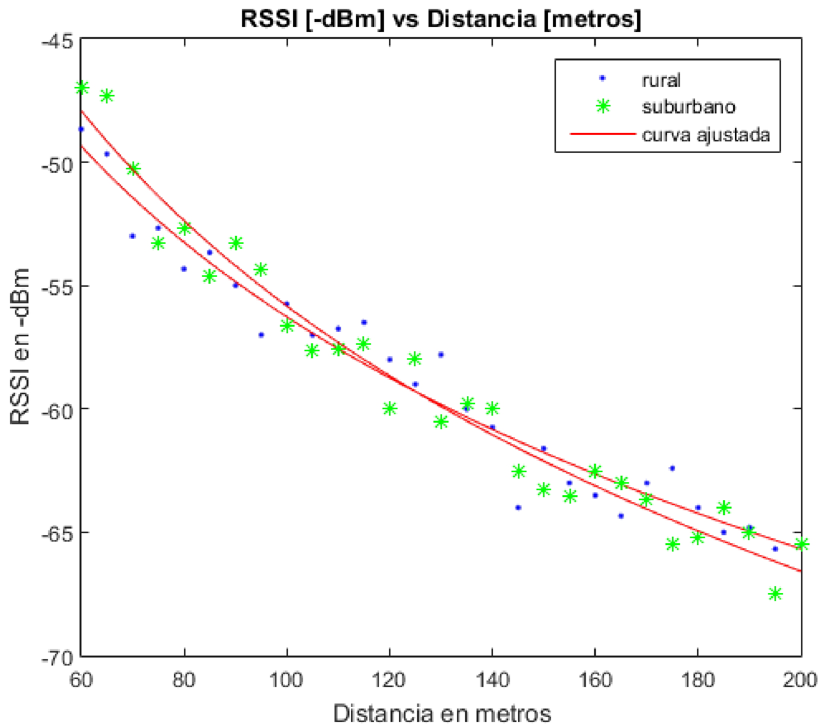

Figure 10. adjusted to a logarithmic equation between 60 and 200 Curves

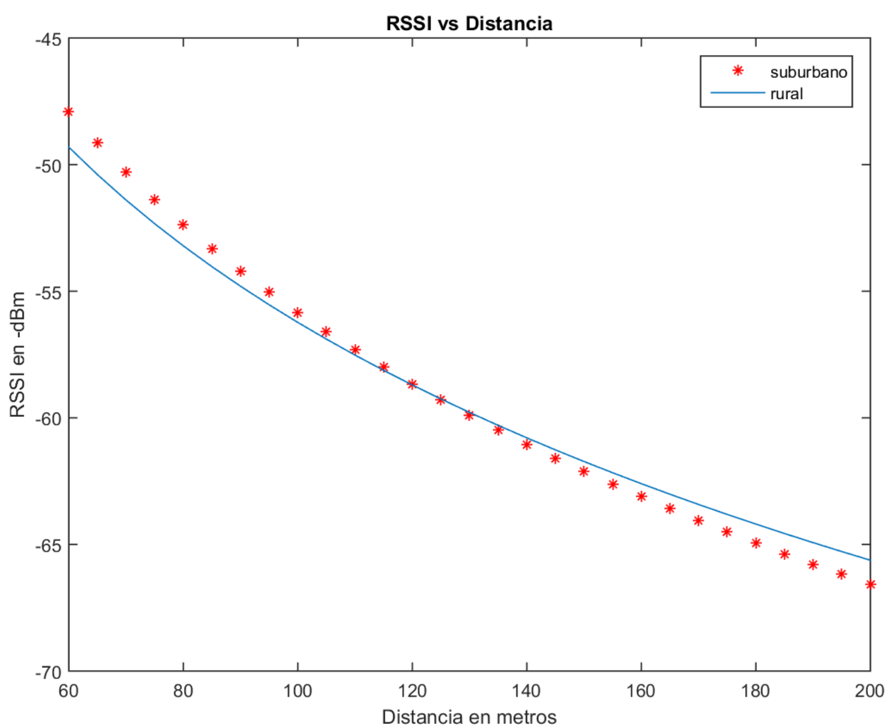

Figure 11. Curves with the correction factor K_2

Propagation model obtained

Comparing the two intervals analysis at each stage a single model that groups was obtained. Using Equation 9 and Equation 15 the general model for the two scenarios (rural and suburban) on the two intervals is created.

$$L_{rural} = \begin{cases} -36.425 - 5.055 \times \log(x), & si\ 2 \leq x \leq 60 \\ 6.1147 - 31.193 \times \log(x), & si\ 60 < x \leq 200 \end{cases}$$

$$L_{suburbano} = \begin{cases} -35.8702 - 5.055 \times \log(x), & si\ 2 \leq x \leq 60 \\ 6.1526 - 31.193 \times \log(x), & si\ 60 < x \leq 200 \end{cases}$$

Discussion and conclusions

Now (Moschitta, Maci, Trentino, Dalpes, & Bozzoli, May 2012) the value of RSSI vs Distance parameter within an anechoic chamber is measured. It is consistent that there is no discontinuity mentioned because the anechoic chamber prevents the passage of external or environmental interference, which ultimately influence the results of modeling. Nor you can appreciate a discontinuity because the tests are run over distances of 1-4 meters, checking that the curve has a logarithmic trend.

Thus (Hoon Yoo, Hyoung Lee, & Ho Cho, October 2011) propagation model ISM band at 2.4 GHz is achieved for a single outdoor environment. In this project a logarithmic adjustment is observed, but the point of discontinuity is not found, which can be attributed to the number of measurements; while this paper the point of discontinuity in the two scenarios. Therefore it was decided to divide the analysis in two ranges: the least 60 meters and 60 meters majority in both scenarios. This independent analysis yielded a general modeling for the two rooms on two different distance intervals for suburban and rural areas. An adjustment for modeling was used based on a logarithmic equation, performing a linear regression in which constant values are obtained. Finally, the values obtained were able to calculate correction factors K_1 and K_2 for each distance interval (2-60 meters and 60 200 meters) in the two scenarios. It is noted that in both intervals setting data shows a slight deviation, so it is concluded that the correction factor should not be linear.

We are interested in pursuing this line of research, which aims to develop tests with a larger number of scenarios and thus obtain a more general model that can meet the different needs of new applications. The data were recorded in summertime, without the presence of rain, cloudiness or other climatic factors having an impact on an abrupt change in signal loss or power, so the climate changes that will interfere will be taken into account propagation model. In addition, the height of the transmitting and receiving antennas vary. Moreover, even when it has found a discontinuity at 60 meters, they have not determined the causes of the appearance of this gap, so it will be identified and a correction factor to adjust the curves in various scenarios to be determined lower mean square error.

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