INDOOR & OUTDOOR CHARACTERIZATION FOR WLAN ENVIRONMENTS

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ABSTRACT

This paper is oriented to present the outcome when making measurements in controlled environments indoor and outdoor for wireless transmissions using WLAN technology in the 2.4GHz band. From these measurements and using mathematical models existing we made a characterization of indoor and outdoor environments to obtain an equation to calculate the power would come to the receivers based on the losses arising from conditions such as distance and obstacles.

KEYWORDS: *Indoor, Outdoor, WLAN, Characterization*

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1.INTRODUCTION

When we want to perform wireless transmissions in outdoor environments the distance of the propagation is linked to the characteristics of the transmitting and receiving devices, and environmental conditions. Thereby to determinate the coverage area in outdoor transmission should be use variables such as transmitter power, receiver sensitivity, and loss of free space, among others 1 2. To calculate the free space loss is has models like as Hata-Okumura model 3, Hata model 4, Walfisch model 5, and Ikegami model 6, among the most relevant. These models have served as a precedent for the calculation method more accepted in outdoor environments the propagation model Cost 231 7. This model comes from the combination of the Walfisch-Bertoni model 5, the Ikegami model 6 and the contributions of *COST 231 Subgroup on Propagation Models*¹. This model is designed to work in systems that operate in the UHF band 800 MHz to 2000 MHz for dense urban environments. The model takes into account the height of buildings, the width of streets, the separation between buildings and street sense regarding the spread of the signal.

For wireless transmissions in indoor environments the case is a bit more complex because in addition to the variables proposed for outdoor environments (transmitter power, receiver sensitivity, and free space loss) in indoor is involved the materials with which it is made the building. The indoor environment has the effect of reducing the coverage area of wireless telecommunications because the obstacles block the transmission. This issue is showed in the analysis made in the paper *A survey of indoor positioning systems for wireless personal networks* 8 where indicate that the transmitters operating at 27dBm (500mW) the coverage area with line of sight (LOS) is 42m (referenced to -90dBm). When obstacles such as brick and wood plates the coverage area is reduced by up to 35% giving a range of about 15m, obstacles such as concrete with iron reduces the signal by up to 90% giving a range of about 8m, in the paper evince that obstacles such as metal sheets the signal is reduced wholly.

¹ Source: http://www.lx.it.pt/cost231/final_report.htm

For characterization of indoor environments have been made models such as showed in the paper *Experimental Characterization and Modeling of Outdoor-to-Indoor and Indoor-to-Indoor Distributed Channels* 9 where proposing an evaluation criteria for reliability in indoor environments, in addition to an analysis of cost, performance, robustness, complexity, availability and limitations. This paper also proposes an empirical model to parameterize outdoor and indoor environments with cooperative radio channels from experimental data in the 2.4GHz band. The paper shows an analysis of physical effects for path loss, shadowing and fading, including new variables in the model that are specific for distributed multiuser channels. These variables are: shadowing correlation between different point to point; different types of mobility of interior nodes from the transmitter and receiver nodes, which implies a distinction between static and dynamic shadowing motivated by the measurement data; and a distribution of small scale fading to capture the highest level of fading given in terms of the distribution.⁹

The intent of this paper is to show the results obtained from the characterization of indoor and outdoor environments in controlled settings and achieve formalize from a mathematical model using statics tools.

2.TEST ENVIRONMENT

In the test environment was selected the WLAN technology because its wide dissemination. In addition, this technology was used since it works in the unlicensed bands recommended by the ITU for 2.4GHz. As test channel was chosen channel 6 (2.437GHz), the standard used was the 802.11g with a 27dBm (500mW) power through an omnidirectional antenna with vertical polarization and gain 4dBi. The measuring instrument was an Android 4.0 device and the software used was wifi analyzer (Figure 1) that displays the SSID being transmitted in the operation area (With a spectrum analyzer E4411B-ESAL was verified did not exist hidden carriers in the band since 2412MHz to 2484MHz). The software selected provides a analysis of the power level in the receiving equipment, the channel occupancy, the type of confidentiality used, and the data of the network such as IP address, subnet mask, gateway address and DNS.

Figure 1: Wi-Fi Analyzer

As measurement place for outdoor test, was selected the site shown in **Error! Reference source not found..** This is the campus of UMNG university at Bogota, Colombia. The site was chosen by virtue of their line of sight and workspace.

Figure 2: Outdoor test area²

The indoor measurement tests were conducted in the environment shown in **Error! Reference source not found.**. This is inside the engineering building of the UMNG University, in the office of Davinci research group. This space is characterized because its construction is made of brick, concrete, and a metal mesh structure.

Figure 3: Indoor test area

3. COVERAGE AREA TESTING AND CHARACTERIZATION FOR OUTDOOR ENVIRONMENTS

For coverage area test, was performed the measurement three times taking such as reference the power in the receiver.

Table shows the results obtained in outdoor environment.

Table 1: Outdoor parameters measurement

Power	Distance			
	Measure 1	Measure 2	Measure 3	Average
< -40dBm	<1m	<1m	<1m	<1m
-40dBm	1.6m	1.5m	1.5m	1.5333m
-45dBm	2.8m	2.7m	3m	2.8333m
-50dBm	5.1m	5.3m	5m	5.1333m
-55dBm	9.1m	9.1m	9.3m	9.1666m
-60dBm	16.4m	16.1m	16.2m	16.233m
-65dBm	28.7m	28.9m	28.5m	28.7m
-70dBm	51m	50.2m	48.7m	49.966m
-75dBm	90.7m	89.5m	91.4m	90.533m
-80dBm	161m	164.5m	153.4m	159.633m

Error! Reference source not found. shows the graph of measured power level with respect to the distance for outdoor environments. The figure shows that most of power data measured is in short distances.

² Source: Google Maps

Figure 4: Outdoor parameters measurement

Due to the location selected for testing in outdoor environment, the maximum distance was 180 m. Table 1 shows the power measurements obtained for this distance.

Table 1: Measured power at 180m (Outdoor Environment)

Measure 1	Measure 2	Measure 3	Average
-86,4dBm	-89,2dBm	-82,5dBm	-86,033dBm

For characterize the outdoor environment, we use the statistical tool of regression 10 using the measured values for outdoor environments (

Table). We use and compare the linear regression, Equation (1) and exponential regression, Equation (5), to determinate which gives best response.

LINEAR REGRESSION

To perform the linear regression, we calculate the values of general variables needed. These variables are:

$\bar{P} = -60dBm \rightarrow$ Average Power

$\bar{D} = 40.71m \rightarrow$ Average Distance

$\sigma_x = 50.6 \rightarrow$ Standard deviation of distance

$\sigma_{xy} = -562.61 \rightarrow$ Covariance

$\sigma_x^2 = 2560.43 \rightarrow$ Variance

The equation to calculate the linear regression is 10:

$P = A \cdot D + B$	(1)
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Using the equation (2) and the equation (3) we calculate the coefficients A and B.

$A = \frac{\sigma_{xy}}{\sigma_x^2} = -0,21$	(2)
$B = \bar{P} - A \cdot \bar{D} = -51,05$	(3)

With the calculated equation of the linear regression for outdoor environments, Equation (4), we proceed to calculate the power using linear regression and calculate the error level between power measured and power calculated (

Table 2).

$P = -0,21 \cdot D - 51,05$	(4)
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Table 2: Power calculated with the equation of linear regression and error level between power measured and power calculated

Average Distance Measured	Power Measured	Power Calculated (Equation 4)	% Error
1.5333m	-40dBm	-51.371993dBm	28.43%
2.8333m	-45dBm	-51.644993dBm	14.767%
5.1333m	-50dBm	-52.127993dBm	4.256%
9.1666m	-55dBm	-52.974986dBm	3.682%
16.233m	-60dBm	-54.45893dBm	9.235%
28.7m	-65dBm	-57.077dBm	12.189%
49.966m	-70dBm	-61.54286dBm	12.082%
90.533m	-75dBm	-70.06193dBm	6.584%
159.633m	-80dBm	-84.57293dBm	5.716%

Figure 5 shows that the slope line of the calculated values is very separate from the measured values, which is corroborated with the average error that is 10,771%.

Figure 6: Power measured vs Power calculated for linear regression

LOGARITHMIC REGRESSION

Following with the analysis of statistical regression, the equation to calculate the logarithmic regression is 10:

$P = A \ln(D) + B$	(5)
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In this equation we replace the term $\ln(\bar{D})$ such as $\bar{D}^*$, the result of the equation would be:

$P = A\overline{D^*} + B$	(6)
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Using the values of the general variables (the same of linear regression) in the equations 7 and 8, we calculate the coefficients A and B of the equation (6).

$A = \frac{n \sum(\overline{D^*} \cdot \overline{P}) - \sum(\overline{D^*}) \sum(\overline{P})}{n \sum(\overline{D^*})^2 - \sum(\overline{D^*})^2} = -8,662$	(7)
$B = \overline{P} - A\overline{D^*} = -35,928$	(8)

With the calculated equation of the logarithmic regression for outdoor environments, Equation (9), we proceed to calculate the power values using logarithmic regression and calculate the error level between power measured and power calculated (

Table 3).

$P = -8,662 \cdot \ln(D) - 35,928$	(9)
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Table 3: Power calculated with the equation of logarithmic regression and error level between power measured and power calculated

Average Distance Measured	Power Measured	Power Calculated (Equation 9)	% Error
1.5333m	-40dBm	-39.62833175dBm	0.929%
2.8333m	-45dBm	-44.94697156dBm	0.118%
5.1333m	-50dBm	-50.09485548dBm	0.19%
9.1666m	-55dBm	-55.11723653dBm	0.213%
16.233m	-60dBm	-60.06739425dBm	0.112%
28.7m	-65dBm	-65.00344288dBm	0.005%
49.966m	-70dBm	-69.80605111dBm	0.277%
90.533m	-75dBm	-74.95449835dBm	0.061%
159.633m	-80dBm	-79.8672643dBm	0.166%

Figure 1 shows that the curve for calculated power with logarithmic regression is very near to the values measured of power, which allows an important validation of the equation obtained. This is corroborated with the average error for logarithmic regression that is 0.23%, improved the 10.771% obtained with linear regression.

Figure 1: Power measured vs Power calculated for logarithmic regression

Comparing the statistical regressions make evident that the equation for outdoor environments is the equation (9) (logarithmic regression).

4. COVERAGE AREA TESTING AND CHARACTERIZATION FOR INDOOR ENVIRONMENTS

For indoor environments the issue is different because the measures were made in the points with obstacles, by this situation the measures patterns will change. Table 4 shows the power values measured as a function of the distance.

Table 4: Indoor parameters measurement

Distance	Power			
	Measure 1	Measure 2	Measure 3	Average
1m	< -40dBm	< -40dBm	< -40dBm	< -40dBm
2m	-45.44dBm	-44.96dBm	-45.46dBm	-45.287dBm
2.3m	-48.83dBm	-50.15dBm	-48.81dBm	-49.263dBm
3m	-55.79dBm	-56.6dBm	-53.24dBm	-55.210dBm
4m	-62.17dBm	-64.07dBm	-59.73dBm	-61.990dBm
5m	-67.12dBm	-69dBm	-65.62dBm	-67.247dBm
6m	-71.17dBm	-74.29dBm	-74.08dBm	-73.180dBm
7m	-74.59dBm	-72.48dBm	-75.96dBm	-74.343dBm
8m	-77.55dBm	-80.08dBm	-80.03dBm	-79.220dBm
9m	-80.16dBm	-82.55dBm	-80.34dBm	-82.017dBm
10m	-82.1dBm	-84.85dBm	-83.15dBm	-83.033dBm
10.7m	-84.51dBm	-86.08dBm	-84.32dBm	-84.303dBm
11m	-89.89dBm	-87.31dBm	-86.46dBm	-87.887dBm

Figure 2 shows the graph of measured power level with respect to the distance for indoor environments.

Figure 2: Indoor parameters measurement

For indoor case to determine the maximum distance of coverage, we take the value of distance in the environment shown in Figure 3 when the signal at the receiver is -90dBm. The results of distance are:

Table 5: Measured distance with -90dBm (Indoor Environment)

Measure 1	Measure 2	Measure 3	Average
11.1m	11.08m	11.3m	11.16m

The results obtained confirm the low coverage expected in indoor environments. In this case, it is because the building where the tests were done has a special feature in its construction, the building was constructed with reinforced concrete with a metal mesh for protection. This kind of construction makes it a particularly complex area of radiate.

With measured values for indoor environments (table 5), we make a linear regression and a logarithmic regression to characterize the environment. With this result, we compare and select the best response.

The equation (10) shown the equation obtained for linear regression.

$P = -4,2789 \cdot D - 42,4354$	(10)
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We use the equation (10) to calculate the power in indoor environments using linear regression. With this value we calculate the error level between power measured and power calculated. The results are show in the

Table 6.

Table 6: Power calculated with the equation of linear regression and error level between power measured and power calculated

Distance Measured	Average Power Measured	Power Calculated (Equation 10)	% Error
1m	< -40dBm	< -40dBm	--
2m	-45.287dBm	-50.9932dBm	12.6%
2.3m	-49.263dBm	-52.27687dBm	6.118%
3m	-55.210dBm	-55.2721dBm	0.112%
4m	-61.990dBm	-59.551dBm	3.935%
5m	-67.247dBm	-63.8299dBm	5.081%
6m	-73.180dBm	-68.1088dBm	6.930%
7m	-74.343dBm	-72.3877dBm	2.630%
8m	-79.220dBm	-76.6666dBm	3.223%
9m	-82.017dBm	-80.9455dBm	1.306%
10m	-83.033dBm	-85.2244dBm	2.639%
10.7m	-84.303dBm	-88.21963dBm	4.646%
11m	-87.887dBm	-89.5033dBm	1.839%

With these values we make a comparative graph between the measured values and values calculated from the linear regression (Figure 3). The graph shows a relatively good trend between measured and calculated values, this trend can be corroborated with the average error level calculated of 4.255%.

Figure 3: Power measured vs Power calculated for linear regression

To compare, we calculate the equation for logarithmic regression, Equation (11), and calculated the power with this equation (

Table 7). The table also shows the error level calculated between power measured and power calculated with the equation of logarithmic regression.

$P = -23,89 \cdot \ln(D) - 29,034$	(11)
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Table 7: Power calculated with the equation of logarithmic regression and error level between power measured and power calculated

Distance Measured	Average Power Measured	Power Calculated (Equation 10)	% Error
1m	< -40dBm	< -40dBm	--
2m	-45.287dBm	-45.5932861dBm	0.676%
2.3m	-49.263dBm	-48.9321989dBm	0.672%
3m	-55.210dBm	-55.2798476dBm	0.127%
4m	-61.990dBm	-62.1525723dBm	0.262%
5m	-67.247dBm	-67.4834717dBm	0.352%
6m	-73.180dBm	-71.8391337dBm	1.832%
7m	-74.343dBm	-75.5217935dBm	1.586%
8m	-79.220dBm	-78.7118584dBm	0.641%
9m	-82.017dBm	-81.5256952dBm	0.599%
10m	-83.033dBm	-84.0427579dBm	1.216%
10.7m	-84.303dBm	-85.659123dBm	1.609%
11m	-87.887dBm	-86.3197181dBm	1.783%

With the results of the power calculated for logarithmic regression and the power measured, we make a comparative graph (Figure 4). The figure show that the trend of the calculated values is approximate to the measured values. This result is corroborated for the average error level of the logarithmic regression (0.946%) improving the average error level for linear regression (4.255%).

Figure 4: Power measured vs Power calculated for logarithmic regression

Comparing the statistical regressions make evident that the best results for indoor environments it is what gives the equation (11) (logarithmic regression).

5.CONCLUSIONS

From measurements performed we obtained a good characterization for outdoor and indoor environments for the controlled sites used. In outdoor environment with line of sight we achieve an error level to 0.23% using the equation 9 [$P = -8.662\ln D - 35.928$] obtained from the logarithmic regression improving the error level of 10.771% calculated with the equation of linear regression. For indoor environment we found that the logarithmic regression also delivers better results, the calculated values with the equation 11 [$P = -23.89.\ln(D) - 29.034$] have an error level to 0.946% improving the error level of 4.255% obtained with the linear regression.

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