Analysis of electromagnetic propagation of 5 scenarios in Mexico City

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Abstract. **We present a study of electromagnetic attenuation over different environments of Mexico City, for an empirical modification of Free Space Attenuation (FSA). Our work uses results of in-site measurements in different places in the city. We intend to measure attenuation in different places to compare and validate modification of FSA. Even we are working in different communications standards, we present results for WiMAX at 3.5 GHz.**

Resumen. **Presentamos en este trabajo un estudio de atenuación en propagación electromagnética en diferentes escenarios en la ciudad de México, para una modificación empírica de la Atenuación del Espacio Libre (AEL). Nuestro trabajo usa resultados de medición en diferentes lugares de la ciudad. La intención es comparar con las mediciones de atenuación para comparar y validar la modificación de AEL. Aunque hemos hecho el experimento para diferentes estándares de comunicaciones, presentamos en este trabajo los resultados para WiMAX en 3.5 GHz.**

Keywords: Modification of Free Space Attenuation, Measurement of urban attenuation, WiMAX.

Palabras clave: Atenuación del espacio libre, Mediciones de atenuación en zonas urbanas, WIMAX.

I. INTRODUCTION

Wireless communication systems are evolving rapidly, EM attenuation in urban areas is now a most for the system design. Altough models as Okumura [1], Hata [1], Cost 231 (a modification of that of Hata), Erceg [3], Shittu [4] and others, are used all around the world to predict propagation losses, for each site should be tested to prove at least, the deviation between prediction and measurement. We have done measurements all over Mexico City in different frequencies, comparing them with prediction of most popular models, for different communications standards as WiMAX (Worldwide Interoperability Microwave Access), which is a metropolitan area service used with one or more base stations at different frequencies: 2.3 GHz, 2.5 GHz, 3.3 GHz, 3.5 GHz and 5.8 GHz [5,6].

Our analysis considers comparison of two models: COST 231 and Erceg, for similar environment as the scenario 2 (shown below); for COST we use the big city model, applying all communications system parameters to equation (1)

$$P_{COST} = 46.3 + 33.9 * \log f - 13.82 * \log A_T - a(A_R) + (44.9 - 6.55 * log\ A_T) * log\ d + C \qquad \ldots (1)$$

Where:
f = 3.5 GHz.
A_T = 30 m (Transmission height antenna)
d = 100 – 1200 m
C = 3 (correction factor)
Receiver height antenna correction:
$a(h_R) = 3.2 * [log\ (11.75 * A_R)]^2 - 4.97$, with A_R = 1.5 m
EIRP=19.5 dB
For Erceg Model we use the A zone, meaning hills and a medium density of trees. Then we use equation 2:

$$P_{Erceg} = P_{FSA.} + 10 * \gamma \log\left(\frac{d}{d_0}\right) + s; \quad d \geq d_0 \ \ldots(2)$$

Where:
$P_{FSA.}$ = Free space loss
d_0 = Reference distance (100 m).

$$\gamma = \left(a - b * h_b + \frac{c}{h_b}\right) + x * \sigma_\gamma; \quad 10\ m \geq h_b \geq 80m$$

$$s = y\sigma \qquad \sigma = \mu_\sigma + z * \sigma_\sigma$$

Using Erceg parameters, we define:

$$a = 4.6 \quad b = 0.0075 \quad c = 12.06$$

$$\mu_\sigma = 10.6 \quad \sigma_\sigma = 2.3 \quad \sigma_\gamma = 0.57$$

Results of our comparison between measurements made in Mexico City and actual models, show important differences, as seen in figure 1.

Figure 1 shows that Mexico City environment is different to those where, the models are defined. This paper, analyze our own scenarios and adjust the Free Space Model (FSM) trying to find the best relationship between measurements and model modifications. Considering those differences of figure 1, we propose to use a modification of FSA equation, comparing it with regression curves of measurement.

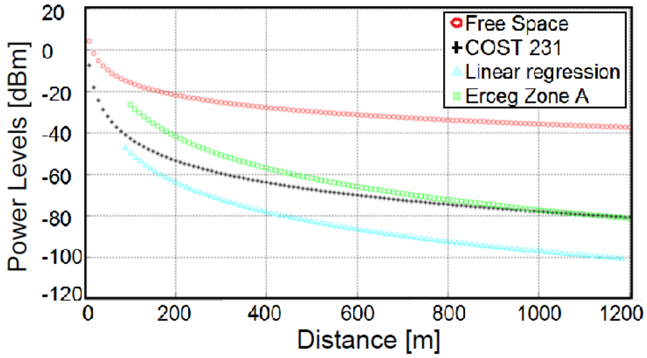

Figure 1. Comparison of measurement with COST and Erceg

The idea is to measure field attenuation in an area with defined characteristics, make modification of FSA equation and after that, take measurement in other different place in the city, with similar characteristics and compare the new measurement regression curves with former modification of FSA. For the experiment we choose to different places, 30 Km apart, one in the north and the other in the south of Mexico City. Experiment starts with choosing similar scenarios in both sites, we find 4 areas with similar characteristics, those from 1 to 4. The fifth scenario was in downtown, which is a unique place in the city and do not have a similar site to be compared with, but we presented because it was part of the measurements.

We propose to use Free Space Attenuation, modifying the equation exponent. As is known, FSA supposes a free obstacle region between transmitter and receiver; it is given by [3]:

$$PL_{FS} = \left(\frac{4\pi df}{c}\right)^2 \quad (3)$$

where

d: distance between transmitter and receiver
f: operating frequency
c: speed of light
Equation (3) is often expressed in dB as:

$$LP_{EL} = 20\log\frac{4\pi}{c} + 20\log d + 20\log f \quad (4)$$

The new proposed equation is:

$$PL_{FS} = \left(\frac{4\pi df}{c}\right)^{\boldsymbol{X}} \pm \boldsymbol{Y} \quad (5)$$

Adjustment is made changing the exponent value (***X***) for the slope and (***Y***) for losses magnitude, in equation (5). Next step was to adjust FSM finding a match for slope and attenuation as best as possible with measurement regression curves. After that we compare modified curves with similar scenario in other place, and if there is concordance, we can suppose that modification of equation (5) is good enough. We understand that this analysis is valid only for the used frequency, for a different one we have to repeat the procedure. On the other hand we want to emphasize that we are comparing only attenuation due the environment, this means that we take a measurement power at some distance of base station and relate it to the measurement at other distance. We are still working in the procedure, and we are now measuring in similar areas in other places in the city, to compare the original results.

II. Measurement Methodology

Measurements were performed using base stations located in National University (UNAM) with base station in the Humanities Building at the south of the city, in Instituto Politécnico Nacional (IPN) with station located in the Dirección de Cómputo y Comunicaciones (DCyC) at the city's north and the Instituto de Ciencia y Tecnología (ICYT) in downtown. Three scenarios were chosen due their similarities but also by their differences. Table I shows characteristics of communications system, transmitter antenna height is almost the same for all scenarios.

TABLE I COMMUNICATION SYSTEM FEATURES

Operating frecquency	3,4785 GHz
Bandwidth	3,5 MHz
Transmitter power	-7 dBW
Transmitter antenna height	29 – 70 m
Receiver antenna height	2 m
Transmitter antenna gain	14,8 dBi
Receiverer antenna gain	3,6 dBi

Measurements were made using an analyzer Anritsu Master Spectrum MS2721B, which includes a GPS antenna for referenced positioning. Figure 2 shows the measurement scheme; the equipment was mounted on top of a vehicle, saving the received power level and geographic location (latitude and longitude coordinates) at each measurement point.

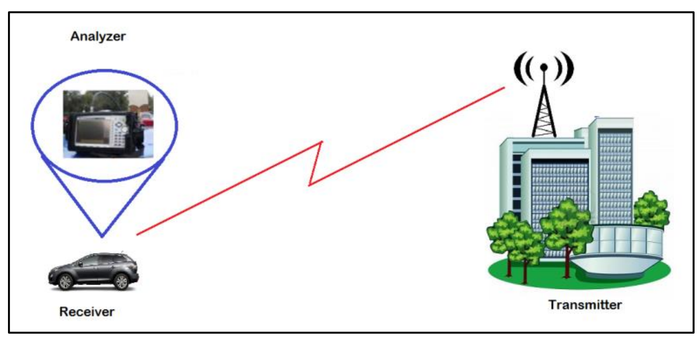

Fig 2. Measurement scheme

Measurements were taken every 20 seconds, at that time analyzer updates GPS position. A data base with extension wxme is constructed, extracting measurements from spectrum analyzer, becoming in computer txt files containing latitude, longitude, distance and input power. Database is used to construct linear regression curves, to be compared with adjustments of FSA.

III. Identification of Scenarios

We identified 5 scenarios accordingly of existing features of different areas in Mexico City, which are described in following paragraphs:

A. Scenario 1: low buildings with low tree density

This scenario considers an area with a low tree density, and low high buildings, as shown in Figure 3.

Figure 3. Scenario 1

B. Scenario 2: low buildings with medium tree density

The scenario considers an area with medium tree density and a low height of the buildings as the one shown in figure 4.

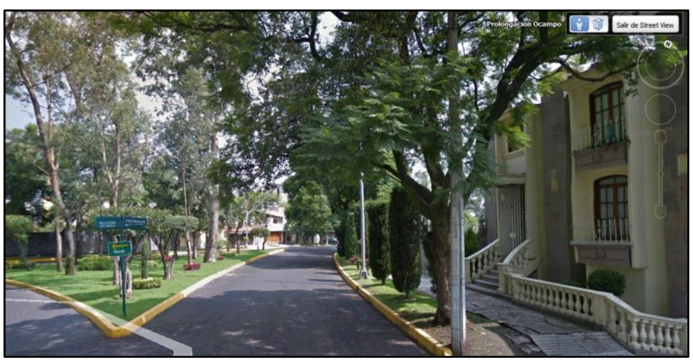

Figure 4. Scenario 2

C. Scenario 3: area with a high tree density

Figure 5 shows a scenario with a high tree density.

D. Scenario 4: tall buildings with medium tree density

The scenario considers an area with medium tree density and high height buildings.

E. Scenario 5: colonial city

Figure 5. Scenario 3

Figure 6. Scenario 4

Figure 7. Scenario 5

Scenario 5 is a unique environment of Mexico City (and many Latin American cities), it is located at historic downtown; it has some very unique construction features such as: large width walls, tall buildings, and narrow streets.

Figures 8 and 9 show UNAM (south of the city) with yellow mark, showing position of base station at Humanidades II building and the one at IPN (north of the city) with mark in DCyC building (Dirección de Cómputo y Comunicaciones). Measurements were taken in both zones for scenarios 1 through 4, each one bounded for different colors. The blue frame define scenario 1, while scenario 2 is red, green is the scenario 3 and scenario 4 orange.

Each scenario was visually distinguished from both base stations photos. As an example, area for scenario 1 is mostly filled by buildings with few green zones. Others can be distinguished in photographs from tree density.

Figure 8. Radio base located in the UNAM

Figure 9. Base station in IPN

Figure 10 shows the unique scenario 5. Although is not clear from the photo the differences with other scenarios, is possible to distinguish them from Figure 10, specially the narrow background street between the colonial buildings.

After each bounded polygon was defined by its geographical position, we created tables with each point measurements and then constructed regression curves showing attenuation behavoir. To validate scenarios 1-4 we take measurements in UNAM to define FSA new parameters and then compare them with those taken in IPN to validate ***X*** and ***Y*** parameters.

Figure 10. Base Station of scenario 5.

IV. RESULTS

Once the scenarios were identified in maps, measurement tables were constructed and obtained linear regression curves we were ready to modify FSA using UNAM measurement and then compare them for those at IPN. To do so we adjust FSA finding a match for slope and attenuation as best as possible. Adjustment is made changing the exponent value (***X***) for the slope and (***Y***) for losses magnitude, in equation 5 considering a difference no higher than 3 dB:

$$L_{FSA} = \left(\frac{4\pi df}{c}\right)^{\boldsymbol{X}} \pm \boldsymbol{Y} \quad (5)$$

Following curves show results of our analysis. Figure 11 shows adjustments for scenario 1; we found that ***X=3*** and ***Y=29*** then:

$$\mathrm{L_{S1}} = -\left(\frac{4\pi \mathrm{df}}{\mathrm{c}}\right)^{\mathbf{3}} + \mathbf{29}$$

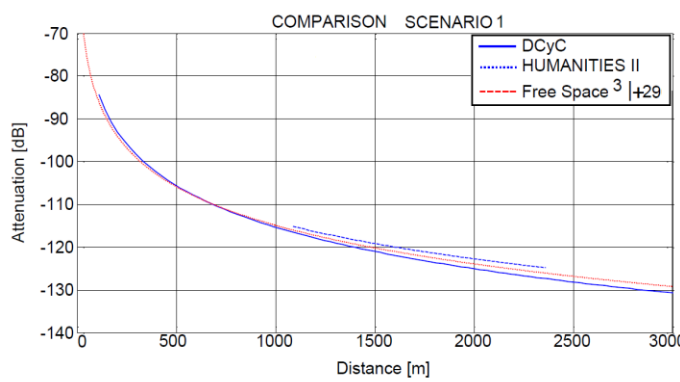

Figure 11. Adjustment of FSM for scenario 1.

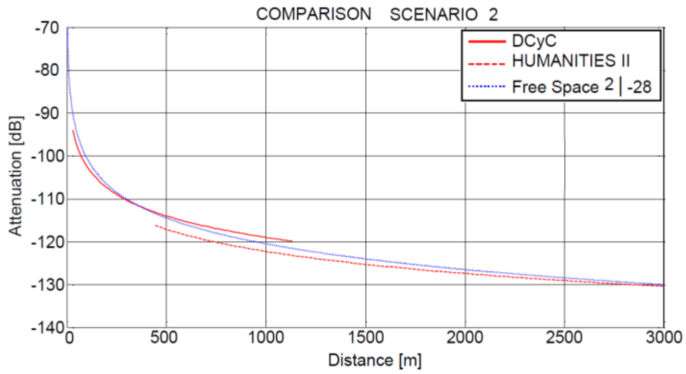

Figure 12. Comparison and adjust of FSA for scenario 2.

Figure 12 depicts measurements comparison for scenario 2. giving:

$$L_{S2} = -\left(\frac{4\pi df}{c}\right)^{\mathbf{2}} - \mathbf{28}$$

We select a FSM adjust curve between both base station regression curves, giving a difference between FSM and measurement no higher than 1.5 dB. As seen the exponent value do not change (***X=2***); magnitude of attennuation factor is selected as ***Y = -28*** for scenario 2.

In the same way we compare curves for scenario 3, as shown in Figure 13; again the slope of regression curves are similar, with a difference of power no greater than 5 dB. After adjustment, we select a curve for FSA between both regression curves; lost equation is expressed as:

$$L_{S3} = -\left(\frac{4\pi df}{c}\right)^{\mathbf{2}} - \mathbf{31}$$

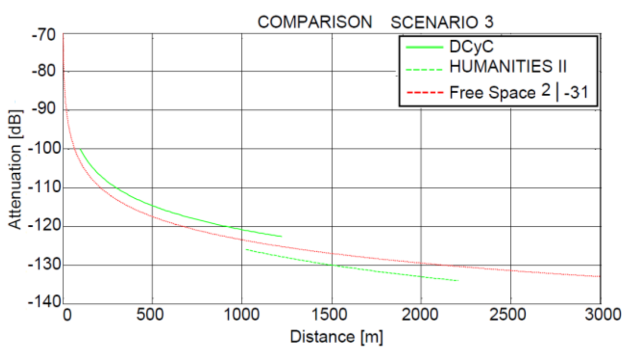

Figure 13. Comparison and adjust of FSA for scenario 3.

Following same procedure, we compare results for scenario 4. Regression curves are shown in Figure 14. As seen slopes of both curves are different, although no more than 1.5 dB between 100 m and 1200 m. Differences are greater for larger distances, meaning scenario 4 needs further analysis.

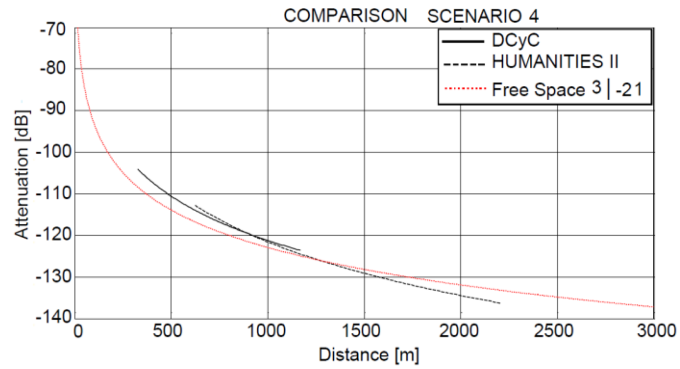

Figure 14. Comparison and adjust of FSA for scenario 4.

Although two power slopes are different, a good FSA adjustment was found as:

$$L_{S4} = -\left(\frac{4\pi df}{c}\right)^{\mathbf{3}} + \mathbf{21}$$

As scenario 5 is unique, is not possible to compare with any other curve. Figure 15 shows FSA adjustment of regression curve. As can be seen from Figure 15, there is a sharp slope fall, similar to that of scenario 3, meaning a zone of high attenuation, due the tall buildings with very dense walls and narrow streets. Adjustment for FSA is:

$$L_{S5} = -\left(\frac{4\pi df}{c}\right)^{\mathbf{2}} - \mathbf{36}$$

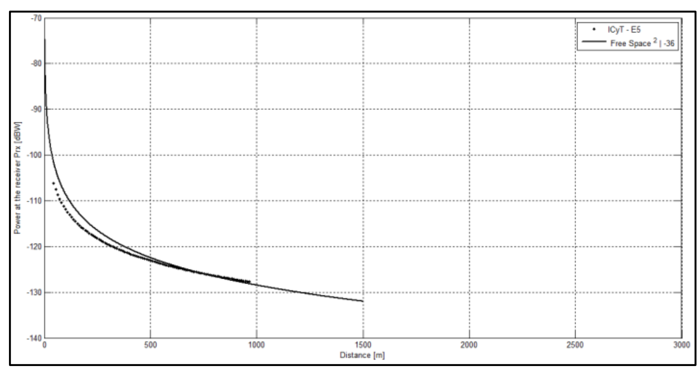

Fig. 15. Adjust of FSM for scenario 5.

Table II shows a summary of adjustments for all scenarios.

TABLE II SUMMARY OF FSM ADJUSTMENT

	Exponent	**Loss (dB)**
Scenario 1	3	+ 29
Scenario 2	2	- 28
Scenario 3	2	- 31
Scenario 4	3	+ 21
Scenario 5	2	- 36

As seen in Table II, scenarios 1 and 4 have similar slopes, with an exponent of 3. Furthermore the loss adjustment for FSM is increased with 29 and 21 dB respectively.

For scenarios 2 and 3, the slope has the same exponent of 2, and loss requires an adjustment of -28 and –31 dB respectively, only a 3 dB difference.

V. CONCLUSION

After identification of some common scenarios in Mexico City as: low buildings-low tree density; low buildings-medium tree density; high tree density zone; tall buildings-medium tree density; Colonial City, we compare measurements over city streets with FSA, to find a relationship between them.

Considering similarities for two base stations, we validate scenarios selection, at least for 4 of them, leaving scenario 5 as unique.

Comparing measurements for each scenario with adjusts of exponent and amplitude of FSA losses, we conclude that model can predict path loss for WiMAX or similar communication standard. We think that 5 dB differences is a good margin, to predict propagation of mobile communication systems over an environment as Mexico City. Probably we have to define an accepted margin, but accordingly with our experience a 10 dB could be a good number.

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