Loss prediction model of a 850 MHz system using radio wave recommendations for terrestrial services

J E Herrera¹, and C Trujillo²
¹ Grupo de Investigación en Telecomunicaciones y Nuevas Tecnologías, Universidad de Pamplona, Pamplona, Colombia
² Facultad de Administración de Seguridad Ocupacional, Universidad Uniminuto, San José de Cúcuta, Colombia

E-mail: jherrera@unipamplona.edu.co

Abstract. In the implementation of radiocommunication links necessary to determine the possible coverage areas for mobile communications services in urban environments, through modeling and statistical prediction by means of measurements of signal intensity in the field; therefore, it is necessary to have recent and updated mathematical models to predict the propagation losses considering the most appropriate correction parameters according to the working frequencies. The research focuses on establishing the losses obtained by means of power measurements according to the regulations of the International Telecommunications Union of a mobile radio system in the city of San José de Cúcuta, Colombia, in order to estimate the coverage and compare the performance of the model obtained with models similar.

1. Introduction
The mobile communication systems for micro cells can be modeled mathematically in order to determine the coverage area by means of the power [1] of radiation from the base stations, for this purpose mobile computing tools are used according to the recommendations of the International Union in Telecommunications [2], in the research, the recommendation prediction method [3] is applied to calculate the field intensities and the propagation losses at a frequency of 850 MHz in the land rout, an experimental type methodology was applied and the obtained data are analyzed. Are tested to observe the behavior with respect to the samples taken in four different routes, finally we compare the data obtained with the model Okumura Hata [4], Cost-231-Hata [5] and Erceg-SUI [6] as the most representative for this type of environment and frequency of work.

2. Technical background
Determine the trajectory losses of a mobile system is possible with the use of propagation models for estimation of power [7] which allow an adjustment and control according to the type of environment, the models can be of empirical type, semi empirical, theoretical and experimental [8] which are widely used in the planning and optimization of mobile and wireless networks.

Although the models validate the balance between precision, speed and ease of implementation, there are atypical conditions such as the case study [5] where they present three forms of route loss modelling in outdoor atypical outdoor environments. This indicates that the empirical conditions depend on the external characteristics where they are obtained, such models are particularly important for planning the
network of new deployments, estimating in particular the exponent of trajectory loss, statistical errors, among others, [9].

In the case of mobile applications, there are a large number of models that analyze different external scenarios: urban, suburban and rural [10]. Currently the ITU-R model. P.1546-5 [11] is a practical reference in land links. Also [12] performs tests of coverage estimation through a test drive presenting a new form of calculations to obtain propagation losses, likewise [13] performs measurement campaigns in 850 MHz to predict the coverage of a third generation cell.

3. Experimental methodology
The research is experimental and exploratory, initially the propagation models and recommendations of ITU-R [3] referring to the case study are examined; an arbitrary cell is selected with a transmitter that has a power of 20W (43dBm) according to the regulation defined by the 3GPP and its technical specifications [14], the mobile receiver is located at a height of 1.5m, the transmitting antenna is At 30 m above ground level with gain of 14.5dB, the mobile system works at 850 MHz in the city of San José de Cúcuta, Colombia, as shown in Figure 1.

3.1. Measures campaign
The measurements are made in an area of the city of San José de Cúcuta, Colombia, using a mobile device as a computer equipment through a freeware application, the research is developed for an urban environment in the presence of real physical conditions for line-of-sight links, the measurement points are set every 70λ to capture the intensity of power on four different routes [15], in an arbitrary cell.

3.2. Configuration probe
In mobile devices the application is installed and configured to perform the measurement taking into account the parameters: cell identification (CID), radio controller number (RNC), technology type (TYPE), network (NET), Received signal strength indicator (RSSI), date and time [15].

3.3. Connectivity tests
In practice the captured signal measurement is generally expressed as the power value of the pilot signal received signal code power (RSCP) in case of 3G or Reference Signal Received Power (RSRP) in case of 4G [16].

The application is activated and the registration on the RSSI level screen is verified according to [17] of both the usable signal and the noise. The average power levels received for HSPA is -90 dBm on foot in outdoor environments from a user equipment (UE), with a cell edge location percentage of 90% and
for nearby high interference limits and high load is of -120 dBm when the edge of the cell reaches 95% [18].

3.4. Acquisition of data
The recording of the power data is made over a prolonged period of 4 minutes, according to Equation (1) [19] in order to determine the number of samples for a microcell [20, 21].

\[
n = \frac{(N + z^2 + \sigma^2)}{\left(\frac{z^2}{(N-1)} + \frac{\sigma^2}{2}\right)}
\]  

(1)

3.5. Data collection
In the event of limitations due to the noise level of the receiver, atmospheric noise or external interference, the precision that can be expected in field strength measurements is less than ± 3 dB for frequencies above 30 MHz [22], to preserve this condition of reliability 3830 samples were obtained per measurement route, after filtering the unnecessary samples with an average power level, processing and selecting a standard deviation (σ), the variance (σ2) and standard error of each of the measurement points [23].

3.6. Checking the reference model ITU-R.1546-5
In the application of the model, the following input parameters are taken into account, according to Table 1.

| Parameter | Functional description | Limits          |
|-----------|------------------------|-----------------|
| f (MHz)   | Frequency of work      | [30; 3000]      |
| d (km)    | Path length            | [1; 1000]       |
| p (%)     | Percentage of time     | [1; 50]         |
| h1 (m)    | Height of the transmitting antenna / base | [1; 3000] |
| h2 (m)    | Height of the receiving / mobile antenna | [1; 3000] |
| R1 (m)    | Occupation of the land at the location of the transmitter | Ninguno |
| R2 (m)    | Occupation of the land at the receiver's location | Ninguno |

For the study case, the east route is taken as an example, the estimation of the path losses is made from measurements in similar situations, such estimation must be of a statistical nature [3], to find the distance Equation (2) is applied:

\[
d_{slope} = \sqrt{d^2 + 10^{-6}(h_a - h_z)^2}
\]  

(2)

The field strength is calculated with the Equation (3):

\[
E = 106.9 - 20 \log(d_{slope}) \ [dB (\mu V/m)]
\]  

(3)

The percentage of time required is equal to 50% in function of distance parameters (lower 0.0401 km and higher 1.0004 km) and the lower and upper rated frequencies are 600 MHz and 2000 MHz. From the lower and upper distance is obtained the upper electric field 106.8964 dBμV/m and lower 133.0757 dBμV/m.

The height locations of the receiving mobile antenna are extracted from Annex 3 of the standard and the extrapolation of frequencies for 600 MHz and 2000 MHz is applied [3], the lower heights of 20m and upper 37.5 m of the transmitting antenna are obtained: for 600 MHz (Einf = 94.6315 dBμV/m and Esup = 96.9473 dBμV/m), similarly for 2000 MHz (Einf = 96.1052 dBμV/m and Esup = 98.315 dBμV/m), values that are tested in Equation (4).
\[ E = E_{inf} + (E_{sup} - E_{inf}) \log(h_1/h_{inf}) / \log(h_{sup}/h_{inf}) \text{ dB } \mu \text{V/m} \] (4)

The correction factors obtained after applying the above Equations are: a) for the transmitting height \( C_{h1} = 6.03 \text{ dB} \), b) for the receiving antenna the average value is \( C_{h2} = -24.2085 \text{ dB} \), the correction of the free angle of the terrain is \( C_{h3} = -11.0804 \text{ dB} \) and the difference in height between two antennas is \( C_{h4} = -1.0146 \text{ dB} \) [3], according to Equation (5).

\[ C_{h4} = 20 \log \left( \frac{d}{d_{slope}} \right) \] (5)

Therefore, two possible scenarios must be considered: a) using Equation (3) and then, b) adding the correction factors to obtain the Equation (6):

\[ E = 106.9 - 20 \log(d_{slope}) + C_{h1} + C_{h2} + C_{h3} + C_{h4} \text{ [dB( } \mu \text{V/m) ]} \] (6)

Finally, obtain the basic losses of transmission equivalent to a field strength by means of the Equation (7):

\[ L_b = 139.3 + 20 \log f - (106.9 - 20 \log(d_{slope}) + C_{h1} + C_{h2} + C_{h3} + C_{h4}) \text{ [dB( } \mu \text{V/m) ]} \] (7)

In Figure 2, the different types of field are illustrated according to recommendation P.1546-5; by contrasting the electric field that includes the correction factors of Equation (7), it presents high values, above the Okumura-Hata model, the calculated and the measured one; situation that is desirable, because of short distances between the mobile equipment and the transmitting station there are no losses to the line of sight with a path free of obstructions, however, there is an exponential decay from 100 meters by the propagation effects of streets, buildings, moving vehicles, forest density in blind spots, among others.

![Figure 2. Comparison of electric field strength.](Image)

It is also observed that the calculated electric field has an average value of 26.7 dBuV / m compared to the electric field received by the effect of evaluating the received power as a function of the electric field [24] in each measurement distance and considering a Isotropic gain antenna [25], which allows to calculate the basic losses as a function of the power received according to Equation (8):

\[ L_b = Pr(\text{dBW}) - E(\text{dBu}) + 20\log f(\text{MHz}) + 107.2 \] (8)
A real approximation is obtained with the Okumura-Hata model by correcting the adjustment factors that are included in the analytical expression, but as the distance exceeds 400 meters the weakening of power is more representative, therefore, there will be losses due to undulations of the terrain, shadowing of obstacles in mixed paths with line of sight/no line of sight (LOS/NLOS) and tropospheric dispersion.

4. Results and discussions

In the verification of the curves (see Figure 3) of the power levels measured experimentally, these are good in real conditions, however, when using the model ITU-R P.1546-5 and annexing the correction factors, the Intensity values improve when taking into account height corrections, height differences and obstacle-free angle.

The model provides the statistics of reception conditions in a suitable way to make a more accurate prediction when implementing base stations in mobile systems, likewise the representation of the logarithmic regression curve allows to estimate 95% confidence levels with a margin of error of 5%, up to where the power extends at the edge of the coverage area of a cell to guarantee service connectivity.

Figure 3. Comparison of received power.

When comparing the statistical prediction method without the correction factors, it is more realistic than the Erceg-Sui, Okumura-Hata and Cost-231-Hata models [26], logically without detracting that the analysis parameters of these models consider other variables that model ITU-R P.1546-5 does not examine and that they are also valid when planning coverage.

Table 2 collects the values of the basic losses, it is observed that the model ITU-R P.1546-5 is much more efficient under the two conditions with and without correction factors, but the models of Erceg-Sui, Okumura-Hata and Cost-231-Hata (see synthesis Equations (9) through (12)) are more practical because they take into account the types of environments and add other components in theoretical prediction terms, structural conditions of the buildings and the 5 factors included in the model for which the investigation was made. For the Okumura-Hata loss model, in urban environment [27] Equation (9) is used:

\[
l_{urb} = 69.55 + 26.16 \log(f) - 13.82 \log(hte) - a \log(hre) + (44.9 - 6.55 \log(hte)) \log(d) \quad (9)
\]

The basic losses for the Cost-231-Hata model [28] are obtained from Equation (10):

\[
PL[dB] = 46.3 + 33.9 \log f - 13.82 \log hte - a(hre) + (44.9 - 6.55) \log d + c \quad (10)
\]

The losses for the Erceg-SUI model [6] are summarized in Equation (11):


\[ PL[\text{dB}] = 20 \log\left(\frac{4\pi d_0}{\lambda}\right) + 10\gamma \log\frac{d}{d_0} + s \quad (11) \]

Where \( f_c \) (MHz) is the operating frequency, \( h_{te} \) (m) is the height of the transmitting antenna, \( d \) is the distance between the base station and the mobile station, \( d_0 \) is the reference distance, \( \lambda \) is the wavelength, \( \gamma \) is the exponent of losses already, \( h_{re} \) is the correction factor of the height of the mobile for urban area according to the Equation (12):

\[ a(h_{re}) = 3.2 \left( \log(11.75h_{te}) \right)^2 - 4.97 \quad (12) \]

The basic losses in the last column of the Table 2 does not examine the environmental factors and conditions, only the power received and the frequency of work.

### Table 2. Loss model for the electric field.

| Distance (m) | UIT-R P.1546-5 (dBm) | UIT-R P.1546-5 With correction | Okumura-Hata (dBm) | Erceg-Sui (dBm) | COST-231-Hata (dBm) | Basic losses (dBm) |
|-------------|----------------------|---------------------------------|-------------------|----------------|---------------------|-------------------|
| 31.623      | 60.590               | 30.316                          | 72.450            | 58.555         | 72.343              | 114.788           |
| 39.051      | 62.564               | 32.290                          | 75.678            | 62.564         | 75.570              | 115.271           |
| 58.310      | 66.190               | 35.916                          | 81.811            | 70.181         | 81.703              | 105.677           |
| 80.777      | 69.075               | 38.802                          | 86.797            | 76.374         | 86.689              | 107.188           |
| 104.403     | 71.328               | 41.054                          | 90.722            | 81.249         | 90.614              | 106.074           |
| 128.550     | 73.147               | 42.873                          | 93.905            | 85.202         | 93.797              | 118.038           |
| 152.971     | 74.664               | 44.391                          | 96.565            | 88.507         | 96.458              | 119.455           |
| 177.553     | 75.963               | 45.689                          | 98.845            | 91.338         | 98.738              | 111.498           |
| 202.237     | 77.096               | 46.823                          | 100.837           | 93.812         | 100.729             | 123.074           |
| 226.991     | 78.101               | 47.828                          | 102.603           | 96.006         | 102.495             | 118.455           |
| 251.794     | 79.003               | 48.730                          | 104.189           | 97.976         | 104.082             | 119.663           |
| 276.632     | 79.821               | 49.548                          | 105.628           | 99.763         | 105.521             | 124.788           |
| 301.496     | 80.57                | 50.296                          | 106.945           | 101.399        | 106.838             | 103.288           |
| 326.382     | 81.259               | 50.986                          | 108.158           | 102.906        | 108.051             | 100.425           |
| 351.283     | 81.898               | 51.625                          | 109.283           | 104.303        | 109.176             | 113.741           |
| 401.123     | 83.052               | 52.778                          | 111.313           | 106.824        | 111.205             | 104.188           |

According to Table 2, the COST-231-Hata model represents the best conditions in theoretical prediction terms, but the estimation model obtained is the one that most adapts to the external conditions LOS/NLOS, considering that since there are nearby cells the power levels are adjusted to the position of the mobile allowing stability in the link and the phenomenon of handover, noise and loss of the signal does not occur; similarly, when the correction factor is included, the RSSI level is considerably good as a method of prediction and losses in point-to-area paths for the mobile service.

### 5. Conclusion

The method of correction by height by means of extrapolation is an analytically good correction indicator to determine the electric field strength for urban areas, as well as correction by clearing angle for small reception areas, this is effective when there are no obstacles in line of sight and therefore the angle is small and positive; when the effective height is negative in the calculations, the diffraction effect caused by the obstacles must be assessed.

A non-linear regression curve with logarithmic trend of the received power reflects the effect of the coefficient of determination (R) as the tolerance of the adjustment of the correction factors that were obtained in the field experiment (similarly it was executed for the others three routes), which aims to explain how a portion of the power decreases with respect to the coverage distances, however, to obtain
more accurate results it is necessary to extend the number of measurements, characterize the terrain and observe the effects of the environment.

The statistical predictions of power levels facilitate the probability of being able to predict around the radio stations the availability of coverage signal by means of the analysis of real measurements in comparison with the empirical models for distances less than one kilometer. It is important to note that the Erceg-Sui, Okumura-Hata and Cost-231-Hata models are appropriate study options only when the respective adjustments are made according to the type of terrain, frequency, external factors and the delimitation of the work area.

References
[1] Salvade A, Guggliari P, Lanini M, Pagani T, Bartesaghi T 2004 Basis for UMT measurement recommendation (Bern: Swiss Agency for environment, Forest and Landscape)
[2] International Telecommunications Union 2015 Handbook on National Spectrum Management (Suiza: United Nations Publications)
[3] International Telecommunications Union (ITU) 2013 Method for point-to-area predictions for terrestrial services in the frequency range, ITU-R P.1546-5 (Suiza: International Telecommunications Union)
[4] Herrera J E 2013 Predicción de cobertura en ambientes semiurbano mediante método experimental para sistemas inalámbricos en la banda de frecuencia 2.4 GHz Revista Colombiana de Tecnologias de Avanzada 2(22) 1-10
[5] Ambroziak S J, Katulski R J 2014 Path loss modelling in the untypical outdoor propagation environments 2014 31th General Assembly and Scientific Symposium URSI GASS 2014 (Piscataway) (New Jersey: IEEE) p 3–6
[6] Giambene G, Yahiya T A 2013 LTE planning for Soft Frequency Reuse IFIP Wireless Days WD (Valencia) (Valencia: IEEE)
[7] Vera Rivera A, Núñez Anda A, Ramos B, Macías E, Suárez A, Gómez J 2015 Lee microcell propagation model: A complex case empirical study WSEAS Transactions on Communications 14(1) 33–42
[8] Cadavid A N, Ardila C A 2012 Ajuste estadistico de modelos de propagación de señal usando medidas de la ciudad de Cali Ingenium 6(11) 11–18
[9] Carlos Vesga F, Contreras M F, Vesga J A 2018 Design of empirical propagation models supported in the log-normal shadowing model for the 2.4GHz and 5GHz bands under indoor environments Indian Journal of Science and Technology 11(22) 1–18
[10] Artemenko O, Nayak A H, Menezes S B, Mitschele-Thiel A 2015 Evaluation of different signal propagation models for a mixed indoor-outdoor scenario using empirical data International Conference on Ad Hoc Networks ADHOCNETS 2015 (San Remo) vol. 155 (Cham: Springer) p 3-14
[11] Elsheikh E, Islam M, Habaebi H, Ismail A, Zyoud A 2017 Dust storm attenuation modeling based on measurements in Sudan IEEE Transactions on Antennas and Propagation 65(8) 4200–4208
[12] Calderon J 2012 Estimación de comunicaciones móviles 2G/3G en interiores a partir de medidas drive test (Valencia: Universidad Politecnica de Valencia)
[13] Martinez O, Rodriguez Z, Arias C 2014 Propagation characteristics of Managua city based on Standard Propagation Model (SPM) at 850 MHz for 3G-WCDMA systems 2014 IEEE Central America and Panama Convention (CONCAPAN XXXIV) (Panama) (New York: Curran Associates Inc.) p.1-6.
[14] European Telecommunications Standards Institute (ETSI) 2017 Evolved universal terrestrial radio access (E-UTRA), base station (BS) conformance testing. 3GPP TS 36.141 version 10.1.0 Release 10 (Saint-Philippe: European Telecommunications Standards Institute)
[15] International Telecommunications Union (ITU) 2013 Studies related to the impact of devices using ultra-wideband technology on radiocommunication services ITU-R SM2057 (Suiza: International Telecommunications Union)
[16] Kim B H, Jun H J 2015 Cooperative wireless power signal transmission method and device U.S. Patent No. 9,219,385B2
[17] Chertchom P 2012 Micro-mobile MPLS: Performance analysis and improvement with RSSI Proceedings of the Asia-Pacific Advanced Network 33 76-85
[18] Das S K, Ramesh C 2014 Modulation and transmitted data sequence independent carrier RSSI estimation. 20th Annual International Conference on Advanced Computing and Communications ACOM (Bangalore) (New York: IEEE Computer Society) p 16-21
[19] European Telecommunications Standards Institute (ETSI) 2012 Universal Mobile Telecommunications Systems (UMTS)
System (3GPP TS 25.215 version 11.0.0 Release 11 (Saint-Philippe: European Telecommunications Standards Institute)

[20] Peck R, Olsen C, Devore J, Sovak M 2016 *Introduction to statistics & data analysis* (Mexico: Cengage Learning)

[21] International Telecommunications Union (ITU) 2015 *Propagation effects relating to terrestrial land mobile and broadcasting services in the VHF and UHF bands, ITU-R P.1406-2* (Suiza: International Telecommunications Union)

[22] Verma R, Garg P 2013 Mobility management in 4G networks *Global Journal of Computer Science and Technology* 13(7) 1-7

[23] Bureau R 2011 *Handbook Spectrum Monitoring* (Suiza: International Telecommunications Union)

[24] Désenfant M, Priel M Reference and additional methods for measurement uncertainty evaluation *Measurement: Journal of the International Measurement Confederation* 95(October) 339–344

[25] Hernando J M 2012 *Transmision por Radio* (Madrid: Editorial universitaria Ramon Areces)

[26] Fuentes J 2013 *Problemas de Radiocomunicación* (Sevilla: Universidad de Sevilla)

[27] Quintana A, Bordón R, Montejo S 2013 Estudio comparativo de los modelos de propagación de canal inalámbrico *Ingeniería Electrónica, Automática y Comunicaciones* 34(1) 12-26

[28] García F 2016 *Modelos de propagación para comunicaciones móviles 4G y 5G* (Madrid: Universidad Politecnica de madrid)