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Simplified Equation for Received Power Calculation of the LTE Signal in 2.13 GHz.

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Abstract: In this paper, an analysis of path loss is made using an empirical method that allows obtaining a simplified equation for the received power calculation, which depends on fewer variables than the propagation models traditionally-used in 2.13 GHz. The final part is about the simplified equations obtained for two areas of México city, which can be used to generalize the estimation of losses to other areas with similar characteristics.

Keywords: Propagation models, Walfisch-Bertoni, Xia-Bertoni, LTE

1 Introduction

At the present in the study of the LTE cellular mobile communications signal, in tasks such as planning for new networks deployment, enlargement or adjustment of existing coverage has a great dependence on theoretical propagation models to estimate the path loss in the signal propagation. These theoretical propagation models were generally developed in other countries or cities where the constructions of buildings are made under different regulations and conditions than those of México city [1] [2], also adding different geographic, demographic and environmental conditions.

The propagation models used, such as Xia-Bertoni, Walfisch-Bertoni or Winner II communications channel, require previous calculation of several parameters that depend on the environment in which they are going to be used [2] [3] , which in some cases require a more delicate calculation due to the various factors involved. In addition to the entry of new service providers in the country, led to the approach of the need to have a method to generate a simpler equation that characterizes the path loss of the LTE cellular mobile communications signal in the 2.13 GHz frequency band, is important to be developed in urban environments of interest, in this case, México city.

In Release 8, 3GPP completed LTE system specifications. The main objective is to provide high-performance radiofrequency access, which allows high transmission and reception speeds on mobile devices, and which can coexist with HSPA and previous systems, allowing operators a fast and simple migration to this new technology. LTE uses OFDMA (Orthogonal Frequency Division Multiple Access) links to minimize interference and increase spectral efficiency using channels of variable size between 1.25 and 20 MHz.

LTE is a radio technology that allows operators to achieve even higher data speeds than with HSPA+. Spectrum management is also more flexible, allowing greater bandwidth. It is part of the evolutionary path of GSM towards mobile broadband, EDGE, EDGE Evolution (EDGE +), UMTS, HSPA (HSDPA y HSUPA combined) and HSPA Evolution (HSPA +). Although HSPA and its evolution (HSPA+) are well positioned to provide mobile data services, LTE provides better latency performance, higher transmission speeds, more flexible spectrum usage, and better use of multi-antenna technologies (MIMO). LTE is also a packet-only network (PS, Packets Switching), thereby eliminating circuit switching (CS, Circuit Switching). In LTE, the entire network architecture is based on IP. LTE also allows the handling of greater bandwidths.

According to [4], LTE main capabilities are:

– Maximum theoretical transmission rate in the downlink (from the base station to the mobile) up to 326 Mbps using 20 MHz bandwidth and 4x4 MIMO or 173 Mbps with 2x2 MIMO; or 86 and 58 Mbps with 1x2 64 QAM respectively.

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–Maximum theoretical transmission rate in the uplink (from mobile to base station) of 86.4 Mbps with 20 MHz bandwidth.
–Operation in both TDD (Time Duplex Division) and FDD (Frequency Duplex Division).
–Scalable bandwidth from 1.25 to 20 MHz, including 1.25 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz.
–Considerable increase in spectral efficiency (number of bits that can be transmitted per Hz), with an increase regarding HSPA between 100% and 200%.
–Latency reduction, up to 10 milliseconds (ms), back and forth between the user's equipment and the base station, and less than 100 ms the transition time from inactive (idle) to active (connected) modes.

A propagation model is a set of mathematical expressions, diagrams and algorithms used to represent radio characteristics of a given environment. Generally prediction models can be classified as empirical or statistical, theoretical or deterministic or a combination of these two or semi-empirical.

While empirical models are based on measurements, theoretical models are based on the fundamental principles of radio wave propagation phenomena. The propagation models predict the path loss that an RF signal can have between a base station and a mobile or fixed receiver. The advantage of modeling radio channels taking into account the characteristics of the path between Transmitter (Tx) and Receiver (Rx), is to know the projects feasibility that are desired to plan in certain sectors. In this way you can make estimation about the need, costs and capacity of the required equipment [5].

In this work, an analysis of the behavior of the LTE signal in the 2.13 GHz frequency is made using a procedure that allows us to obtain a simplified equation for received power calculation [6] [7] [8]. The equation that defines the received power affected by path losses as a function of distance is given by (1).

$$P_r = P_t K \left[\frac{d_0}{d}\right]^{\gamma} \tag{1}$$

Where:

–P_r is the received power expressed in dB_m
–P_t is the transmitted power expressed in dB_m
–d_0 is reference value for the far field of the antenna, for this work it is proposed to use $d_0 = 1m$
–d is the distance between the transmitter (eNodeB) and the point where the measurement is made with the spectrum analyzer (mts)
–γ is the exponent of the path loss.

Based on (1), received power (dB_m) is defined by (2)

$$P_r(dB_m) = P_t(dB_m) + K(dB) - 10\gamma log_{10}\frac{d}{d_0} \tag{2}$$

Where K is given by (3):

$$K(dB) = -20log_{10}\left[\frac{4\pi d_0}{\lambda}\right] \tag{3}$$

$P_t(dB_m)$ is considered to be 20W ($43dB_m$).
Equation (2), is valid if $d > d_0$

The value of γ depends on the propagation environment and together with K, determines the signal attenuation. To obtain the optimized value of γ , we use the adjustment method using the mean square error of the measurements made in the field (4) and the calculated values.

$$F(\gamma) = \sum_{i=1}^{n}\left[P_{empirical}(d_i) - P_{calculated}(d_i)\right]^2 \tag{4}$$

Where:

–$P_{empirical}(d_i)$ is the power measured by the spectrum analyzer
–$P_{calculated}(d_i)$ is $K - 10\gamma log_{10}(d)$, which is based on (2)

Using (3) , and considering , $d_0 = 0$ $f = 2130MHz$, K value is obtained in (5) :

$$\begin{aligned} K(dB) &= -20log_{10}\left[\frac{4\pi d_0}{\lambda}\right] \\ &= -20log_{10}\left[\frac{4\pi(1m)}{0.14085m}\right] \\ &= -39.009dB \end{aligned} \tag{5}$$

Substituting (2) and (5) in (4), we get (6):

$$F(\gamma) = \sum_{i=1}^{n}\left[P_{Empirical}(d_i) - (-39.009 - 10\gamma log_{10}(d_1))\right]^2 \tag{6}$$

Considering that $\frac{\partial F(\gamma)}{\partial \gamma} \to 0$, γ is obtained from (6), resulting in (7)

$$\frac{\partial F(\gamma)}{\partial \gamma} = \sum_{i=1}^{n}\left[P_{Empirical}(d_i) - (-39.009 - 10\gamma log_{10}(d_i))\right]^2 = 0 \tag{7}$$

An Anritsu Spectrum Analyzer (MS2713E) [9], configured in LTE Band 4 [10] in the downlink and EUARFCN 2150 channel [10] is used to perform eNodeB power measurements. The distance d_i is calculated by the Haversine equation, with the data of the eNodeB coordinates and the point where the measurement with the MS2713E is made [9]. For Lindavista zone, a 5.7 Km^2 area is analyzed in which 24 eNodeB are located and 8000 power measurements are made; for San Rafael zone is 7.5 Km^2 and 17 LTE transmitters are detected and 3000 power measurements are made.

In LTE networks, the Cell-ID is a global identifier that is assigned to each sector of a cell, the values that can be taken are 0-503, to make the measurements the MS2713E detects the Cell-ID with greater power and with base in it the measurements are made; Table 1 shows the data of the Cell-ID 99 for Lindavista zone, its location, number of measurements made for that transmitter and the minimum and maximum distances at which the measurements are made.

Table 1: Cell identifier for Lindavista zone (Cell-ID 99)

Cell ID	Longitude	Latitude	Measurements
99	19.448511	-99.156231	232

The minimum distance between eNodeB and the measurement is 10 mts, while the maximum distance between eNodeB and the measurement is 397 mts.

Substituting the 232 values of d_i Table 1 in (7), results in (8)

$$\gamma = 3.8188 \tag{8}$$

Substituting (8) in (2), we get (9)

$$P_r(dB_m) = 43 - 39.009 - 10(3.8188)log_{10}(d_i) \tag{9}$$

Hence, from (9) we can generalize the final form of the simplified equation for losses calculation of the LTE signal at the 2.13 GHz frequency, which is shown in (10).

$$P_r(dB_m) = 43 - 39.009 - 10(\gamma)log_{10}(d_i) \tag{10}$$

2 Measurement areas

To perform this work, two of the most common and interesting areas in México city are identified. For the election of these zones, the following criteria are taken into account:

- Constructive features
- Population
- Main activity in the zone
- Existence of open spaces
- Vegetation level
- Wideness of roads

After analyzing different zones to perform the study, a section of Lindavista colony and a section of San Rafael colony are chosen as measurement and analysis zones.

Zone 1, known as Lindavista, is located in the North of México city, which is an area of residential use, its main features are:

- Height between 10 and 15 meters. Very few constructions above 15 meters with mainly residential use
- Population: 21,601 inhabitants with little population most of the week.
- Main activity in the zone: residential and school zone.
- Existence of open areas: A big sports park, sports, cultural and governmental zone.
- Vegetation level: medium
- Roads amplitude: In the area analyzed, 4 primary roads with amplitudes of 5, 6 and 8 lanes are included. Remaining streets are mainly local traffic with an average of 4 lanes so it is considered an area of wide roads.

Zone 2, known as San Rafael, is located in México city center. The area has old buildings (dating from around 1900-1910) as well as a high development of apartment buildings. Additionally, it is one of the most important work and school zones in México city with a high level of floating population that considerably increases the people number who are present daily in the area.

- Constructive features: constructions of middle and high height that on average go from 3 to 10 floors. Oldest buildings are made of thick blocks
- Population: 60,644 inhabitants with high population most of the week. Being the headquarters of various companies and businesses, the amount of floating population is high most of the days
- Main activity in the zone: residential, labor and commercial zone
- Existence of open spaces: few, some sports courts in schools.
- Vegetation level: low
- Roads amplitude: In the area analyzed, 2 primary roads with amplitudes of 6 and 8 lanes are included. Remaining streets are mainly for local traffic with an average of 3 lanes so it is considered a zone of roads of medium amplitude.

Figure 1 shows the measurement zones selected

Fig. 1: Measurements areas (Lindavista zone and San Rafael zone)

3 Data processing and analysis

The empirical values are collected by the spectrum analyzer, and by the method shown in this work, equation (10) is found. The measured power values show a random behavior since electromagnetic propagation is affected by fading and multipath; that is why for the purpose of comparing the measured data against calculated in (10); a linear regression [11] is used in order to adjust the measured data to a straight line, Table 2 shows the first 5 values of the 232 measured for Cell-ID 99.

Table 2: Summary table for Cell-ID 99

#	Latitude	Longitude	Distance	Measured power (dBm)	Linear regression (dBm)	Calculated power (dBm)
1	19.448503	-99.156326	10.011	-65.6	-69.1263	-34.2094
2	19.448576	-99.156311	11.084	-68.6	-69.2000	-35.8977
3	19.448629	-99.156258	13.437	-68.1	-69.3617	-39.0898
4	19.44854	-99.156067	17.514	-58.5	-69.641	-43.4838
5	19.448605	-99.156082	18.817	-67.6	-69.7315	-44.6737

With the data calculated in (10) and the data in Table 2, Figure 2 is constructed, which shows the measured power values, the linear regression and the values calculated by (10).

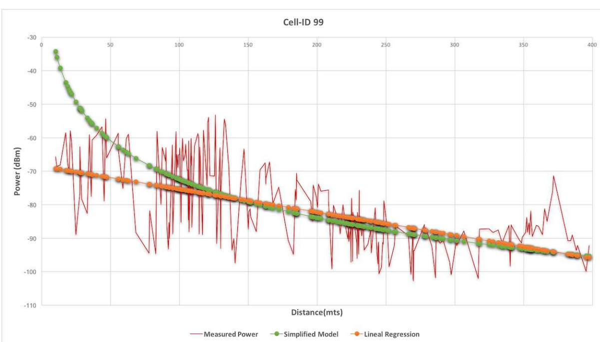

Fig. 2: Measured power values, linear regression and calculated values

From Figure 2 it is observed that the simplified equation has a good approximation to what is measured in field. To compare the power prediction of the simplified equation, Figure 3 shows the curves of Xia-Bertoni and Walfisch-Bertoni models which are widely used to model electromagnetic signals behavior.

From Figure 3, it can be seen that both Xia-Bertoni and Walfisch-Bertoni make a lower estimate compared with power measured in field. Equation proposed in (10) has a better approximation to what is measured with the spectrum analyzer. This same analysis is performed for all eNodeB found in Lindavista and San Rafael Zones. Figures 4 and 5 show the graphs for Cell-ID 453 (γ = 3.91951) and Cell-ID 370 (γ = 3.8306).

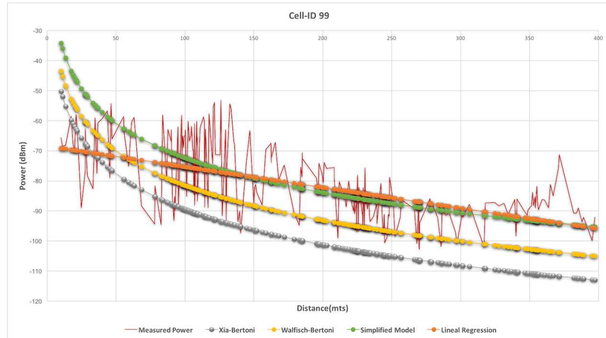

Fig. 3: Curves of Xia-Bertoni and Walfisch Bertoni models

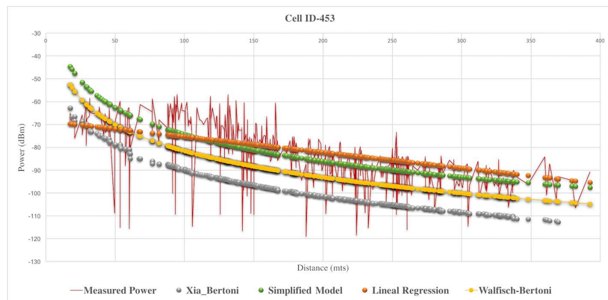

Fig. 4: Received power curves for Cell-ID 453

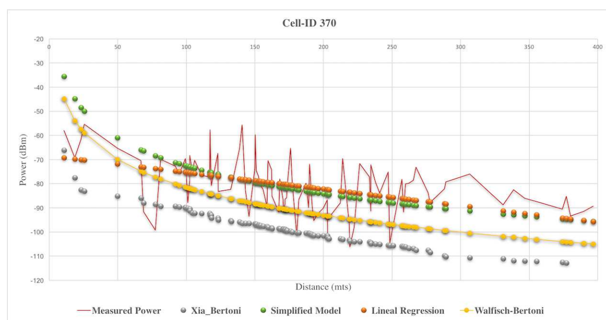

Fig. 5: Received power curves for Cell-ID 370

This procedure is repeated for the 24 eNodeB of Lindavista and the 17 of San Rafael, Table 3 shows the summary of the values of γ.

Table 3: Summary of γ values

Zone	Calculated Gamma (γ)	Average Gamma (γ)
Zone 1	3.2 up to 3.9	3.51
Zone 2	3.6 up to 4	3.84

Substituting the average value of γ in (10), the equation that describes electromagnetic propagation in Zone 2 (San Rafael) is given by (11).

$$P_r(dB_m) = 43 - 39.009 - 10(3.84)log_{10}(d_i) \quad (11)$$

And the equation for Zone 1 (Lindavista) is given by (12)

$$P_r(dB_m) = 43 - 39.009 - 10(3.51)log_{10}(d_i) \quad (12)$$

4 Conclusions

The result of this work is a simplified mathematical expression that calculates the received power of a LTE signal. Equation (10) has two advantages over the traditionally-used models, the first is its simplicity since, once the environment is characterized via γ, it depends only on the distance between the eNodeB and the receiver; the second is that based on Figures 3, 4 and 5, it presents a better fit to the data collected in the field compared to what is obtained via other models.

The above represents an advance in electromagnetic propagation, because this work provides a theoretical-practical procedure which simplifies the calculation of the received power of a mobile communications signal and that can be easily replicated in any environment of interest.

In México, the federal government is developing an LTE network with national coverage in the 700 MHz frequency band, this method can be applicable to this frequency band, characterizing the different propagation environments depending on the geographical region of the country.

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