TESTING THE COST231-WI PROPAGATION MODEL IN THE CITY OF LISBON

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Abstract - **The need for accurate propagation models has stimulated the development of theoretical methods taking into account the real buildings' structure. This paper presents results of an implementation of the COST231-WI model in the city of Lisbon and a comparison with measurements at the 900 MHz band. An additional attenuation has been introduced to account for the slope between the base station and the last building of the radio-path before the mobile station. Good results have been obtained with the new formulation: the average values of the mean error and of the standard deviation error are 3.9 and 2.3 dB, respectively. The main limitation in the application of the model to the urban area of Lisbon is the requirement for flat terrain and regular buildings' structure.**

I. INTRODUCTION

The increasing demand for mobile communication services and the consequent reduction of cell size has lead to the need of efficient planning tools and coverage predictions, especially in urban microcellular environments, where conventional empirical models fail. These models do not take into account the physics of the problem and, in spite of their small computational time, they have restricted area of application. The need for more accurate models has stimulated the development of theoretical methods, taking into account the real buildings' structure.

COST231 has developed a propagation model for predicting the transmission loss in urban small and micro-cells, the COST231-WI model [1]. This model accounts for the free space loss, the diffraction loss due to equally spaced buildings along the direct radio path and the diffraction and reflection losses from the roof-top of the near-by-building down to the mobile. It is based on the models of Walfisch and Bertoni [2] and Ikegami et al. [3]. Additionally, empirical corrections based on measurements performed in European cities were introduced.

In the following, the application of COST231-WI model to the city of Lisbon is discussed and the introduction of a new correction is proposed. The next section addresses the model implementation and its parameters calculation. The buildings' characteristics and the topographical data are presented in section III. Section IV describes the application of the model to the "Baixa" area and, as a result, the introduction of a supplementary loss with ground slope. In section V, a comparison between theoretical results and measurements is done, showing improved agreement. Finally, section VI draws the conclusions.

II. MODEL IMPLEMENTATION

The model developed by COST231 [1] is well know and has been recognized as a good one for small distances in urban environments, since it is recommended by ETSI for GSM [4]. The model is not general purpose because it must be applied to fairly regular urban structures, concerning streets width, buildings height and terrain level. These limitations pose some problems concerning its application in many cities. Lisbon in particular, with its "seven hills", is not a very good example of an area to test the model in a wide scale, because of its irregularity. However, some areas are very regular and its application to others less regular is a good test to see how the model behaves in those conditions.

The model has been applied to a zone of Lisbon for which a digitized terrain map with a 50 m resolution is available. In the implementation several parameters defining the urban structure must be calculated: street orientation (φ), road width (w), building separation (b) and building height (h_{roof}). One critical point in the model application to a real urban environment appears to be the definition of the propagation parameters. Due to the irregularity of real buildings' structure in respect to the assumed regular one, the values of b and h_{roof} have to be averaged along the direct radio path. However, a definition of the averaging zone is not simple and depends on the type of values that have to be calculated.

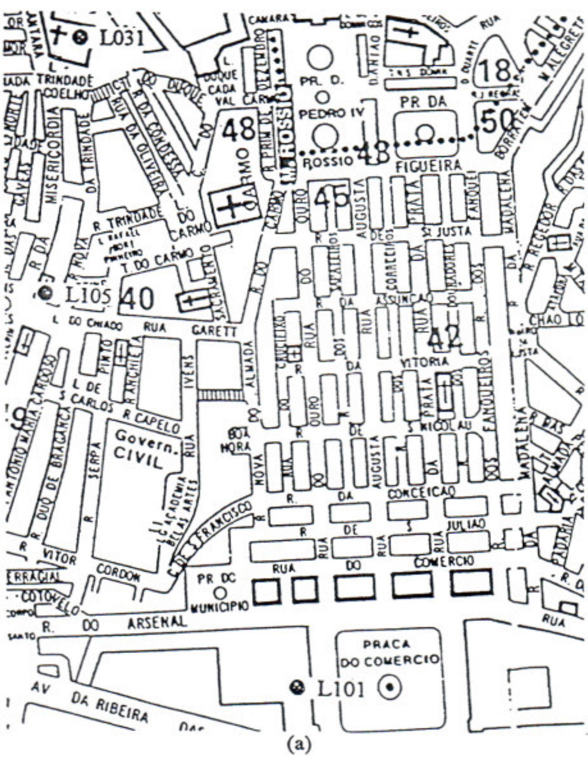
The b parameter is obtained by calculating the average of the bs of the streets interfering with the first Fresnel ellipsoid, associated to the direct ray between the base station (BS) antenna and the top of the last building before the mobile station (MS). To determine the buildings' average height all the buildings along the settling distance were considered at first, as indicated in [5]; however, the results obtained with this method were not satisfactory since it should only be used in case of small building height variation along the settling distance. For this reason, only the buildings that interrupt the first ellipsoid were included in the calculation of the average height and therefore the influence of the lower buildings was not considered.

Another problem was that in certain cases the attenuation due to buildings near the BS is underestimated by the model. It has been solved with the addition of a supplementary loss, as it will be seen later.

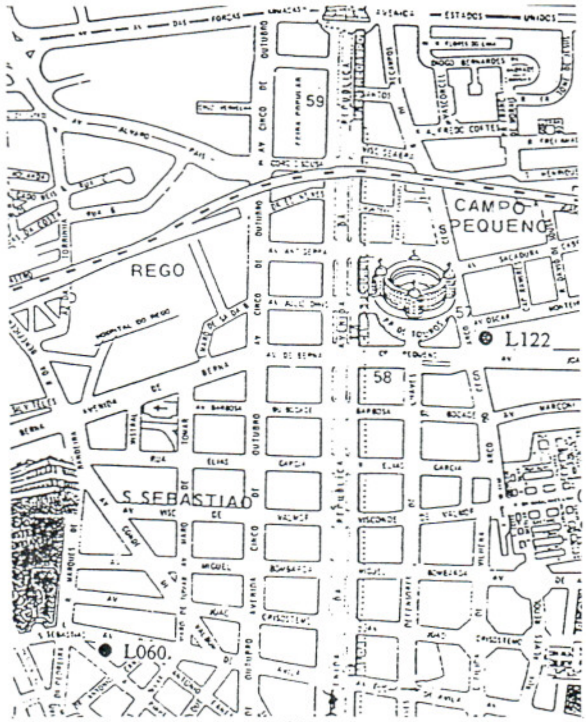
III. Measurement Areas

To assess the model, signal measurements at the 900 MHz band were performed in cooperation with one of the two Portuguese GSM operators, TELECEL [6]. These measurements were performed with the software Thems (from Erisoft) and a GPS system was used to register the mobile's position. A data processing application [7] was used to correct GPS errors.

The choice of the area for the model assessment was determined by the need to satisfy, as best as possible, the requirements of the model: homogeneous constructions, perpendicular streets and flat terrain. Therefore, the model was tested in "Baixa", which is the area of Lisbon that fits best all these characteristics. As it can be seen in Fig. 1.a, the perfect conditions mentioned above only exist in the area between "Rua do Ouro" and "Rua dos Fanqueiros", outside of which the level of the terrain



(a)



(b)

Fig. 1. Maps of "Baixa" area (a) and "Avenidas Novas" area (b), with the location of the base stations.

increases rapidly and the streets' pattern is no longer regular.

Having corrected the original model according to measurements done in "Baixa", the applicability of this new version to other areas of Lisbon where the streets' pattern is less regular and the variation of building height and roof shape is larger was tested. "Avenidas Novas" area, Fig. 1.b, was chosen since the area morphology and its surroundings fulfilled the requirements of the original model. Due to the difficulty in taking into account the inner yards, existent in some buildings of both studied areas, they were not implemented in the model.

The selection of the base stations was done considering the orientation of the main lobe: only the stations directly covering the mobile were chosen. This was done to avoid possible reflections on buildings surrounding the BS, not considered by the model, and also because of the inaccuracy of antennas' radiation patterns (made available by manufacturers) outside the main lobe.

IV. Application of The Model to "Baixa"

The parameters used to evaluate the results, i.e., to measure the difference between the theoretical and the experimental curves, were the mean error (μ) and the standard deviation error (σ) between predicted values and measurements' local mean. The local mean was estimated for each point with a "sliding window" in order to eliminate the fast variations of the signal.

A. Ground Slope Supplementary Loss

As expected, the results obtained with the original model for the BS L101A were very good, Fig. 2, since the model requirements for this BS were fulfilled. On the other hand, the theoretical curves calculated for the BS L031A presented a shift in relation to measurements, for all measured streets, being the predicted propagation loss inferior to the measured one. Therefore, a supplementary attenuation, affecting only this BS, was added to the model expressions.

Comparing the profiles of "Rua da Prata", Fig. 3, for the BS L101A and the BS L031B, the main difference that shows out is the level of the ground: while for the BS L101A the ground is practically flat, for the BS L031B there is an enormous slope between the BS antenna and the top of the last building (immediately before the mobile). Through a linear regression, for all streets, between this slope and the difference (in dB) between the theoretical and experimental curves, Fig. 4, the following empirical expression for the ground slope supplementary loss was found:

$$L_{desn[dB]} = \begin{cases} 1.37\Delta h_{[m]} - 59.3 & , \text{if } 43.7 \leq \Delta h \leq 56m \\ 0 & , \text{if } \Delta h \leq 43.7m \end{cases} \quad (1)$$

where Δh is the difference between the height of the BS antenna and the top of the last building (plus the respective terrain levels). This expression is not validated for height differences between 10 m (maximum slope registered for the BS L101A) and 45 m (minimum slope registered for the BS L031B).

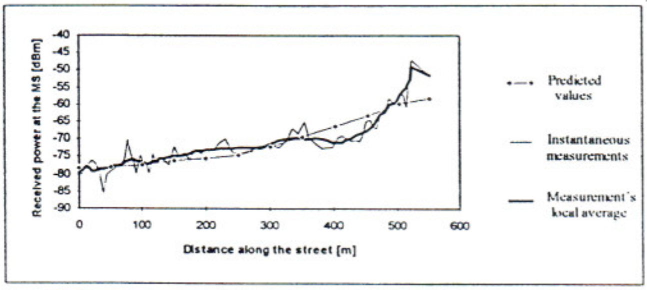


Fig. 2. Comparison of predicted and measured results for "Rua da Prata" with BS L101A: μ=2.2 dB and σ=2.0 dB.

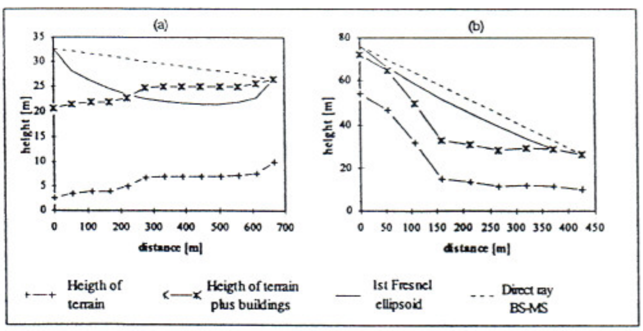


Fig. 3. Radio path profile at the beginning of "Rua da Prata" for: (a) BS L101A; (b) BS L031B.

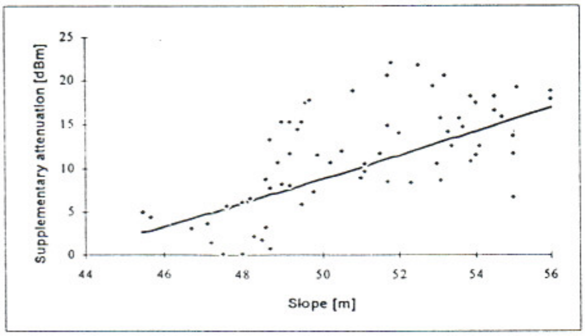


Fig. 4. Linear Regression between the ground slope and the prediction error.

This supplementary loss includes the effect of the obstruction due to buildings near the BS: in the original COST231 model, an increase in the Δh parameter means a more isolated antenna above the roofs (increase in Δh_{base}). However, in "Baixa" this does not happen because this increase in Δh is not caused by the use of a higher tower but by an increase in the ground level. This effect requires a more detailed analysis, with a theoretical approach, which will be done in the near future.

With this correction the pathloss estimated by the model is given by:

$$L_p = \begin{cases} L_0 + L_{rts} + L_{msd} + L_{desn} & \\ L_0 + L_{desn} & , \text{if } L_{rts} + L_{msd} \leq 0 \end{cases} \quad (2)$$

with:
- L_0 - Free-Space Loss [dB];
- L_{rts} - Roof-Top-to-Street Diffraction and Scatter Loss [dB], given by (8) in [1];
- L_{msd} - Multi-Screen Diffraction Loss [dB], given by (12) in [1];
- L_{desn} - Ground Slope Supplementary Loss [dB], defined in (1).

B. Correcting Factor with Street Orientation

There are two possible expressions for the correcting factor with street angle φ: the theoretical function defined by Ikegami [3]

$$L_{ori} = 10\log(\sin\varphi) \quad (3)$$

and an empirical function, (4), derived by COST231. The latter was obtained using measurements performed in Mannheim [8], a regular homogeneous built-up area and where the antenna height was in general lower than the average height of the surrounding buildings.

$$L_{ori[dB]} = \begin{cases} -10 + 0.354\varphi & , 0° \leq \varphi < 35° \\ 2.5 + 0.075\,(\varphi - 35) & , 35° \leq \varphi < 55° \\ 4.0 - 0.114\,(\varphi - 55) & , 55° \leq \varphi < 90° \end{cases} \quad (4)$$

Since the area where the model is to be applied does not verify, in general, all the requirements, it is important to determine which of the two definitions fits best. The results obtained, Table 1, show no significant difference between the two functions. Nevertheless, COST's definition was used in the final formulation of the model since it gives the best results.

It was also not possible to conclude whether Ikegami´s definition was a better approximation for non homogeneous urban areas, as defended by some authors.

Table 1. Mean values obtained for Ikegami´s and COST231´s definitions of correcting factor with street orientation.

Definition	$\overline{\mu}$ [dB]	$\overline{\sigma}$ [dB]
COST231	3.9	2.3
Ikegami	4.9	2.8

V. Comparison with Measurements

A. "Baixa" Area

The average of the mean error and of the standard deviation error for all the studied streets of "Baixa" was 3.9 dB and 2.3 dB, respectively. Considering the typical values obtained with this model, $\overline{\mu}$ = 4 dB and $\overline{\sigma}$ =6 dB, it can be said that the results obtained for this area were very good.

One of the best predictions was obtained for "Rua da Prata", Fig. 5. As it can be seen, the theoretical curve follows the measurements curve well, which results in a low mean error and low standard deviation error. It can also be noticed that with the introduction of the ground slope supplementary loss the results improved significantly: the mean error decreased from 10.5 dB to 2.5 dB.

Fig. 6 is an example of one of the worst results, found for "Rua dos Sapateiros" with the BS L101A. In this case the signal was expected to increase with distance as the MS was approaching BS L101A. However, as a consequence of the narrowness of this street, the diffraction loss at the last building down to the mobile is significant. So the pathloss is not determined only by diffraction and scattering at roof-tops but also by

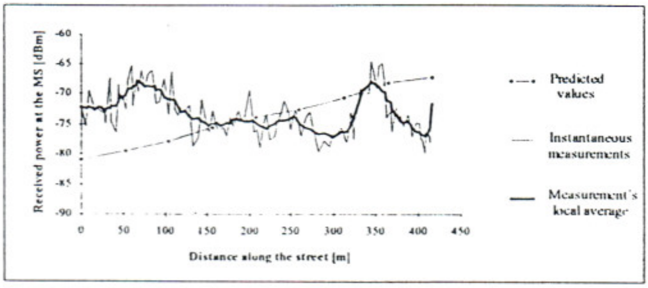


Fig. 6. Comparison of predicted and measured results for "Rua dos Sapateiros" with BS L101A: μ=4.7dB and σ=3.1dB

reflection and diffraction around the building corners. Because the main rays propagate in street canyons, the signal at the mobile is very influenced by the crossroads with transversal streets, as it can be seen in the experimental curve. The signal variations caused by the crossroads are not followed by the theoretical curve because the model does not consider them.

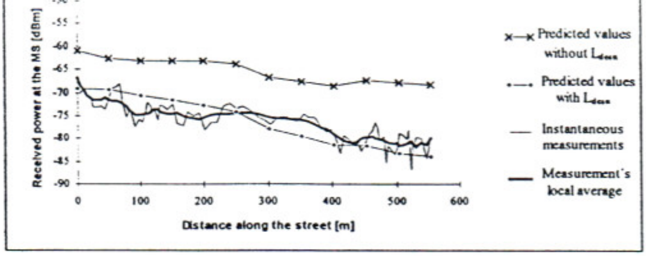


Fig. 5. Comparison of predicted and measured results for "Rua da Prata" with BS L031B: μ=2.5 dB and σ=1.0 dB with L_{desn}; μ=10.5 dB and σ =2.1 dB without L_{desn}

B. "Avenidas Novas" Area

The study performed in "Avenidas Novas" area was restricted to the analysis of the applicability of the model already developed.

The area is characterized by flat terrain, reasonable homogeneous building height and a regular building structure, with perpendicular streets. The distance to the base stations ranges from 450 m to 1500 m. However, there is also vegetation and tunnels not taken into account by the model.

The results are worse than those obtained in "Baixa", but the model still shows reasonable agreement with measurements. The average values of the mean error and of the standard deviation error, without considering the tunnels but including the effects of vegetation and crossroads, were $\overline{\mu}$ = 7.6 dB and $\overline{\sigma}$ = 3.5 dB.

One example of the influence of vegetation is presented in Fig. 7 for "Avenida 5 de Outubro" with the BS L060A. As it can be seen, the theoretical curve is consistently above measurements in the second half of the street, with a difference of approximately 8 dB. This attenuation is due, in particular, to the trees existent in the middle of the street in this stretch and that do not exist in the beginning of the street.

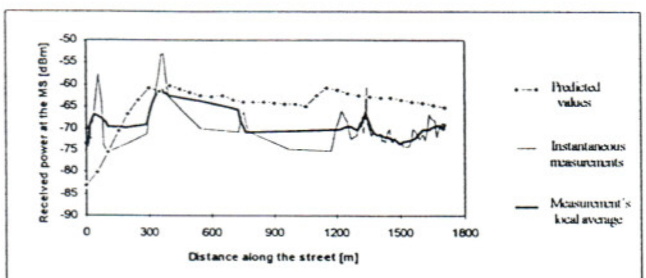


Fig. 7. Comparison of predicted and measured results for "Avenida 5 de Outubro" with BS L060A: μ=5.7dB and σ=3.1dB

Possible values for the supplementary loss due to vegetation are 15 dB for streets where vegetation is dense and large and 10 dB for vegetation not so dense. In the case of tunnels the proposed supplementary loss is 20 dB.

VI. Conclusions

Using measurements performed in a part of Lisbon, "Baixa", the model proposed by COST231-WI was corrected and a supplementary attenuation was added to its initial formulation. This new correcting factor only influences the results related to the base station located at a high level, L031B, and is not defined for height differences of the terrain greater than 53 m.

Good results have been obtained with the new formulation for both transmitters located in "Baixa": average values of the mean error and of the standard deviation error of 3.9 and 2.3 dB, respectively, below the typical values of 4 and 6 dB.

Results obtained when applying the model to "Avenidas Novas" indicate a reasonable adaptation of the model to measurements: $\overline{\mu} = 7.6$ dB and $\overline{\sigma} = 3.5$ dB. Only the mean error is above the typical mean error attributed to this model.

The main limitation in the application of the model COST231-WI to the urban area of Lisbon is the requirement of flat terrain and regular building structure. It is also important to include correcting factors to take into account the additional loss due to tunnels and vegetation.

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