SIGNAL ATTENUATION IN URBAN ENVIRONMENTS: A TEST CASE IN OPORTO

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1. Introduction

During the last decade, the field of mobile communications has gone through a veritable explosion, in terms of the number of system users and of geographical coverage. But the apparatus needed to provide "good coverage" depends on the area to be covered. Whereas in the countryside a small set of Fixed Stations (FS) will suffice, the situation is more challenging in an urban environment. This is primarily due to the presence of more complicated signal propagation phenomena and the larger concentration of systems users.

Another aspect that further complicates the task of providing urban coverage is the fact that some solutions applicable in a countryside situation, such has adding taller antennae systems, are not acceptable for cities. Related to this is the ever increasing political resistance to the implantation of operator antennae in places where people live or work. There are presently movements afoot that not only oppose the installation of new but also demand the removal of existent ones. Thus, the operators are faced with the difficult task of having to augment capacity in areas where it is very difficult to do so.

Knowing the signal propagation characteristics of urban environments has become very important for efficient signalling techniques used by the mobile communications systems. The net effect is that phenomena which, in a not too distant past had mostly academic interest, have become the concern of commercial systems operators.

In the literature there are various models, with varied complexity, used to predict the behaviour of signal propagation in an urban environment. With the purpose of providing another data point, a mobile system signal was tracked during a Test Drive in the downtown area of Oporto, which here will be referred to as the Baixa Area. The measured values were then compared with the predictions generated by three of the most pertinent models.

2. The Taking of measurements

The signal strength measurements were made using a Mobile Station (MS) provided by the *VODAFONE* operator. The equipment consisted of an Ericsson mobile terminal, the TEMS software from Ericsson and a GPS unit. The MS made inter- and intra-cells handovers systematically, in order to keep the received power above −85 dBm. According to *VODAFONE,* signal power values below this level will lead to unsatisfactory output quality. Figure 1 shows the variation in received power throughout the Test Drive.

The data were collected while the MS travelled within the rectangular area delimited by the co-ordinates: 41º09´50´´N, 08º06´47´´W to left top corner; and 41º08´34´´N,08º06´15´´W to right bottom corner.

During this interval, the MS interacted with three FS, namely:

1) FS 2828 at (41º09´39´´N,08º06´36´´W), with an omni-direcional antenna, down-tilted mechanically 3º to the North, located near the Santa Maria Hospital;

2) FS H271 at (41º09´26´´N,08º06´32´´W), with three symmetric sectors, located next to the Faria Guimarães Street and

3) FS H2026 at (41º08´45´´N,08º36´26´´W), with three sector symmetric sectors, located in the Batalha Area.

3. Theoretical background

A desired, simple, robust model for path loss is one which depends on the distance *d,* the frequency *f* and the MS antenna height ΔG. One possible expression for it is

$$PL(d)=A + B \log_{10}(d)+C \log_{10}(f_{MHZ})+\Delta G \tag{1}$$

with ΔG being given by [3]

$$\Delta G=20 \log_{10}(h_{re}/h_{ref}) \tag{2}$$

and where

h_{re}: MS antenna height (m);
h_{ref}: MS antenna reference height (m).

In a linear scale, equation (1) gives a path loss $pl(d)$

$$pl(d)=\alpha.d^{B/10}.f_{MHz}^{C/10}.10^{\Delta G/10}, \text{ with } \alpha<1 \tag{3}$$

In this expression, the distance d is raised to the negative of the propagation factor, $n=-B/10$ being greater than zero.
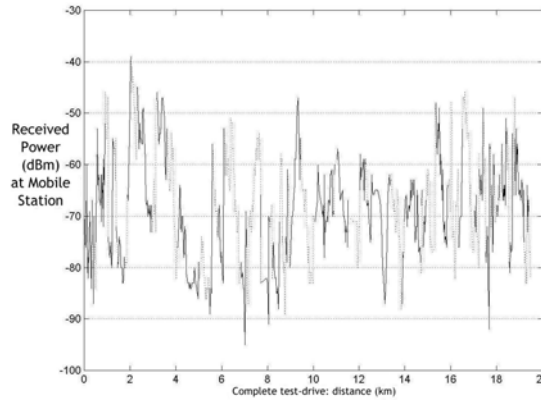

Figure 1: Received Power (dBm) during the Test Drive

As mentioned earlier, the measured signal power values were compared with those predicted by three propagation models, which were:
1) The Linear Regression (LR) model [4][5];
2) Lee's models for macro-cells [3][6];
3) The model based on the Okumura curves [7][8][9].

The expression for the LR model is $PL(d)=A_{reg}+B_{reg} \log_{10}(d)$, where the parameters A_{reg} and B_{reg} are obtained using a minimum square criterion. For its development, this model needs a certain number of data points, with which a line is created, the line then being used to predict values for distances not covered by the measurements. A consequence of the way the model is built up, the resulting logarithmic lines describe reasonably well the propagation behaviour of the zone under study. This type of model lends itself to an easy implementation and, accordingly, it is often found in the commercial software used for predicting propagation losses.

The second choice, Lee's model for macro-cells, establishes path loss formulas for three scenarios:
(a) LOS condition: The FS is in line-of-sight with the MS;
(b) NLOS condition: None or poor line-of-sight between the FS and the MS and
(c) There is a large water extension between the FS and the MS.

Building blockage being the prevailing situation during the Test Drive, the NLOS condition was chosen for the data analysis.

The third model considered is based on the Okumura curves. Values were read from the curves on the figures 41c) and 41d) in [9], for 900 MHz and 1500 MHz, respectively. A curve for 1800 MHz not being provided, the one for 1500 MHz was chosen as a good approximation. The general expression for this model is

$$PL=A(f_{MHZ}, h_{te})+B(f_{MHZ}, h_{te}) \log_{10}(d_{km})+\Delta G(h_{re}) \tag{4}$$

where $\Delta G(h_{re})$ is the gain defined by equation (2). During the Test Drive the MS antenna height was h_{re}=1.6 m, which is close to the h_{ref}=1.5 m recommended by [7].

From Figure 41 of [7], and taking into account that in the City of Oporto the antenna heights of the FS do not exceed 70 m and the distances of do not exceed 20 km, one obtains the path loss for 900 MHz and 1500 MHz, respectively. $A(f_{MHZ},h_{te})$ and $B(f_{MHZ},h_{te})$ are [8]

$$A(f_{MHZ},h_{te})=-116.6-0.0117f_{MHZ}+0.1h_{te} \tag{5}$$

$$B(f_{MHz}, h_{te}) = -\left(37.525 + 0.441\frac{f_{MHz} - 900}{600}\right) + \left(0.0625 - 0.0025\frac{f_{MHz} - 900}{600}\right) \times h_{te} \tag{6}$$

The path loss were obtained from equation (4) in Hata [9].

4. Comparison of the results

Table 1 contains the four lines obtained via regression. The first three are for the individual FS and the fourth is the line for test situation, that is, with the system going through a handover whenever the -85 dBm level was encountered, thus using all three FS.

Table 1: RL obtained for the path loss.

FS	Regression Lines (RL)	FS	Regression Lines (RL)
2828	$PL(d) = -34.92 - 34.06\log_{10}(d)$	H2026	$PL(d) = 389.97 - 194.1\log_{10}(d)$
H271	$PL(d) = 33.00 - 58.27\log_{10}(d)$	All Three FS	$PL(d) = -33.41 - 29.09\log_{10}(d)$

In Lee's model for macro-cells the path loss formula for a NLOS scenario is given by [3][6]

$$PL(d) = PL_{REF} + 10n\log_{10}(d_{REF}/d) + PL_D(d) + 10y\log_{10}(850/f_{MHZ}) \tag{7}$$

where

PL_{REF}: is the reference power (dBm) at a reference distance d_{REF} (m) from the FS antenna;

n: is the distance-dependent propagation factor, greater than 0 - equation (4);

$PL_D(d)$: is the diffraction loss due to obstructions between the FS and the MS, using one of several methods in [5][6];

f_{MHz}: is the frequency (MHz);

y: is the frequency-dependent propagation factor, with a value of 3, for f_{MHz}>850 MHz, and a value of 2 otherwise.

A value of 2.9 for the propagation factor n was obtained from the fourth Regression Line listed above, the one that used all three FS. As far as PL_{REF} and d_{REF}, given the scarce number of data points, the value of d_{REF}=1 m was assumed, which leads to the value of $PL_{REF} = PL_F(d=1$ m$) = -31.53$ dB.

Path loss and power prediction were obtained for each position i of the MS on the Test Drive [8]

$$PL_{observed}(d_i) = P_{observed} - EIRP_{jk} - G_n(\theta_{jk}, \varphi_{jk}) \tag{8}$$

$$P_{predicted}(d_i) = EIRP_{jk} + G_n(\theta_{jk}, \varphi_{jk}) + PL_{predicted}(d_i) \tag{9}$$

where the various parameters are listed below.

$PL_{observed}(d_i)$: observed path loss (dB);

$PL_{predicted}(d_i)$: predicted path loss (dB);

d_i: distance between antennas with MS at point i (m);

$P_{observed}(d_i)$: received signal power (dBm);

$P_{predicted}(d_i)$: predicted value of the received signal power (dBm);

$EIRP_{jk}$: EIRP power (dBm), radiated by antenna k from FS j already includes maximum gain g_{max};

$G_n(\theta_{jk}, \varphi_{jk})$: normalised radiation pattern of antenna k on FS j;

θ_{jk} and φ_{jk}: vertical and horizontal angles from antenna k in FS j with respect to MS.
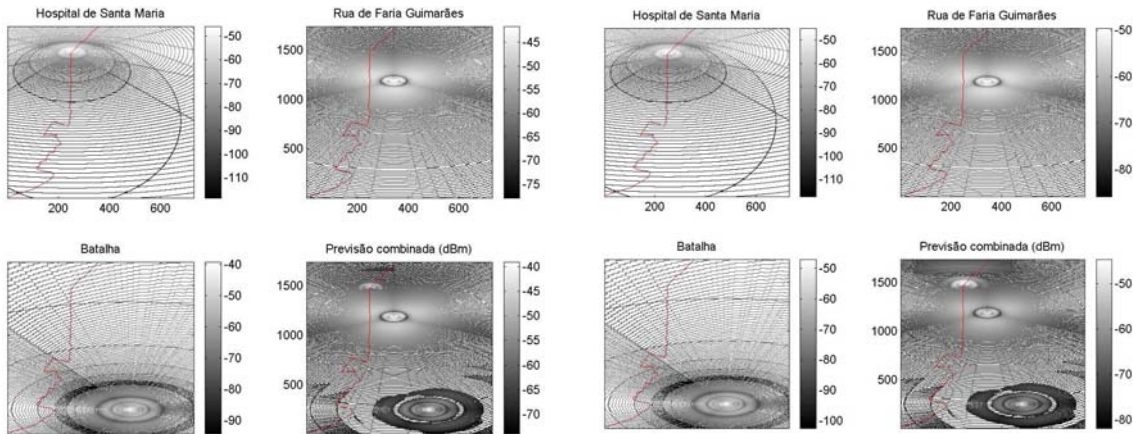

Figure 2: Power predicted using RL model.

Figure 3: Power predicted using Lee's model.

Figures 2, 3 and 4 show the results, for each considered model, when one goes through the prediction of the power from each FS and selects the maximum of the three. Using this criterion, the resulting graphs do not have discontinuities.

Figure 5 compares the predicted and measured power for the segment of the Test Drive in the Baixa Area. For each point, the predicted value selected is the largest of the three generated by the models.
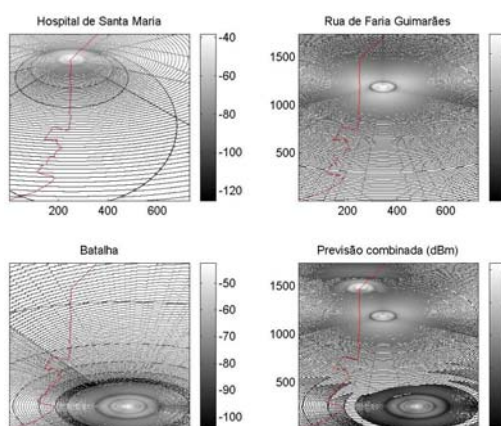

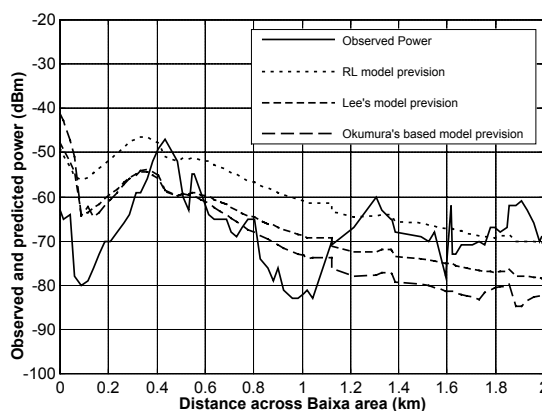Figure 4: Power (dBm) predicted using Okumura's based model.

Figure 5: Baixa Area: Predicted power (dBm) versus observed power.

5. Discussion and conclusions

Is expected that first three RL at Table 1 is in accordance with local propagation conditions near its FS, due to. the accordance of the fourth RL with propagation conditions of the overall Baixa Area. That conclusion is obtained if we look the low values of the absolute error and a standard deviation, of 0.16 dBm and 1.56 dB, respectively. The propagation factor n=2.91 is a good confirmation of the fact.

The obtained values for the absolute errors and standard deviations were, for the Okumura based model, 0.15 dBm and 1.42 dBm, respectively. In the case of Lee's model for macro-cells, the corresponding values were 0.13 dB and 1.23 dBm.

Of the three tested, the best model was Lee's, most likely due to n factor calculated with the RL model. The predicted results match quite well those generated by the predicting software tools used by the *VODAFONE* operator. To conclude, all three models are well suited to predict the behaviour of the path loss at Oporto's Baixa Area.

A. References

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B. Acknowledgement