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Radio Attenuation in Urban Environment: a test case in Oporto

João Paulo Pereira do Carmo
Instituto Politécnico de Bragança,
Campus de Santa Apolónia, 5301-857
Bragança, PORTUGAL,
jcarmo@ipb.pt

Joaquim José de Amaral Vieira e Costa
Faculdade de Engenharia da Universidade do Porto,
Rua Roberto Frias, 4200-465
Porto, PORTUGAL,
jjcosta@fe.up.pt

Abstract - This paper compares the measured performance of a mobile link in an urban environment with the values predicted by three models from the literature, namely: 1) the Linear Regression (LR) of the measurements, 2) Lee's model for macro-cells, and 3) the model based on the Okumura Curves. Globally, the agreement between predicted and measured values was good, the first two models being somewhat better than the third. The maximum observed absolute mean error and standard deviation were 0.16 dB and 1.56 dB, respectively.

I. 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.

The main contribution of this paper is a new propagation model to the downtown of Oporto, as well as, proposing modelling methodologies, in order to characterize the behaviour of propagation losses in any environment.

II. 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. Each sample was collected with a window having a 6 to 7 seconds duration, which, at 900 MHz and with a collection platform speed of about 60 km/h, is equivalent to 300 to 350 wavelengths.

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. Fig. 1 shows the variation in received power throughout the Test Drive, whose path – is rendered with the MATLAB - is illustrated in Fig. 2, with the indication of the downtown of Oporto (zone under study).

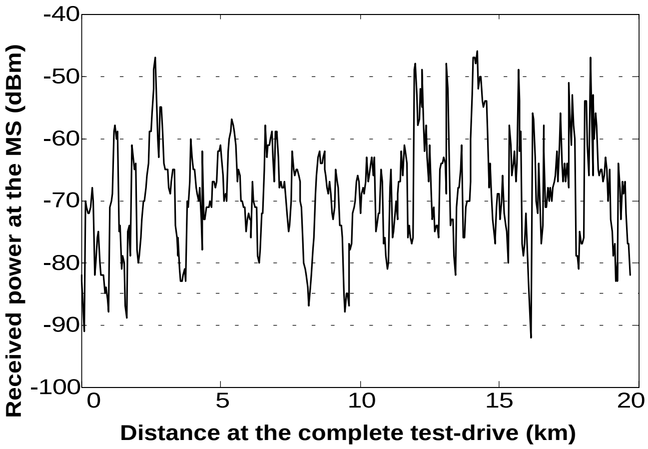

Fig. 1. Received Power (dBm) during the Test Drive.

The data were collected while the MS travelled within the rectangular area delimited by the co-ordinates:

- left top corner: 41º09´50´´N, 08º06´47´´W;
- right bottom corner: 41º08´34´´N,08º06´15´´W.

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

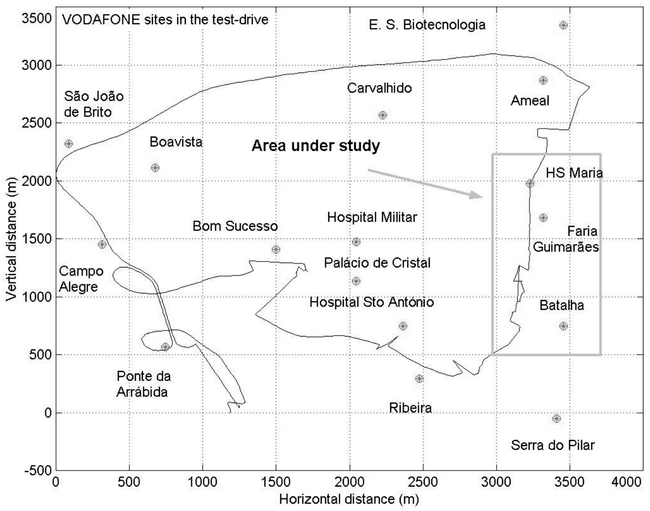

Fig. 2. Full path of the Test Drive.

III. 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 Δ*G*. One possible expression for it is

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

with Δ*G* being given by [3]

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

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*)

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

In this expression, the distance *d* is raised to the negative of the propagation factor, *n* being greater than zero, defined by

$$n=-B/10 \qquad (4)$$

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 $PL(\mathrm{d}) = A_{reg} + B_{reg}\log_{10}(d)$, 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 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 Figs 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

$$PL=A(f_{MHZ}, h_{te})+B(f_{MHZ}, h_{te})\log_{10}(d_{km})+\Delta G(h_{re}) \qquad (5)$$

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 Fig. 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 listed in Tables I and II, for 900 MHz and 1500 MHz, respectively. $A(f_{MHZ},h_{te})$ and $B(f_{MHZ},h_{te})$ are [8]

$$A(f_{MHZ},h_{te})=-116.6-0.0117 f_{MHZ}+0.1 h_{te} \qquad (6)$$

$$\begin{aligned} B(f_{MHz},h_{te}) = &-\left(37.525+0.441\frac{f_{MHz}-900}{600}\right)+\cdots \\ &+\left(0.0625-0.0025\frac{f_{MHz}-900}{600}\right)\times h_{te} \end{aligned} \qquad (7)$$

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

TABLE I
Values from Fig. 41c) in [7] for 900 MHz.

h_{te} (m)	d_{km} (km)	Field strength (dBμV/m)	Path loss (dB)
30	1	74	-124
	10	38	-160
	20	28	-170
50	1	76	-122
	10	42	-157
	20	32	-167
70	1	79	-120
	10	46	-153
	20	36	-163

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TABLE II
Values from Fig. 41d) in [7] for 1500 MHz.

h_{te} (m)	d_{km} (km)	Field strength (dBμV/m)	Path loss (dB)
30	1	71	-131
	10	35	-168
	20	25	-178
50	1	74	-129
	10	39	-164
	20	29	-174
70	1	76	-127
	10	42	-161
	20	32	-171

VI. Comparison of the results

Table III 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 III
RL obtained for the path loss.

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

$$PL(d)=PL_{REF}+10n\log_{10}(d_{REF}/d)+PL_D(d)+\cdots \quad (8)$$

$$\cdots+10y\log_{10}(850/f_{MHZ})$$

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 $PL_{REF} = PL_F(d=1\ \text{m}) = -31.53$ dB.

Path loss and power prediction were obtained for each position i of the MS on the Test Drive [8] by following the methodology depicted in Figs 3 and 4, respectively.

$$PL_{observed}(d_i)=P_{observed}-EIRP_{jk}-G_n(\theta_{jk},\varphi_{jk}) \quad (9)$$

$$P_{predicted}(d_i)=EIRP_{jk}+G_n(\theta_{jk},\varphi_{jk})+PL_{predicted}(d_i) \quad (10)$$

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, that 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.

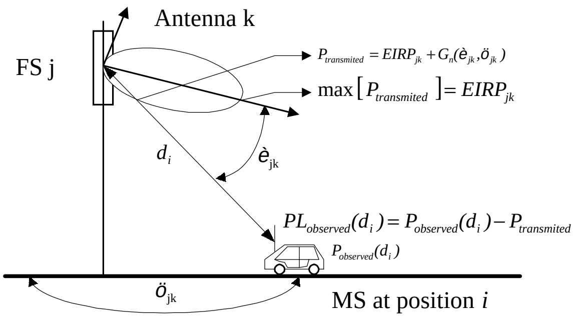

Fig. 3. Methodology used on observed path loss.

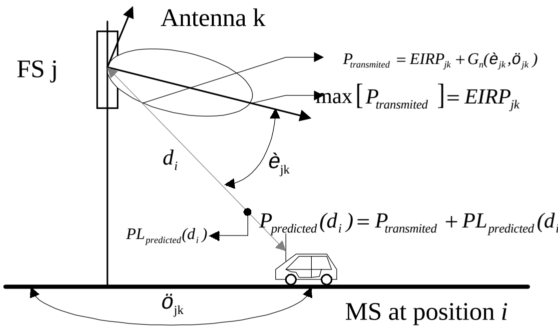

Fig. 4. Methodology used on power prevision.

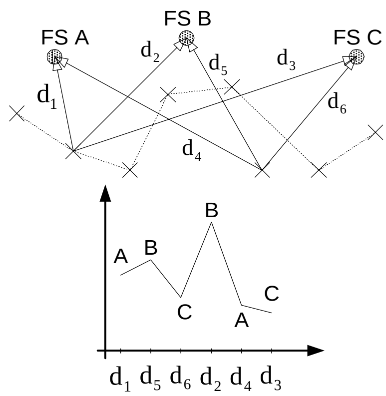

Fig. 5. Method used to combining all FS.

The predicted values signal power for the three models

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are given in Figs 6, 7 and 8. The right-bottom picture represents the combined signals from the three FS. That combination was made by sorting the distances to the FS in an increasing order, as illustrated in Fig. 5. The other three pictures are the predicted power, taking in account a separated FS.

For each considered model, the combined power is obtained 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.

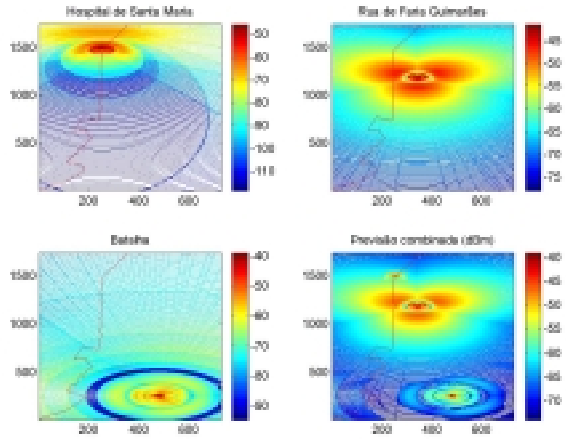

Fig. 6. Predicted power (dBm) at MS using RL model.

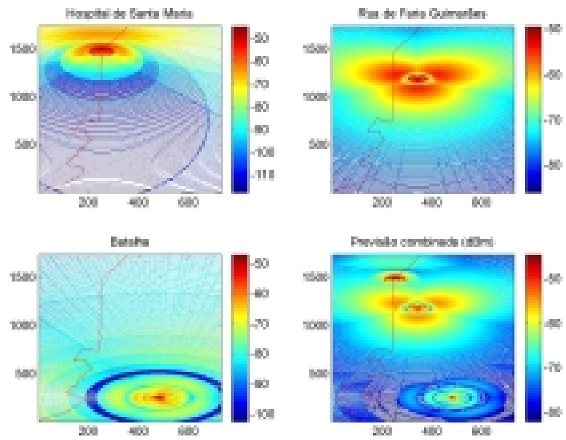

Fig. 7. Predicted power (dBm) at MS using Lee's model.

Table IV lists, for each of the models, the mean of the absolute errors at each position i and the respective standard deviation . The absolute error ε_i given by

$$\varepsilon_i = |P_{predicted}(i) - P_{observed}(i)| \qquad (11)$$

where

- $P_{observed}(i)$: power of the signal received (dBm);
- $P_{predicted}(i)$: prevision to the power of the received signal (dBm).

The mean absolute error (dB) and the standard deviation (dB) are respectively,

$$\bar{\mu} = \frac{\sum_{i=1}^{N} |\varepsilon_i|}{N} \qquad (12)$$

$$\sigma = \left[\frac{\sum_{i=1}^{N} \left(|\varepsilon_i| - \bar{\mu} \right)}{N} \right]^{\frac{1}{2}} \qquad (13)$$

In each sum above, N is the number of samples acquired on the Baixa Area, a subset of those collected during the Test Drive.

Fig. 9 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

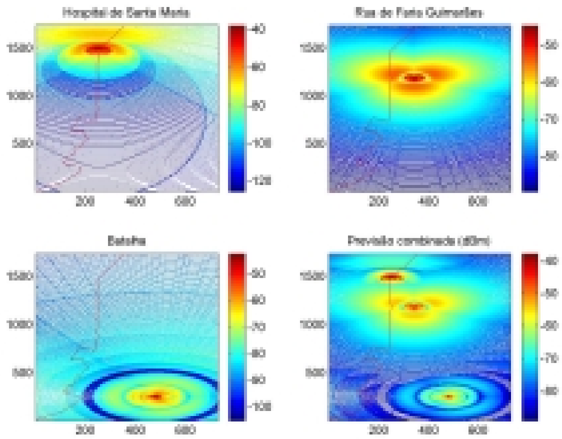

Fig. 8. Predicted power (dBm) at MS using Okumura based model.

TABLE IV
Mean absolute error and standard deviation.

FS	Model	$\bar{\mu}$ (dB)	σ (dB)
2828	RL	17.69	0.99
	Lee	16.89	0.97
	Okumura	21.68	1.04
H271	RL	10.24	0.89
	Lee	8.11	0.59
	Okumura	9.44	0.75
H2026	RL	7.56	0.72
	Lee	12.46	0.91
	Okumura	16.80	1.11
Three FS	RL	0.16	1.56
	Lee	0.13	1.23
	Okumura	0.15	1.42

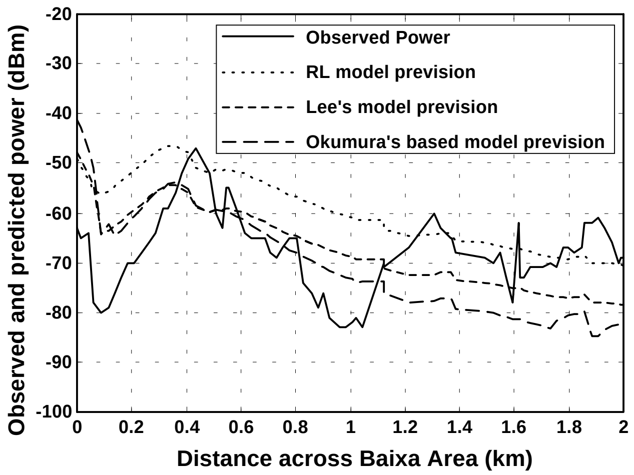

Fig. 9. Baixa Area: Predicted versus observed power (dBm).

V. Summary and Conclusions

Is expected that first three RL at Table III 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 dB 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 dB, respectively. In the case of Lee's model for macro-cells, the corresponding values were 0.13 dB and 1.23 dB. Of the three tested, the best model was Lee's, most likely due to n factor calculated with the RL model.

Finally, 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.

Appendix

Figs 10, 11 and 12 illustrates the radiation patterns (RP) of the antennas at the three fixed stations referred above.

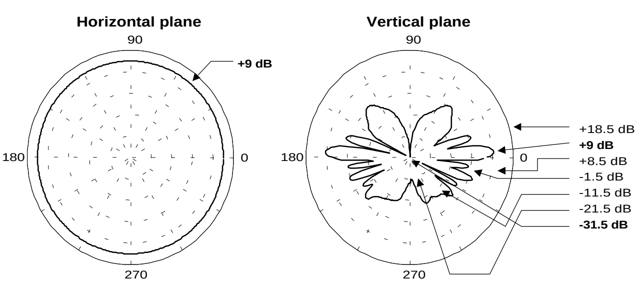

Fig. 10. RP of the antenna at the fixed station 2828.

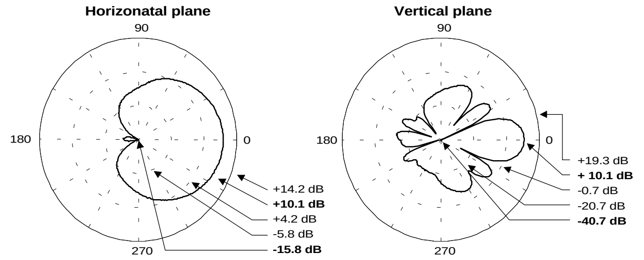

Fig. 11. RP of the antennas at the fixed station H271.

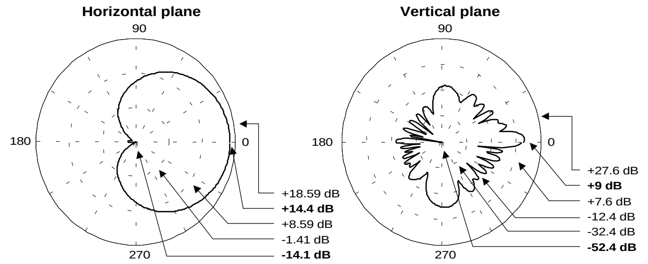

Fig. 12. RP of the antennas at the fixed station H2026.

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