Validation of the Unified Propagation Model for Wi-Fi, UMTS and WiMAX Planning

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Abstract—**This paper presents the validation of the unified propagation model, the Lisbon University Institute (LUI) model, which is valid for three wireless technologies: Wireless Fidelity, Universal Mobile Telecommunications System and Worldwide Interoperability for Microwave Access. With this purpose in mind, several experimental trials for those technologies were performed in different scenarios, where mixed environments (outdoor and indoor) were included. This generalized and unified propagation model was tuned by adjusting specific parameters for each different technology, based on the achieved results from the field experiments.**

Keyword—LUI Model, Unified Model, Propagation Model, Outdoor, Indoor, Mixed, Path Loss, Wi-Fi, UMTS, WiMAX, Experimental Trials.

I. INTRODUCTION

Nowadays, planning tools are very important in the planning or optimization processes of a wireless network. These tools, with the help of propagation models and geographic and topographic information systems, have the ability to simulate and plan wireless networks. The main objective of the propagation models is to estimate the received power at a given reception point, at a certain distance from the transmitter. With that average value of the received power at the given reception point, it is possible to define goals and objectives in building wireless networks. If the propagation models together with the geographic and topographic information systems represent reality as accurately as possible, there is an increase of the probability of having a better correlation between the real acquired signal and the signal simulated by planning tools.

To develop a reliable propagation model it is necessary to validate it by obtaining results from experimental field trials. Nowadays, most propagation models are developed to be used in an outdoor or indoor environment. The objective of this paper is to validate the unified propagation model proposed in [1], the Lisbon University Institute (LUI) model, whose main objective is to obtain the estimation of the path loss of the received signal in a scenario with one (outdoor or indoor) or two types of environments (outdoor and indoor) considering the range of frequencies that allow the planning with Wireless Fidelity (Wi-Fi), Universal Mobile Telecommunications System (UMTS) and Worldwide Interoperability for Microwave Access (WiMAX) technologies, operating in pico-cells, micro-cells and macro-cells, respectively.

The arrangements for all experimental trials foresaw to have at least one mixed scenario for each technology. However, in the Wi-Fi case, in addition to the mixed scenario, a scenario with only the indoor environment was also considered, since the transmitter antenna from the Access Point (AP) can be mounted inside the building, aiming to provide dedicated network services only for indoor users.

Different procedures were adopted for each trial, according to each scenario and technology. Different transmitter and receiver stations were used. In all experimental results it was obtained 2000 samples for each point considering a confidence level of 99%.

The remaining of this paper is organized as follows. Section II describes the scenarios and the equipment involved in Wi-Fi experimental trials. Sections III and IV follows a similar approach for UMTS and WiMAX field trials, respectively. Section V addresses the parameters to be used in the LUI model, distinguishing them by the type of environment and technology used. Finally, Section VI presents the conclusions.

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II. Wi-Fi Experimental Trials

A. *Wi-Fi – Mixed Scenario*

For Wi-Fi technology, the experimental field trials were carried out in the ISCTE-LUI building (Edifício 1), as well as other surrounding buildings (Corpo A, B, C and INDEG). Fig. 1 shows the scenario and the path for the measurements in the site survey. In this figure the blue dot represents the AP position (its height is 7.5 metres); the red dots represents the ground positions for the first section of the outdoor measurement path (terminal station, TS, height is 1.5 metres); the yellow dots represents the ground positions for the last section of the outdoor measurement path (terminal station height is 3 metres); the green dots represent the indoor measurement positions, for floors 0, 1 and 2, with heights of 4.5, 8 and 11.5 metres, respectively).

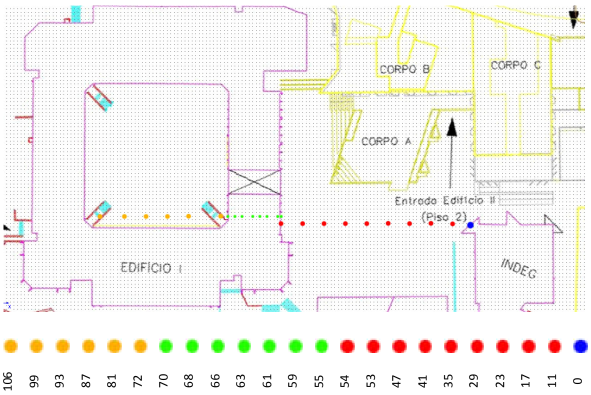

Figure 1. ISCTE-LUI complex and distances from each TS point to the AP.

The rectangular grid (with small dots) defines a spacing of 1 metre. The legend in Fig. 1 shows the distance (in metres) from the AP to the respective positions of the terminal stations.

The height of each floor is about 3.5 metres and the interface is composed by glass windows separated by aluminium frames. Each window has 2.5 metres of height and 2 metres of width.

The Path Loss (PL) between the transmitter and the receiver is given by the following equation [2]:

$$PL_{[dB]} = EIRP + G_R - P_R \tag{1}$$

where the Effective Isotropic Radiated Power (*EIRP*, usually in dBm) is the sum of the transmitting power, P_T, with the transmitting antenna gain, G_T; G_R is the receiving antenna gain, in dBi, and P_R is the received power for the position of the receiving terminal, in dBm. The losses of cables are disdained.

In this scenario we have P_T=17 dBm, G_T=2 dBi and G_R=0 dBi. Fig. 2 represents the experimental and the LUI model results for the PL. In Fig. 2 shows that, for the indoor path, the results obtained by LUI model are different for each floor. The PL is lower for the 1st floor, once the height of AP is similar to the height of the floor. This figure shows that the LUI model has the ability to represent these behaviours in three different floors, taking advantage of using the parameter G_f, which represents the height floor gain at the terminal for each floor of Edifício I [1]. This parameter was obtained according to the experimental results and, for this scenario, can be found in Table 3, Section V. In Fig. 2 it is shown that experimental results do not agree with LUI model results for distances higher than 70 metres. This is justified by the shadowing position of the terminal station. However, for distances longer than 90 metres, it is verified that experimental results are closer to those of the LUI model.

B. *Wi-Fi – Scenario with Indoor Environment*

For this scenario we considered one AP at Edificio I – ISCTE-IUL, Fig. 3. The path includes several walls and its materials and the interface between floors.

The paths taken in these experimental trials are represented in Fig. 3. The blue dot shows the position of the AP, at 1st floor, with a height of 3 metres above the ground. The yellow dots show the site survey path for the rooms on the left. The green dots show the site survey path in the hallway between the 1st and 2nd floors. Finally, the red dots show the site survey path for the rooms on the right. The terminal station height was 1.5 metres. The distance of each point from the AP can be observed later on Fig.4, where it shows that the LUI model represents the PL in four different paths. In this scenario, P_T=17 dBm, G_T=3 dBi and G_R=0 dBi.

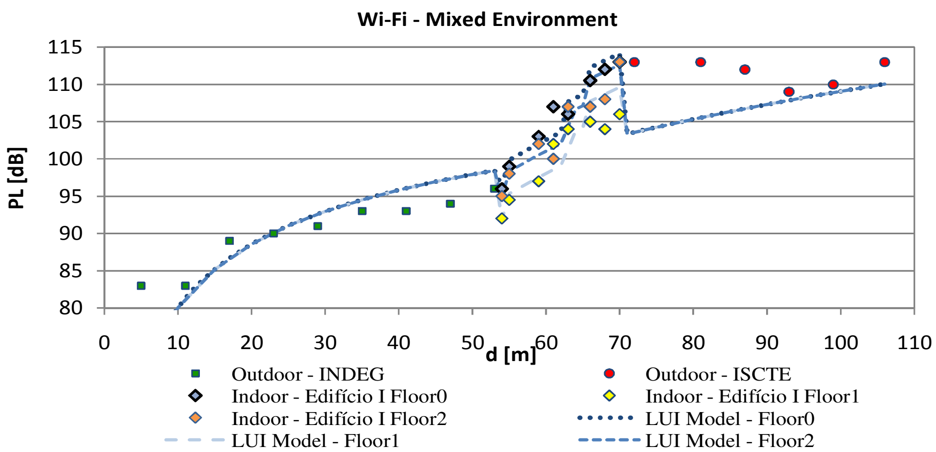

Figure 2. Application of the LUI model for a mixed scenario, using the Wi-Fi technology.

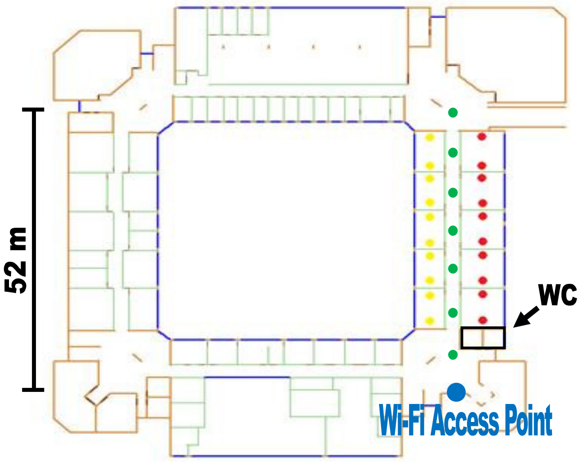

Figure 3. Site survey for indoor environment in Edifício I at ISCTE-LUI.

It can also be verified that experimental results agree with those from the LUI model. Since the breakpoint distance is shorter in the red path than in the yellow one, this leads to greater PL values for this path, because the attenuation from the two toilet walls need to be accounted for. The same can be concluded for the measurements made in the two hallways.

It is important to note that other calculation paths were assumed for this scenario. One option was to establish a direct ray between the transmitter and each terminal point, and another one was to trace the beam across the hallway to the room, where the respective point belongs to, and then to trace another beam cutting the corresponding room wall, till the terminal reception point. Relatively to the first option, the points of the rooms further away from the AP were not accounted as having a concrete wall, but a brick wall instead, which decreased the PL in those last points, in contrast with the results obtained experimentally.

On the other hand, the second option is more consistent with the idea of the dominant path model, where the LUI model results deviated significantly from the experimental results, because a single wall was considered for each terminal point, instead of a brick wall as a breakpoint.

III. UMTS Experimental Trials

The scenario chosen for these trials took into account the location of the Portuguese telecommunications company NetPlan and its surrounding area. This choice relates to the fact that, this was the company that provided the equipment for carrying out the various outdoor trials as well as the indoor trials which took place at the company building.

This company is headquartered in a business building in Telheiras, Lisbon, Portugal. Its neighbourhood is characterized by an urban environment where buildings have irregular heights (between four and eight floors). The streets are also characterized as irregular and may be narrow to wide (between 10 and 50 metres width).

Fig. 5, taken from the Google® Earth application, shows the area chosen for these trials and the location of the building, where the company NetPlan (2nd floor) is installed, while Fig. 6 shows the indoor environment where three different paths of site surveys were performed, which is characterized by a typical office setting.

The interface between environments contains glass windows with about 1.2 metres high and 1 metre wide, separated by a regular metal frames.

In this scenario, the UMTS 120º sectored transmitting antenna is operating at 2.2 GHz. It is placed at 22 metres height with 240º azimuth, 5º electrical down tilt and 0º mechanical down tilt. The distance between the transmitting antenna and the interface is approximately 145 metres. In this scenario, P_T=31.9 dBm, G_T=9.5 dBi and G_R=4 dBi. Fig. 7 represents the experimental and LUI model results considering the mixed scenario (with the blue indoor path, as shown in Fig. 6). Fig. 8 shows the results only for the indoor environment with the three paths.

Fig. 7 shows that for the first part of the outdoor path, the LUI model presents some differences from experimental results. This is due to the fact that these points, in addition to being in a nearest area of the transmitting antenna, have been measured in shadowed areas caused by surrounding buildings. In the second part of the outdoor path, in spite of all points having been measured with Non-Line-of-Sight (NLoS), the model already presents more consistency with experimental results.

In Fig. 7, it can also be observed that the results obtained experimentally in the indoor part have a gain because they were measured on the 2nd floor, which benefits of Line-of-Sight (LoS) to the transmitting antenna. This height floor gain, represented by G_f, was determined by using the same procedures as Toledo and Turkmani [3] and the result could be obtained in Table 3, Section V. The propagation exponents γ_1 and γ_2 were calculated through Tables 1 and 2 since this scenario is characterized as Type C (see Section V).

The behaviour at different paths for indoor environment is shown in Fig. 8, which shows that the model presents small differences between the LUI model and experimental results. In this figure, path 1 (green) shows the worst results. This is due to the fact that this path is on the side of the building, which is influenced by the signal that arrives through lateral windows of the building.

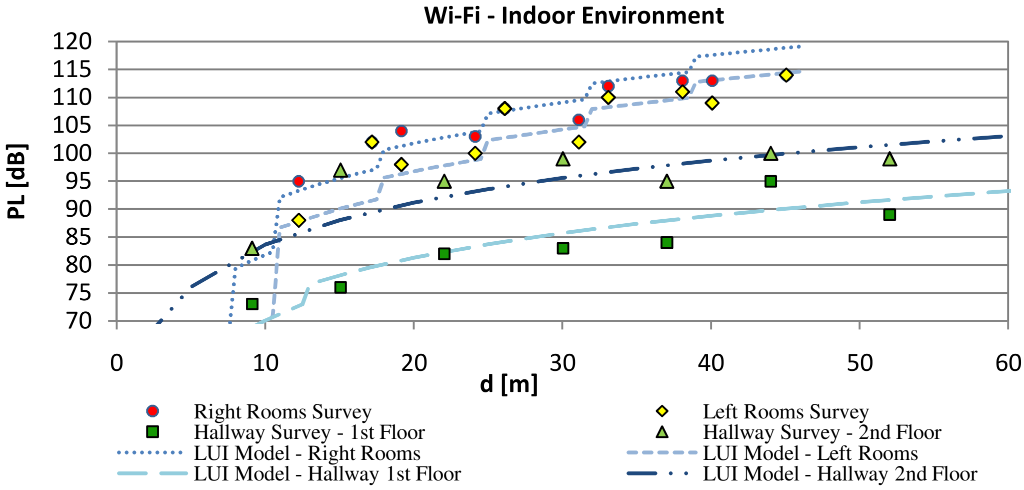

Figure 4. Application of the LUI model for an indoor environment in Edifício I at ISCTE-LUI, with the Wi-Fi technology.

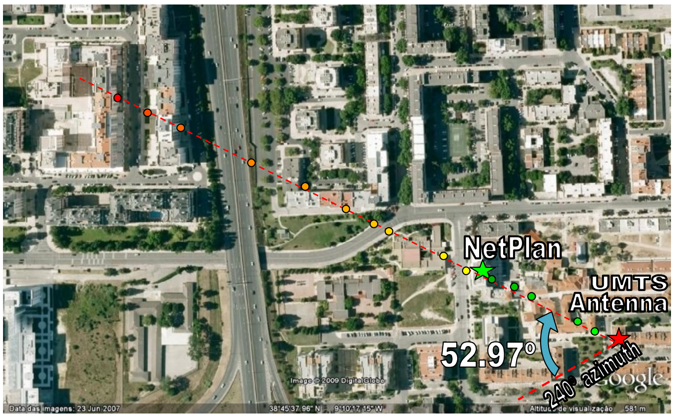

Figure 5. Site survey in outdoor environment for an urban scenario with the UMTS technology.

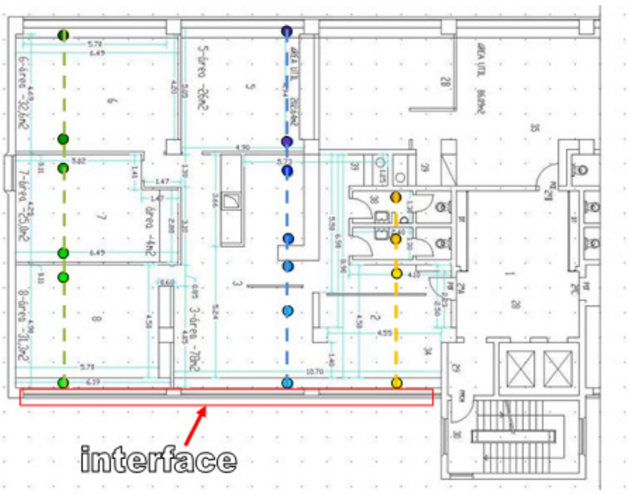

Figure 6. Site survey in indoor environment for the UMTS technology.

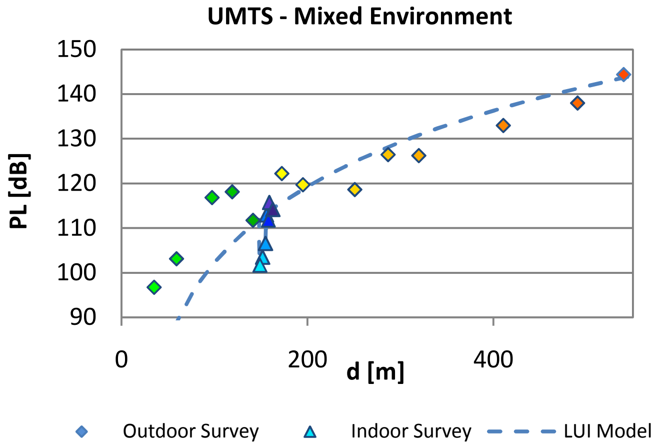

Figure 7. Application of the LUI model for a mixed scenario, with the UMTS technology.

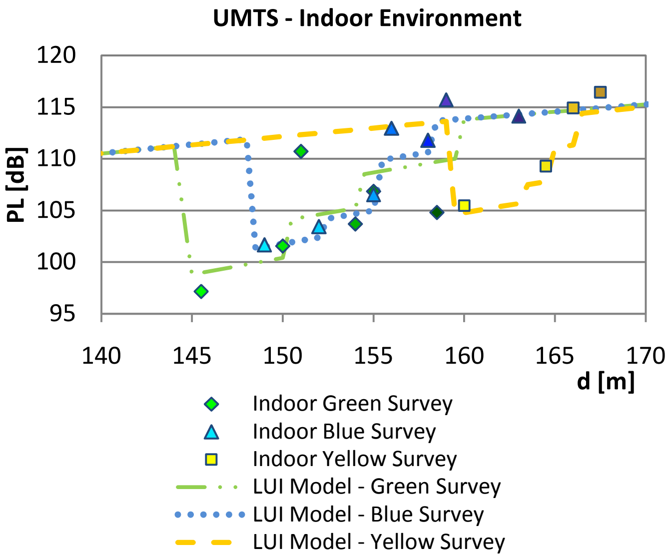

Figure 8. Application of the LUI model for an indoor environment, with the UMTS technology.

IV. WiMAX Experimental Trials

The WiMAX field trials were carried out at the Portela Airport, in Lisbon, Portugal, one of the few mobile WiMAX network (IEEE 802.16e) deployments in Portugal. This network aims to provide voice and multimedia services for the airport users or employees; however, this network is still being tested. Five WiMAX transmitting antennas are implemented to provide coverage to this 2 km^2 area. Fig. 9 illustrates the scenario where trials took place. It represents the outdoor environment as well as the Terminal 2 where the indoor trials took place. Terminal 2 is characterized by having a large open space with no internal walls (but with stores at its end). The windows of Terminal 2 correspond to the interface of the two environments and are composed by glass with metal frames and each one has a height of 2.20 metres and a width of 3 metres.

In order to analyze the signal propagation in this mixed scenario, a transmitting antenna that covers both indoor and outdoor environments was chosen. Thus, the selected antenna was operating at a frequency of 3.5455 GHz; it has an effective height of 15 metres, an azimuth of 245º and a mechanical down tilt of 2º. The dashed straight line which intersects several marked points, shown in Fig. 9, represents the path set for the received signal power measurements over the outdoor and indoor environments. As shown in this figure, some marked points do not coincide with the line drawn. This is because the access to certain areas was restricted and, as such, it was not possible to perform measurements in those positions.

Based on the specification of the equipment the P_T=35 dBm, G_T=18 dBi and G_R=4.5 dBi. This scenario is characterized as Type A (see Section V).

The PL for each reception point is represented in Fig. 10 (mixed scenario) and in Fig. 11 (scenario with only indoor environment), considering experimental and LUI model results.

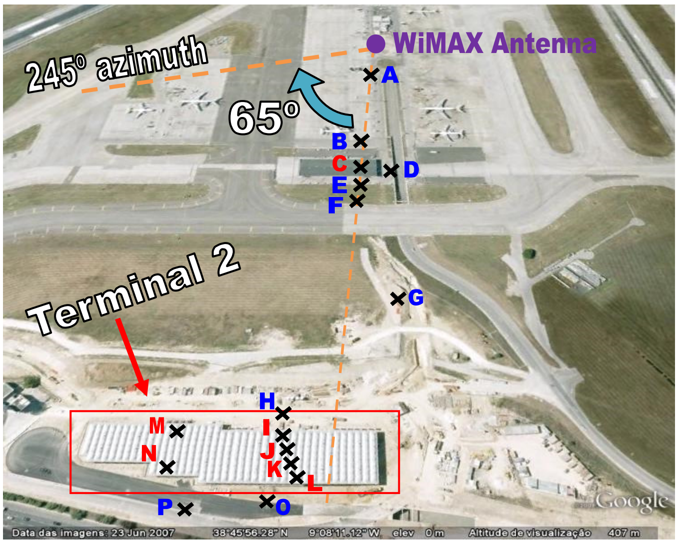

Figure 9. Site Survey route for the mixed scenario with WiMAX technology.

Fig. 10 shows that the LUI model presents some differences to experimental results, since several points had been measured in areas of shadowing. Besides, there was no possibility to take measurements at certain positions of the path. For the indoor environment, despite the small number of measurements, the LUI model presents results consistent with those obtained experimentally. Fig. 11 shows that the model does not follow the measurements made at the last indoor point, since the loss caused by one bookshelf was not accounted for, as we could not find an appropriate model in references for this type of object.

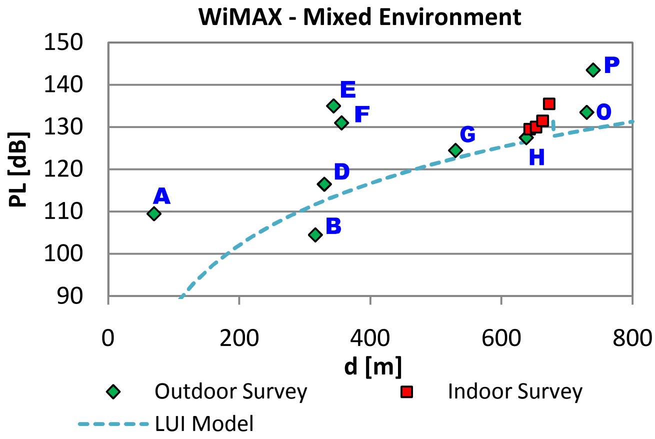

Figure 10. Application of the model LUI for a mixed scenario with the WiMAX technology.

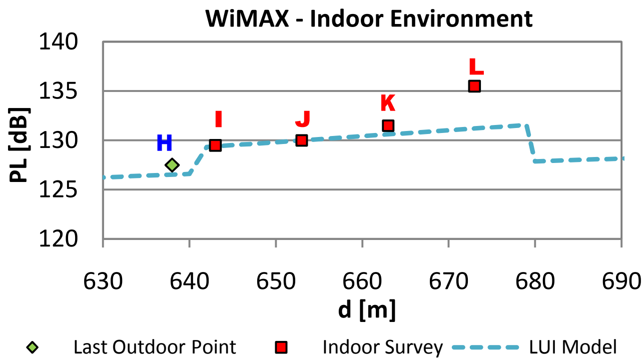

Figure 11. Application of the model LUI for an indoor environment with the WiMAX technology.

V. Parameters For the LUI Model

According to several experiments for the different communication technologies considered in this work, we showed that the LUI model behaves differently for each scenario. Tables 1, 2 and 3 summarize the most appropriate parameters to be used in the LUI model for the three technologies of this study. Table 1 presents the frequency, f, used for these three kinds of technologies; the reference distance, d_0; and k_{TEC} which is a constant that represents the dependence on the cell dimensions (and on the technology) used for the effective height correction factor, X_h, calculation [1].

Parameters	Wi-Fi	UMTS	WiMAX
f [Hz]	2.4×10^9	2.2×10^9	3.5×10^9
d_0 [m]	1	25	100
κ_{TEC}	24	10.8	20

Table 1. Parameters to be used in the LUI model for the three technologies.

γ_1 parameters	Terrain Category		
	A	*B*	*C*
a	5.15	4.0	3.6
b [m^{-1}]	0.0075	0.0065	0.0050
c [m]	14.6	17.1	20.0

Table 2. Parameters of γ_1 to be used in the LUI model for outdoor or mixed scenarios of the UMTS and WiMAX, by the different terrain categories.

Results from Table 2 were obtained from the experimental fields trials for WiMAX technology [4]. However, it was adjusted by the results of the UMTS and WiMAX experimental trials, being able to represent these two technologies. In this Table three types of terrain are distinguished: A, B and C. Type A represents a light path loss terrain and can be used for hilly areas with moderate or very dense vegetation. Type B mainly characterizes flat terrains with moderate or very dense vegetation or hilly terrains with rare vegetation. Type C is suitable for flat terrains with rare vegetation where path loss is the lowest.

The LUI model parameters from Table 3 were also adjusted throughout experimental results for the three technologies: γ_1 and γ_2 stands for the propagation exponents [1]; G_f represents the floor height gain (and its fitting technique was based in Toledo and Turkmani [3]); X_h represents the effective height correction factor where topographic differences between the transmitter and receiver must be added in the effective terminal antenna height. Note that for pico-cell Wi-Fi technology there were notorious differences with received signal in slopping paths h_t and h_b represent the effective terminal antenna and base station heights, respectively.

VI. Conclusions

This paper validates the LUI model, presented in [1] able to predict the PL for three widely used wireless technologies. This unified model was adjusted with the experimental results carried out in this work. However, to incorporate such propagation models into a planning tool, it is necessary to make an extensive and exhaustive measurements campaign to improve the model.

The considered scenarios did not include vegetation. Hence we were not able to validate the resulting supplementary attenuation in these experiments.

The main challenge in the development of this model was to incorporate experimental data for the points measured in shadowed areas.

This model will provide improvements in the quality of the planning techniques for the optimization of coverage and/or network capacity of wireless communications.

Acknowledgment

The authors would like to acknowledge the contribution of ANA Aeroportos, Alcatel-Lucent and NetPlan, who made possible to perform the experimental measurements mentioned in this study. This work was partially supported by the internal IT project designated as COILS, by "Projecto de Re-equipamento Científico" REEQ/1201/EEI/ 2005 (a Portuguese Foundation for Science and Technology project), by UBIQUIMESH and by the Marie Curie Intra-European Fellowship OPTIMOBILE (Cross-layer Optimization for the Coexistence of Mobile and Wireless Networks Beyond 3G, FP7-PEOPLE-2007-2-1-IEF). Frederico Varela acknowledges his MSc grant from Instituto de Telecomunicações (IT), while Daniel Robalo also acknowledges his research grant from IT. The authors acknowledge the support from COST Action 2100 on "Pervasive Mobile & Ambient Wireless Communications". The authors acknowledge the MSc student João Oliveira for his contributions given in the WiMAX field trials in the Lisbon airport.

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Parameters	Indoor	Mixed		
	Wi-Fi	*Wi-Fi*	*UMTS*	*WiMAX*
γ_1	3	3.85	Table 2	Table 2
γ_2	2.5	3.35	$\gamma_{1\,\mathrm{UMTS}} - 0.5$	$\gamma_{1\,\mathrm{WiMAX}} - 0.5$
G_f	–	$\begin{cases} 1.285 \cdot h_t - 3.285, & h_t \le h_b \\ -0.857 \cdot h_t + 13.85, & h_t > h_b \end{cases}$	$\begin{cases} 2.097 \cdot h_t - 17.41, & h_t \le h_b \\ -1.758 \cdot h_t + 44.93, & h_t > h_b \end{cases}$	Not tested
X_h	–	Add topographic height difference to the effective height of the terminal	Do not add topographic height difference to the effective height of the terminal	Do not add topographic height difference to the effective height of the terminal

Table 3. Parameters to be used in the LUI model for the three technologies by type of scenario.