WLAN Planning Tool: a Techno-Economic Perspective

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Abstract

A simple wireless local area network (WLAN) planning tool was developed to optimize the position and number of access points (APs), as well as the total cost of the required equipment, according to different WLAN suppliers, in indoor and outdoor environments. This planning tool can be distinguished in two mains scopes: technical (defining the number and position of APs) and economic (generating a budget according to all planned equipment and its suppliers).

The proposed planning tool enables manual and automatic planning modes. It only needs some inputs, like the digital format of the floor plan, the obstacle types and their positions, the areas to be covered, the user's most probable position and the applications used by them. The propagation model used in this tool was validated using experimental results for some scenarios. In the manual mode, the APs positions are defined by the network designer. The output of the tool is the received power or the throughput, depending on the chosen option. However, in the automatic mode the tool defines the AP position and minimizes the total amount of APs in a given area. For the implementation of the latter mode, two hot spots position planning algorithms were developed and implemented; they depend on the values of the received power or throughput, while guaranteeing the total coverage or service supply for all users, respectively. This tool also provides an estimation of the budget for the required implementation, and can avoid several days of tedious site-survey work.

Except for the lowest distances, experimental values for the received power generally agree with the DP model for the range of distances considered, from the terminal station to the AP, both for outdoor and indoor environments. The differences near the AP are due to different antenna radiation patterns between the tool (omnidirectional isotropic) and the experimental setup (dipole antenna). In the indoor paths, the slight differences between the results of two floors may be due to the interaction of the direct ray with the floor direction itself.

1. Introduction

This work addresses the development of a new wireless local area network planning tool (WPT) that automates the planning of a wireless local area network (WLAN), for IEEE 802.11a/b/g/n technologies [1], available for outdoor/indoor environments. The tool produces a budget that depends on the equipment's manufacturers. This planning tool optimizes the number of access points (APs) and their position, according to the propagation model and/or the necessary user's capacity, as well as the total cost of the equipment. The software is user friendly and allows developing a project in two different modes, automatic (the positions of APs is defined by the tool) and manual (the designer decides the positions for the APs). In the automatic mode two algorithms may be used: dynamic or static.

The tool only needs as input a file containing the plan where the WLAN will be deployed, the obstacles positions and their material and the most probable user's position.

The remaining of the paper is organized as follows: Section 2 starts by presenting the Wireless Planning Tool. Section 3 addresses the capacity model, as well as some experimental results for the received power. Section 4 presents the required input data, the algorithms and the output for the tool. Finally, conclusions are presented in Section 5.

2. Presentation of the Wireless Planning Tool

The wireless planning tool helps in the planning process of indoor/outdoor wireless local area networks, frequently known as Wireless Fidelity (Wi-Fi). It optimises the number of the required access points (APs) or base stations (BSs) to be deployed, their positions, and the total cost of the equipment by considering the choice of different Wi-Fi technology suppliers.

The manual distribution mode was implemented to enable experimenting and testing different possibilities for the received signal power distribution. The options given to the user include the manipulation of APs, obstacles, covered areas (CAs) and terminal stations (TSs) positions. This mode is very attractive to develop and configure the area to be covered, case-by-case. In the automatic distribution mode, the tool defines the positioning and number of AP needed to optimise the coverage and/or the associated capacity, depending on obstacles, user's position and their capacity.

The inputs of the tool are written in a file, including the building or campus plan in digital format, the position and type of obstacles material, the total covered area, the most probable position of TSs (e.g., laptops, PCs, and PDAs) and the type of user's applications. For outdoor design, besides the plan, the maps must include the elevation of the terrain.

The WPT development comprises two main scopes:

- *Technical* - it defines the APs position by using one of the following options: either it considers the distribution of signal power following a given propagation model or the capacity of the user's applications and their most probable positions.
- *Economic* - it generates a budget according to the required quantity and type of equipment, based on information provided by the suppliers.

The tool was developed to help network designers with a fast, technical and economic planning tool. It supports the IEEE 802.11 a/b/g and WiMAX standards and it is able to estimate the TR (transmission data rate) needed by the network, according to the capacity model. Items such as obstacles, APs characteristics and network card types can be directly updated into the software. Different propagation models can also be introduced and tested.

The WPT helps in the process of making a complete plan for the coverage of a given area based solely on a digital format of the floor plan, obstacles, their materials and the locations for the wireless terminals. The program then generates an output with the layout, showing the received power/capacity and the positions for the APs.

The optimum location for the APs, so as to minimize their number, was achieved using two methods. One method considers the received power in each position of the coverage area using empirical propagation models. The other one allows to choose the most probable position for each user and its capacity, according to the foreseen applications.

Although mature and tested with good results, this tool continues to be developed in order to include more options, such as wireless standards, e.g., the possibility of upgrading the tool for QoS support. The inclusion of the IEEE 802.11e standard at different frequency bands, was also foreseen, and can be easily implemented.

The total capacity of the system was determined according to the number of users in a given area, the type of applications used and the user's simultaneous factor (USF) for each application.

The Wi-Fi component of the WPT was developed using C# graphic object oriented methods [2] and it interacts with a SQL Server 2000 Data Base [3]. There are other tools for Wi-Fi planning in the market which involve higher complexity and costs [4-14], however, they do not comprise both technical and economic/budget issues such as this proposed WPT [15].

3. Capacity Model and Propagation

3.1 Capacity Models

Usually, the planning of a WLAN is mainly focused on the coverage of all planed PCs. The suppliers of wireless equipment visit the intended location and make a site survey using a laptop, for instance, to verify if the area has enough power to establish the link between AP and a PC in that location. Unfortunately, this procedure is not adequate to make a correct planning, from the economic point of view. Thus, it is necessary to define the number of APs, their position and to take into account the capacity used by each user, which depends on the user's intended applications. Table 1 presents the application average throughput, considering packets with an average size of [16].

TABLE 1

Average throughput for each application.

Applications	Throughput [kbps]
e.mail	2
www trans.	16
Data base transf.	4
Remote interaction	0.4
WLAN file transf.	160
WAN file transfer	80
Internet file transfer	40
VoIP	6
VCoIP	64

According to the thresholds for the received power and its correspondence with the maximum capacity for each standard shown in Table 2, the WPT defines the total number of APs and their positions by considering a given value for the USF, for each application. The choice of the value for USF depends of the type of usage scenario (the percentage of simultaneous users that are using the same application).

Theoretically, each AP can guarantee the maximum throughput in each of the coverage rings, according to the values for the received power from Table 2. Thus the APs positions depend on the PC positions and the applications used by these Wi-Fi users. Figure 1 shows the AP positions and the throughput threshold for each ring.

TABLE 2

Relationship between the received signal power (in dBm) and the throughput (in Mbps) in IEEE802.11a, 802.11b and 802.11g standards.

IEEE 802.11a	IEEE 802.11b	IEEE 802.11g
6 Mbps -85 dBm	1 Mbps -94 dBm	9 Mbps -84 dBm
9 Mbps -84 dBm	2 Mbps -91 dBm	11 Mbps -88 dBm
12 Mbps -82 dBm	5,5 Mbps -89 dBm	12 Mbps -82 dBm
18 Mbps -80 dBm	11 Mbps -85 dBm	18 Mbps -80 dBm
24 Mbps -77 dBm	-	24 Mbps -77 dBm
36 Mbps -73 dBm	-	36 Mbps -73 dBm
48 Mbps -69 dBm	-	48 Mbps -72 dBm
54 Mbps -68 dBm	-	54 Mbps -72 dBm

The throughput in each ring, D_r must obey to the following inequality:

$$D_r \leq DT_r \qquad (1)$$

where DT_r defines the throughput threshold for ring r. D_r is given by

$$D_r = NU_r \sum_{a=0}^{A} D_a \, USF_a \qquad (2)$$

where NU_r is the number of users in each ring, A is the total number of applications and D_r is the application throughput.

The total throughput supported by each AP must verify the following inequality

$$D_{TOTAL} \leq DT_{TOTAL} \qquad (3)$$

where

$$D_{TOTAL} = \sum_{r=0}^{R} NU_r \sum_{a=0}^{A} D_a \, USF_a \qquad (4)$$

The proposed algorithm only accepts a given position for an AP if the following condition is verified

$$\begin{aligned}&(D_0 \leq DT_0) \cap \cdots \cap (D_r \leq DT_r) \cap \cdots \\ &\cdots \cap (D_R \leq DT_R) \cap (D_{TOTAL} \leq DT_{TOTAL})\end{aligned} \qquad (5)$$

With $0 \leq r \leq R$. Otherwise, this AP position must be changed and another one may have to be included in the same floor.

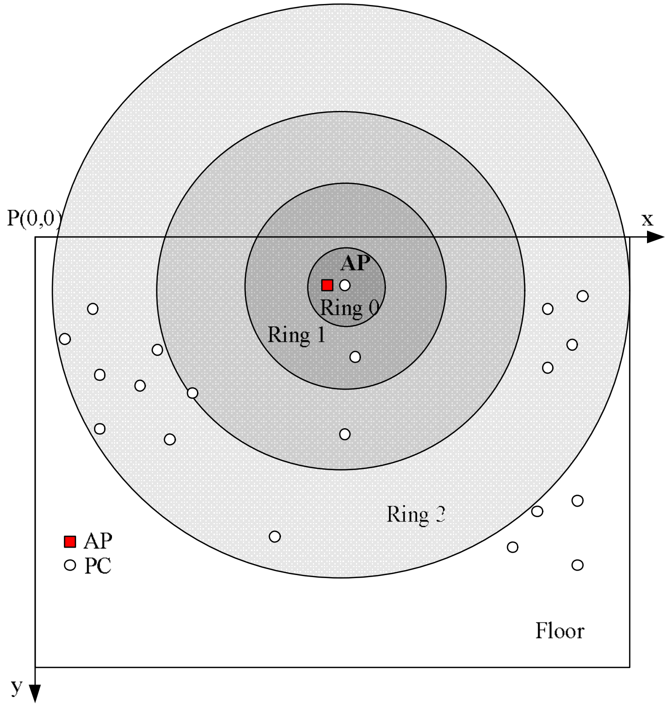


Figure 1: Capacity rings example, considering the IEEE802.11b standard.

3.2. Experimental Results

Figure 2 shows the plan of the ISCTE\LUI building (Edifício 1), as well as other surrounding buildings (Corpo A, B, C and INDEG), where experiments took place. The path followed for measurements during the site survey is identified by blue, red, green and orange dots, with the following meaning:

- Blue dot - AP position (its height is 4 meter);
- Red dots - ground positions for the first section of the outdoor measurement path (terminal station height is 1.5 meter);
- Green dots - floor positions for the indoor section of the measurement path (measurements took place on floors 1 and 2, with heights of 5 and 8.5 meter, respectively);
- Yellow dots: ground positions for the last section of the outdoor measurement path (as this part of the ground in the interior terrace, it is at a slightly different level, here the terminal station height is 3 meter).

The rectangular grid (with small dots) shown in Figure 2 defines a spacing of 1 m. The legend in Figure 2 shows the distance (in meters) from the AP to the respective positions of the terminal stations.

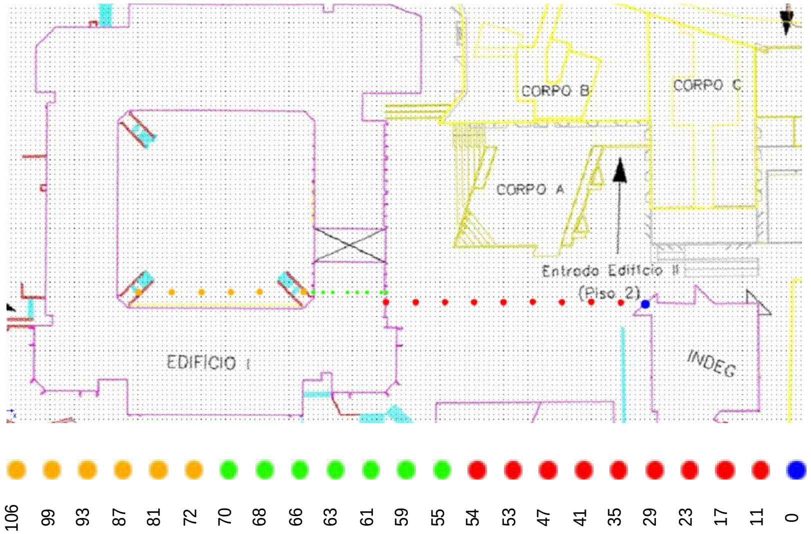


Figure 2: Plan of ISCTE\LUI and distances from each terminal to the AP.

As our tool still does not support 3D functionalities, the simulation of the 3D coverage for the building was obtained by using WinProp^{TM} [REF-site AWE]. The materials considered for the walls were chosen among those most adequate for the ISCTE\LUI building (EDIFÍCIO 1) characteristics from a list made available by AWE, the company that commercializes Winprop^{TM}, Table 3. All the details of the buildings were defined into the tool database, including roofs and floors. Figure 3 presents the relationship between EDIFÍCIO 1 plan and its 3D representation.

TABLE 3

Characteristics of the materials for the buildings.

Material	Path loss [dB]	Color
Brick; thickness: 30cm	11.93	Orange
Brick; thickness: 10cm	4.66	Green
Wood; thickness: 5cm	2.48	Brown
Glass; thickness: 5mm	1.71	Blue

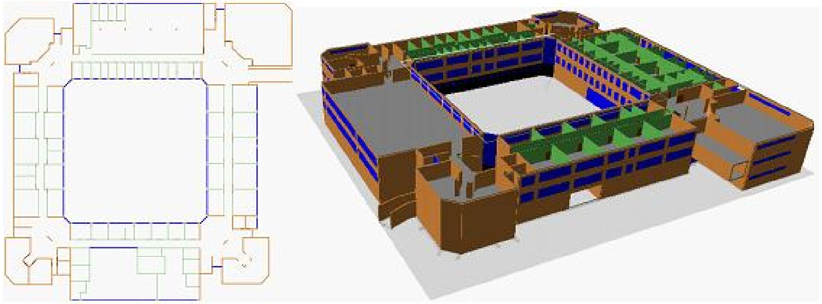


Figure 3: Plan for ISCTE\LUI building and its 3D representation.

Winprop^{TM} enables the simultaneous simulation for both outdoor and indoor environments, using the same file. After producing the outdoor database (where buildings are only defined by straight lines in the 3D mode, the indoor database for Edifício 1 was imported into the database.

Although Winprop^{TM} uses a common “indoor/outdoor” database, it separates the indoor environment from the outdoor one, by using different propagation models, as presented in Table 4.

Figures 4 and 5 show the output from the Winprop^{TM} tool for indoor and outdoor, respectively. The received power (in dBm) is spatially represented with different colours, according to the legend, throughout the coverage area.

TABLE 4

Propagation models for the 3D coverage tool.

Outdoor	Indoor
COST 231 *Walfisch-Ikegami*	COST – Multi-Wall Model
Urban Dominant Path	Indoor Dominant Path

The parameters considered in these simulations are presented in Tables 5 and 6.

TABLE 5

Simulation parameters for the AP (represent by a blue sphere in the 3D model).

Parameter	Actual value/case	Simulation
AP height	7 m from the ground (4 m relatively to the first floor from Edifício I)	4 m (as topography is not considered)
Type of antenna	Dipole (*G*=2dBi)	Omnidirectional isotropic
Transmitter power	17dBm	17dBm
Standard	IEEE 802.11b/g	IEEE 802.11g

TABLE 6

Heights for the measurements.

Section of the path	Height [m]	
	Site Survey	Simulation
Outdoor – INDEG	1.5	1.5
Indoor – Floor 1	5.0	5.0
Indoor – Floor 2	8.5	8.5
Outdoor – ISCTE	3.0	3.0

The propagation models considered are the *Urban/Indoor Dominant Path* (DP) model (green curve on the chart), the *COST-231 Walfisch-Ikegami* [17] [18] (red curve for floor 1 and orange curve for floor 2) and the modified Friis (purple dashed curve) one. The Stanford University Interim (SUI) model was not considered because the distances are too short. While the parameters for the DP were adjusted to fit experimental data, *COST-231 Walfisch-Ikegami* was not parameterized by Winprop^{TM}.

DP overcomes the limitations of the possible inaccuracy of the empirical models like SUI or *COST-231 Walfisch-Ikegami* (which may be inaccurate if the direct ray represents only a small percentage for the received power) and is less complex than ray tracing.

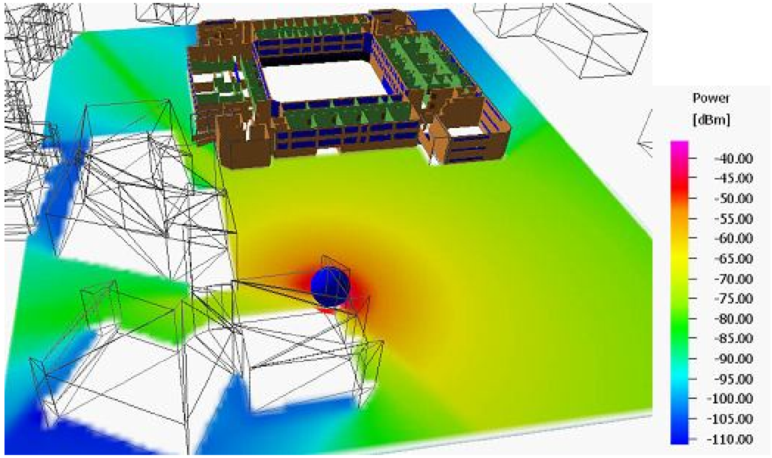


Figure 4: 3D spatial representation of the received power (outdoor).

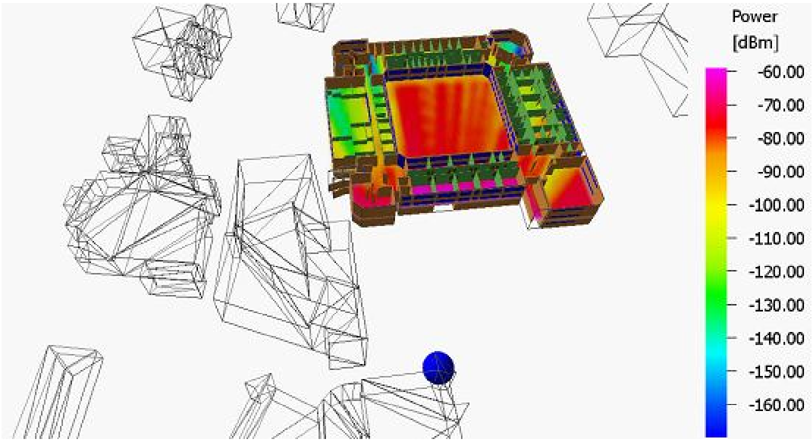


Figure 5: 3D spatial representation of the received power (indoor).

By using a tree to organize the possible patterns it only choose the dominant path to compute the dominant path loss, Figure 6. Table 7 presents the values for the propagation exponent used in the simulations. The values before and after the breakpoint (defined by the first obstacle) are distinguished for outdoor environment. Details are given in [19].

TABLE 7

Propagation models for the 3D coverage tool.

Environment	Breakpoint	LoS	oLos	NLoS
Indoor	-	2.1	2.3	2.5
Outdoor	Before	2.9	3.1	-
	After	4.1	4.2	-

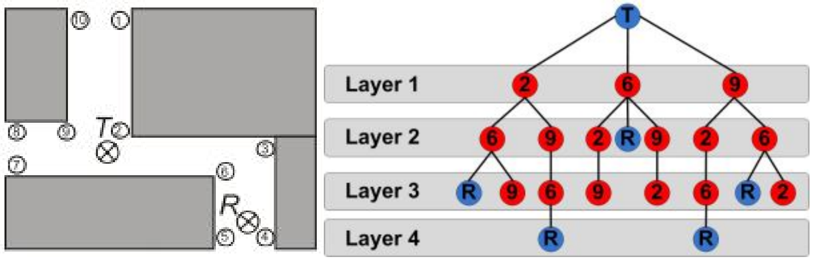


Figure 6: Scenario with walls, transmitter and receiver (left) and tree structure built by algorithm (right).

For indoor environments, γ=3.27 is considered in the model represented by equation (1). Although *FAF* was neglected, *PAF* was still taken into account. Figure 7 shows the variation of the received power with distance. DP, COST-231, Friis and modified Friis propagation models were considered for the analytical curves shown. The experimental results obtained are presented as well (for two sections of the outdoor path and also for the indoor path, at floors 1 and 2).

The experimental results presented were based on the average of several measurements, taken for each position and represented by blue dots in Figure 7. Except for the lowest distances they generally agree with the DP model for the range of distances considered, from the terminal station to the AP, both for outdoor and indoor. The dipole antenna has a lower gain for higher values of the angle between the direct ray and the horizontal plane. Due to the differences in the considered antenna radiation patterns, between the tool (omnidirectional isotropic) parameters and experimental setup (dipole antenna), near the AP results from measurements with the DP model are always higher than the experimental values (lozenge blue dots). In the indoor paths, the slight differences between the results of floor 1 and 2 measurements are due to the interaction of the direct ray with the floor direction itself (for some of the zones on floor 2). The results are also different form the *COST-231 Walfisch-Ikegami* empirical model ones. As this model only considers the direct ray it cannot cope with other paths/rays. The slight increase on the results for the last section of the outdoor measurements path may be due to the positive reinforcement owning to the easier propagation through the tunnel, Figure 8. As we can observe there is a good agreement between theoretical and experimental results, except for the indoor/floor 2 case, where there is some deviation from the DP curve.

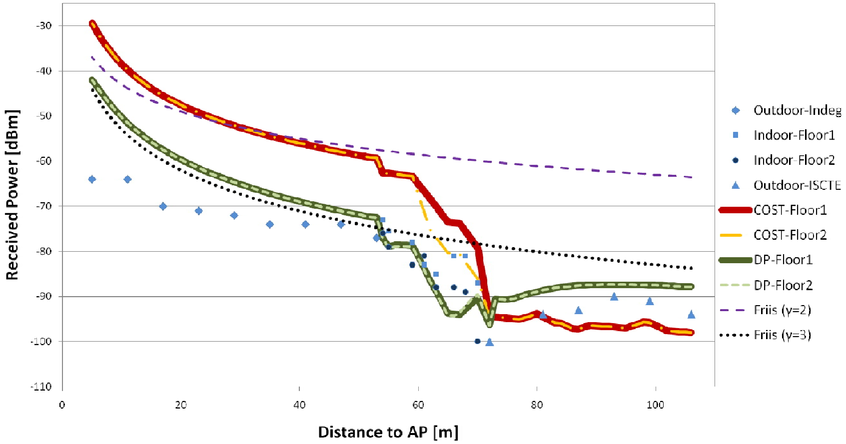


Figure 7: Received power as a function of the distance for the whole path, including indoor and outdoor sections.

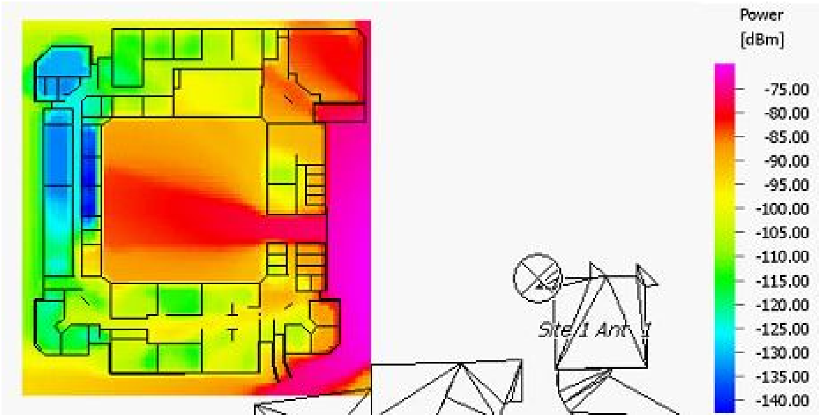


Figure 8: Reinforcement of the received power for the interior terrace due to carrier propagation through the tunnel.

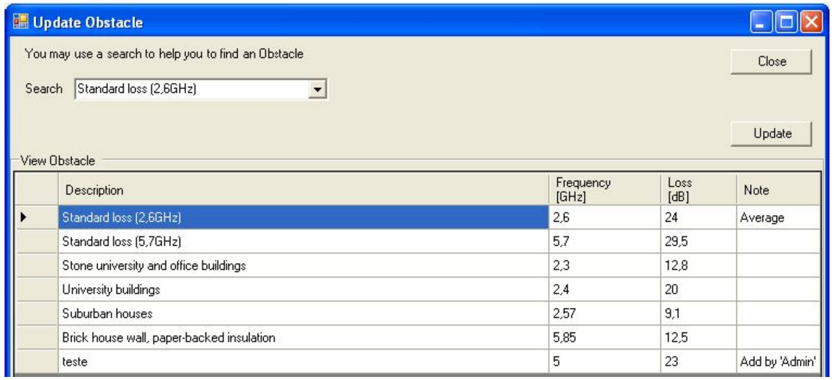
4. The tool

The WPT was developed in order to be as most user friendly as possible and to provide a fast technical and economic planning tool, for helping network designers. All the IEEE 802.11 (a/b/g/n) standards are supported by this application. It estimates the user throughput needed by the network and it uses that estimation as an input for the capacity model.

This tool has several menus in order to enable proper decisions by the network designer. Items such as the obstacles, AP and Network Cards can be updated directly on the application. The planning can be executed, since a floor plan file, including the PCs positions, obstacles positions and their materials were provided. This tool gives, as an output, a layout showing the received power-capacity and the APs position. Following this initial technical planning, the designer can obtain the total budget for the required equipment and their quantities.

4.1 Inputs

As an input, the tool only needs a file with the digitalized area plan to be covered, including the floor(s) of the building(s) where the installation of the WLAN is foreseen, the obstacle's position and their material, as well as the PC most probable positions for user terminals. Items such as obstacles, APs characteristics, and network card types can also be directly inputted into the tool, as depicted in Figure 9. Additionally, different propagation models can also be introduced and tested.



You may use a search to help you to find an Obstacle

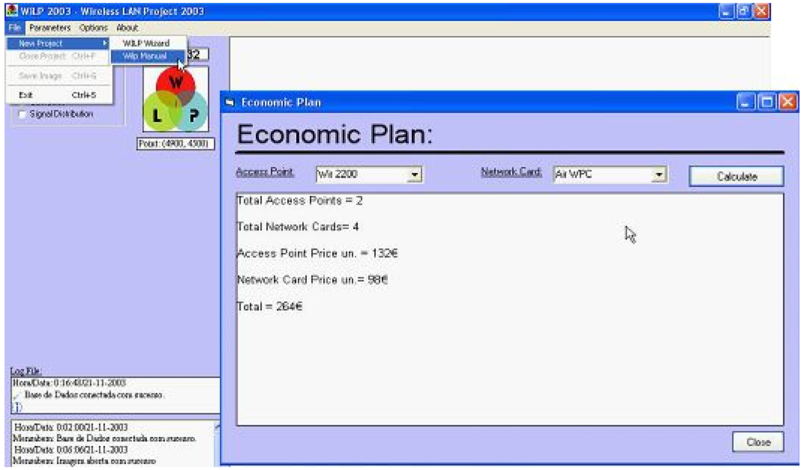
Search: Standard loss (2,6GHz)

Description	Frequency [GHz]	Loss [dB]	Note
Standard loss (2,6GHz)	2,6	24	Average
Standard loss (5,7GHz)	5,7	29,5	
Stone university and office buildings	2,3	12,8	
University buildings	2,4	20	
Suburban houses	2,57	9,1	
Brick house wall, paper-backed insulation	5,85	12,5	
teste	5	23	Add by 'Admin'

Figure 9: WPT – Programme window for updating obstacles.

The WPT has several menus that enable the user to insert appropriate parameters, contextualized by the chosen options. This feature allows to make the complete plan for the required area to be covered, simulating different environments and options, starting from a simple file containing the data already mentioned.

This tool also allows the designer to introduce into a database the characteristics of specific or recent equipment, provided by the manufacturer. Therefore, this WPT can always estimate the total cost for a particular configuration, when specific equipment needs to be defined, Figure 10.



Point: (4900, 4300)

Economic Plan:

Access Point: Wi 2200

Network Card: Ai WPC

Total Access Points = 2

Total Network Cards= 4

Access Point Price un. = 132€

Network Card Price un.= 98€

Total = 264€

```
Hora/Data: 0:16:48/21-11-2003
Base de Dados conectada com sucesso.
```

```
Hora/Data: 0:02:00/21-11-2003
Mensagem: Base de Dados conectada com sucesso.
Hora/Data: 0:06:06/21-11-2003
Mensagem: Imagem aberta com sucesso
```

Figure 10: WPT – Programme window to estimate the total cost of a given WLAN.

4.2 Algorithms

Two types of signal distributions were considered, manual and automatic. The reason for the manual distribution is to provide enough freedom to the radio and network designers for trying and testing different configurations for the received signal distribution. Among this options, we can distinguish the manipulation of APs, obstacles, CAs and user terminals (i.e., PCs).

In the automatic distribution mode, unlike the previous one, the AP positioning is automatically obtained by the tool. Depending on the obstacles, user's location and their capacity, the application computes the quantity and the APs position, to achieve an optimized coverage and/or the desired capacity. The automatic distribution can be performed by using two different approaches for the algorithms types: coverage or capacity.

Figure 11 presents the coverage algorithm flowchart.

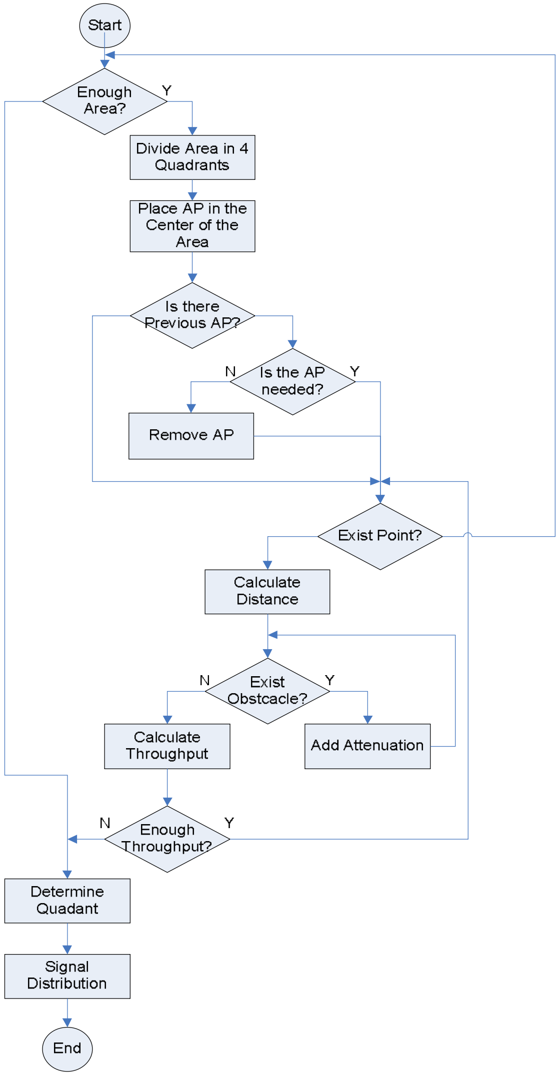


Figure 11: Flowchart for the coverage algorithm.

The purpose of this algorithm is to cover the area(s) defined by the user. This algorithm sets an AP in the centre of the defined area and then splits the area in four quadrants. The coverage is then verified for each quadrant. If the coverage is not enough in a given quadrant, an AP is placed in its centre. This process is repeated until all defined area is properly covered. For each AP placed in a given quadrant, the algorithm checks if the previously defined APs are still needed.

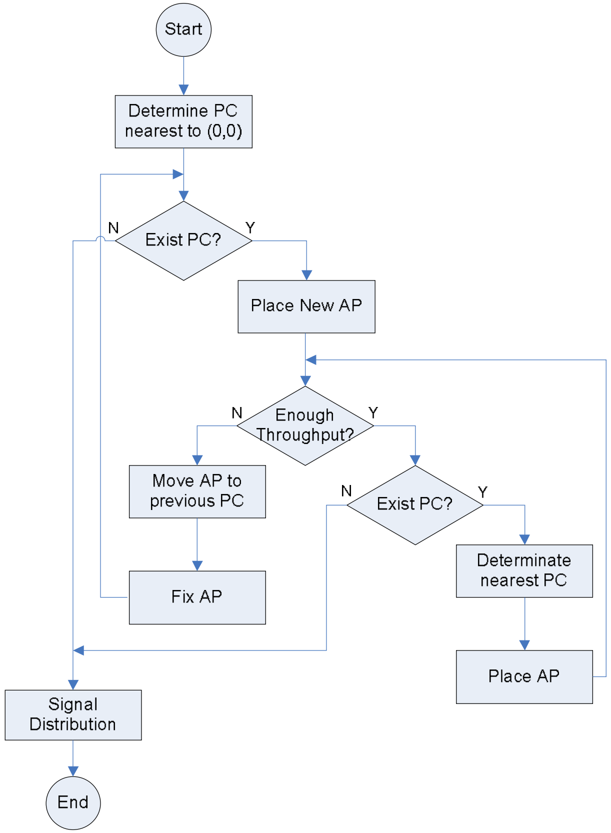


Figure 12: Capacity algorithm flowchart.

Figure 12 presents the capacity algorithm flowchart. This algorithm takes into account each PC position and the foreseen user applications. The

Algorithm starts by placing an AP in the position of the PC, nearest the point with coordinates (0,0). Then, the AP is moved to the next PC, nearest to the previous one. If the first one is covered with the required throughput, the algorithm keep checking the remaining PCs, based on their proximity from the previous ones. This process stops when the AP cannot cover the previous PCs with the required throughput. In this case, and if there are more PCs to be covered, the AP will be positioned in the previous PC position and another AP will be placed in the current PC position. The new AP position starts close to the next PC and all the procedure starts over again, until the required throughput is guaranteed for all PCs. As previously mentioned, this algorithm always verifies inequality (5).

4.3 Output

Figures. 13 and 14 present examples of the actual layout of the WPT for indoor and outdoor environments, including the received power level distribution and the capacity for each area. The possibility of upgrading the tool for QoS support, e.g., IEEE 802.11e, and for different frequency bands was also foreseen and can be easily implemented.

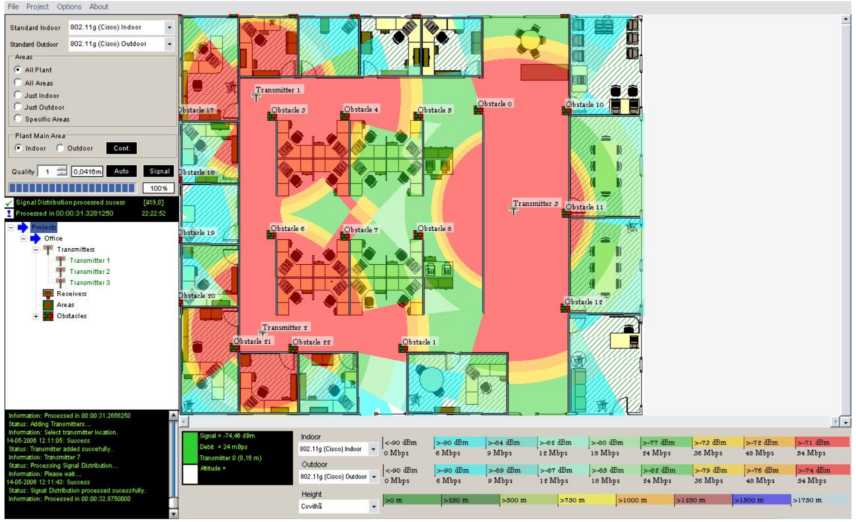


Figure 13: Example of a WPT layout for an indoor environment

The program generates a layout showing the received power, the capacity, and the APs positions. As it can be observed in Figure 14, for an outdoor case, the covered and interference percentage for a given campus, (e.g., Parque das Nações in Lisbon) can be visualized.

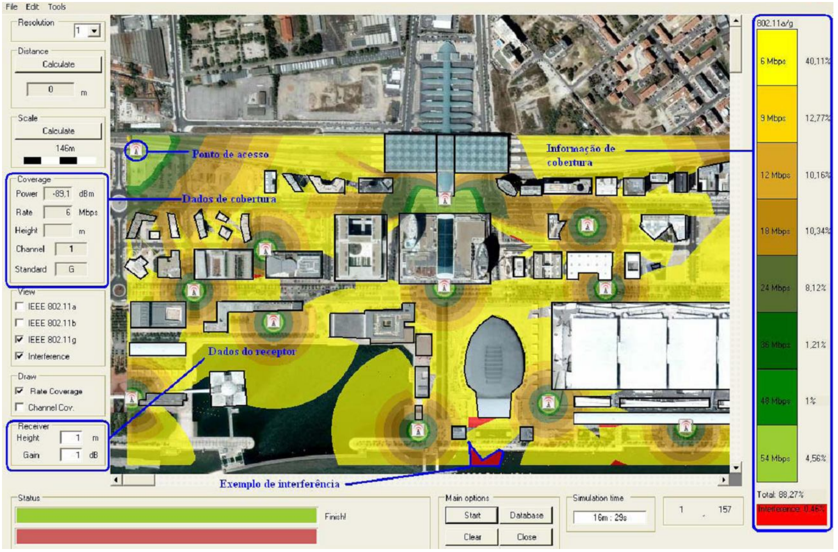
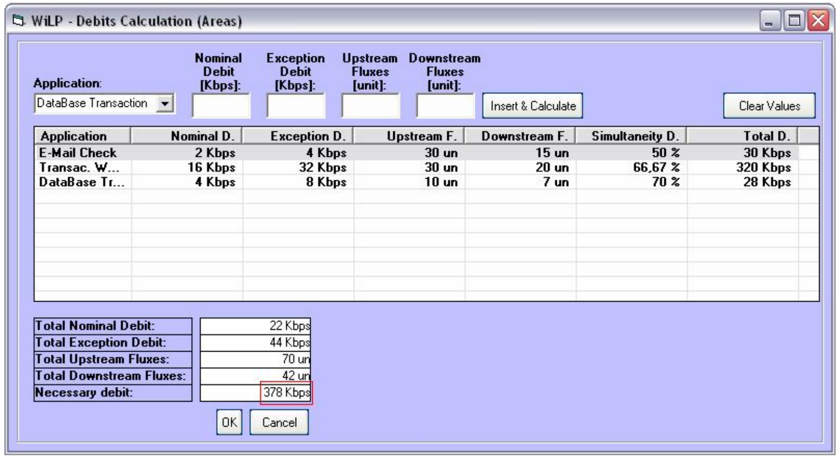


Figure 14: Example of a WPT layout for an outdoor application.

In the program window depicted in Figure 15, we can visualize the total capacity, calculated according to the number of expected users in a given area, their used applications and the USF for each one.

5. Conclusions

This paper describes a new proposed WLAN planning tool. It enables to define the AP layout, to obtain the system's capacity and to compute the budget for the required equipment. It is intended for dimensioning the IEEE 802.11 WLAN topology, and it supports several versions of this IEEE standard family. The signal coverage and throughput maps are obtained over the area plan, for a given building floor or outdoor zone. The planning contemplates all equipment suppliers, by simple introduction of the characteristics of that equipment in the program's database.



Application: DataBase Transaction

Application	Nominal D.	Exception D.	Upstream F.	Downstream F.	Simultaneity D.	Total D.
E-Mail Check	2 Kbps	4 Kbps	30 un	15 un	50 %	30 Kbps
Transac. W...	16 Kbps	32 Kbps	30 un	20 un	66,67 %	320 Kbps
DataBase Tr...	4 Kbps	8 Kbps	10 un	7 un	70 %	28 Kbps

Total Nominal Debit:	22 Kbps
Total Exception Debit:	44 Kbps
Total Upstream Fluxes:	70 un
Total Downstream Fluxes:	42 un
Necessary debit:	378 Kbps

Figure 15: Total capacity required for a given outdoor area.

Depending on the required throughput, derived from expected applications, for a given organization, this tool estimates the total cost for that specific WLAN implementation.

The experimental results were compared with the *Urban/Indoor* DP, the *COST-231 Walfisch-Ikegami* and the modified Friis propagation models. Except for the lowest distances, they generally agree with the DP model for both outdoor and indoor patterns. Due to the differences in the considered antenna propagation patterns between the tool parameters and experimental setup, results from measurements with the DP model near the AP are always higher than the experimental values.

In the indoor paths, the slight differences between the results of floor 1 and 2 measurements are due to the interaction of the direct ray with the floor direction itself, for some of the zones on floor 2. The results are also different form the *COST-231 Walfisch-Ikegami* empirical model ones. As this model only considers the direct ray it cannot cope with other paths/rays.

The slight increase on the results for the last section of the outdoor measurements path may be due to the positive reinforcement owing to the easier propagation through the tunnel. As we can observe there is a good agreement between theoretical and experimental results, except for the indoor/floor 2 case, where there is some deviation from the DP curve.

This WPT has an user friendly interface that allows a fast and simplified techno-economic approach for radio planning. It can be used not only by network designers in industrial environments, but also by teachers and students in their academic and research activities, where it can be used as a simulator. This tool differs from other solutions that are commercially available, since it is very flexible and it also includes system capacity aspects.

This tool was validated by experimental results obtained in a real environment. These were obtained for the average received power and system capacity in several environments, allowing for its fine tuning.

Additional work is being performed to further improve this tool, making it more general with the inclusion of other propagation models and radio standards, namely with support for Wireless Metropolitan Area Networks in outdoor environments.

Future work also envisages the use of stochastic models in the algorithms for system capacity determination, to model the simultaneous use of all applications.

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