

User capacity based planning tool for Wi-Fi and WiMAX networks

Pedro Sebastião¹, Fernando Velez², Ricardo Tomé¹, Rui Costa², António Grilo³,
António Rodrigues⁴, Francisco Cercas¹

¹ Instituto de Telecomunicações/ISCTE,
Av. Rovisco Pais, 1, Torre Norte, 1049-001 Lisboa, Portugal
pedro.sebastiao@lx.it.pt, ricardotome@gmail.com, fc@lx.it.pt
² Instituto de Telecomunicações-DEM, University of Beira Interior
Calçada Fonte do Lameiro, 6201-001 Covilhã, Portugal
fjv@ubi.pt, ruicosta@fcsaude.ubi.pt
³ INESC-ID/IST, Computer Networks and Mobility
Rua Alves Redol, N.º 9, 1000-029 Lisboa, Portugal
antonio.grilo@inesc-id.pt
⁴ Instituto de Telecomunicações/IST,
Av. Rovisco Pais, 1, Torre Norte, 1049-001 Lisboa, Portugal
antonio.rodrigues@lx.it.pt

Abstract. A simple wireless planning tool (WPT) is proposed, which facilitates the design and implementation of wireless fidelity (Wi-Fi), and worldwide microwave access (WiMAX) networks in indoor and outdoor environments. The tool gives to professional planners practical and useful information through quick procedures as the output is the number and position of the access points (APs), or an estimation of the total cost of implementation, based on data provided by different equipment manufacturers. It uses innovative algorithms for computing the best position of each AP. Carrier-to-noise and carrier-to-interference issues are discussed in detail, and a practical deployment of a single WiMAX cell in Covilhã is presented. There is a need of using sectorial antennas to guarantee an adequate coverage and interference mitigation.

1 Introduction

Recent evolution of mobile and wireless multimedia (MM) communications is stimulating the production of new services and applications to be supported in handheld terminals, like mobile phones, pocket digital assistants (PDAs) and Tablet PCs, besides motivating the need for increasing mobility in the context of seamless communications, with continuity from indoors (e.g., wireless local area networks - WLANs), to outdoors environments (e.g., 2.5G or 3G mobile support). After universal mobile telecommunications system (UMTS) introduction, the main market players are realising that higher capacity high data rate seamless communications, supporting high mobility, still requires a lot of research effort to allow for the development of concepts for systems beyond 3G (e.g., Enhanced UMTS, WLANs,

worldwide interoperability microwave access (WMANs), and reconfigurability). People want the kind of coverage and flexibility (e.g., international roaming) that they find in 2G systems but they want much more: to be always best connected (ABC), with exchange of truly wide and broadband multimedia content, simultaneously supporting voice, data, streaming, image, and video multi-rate communications.

Worldwide, the trend is All-IP based communications. Several access technologies are thus in order, and there is room for new ways of giving access to MM users anywhere, anytime, and anyway, in an efficient manner. One strong candidate is the new IEEE 802.16 standard for public (and even private/unlicensed) networks. It provides wireless broadband access in metropolitan areas, with point-to-point and point-to-multipoint (mobile) configurations, and will revolutionize worldwide broadband access. This standard significantly simplifies the entry of independent operators seeking to become providers of broadband services, and will almost certainly bring about declining equipment prices, and improved network reliability and service levels. Besides, it is also attractive for private players (e.g., communication within University Campus, and metropolitan distributed organisations).

IEEE 802.11 (Wi-Fi, Wireless Fidelity) networks have already proven to be easy and cheap to deploy. As the prices of equipment are low, the return of investment is guaranteed. However, the low coverage ranges associated with IEEE 802.11 make these networks mostly suitable for indoor hotspots (or to low coverage range outdoor environments), and there is a need for interoperability with other wide range coverage systems, e.g., UMTS and IEEE 802.16 (WiMAX, Worldwide Interoperability for Microwave Access [1], [2]). This work aims at enabling future interoperability between Wi-Fi and WiMAX by foreseeing the application of IEEE 802.21, and addresses the concepts, the development, and the application of a wireless planning tool for this purpose. While the Wi-Fi component, defined by the IEEE 802.11a, 802.11b and 802.11g [3], is already totally incorporated into the tool, the WiMAX functionalities are still being developed, and the aspects related to service quality will certainly lead to the inclusion of IEEE802.11e functionalities into the tool, allowing for an impairment of WiMAX classes of service to Wi-Fi. The tool will simultaneously present cellular planning results for outdoor WiMAX and indoor/outdoor Wi-Fi for a given zone, e.g., in the area surrounding a University Campus (or a Hospital), and inside its buildings. Previous versions of this simple wireless planning tool (WPT) only included the planning process of WLAN in indoor environments [4]. For a given coverage region and expected user capacity, the WPT estimates the adequate position of APs seeking for cost minimisation, based on data provided by manufacturers.

In Section 2, we start by presenting the functionalities, the input and output data, and the implementation details of our WPT. Section 3 addresses outdoor and indoor propagation models. Section 4 addresses how access point capacity affects its positioning. Manual or automatic algorithms are presented for the choice of the placement of Access Point positions, while guaranteeing a given throughput. Section 5 highlights the functionalities and potentialities of the WPT, and presents a practical deployment in Covilhã. Aspects of coverage and interference are discussed. Finally, conclusions are presented in Section 6.

2 Wireless Planning Tool

It is important to present the functionalities, input data, output data, and implementation details of our WPT. It helps in the planning process of indoor/outdoor wireless local and metropolitan area networks. Its Wi-Fi component optimises the number of access points (APs) or base station (BSs), and their positions, as well as the total cost of the equipment by considering the choice of Wi-Fi or WiMAX technologies suppliers. It is user friendly and allows the development of the cellular design process into two different modes, manual (the designer decides case by case the position of APs), and automated (the positioning of APs is defined by the WPT).

The manual distribution mode was implemented to enable trying 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. The automatic distribution differs from the manual one because AP positioning is automatic. Depending on obstacles, the user's position, and their capacity, the tool defines the positioning and number of AP needed to optimise the coverage, and/or the associated capacity.

The inputs of the tool are the file with the building or campus plan, in digital format, the position and type of obstacle materials, the total covered area, and the most probable position of TSs (e.g., laptops, personal computers, PCs, or personal digital assistants, PDAs, and the type of user's applications). For outdoor design, besides the plan, the maps have to include the elevation of the terrain.

Conceptually, the WPT development comprises two main scopes:

- Technical - it defines the position of APs by using one of the following options: either the distribution of signal power according to given propagation model, or the consideration of the capacity of user's applications, and his/her most probable position.
- Economic - it generates a budget according to the quantities and types of equipment, and the information provided by the suppliers.

The average path loss is computed by using empirical radio frequency propagation models. This enables to positioning APs (or BSs), for each pixel, corresponding to a given area on the field, urban, or building plan. In indoor environments, the radio wave propagation is strongly influenced by the layout of the building and its materials; hence, the adoption of a propagation model takes the several obstacles into account (doors, walls, closets, machines, etc.), and their attenuation coefficients [5], [6]. Extra details on indoor propagation models can be found in [7], [8], [9].

For outdoor environments, the obstacles, such as materials of the building, foliage, and clutter contribute to the increase of the path loss [10] [11]. In this context, two outdoor propagation models have special relevance [10], the SUI and the MMDS band empirical path loss ones.

The total capacity required for each AP (or BS) is defined by using experimental measurements for the applications transmission data rates of : Voice over IP (VoIP), Video over IP, File Transfer Protocol (FTP), E-mail, World Wide Web (WWW), and File Transfer (FT). The total capacity supported by each AP is obtained as a function

of the number of user assigned to it, and of the average duration of applications. For the positioning of APs over the plan, two optimization methods were developed, which allow for the minimization of their total number. One of the methods considers the received power in each position of the coverage area plan by using empirical propagation models. The other method allows to choosing the most probable position of each user, and its capacity according to the foreseen applications.

The WPT was developed by using C# graphic methods [12], and it interacts with a SQL Server 2000 Data Base [13]. There are however other tools for Wi-Fi planning which involve higher complexity and costs [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], and do not comprise both technical and economic/budget issues.

3 Propagation models

3.1 Outdoor Propagation models

In non line-of-sight (NLoS) channel conditions, signals may have undergone scattering, diffraction, polarization changes, and reflection impairments, which affect their strength and phase at the receiver. However, usually these impairments are not important if there is line-of-sight (LoS) between the transmitter and the receiver.

Over the years, various models have been developed which attempt to characterize these radio frequency (RF) environments, and allows for the prediction of the RF signal strengths. These models, based on empirical measurements, are then used to predict large-scale coverage for radio communications systems in cellular applications, and provide estimates for path loss (PL) by considering the distance between the transmitter and receiver, terrain factors, antenna heights, and cellular frequencies. Nevertheless, according to [11] none of these approaches address the needs of broadband fixed wireless adequately. To overcome this limitation, AT&T developed a wireless model from data that has been validated against deployed fixed wireless systems which yielded comparable results. This model was the basis of an industry-accepted model, and is being used by the standardization bodies, such as in the IEEE 802.16 case. The adoption of the AT&T wireless model by IEEE is referred as “Channel Models for Fixed Wireless Applications” by Erceg et al, [25]. The AT&T wireless path loss (PL) model includes, as parameters, antenna heights, carrier frequency, and types of terrain [11]. One possible solution for the WPT is therefore the Stanford University Interim (SUI) model, which is an extension of the earlier work of AT&T wireless model [11].

The SUI model uses three basic terrain types:

- Category A - Hilly/moderate-to-heavy tree density.
- Category B - Hilly/light tree density or flat/moderate-to-heavy tree density.
- Category C - Flat/light tree density.

These terrain categories provide a simple method to estimate more accurately the PL of the RF channel in a NLoS situation. Being statistical in nature, the model is able to represent the range of PLs experienced within an actual RF link. SUI channel models were explored for the design, development, and testing of WiMAX technologies in six different scenarios, (SUI-1 to SUI-6) [26]. By using these channel models,

it is then possible to predict more accurately the coverage probability achieved within a base station site sector. These models do not replace detailed site planning efforts (and site surveying) but can provide an estimate before actual planning. Besides, it is very important to perform RF planning activities to adequately evaluate specific environment factors, co-channel interference, actual clutter, and terrain effects.

This model allows for using several frequencies and terminal stations (TSs) heights. The path loss is given (in dB) by [10]

$$PL(d) = A + 10 \cdot \gamma \cdot \log_{10} \left(\frac{d}{d_0} \right) + X_f + X_h + S, \quad (1)$$

with the following parameters

$$A = 20 \cdot \log \left(\frac{4\pi d_0}{\lambda} \right), \quad (2)$$

and

$$\gamma = a - b \cdot h_b + c/h_b, \quad (3)$$

where d is the distance between the BS and a given point, in meters, $d_0=100$ m, h_b is the BS height above ground, in meters ($10 < h_b < 80$ m), and a , b , and c are parameters which are chosen according to three environments represented by A, B or C, Table 1.

Table 1. Values for the parameters in the context of IEEE 802.16 model (2.5-2.7 GHz band).

Model constant	Terrain Type		
	A	B	C
a	4.6	4.0	3.6
b	0.0075	0.0065	0.0050
c	12.6	17.1	20

Terms X_f and X_h are correction factors for frequency, and TS (receiver) antenna height above the ground, respectively. These corrections are defined as

$$X_f = 6.0 \cdot \log \left(\frac{f}{2000} \right), \quad (4)$$

and

$$X_h = \begin{cases} -10.8 \cdot \log(h_m/20), & \text{for terrain types A and B} \\ -20.0 - \log(h_m/20), & \text{for terrain type C} \end{cases}, \quad (5)$$

where f is the frequency, in MHz, and h_m is the receiver height above the ground, in meters. The term S is a lognormal-distributed random variable with zero mean and standard deviation σ_s , with the typical values from 8.2 to 10.6 dB, depending on the type of terrain [10]. This term takes shadow fading originated by trees and structures into account [10].

In order to obtain the average path loss (attenuation factor), $\overline{PL}(d)$, a random variable is assigned to σ_s . The average received power is given by $\overline{PR}(d) = \overline{PE} - \overline{PL}(d)$, where \overline{PE} is the average transmission power. In the context of the WPT, models with high complexity will be used, namely, the NLoS dominant

ray path loss one [10]. Hence, it is important to compare these results with the other two outdoor models, and validate then against experimental results.

3.2 Indoor Propagation models

In indoor propagation environments, the average received power in a given position depends on the average attenuation factor, $\overline{PL}(d)$ between the AP and wireless terminals, expressed in dB [5]

$$\overline{PL}(d) = \overline{PL}(d_0)[\text{dB}] + 10n_{SF} \log\left(\frac{d}{d_0}\right) + FAF[\text{dB}] + \sum_i PAF[\text{dB}], \quad (6)$$

where, $\overline{PL}(d_0)[\text{dB}]$ is the path loss attenuation for the reference distance $d_0 = 1\text{m}$, n_{SF} represents value of the propagation exponent (for the same floor it is equal to 3.5), $FAF[\text{dB}]$ is the floor attenuation factor (for the same floor it is equal to 12.9 dB), and the obstacle attenuation factor, $PAF[\text{dB}]$, which can be derived from [5] but is only applicable for some materials. The average path loss attenuation for the reference distance is given by

$$\overline{PL}(d_0)[\text{dB}] = 10 \log\left(\frac{\lambda^2}{(4\pi)^2 (d_0)^2}\right), \quad (7)$$

where $\lambda = c/f$, $c = 3 \times 10^8 \text{ms}^{-1}$ and f is the IEEE 802.11 frequency carrier [3]. The threshold values for received and transmitted powers were extracted from [27].

4 Capacity models and Algorithms

The planning of a WLAN is mainly focused in the coverage of all PCs/wireless terminals. Usually, the suppliers of wireless equipment visit the place and make a site survey with a laptop. The procedure consists in verifying if the signal power level surpasses a given threshold for all relevant locations. However, sometimes, this strategy is not enough to produce the most profitable planning, and the evaluation of the user's traffic is also important to define the number of AP and their positions. For example, Table 2 presents the average transmission data rate corresponding to each group of applications, obtained via experimental work at INESC-ID. The values seem to be very high but this is due to overhead bits used in real time transport protocol (RTP), user datagram protocol (UDP), IP, media access control (MAC) and physical (PHY) headers. Protocol overhead is especially significant in the case of VoIP because the data packets are small compared to the overhead.

The WPT defines the total number of AP and their positions by assuming a given user's simultaneous factor (USF) for each application, and a correspondence between the received power threshold and the maximum transmission data rate [27]. For a given usage scenario the choice of the USF of each application depends on the percentage of simultaneous users.

From a theoretical point of view, each AP can guarantee a given maximum transmission data rate in each spatial ring, depending on the received power [27]. Therefore, the choice of AP positions depends on the possible wireless terminal positions, and on the applications to be used.

Table 2. Average transmission data rate at the IP layer for each application.

Applications	Transmission data rate [kbps]
Voice over IP (G.711, sampling of 20 ms, no silence suppression)	80
Video over IP (MPEG 4)	1024
FTP+WWW+E-mail+FT	500

Figure 1 depicts the AP positioning process and the associated transmission data rate threshold for each of the rings. The algorithm starts by placing an AP in the vicinity of the wireless terminal nearest the origin of area to be covered. Note that the transmission data rate in each ring, TR_r , obeys the following inequality

$$TR_r \leq TR_{thr}, \quad (8)$$

where TR_{thr} defines the transmission rate threshold in a given ring while TR_r is given by

$$TR_r = NU_r \sum_{a=1}^A TR_a USF_a, \quad (9)$$

Here, NU_r is the number of users per ring, A is the total number of applications, TR_a is the transmission data rate of each application and USF_a is the user simultaneous factor for each application. Besides, the total TR supplied by each AP must verify,

$$TR_{TOTAL} \leq TR_{th1}, \quad (10)$$

Where TR_{th1} is the total maximum capacity of the AP for a given standard and,

$$TR_{TOTAL} = \sum_{r=1}^R NU_r \sum_{a=1}^A TR_a USF_a, \quad (11)$$

The total number of rings is represented by R . Thus, in the context of this algorithm, the position of an AP is accepted if the following condition is verified

$$(TR_1 \leq TR_{th1}) \cap \dots \cap (TR_r \leq TR_{thr}) \cap \dots \cap (TR_R \leq TR_{thr}) \cap (TR_{TOTAL} \leq TR_{th1}) \quad (12)$$

If (12) is verified the algorithm finds the terminal nearest to the covered one, moves the position of the AP to the vicinity of the new terminal, and verifies (12). If (12) is verified the algorithm goes on until the last user is served.

Otherwise, the AP has to move its position to the previous one (see Figure 1) and a new AP, closer to the next wireless terminal, has to be considered. The same procedure is then repeated to this new AP, and so on.

In the automatic mode, the algorithms guarantee the fulfilment of a given throughput (in Mbps). The distribution of APs is made by applying one of two different methods: either dynamic or static. If no value is defined for the throughput threshold, the algorithm uses the default value of the standard. The purpose of the dynamic algorithm is to properly choose APs positions in the coverage area defined by the network designer. As wireless terminals are portable or mobile, and their location is random, the algorithm sets the optimized number (and location) of APs to cover a given area.

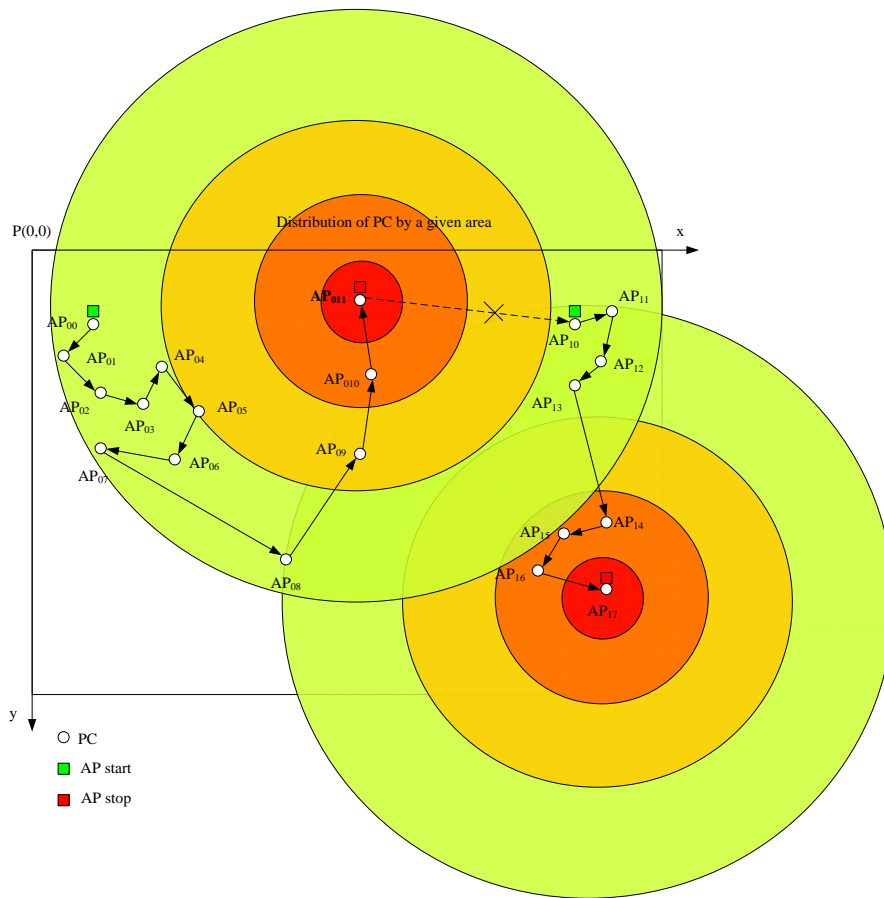


Fig. 1. Transmission data rate rings, according to the IEEE 802.11b standard.

The first step of the algorithm is to guarantee the coverage of the entire boundary, trying to concentrate the highest signal power level inside the coverage area, by moving APs to the centre, as depicted in Figure 2. After covering the boundary, the algorithm checks if its interior has spots with values of the throughput below the required ones. If not, the algorithm covers that spots again with an optimized number (and location) of APs.

The static algorithm is the best approach when the spots are fixed. For each spot, the required throughput can thus be defined. This definition can be simplified with the

creation of user groups. It is therefore possible to define a required throughput, and then associate this group to a user. The algorithm starts by covering the wireless terminals which requires higher signal power level, and finishes with terminals that need lower signal power level. During this process the algorithm checks if the throughput is not overcome, according to the throughput ring areas. This is generated by means of the computation of the average attenuation factor, and of the received power threshold defined by each supplier.

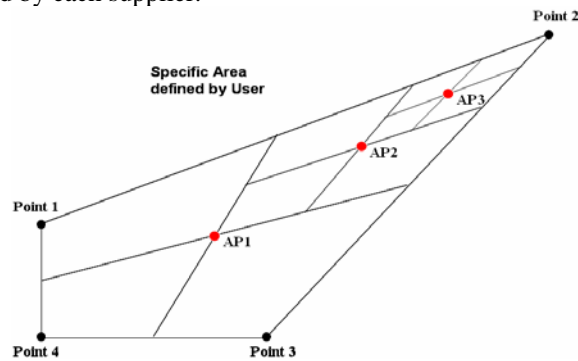


Fig. 2. The Algorithm used for place the AP.

5 Functionalities and Potentialities

The tool was developed by having in mind its user friendly use, and to help network designers with a fast, technical and economic planning tool as well. This tool supports the IEEE 802.11 a/b/g standards and WiMAX as well. It estimates the TR needed by the network according to the capacity model. Items such as obstacles, APs characteristics, and network card types can also be directly updated into the tool. Different propagation models can also be introduced and tested.

Figures 3-4 show examples of the actual layout of the WPT in indoor and outdoor environments, including the received power level distribution, and economic plans. The possibility of upgrading the tool to for QoS support, e.g., IEEE 802.11e, and for different frequency bands was also foreseen, and can be easily implemented.



Fig. 3. WPT layout with indoor application.



Fig. 4. WPT layout with outdoor application.

The heights of the campus terrain are also considered. The WPT has several menus that enable the user to insert the appropriate parameters according to several options. It helps in the process of making a complete plan for the coverage of a given area based solely on a file of the plant, the obstacles, their materials, and the several locations of the wireless terminals. As an output, the program generates a layout showing

the received power/capacity, and the positions of APs. The tool allows the designer to introduce the characteristics of the equipment given by the manufacturer into a database. Based on this data, after the technical planning, the WPT can estimate the total cost of the equipment involved in a particular configuration. By properly running this tool, it is therefore possible to optimise the wireless planning process in a given area in a very simple and efficient way.

Figure 5 presents some of the PTM Alvarion WiMAX equipment we have installed in FCT/UBI, where the antenna and output unit are shown in the first picture, while the BS is presented in the other one, and Customer Premise Equipment is presented in the other. The antenna and ODU (output data unit) are shown in the first picture while the BS and the Customer Premise Equipment are presented in the other ones. Field trials are being performed in Covilhã, and initial results of signal-to-noise ratio, *SNR*, Figure 6, are being obtained. The BreezeMAX duplexing frequency range is 3499.5-3553.5 MHz (3.5a), and 3550-3600 MHz (3.5b) for downlink, and 3399.5-3453.5 MHz (3.5a), and 3450-3500 MHz (3.5b) for uplink [28]. ANACOM, the Portuguese telecommunications regulator gave us a temporary R&D frequency license in the range 3443-3467.5/3543-3567.5 MHz. In these particular field tests, our ODU was operating at 3551.75 MHz (downlink), and 3451.75 MHz (uplink). ODU transmitter power is 28 dBm.



Fig. 5. IEEE 802.16-2004 PTM equipment operating at the 3.5 GHz (licensed) band.

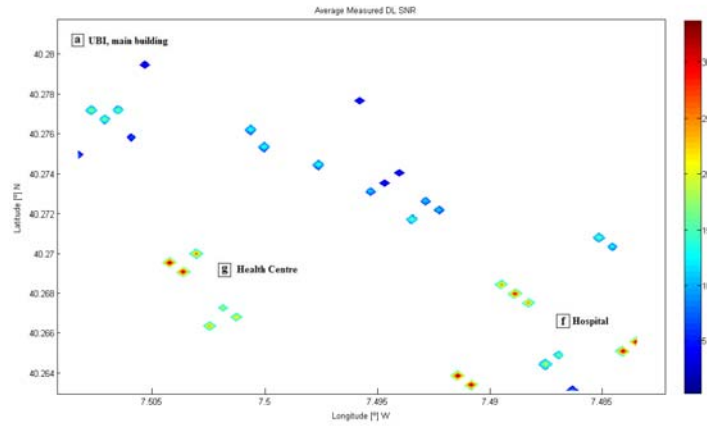


Fig. 6. Initial measurements of *SNR* in the downlink (DL), city of Covilhã.

A scenario using Geographic information Systems (GIS) lead us to the results of Figure 7.

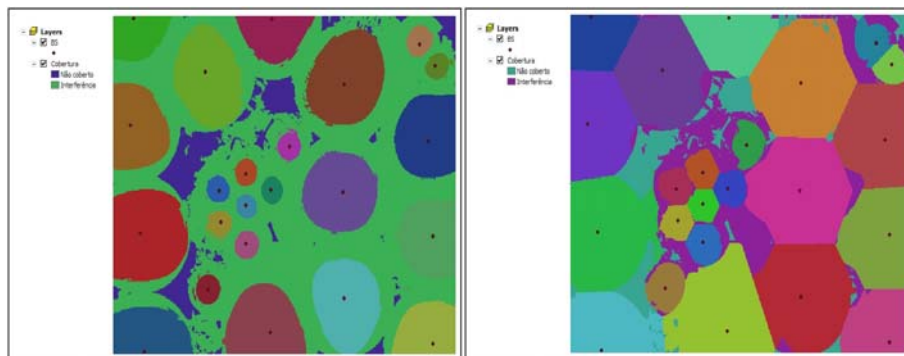


Fig. 7. Advantages of using sectorial antennas in the district of Covilhã.

A solution with omnidirectional antennas was compared with another one with sectorial antennas, and the advantages of using the latter in terms of interference mitigation are clear because the area of interference is reduced from 42 %, in the omnidirectional case, down to 9.3%, when sectorial antennas are used, Table 3. Furthermore, the covered area increases from 52.3 to 85.0 %.

Table 3. Coverage and interference areas in the second exercise for the district of Covilhã.

Type of Antenna	Covered Area [%]	Area of Interference [%]	Non-covered area [%]
Omnidirectional	52.3	42.0	5.7
Sectorial	85.0	9.3	5.7

6 Conclusions

In this paper, a tool was presented that allows a planning designer to dimension WLAN and WMAN topologies via a practical approach. Basically, it is possible to obtain the signal coverage and throughput maps from the plant of a given zone; the implementation cost of such communication wireless networks can then easily be estimated based on the required throughput for the envisaged applications. Hence, this tool constitutes a simple and complete way to implement the most recent WLAN and WMAN solutions. Besides, it also produces budget planning. It can be used by network designers in industrial environments but it is also a workbench for students simulations. Some improvements are being made in the previous tool, the so-called WLPT [4]. One of them is the possibility of planning outdoor Wi-Fi and WiMAX networks. A practical deployment of a single WiMAX cell in the city of Covilhã was presented. LoS dimensioning issues, were briefly addressed, and there is a strong need of using sectorial antennas to guarantee an adequate coverage and interference mitigation. In outdoor coverage the coexistence of Wi-Fi and WiMAX implies a greater flexibility to frequency planning once it can mitigate the interference problems. This is particularly important in IEEE 802.11 once the number of available frequencies is lower.

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