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DESIGN AND PLANNING OF IEEE 802.16 NETWORKS

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ABSTRACT

This paper addresses aspects of design of WiMAX Wireless networks to establish a point-to-point, PTP, link with Alvarion BreezeNET B equipment, from the Health Sciences Faculty of University of Beira Interior to Hospital Sousa Martins (Guarda), and also presents a field trial with pre-WiMAX PTP equipment. The design of the link with relays had into consideration the carrier to noise ratio, C/N, and the minimum carrier to noise ratio with fading, C/N_{min_fad}. From the dimensioning process, with $\gamma = 2$, for the second clause, the three types of modulations (low to high order ones) can be used. Field trials results are similar to the ones extracted from the theoretical model. Cellular WiMAX planning and tests were also addressed and there is a need of using sectorial antennas to optimize coverage and interference.

1. Introduction

This work presents aspects of design of WiMAX (World Interoperability for Microwave Access) wireless point-to-point, PTP, networks. The objective is to connect the Health Science Faculty of the University of Beira Interior, FCS/UBI, in Covilhã, to the Hospital Amato Lusitano, HAL, in Castelo Branco, and to the Hospital Sousa Martins, HSM, in Guarda. The planning process and the development of a point-to-multipoint, PTM, network that covers the whole district of Covilhã are also briefly addressed. A network of this type justified by the need of creating an Intranet that allows to efficiently exchanging contents within a context of mobility, and an efficient use of e-learning multimedia platforms.

WiMAX is the commercial name of IEEE 802.16. In terms of standardisation, the IEEE 802.16-2004 group is dedicated to PTP and PTM networks (without mobility support) while the IEEE 802.16e group is dedicated to PTM networks that support mobility [1]. In terms of technology, WiMAX uses OFDM and a kind of dynamic modulation scaling, i.e., the system is able to adapt itself to the best modulation/coding schemes by considering carrier-to-noise-plus-interference versus data rate constraints, Table I.

Table I: IEEE 802.16-2004 channel characteristics [2].

Bandwidth (MHz)	Data rate (Mbps)		
	QPSK	16-QAM	64-QAM
3.5	3.3	6.5	9.8
5	4.6	9.3	13.9
7	6.5	13.1	19.6
10	9.3	18.7	28.0
20	18.7	37.5	56.2

Different received power levels correspond to different net PHY (physical) bit rates, and to different modulation and coding schemes, Table II.

Table II: Correspondence between modulations, sensivity, and net physical rate for Alvarion BreezeMAX at 3.5 MHz.

Modulation & coding	Net PHY Bit Rate [Mbps]	Sensitivity [dBm]
BPSK 1/2	1.41	-100
BPSK 3/4	2.12	-98
QPSK 1/2	2.82	-97
QPSK 3/4	4.23	-94
QAM 16 1/2	5.64	-91
QAM 16 3/4	8.47	-88
QAM 64 2/3	11.29	-83
QAM 64 3/4	12.71	-82

In IEEE 802.16-2004, channels of 3.5, 7 and 10 MHz are defined [1]. As link distances of the order of tens kilometres can be guaranteed, WiMAX is as a good solution for broadband backhaul; while offering high data rates, it enables a distance range up to 50 km (in the PTP case), and cell coverage radius between 2 and 5 km (in the PTM case).

The WiMAX standard supports adaptive modulation, effectively balancing different data rates and link quality as the modulation method may be adjusted almost instantaneously for optimum data transfer. WiMAX is able to dynamically shift modulations from 64-QAM down to 16-QAM and to QPSK, displaying its ability to overcome QoS issues with dynamic bandwidth allocation over the distance between the BS, Base Station, and the SS, Subscriber Station.

Modulation schemes ensure that a quality signal is delivered over the distance by decreasing throughput thus decreasing the Packet loss rate. One of the best characteristics of WiMAX is the ability to support multimedia and IP (Internet Protocol) communications, e.g., videoconference, voice over IP, and communication of high resolution video/image, which is a must for the practice and teaching of medicine. One example is the possibility of students having access to e-contents while they are at home or moving through the city; it will be enough that they own a laptop or any multimedia device with a WiMAX card. Besides, WiMAX PTM networks can support emergency and safety, Firemen and Polices services, hence it is possible to send real time images, e. g., from the accident, or fire scenes. For the PTP component, the dimensioning of 5.8 GHz WiMAX links was addressed. Field trials were held by using 5.4 GHz pre-WiMAX equipment.

The remaining of this paper has the following structure. Section II presents the dimensioning of the PTP WiMAX link with relays, by having the minimum value of carrier-to-noise ratio, C/N_{min}, and the effect of fading into consideration. Section III presents the results of PTP field trials and measurements, and also addresses initial PTM field trials. Finally, Section IV presents the conclusions of the work.

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2. Design of WiMAX Links

It was necessary to verify the existence of line of sight, LoS, between the transmitters for the placement of the repeater previously determined for the WiMAX link between FCS/UBI, Covilhã, and HAL, Castelo Branco, and if there is no obstruction to the first Fresnel ellipsoid. From a detailed analysis of the terrain profile between Covilhã and Guarda, by considering the localization of the FCS/UBI premises and HSM, it was verified that the base station, BS, cannot be located at FCS/UBI because it does not guarantee the existence of LoS; therefore, the option was to install the BS at Reitoria of the University of Beira Interior. Besides, as the land profile is very irregular, it was necessary to install two relays, one located at Alto da Malhoeira and another in Barracão. The first link is between Reitoria and Alto da Malhoeira, with a length of 11.05 km, while the second one is between Alto da Malhoeira and Barracão, 22.25 km. Finally, the third one is between Barracão and HSM, 6.3 km.

Our approach considers the received power, P_r, the carrier-to-noise ratio, C/N, and the minimum carrier-to-noise ratio with fading, C/N_{min_fad}, as parameters. For dimensioning purposes, the attenuation, L, is computed according to the modified Friis formula [3].

$$L = 32.4 + 30\gamma + 20\log d + \gamma_{rain} d + \gamma_{fog} d + \gamma_{snow} d + 20\log f, \quad (1)$$

where γ it is the propagation exponent, γ_{rain} is the specific attenuation due to rain; γ_{fog} is the specific attenuation due to fog; and γ_{snow} is the specific attenuation due to snow (all these specific attenuations are expressed in dB/km), d is the distance in km, and f is the frequency in GHz [4]. The values for the parameters are the following: γ=2 [3], γ_{rain} = 0.0811 dB/km [5], γ_{fog} = 0.01 dB/km (this value can be neglected since it is much lower than γ_{rain} [4]). γ_{snow} is neglected for frequencies below 30 GHz [4], d varies between 1 and 22.25 km, and f = 5.8 GHz.

To compute P_r it is important to know the values of the following parameters: P_e=-9 dBW, maximum power output [6], G_e = 28 dBi [6], G_r = 28 dBi [6], and L.

$$P_r = P_e + G_e + G_r - L . \quad (2)$$

The carrier-to-noise ratio C/N is computed by

$$C/N = P_r - N . \quad (3)$$

where [5]

$$N = N_0 + N_f . \quad (4)$$

N_0 is the white Gaussian noise power, and N_f is the noise factor. The minimum carrier to noise ratio with fading, C/N_{min_fad}, is obtained by using the following formula [4]

$$C/N_{min\_fad} = C/N_{min} + M_u + M_{ext} , \quad (5)$$

where M_u is the uniform margin in dB, and M_{ext} is an extra margin of 3 dB. To determine C/N_{min_fad}, according to the old ITU-R clauses of the ITU-R, two values for the bit error, ber, have to be considered, 10^{-6} and 10^{-3}. Apart from its variation with ber, C/N_{min} varies with the type of modulation, Table III. The variation of C/N with the distance, d, is presented in Figs. 1-3. By analyzing these curves it is possible to evaluate the viability of the links for the three types of modulations.

Table III: C/N_{min} as a function of ber [5].

Modulation	$ber = 10^{-6}$	$ber = 10^{-3}$
QPSK	14	10
16-QAM	23	19
64-QAM	30	26

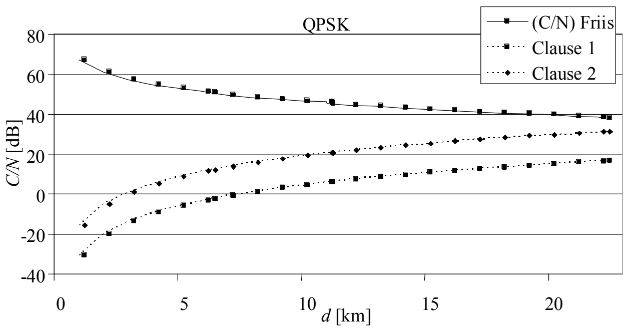

Fig. 1: C/N_{min_fad} and C/N for the QPSK modulation.

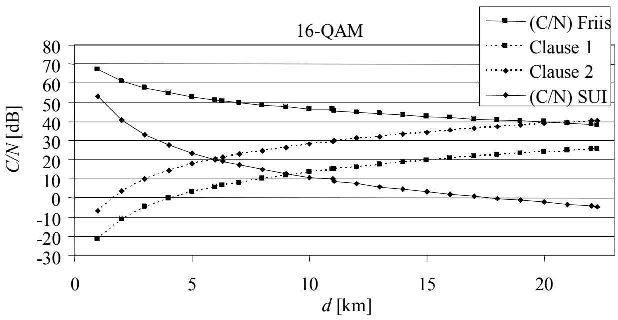

Fig. 2: C/N_{min_fad} and C/N for the 16-QAM modulation.

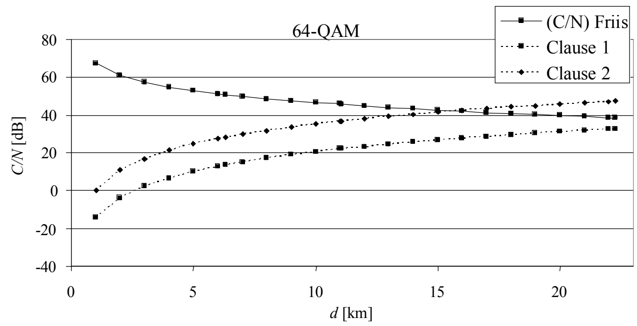

Fig. 3: C/N_{min_fad} and C/N for the 64-QAM modulation.

The links are considered viable when C/N is higher than C/N_{min_fad}, i.e., in the case of the 16-QAM modulation, the use of the SUI model is also highlighted in the Figures.

3. Field Trials

A. Scenario

We used the Alvarion BreezeNET B14 in the field trials. It presents the following characteristics [6]: f = 5.4 GHz [6],

b_{rf} = 20 MHz [6], $G_e = G_r$ = 21dBi [6], and P_e = 9 dBm, the maximum output power [6], Fig. 4. Beyond the Alvarion equipment, we also used two computers, one as a server and another as client, two UTP cables, and two 12-220 V invertors.

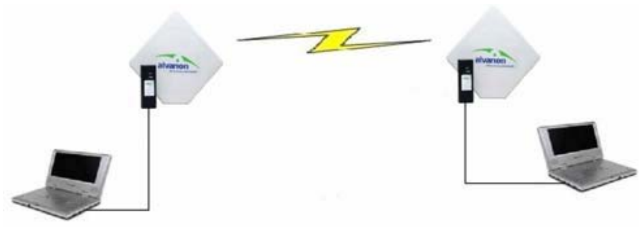

Fig. 4: Topology of PTP network used in the field trials.

With this link, it was possible to create a complete PTP network for the field trials. The tests were made for five different distances. The base unit, BU, was always located at FCS/UBI, which has an altitude of 490 m. The remote bridge was then placed onto the following places:

- Souto Alto -488 m high, and located at 5890 m from FCS;
- Parque de Campismo do Fundão -550 m high, and located at 14860 m from FCS, Fig. 5;
- Casa do Guarda (Serra da Gardunha) - 912 m high, and located at 17563 m of FCS;
- Posto de Vigia (Serra da Gardunha) - 1130 m high, and located at 17922 m of FCS;
- Portugal Telecom microwave link stations (Serra da Gardunha) - 1212 m high, and located at 20939 m from FCS.

Fig. 5: Covilhã view from Parque de Campismo do Fundão

Similarly to what was made for the FCS/UBI-HSM link dimensioning, the terrain profile was also analysed for the five links, and the absence of LoS obstruction (without any obstruction of the 1st Fresnel ellipsoid) was verified.

B. *Results*

Two directories were created on a server computer to enable the evaluation of the traffic conditions in the radio links. One of these directories contains a file with 40MB while the other contains 100 files of small images, with an average size of 350 kB each. The task of the client computer was to download the files from these two directories. Values were recorded for the data rates, carrier-to-noise ratio, order of modulation, and total time for the transmission, for each of the links, Table IV. Table V presents the correspondence among values of *C/N*, the maximum order of modulation, and the modulation type. Fig. 6 presents a comparison between the *C/N* curve by using the Friis formula and the trend line obtained from the field trials results.

Table IV: Field trials results.

Distance to FCS	Data rate, R_b [kbps]		Site Survey		Time 40MB
	40MB	100 Files	$C/N_{[dB]}$	Modulation	
5 890 m (Souto Alto)	9 784	7 128	24	8	46 s
14 860 m (Parque de Camp. Fundão)	9 448	7 144	15	6	47 s
17 563 m (Casa do Guarda)	7 584	6 472	15	6	49 s
17 922 m (Posto de Vigia)	9 407	7 120	17	6	47 s
20 939 m (PT Antennas)	7 016	6 808	15	6	49 s

Table IV: Correspondence among *C/N*, the maximum order of modulation, and the modulation type [6].

C/N	Maximum Order of Modulation	Modulation
C/N> 23 dB	8	64 QAM – 3/4
21 dB > *C/N*> 23 dB	7	64 QAM – 2/3
16 dB > *C/N*> 21dB	6	16 QAM – 3/4
13 dB > *C/N*> 16 dB	5	16 QAM – 1/2
10 dB > *C/N*> 13 dB	4	QPSK – 3/4
8 dB > *C/N*> 10 dB	3	QPSK – 1/2
7 dB > *C/N*> 8 dB	2	BPSK – 3/4
6 dB > *C/N*> 7dB	1	BPSK – 1/2

The highest difference between the results is approximately 10 dB for the lowest distances but it decreases with the increase of the distance, and the trend is to obtain very similar values.

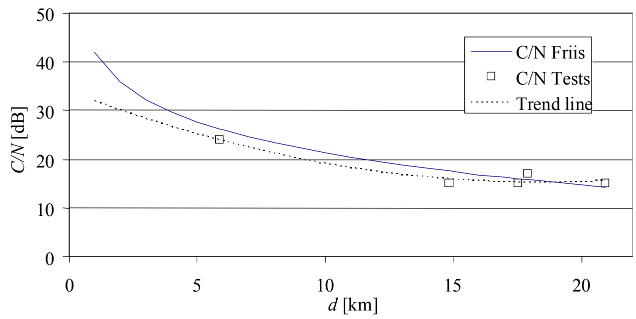

Fig. 6: Comparison between theoretical and practical *C/N*.

C. *Analyses of the Results*

The measured data rate (throughput) and *C/N* decreased with the increase of the distance between the antennas. The exception happens in the link between FCS/UBI and Posto de Vigia, where the date rate and *C/N* are higher relatively to the previous link (immediately lowest distance). This fact can be explained due to the possible existence of exceptional propagation conditions, for example, the parabolic land profile of this zone may benefit the signal reception.

There is a relevant difference between the data rate for the 40 MB file transfer and the 100 files transfer. In the 100 files transfer case, as this small files have approximately 350 kB, which is considered small when compared with the 40 MB of the larger file, the transmission lasts some time until get stable; therefore, the transmission of small file never register peak data rate values as high as ones for the largest file.

After this field trial, one has setup one pilot installation BreezeNET B100 in Covilhã between two buildings of the University, with a distance lower than 2km, Fig. 7.

Fig. 7: Pilot BreezeNET B installation.

Recently, another equipment was made available to test the Gardunha-Castelo Branco link with a relay (Covilhã-Gardunha, 22.5km, and Gardunha-Castelo Branco, 28.5km), Fig. 8. The optimistic results we achieved lead to an actual installation, Fig. 9, and in practice an extra repeater was needed in Castelo Branco to overcome the absence of LoS between the Gardunha mountain and HAL, for the specific position of the receiver in the Hospital. This extra link had approximately one kilometre.

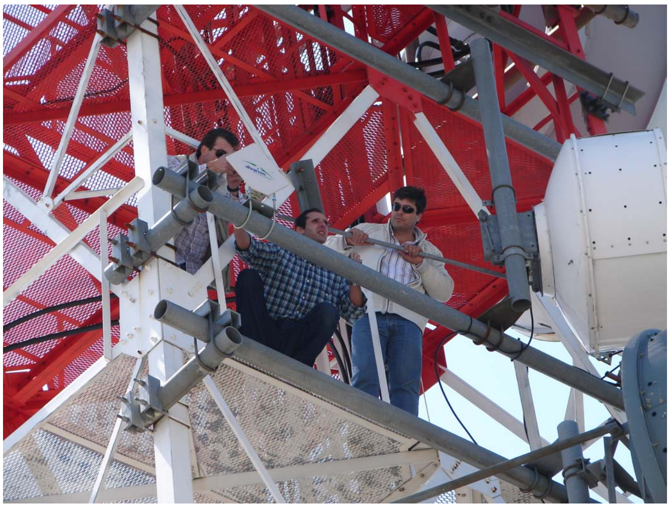

Fig. 8: BreezeNET B equipment at the repeater station (in the Gardunha back-to-back relay).

These radio links will allow for a better cooperation between FCS/UBI and Hospitals, improving the quality of services given to patients, and an easier access to e-learning contents, among other, by professors, students, doctors, nurses, and other professionals.

Fig. 10 presents some of the PTM Alvarion WiMAX equipment we have installed in the Health Sciences Faculty, near the Hospital, allowing for cellular coverage in Covilhã.

The antenna and the ODU (outdoor radio unit) are shown in the first picture while the BS is presented in second one, and Customer Premise Equipment is presented in the last one. Field trials are being performed in Covilhã, and initial results on signal-to-noise ratio, SNR, Fig. 11, and throughput were 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.

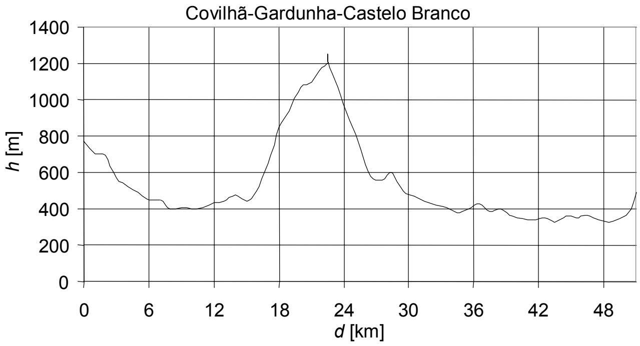

Fig. 9: Obstructed path with a relay (in a tower with 40m).

Fig. 10: IEEE 802.16-2004 PTM equipment operating at the 3.5 GHz (licensed) band.

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.

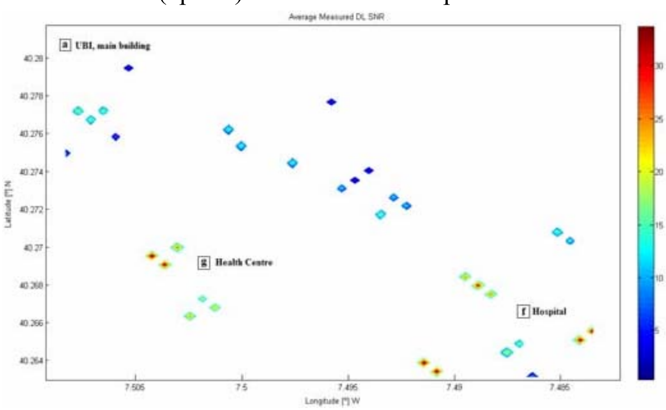

Fig. 11: Initial measurements of SNR in the downlink (DL) with the BreezeMAX 3.5 MHz equipment.

More recent Field trials are being performed, and detailed results on SNR are presented in Fig. 12.

Fig. 12: Detailed measurements of SNR in DL.

For the WiMAX cellular coverage of the whole region of Beira Interior, Portugal, many combinations of the placement of BSs and types of antennas can be explored. By using GIS (Geographic Information Systems), one specific exercise compared the use of omnidirectional antennas with the use of sectorial ones on the whole region, Fig. 13. The advantages of using the latter in terms of interference mitigation are clear because the area of interference is reduced from 36.4 %, in the omnidirectional case, down to 0.3%, when sectorial antennas are used, while increasing substantially the covered area, Table VI.

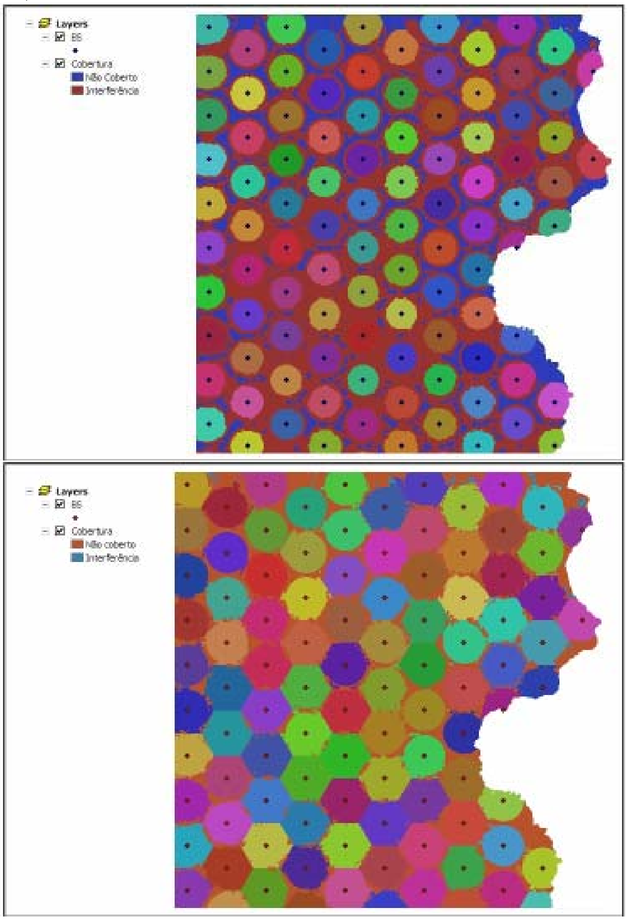

Fig. 13: Advantages of using sectorial antennas in the whole region of Beira Interior.

Table VI: Coverage and interference areas in the second exercise for the whole region of Beira Interior.

Type of Antenna	Covered Area [%]	Area of Interf-erence [%]	Non-covered area [%]
Omnidirectional	50.8	36.4	12.8
Sectorial	86.9	0.3	12.8

4. Conclusions

For the design of the FCS/UBI-HAL WiMAX PTP link, computations were performed to confirm the absence of obstructions to the 1st Fresnel ellipsoid. The use of two relays is needed to guarantee LoS conditions. The use of BreezeNET B equipment from Alvarion was assumed. From the dimensioning process, it was verified that with $\gamma = 2$, for the second clause, the three types of modulations can be used. Field trials results were compared with the theoretical model, and very similar results were achieved. The small differences registered can be explained by the small beam width of the antennas and therefore to imperfect orientation during the field trials. PTM field trials are also being performed, and ranges of up to 5 km are achieved for the Covilhã cell in LoS. 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. The need of existence of LoS to guarantee good quality communications was verified during PTM field trials. It confirms the need of an adequate LoS dimensioning.

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REFERENCES

[1]. Mo Shakouri, WiMAX Enabling Personal Broadband, in *Proc. of WiMAX World Europe*, Vienna, Austria, May 2006.

[2]. Jorge Rodrigues, *WiMAX miragem ou realidade?*, PT Comunicações, Évora, Portugal, 2005.

[3]. Fernando Velez, *An Interactive Computational-Geometric Tool for Microcellular Design in the Millimetrewave Bands*, (in Portuguese), M. Sc. Thesis, Instituto Superior Técnico, Lisbon, 1995.

[4] Fernando J. Velez, Vitor Carvalho, Dany Santos, Rui P. Marcos, Rui Costa, Pedro Sebastião and António Rodrigues, “Planning of an IEEE 802.16e Network for Emergency and Safety Services,” in *Proc. of 3G 2005 - IEE International Conference on 3G Mobile Communication Technologies*, London, UK, Oct. 2005.

[5] Carlos Salema, *Microwave Radio Links*, John Wiley & Sons, Hoboken, New Jersey, USA, 2003.

[6] www.alvarion.com