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DESIGN AND INSTALLATION OF PRE-WIMAX RADIO LINKS AND RELAYS

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ABSTRACT

This paper addresses aspects of design for 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 Amato Lusitano (in Castelo Branco, Portugal), and also presents the respective field trial with pre-WiMAX PtP equipment. The design of the link with relays had into consideration the carrier to noise ratio, and the minimum carrier to noise ratio with fading. Field trials results agree with the ones extracted from the dimensioning process. The small differences registered can be explained by the small beam width of the antennas and therefore to imperfect orientation during the field trials. The actual installation of the three hop link was successfully achieved, followed by a tune up of the tilt of the antennas, by the choice of the best QoS parameters and of the turbo-mode for the equipment, which allowed for obtaining higher values of the throughput.

1. Introduction

WiMAX is the commercial name of IEEE 802.16. In terms of standardisation, the IEEE 802.16-2004 group is dedicated to PtP (Point-to-Point) and PtM (Point-to-Multipoint) networks (without mobility support) while the IEEE 802.16e group is dedicated to PtM networks that support mobility [1]. In the future there will be 802.16m, the so-called Advanced Air Interface that will provide the convergence with Long Term Evolution (in the context of International Telecommunications Union).

In terms of technology, WiMAX uses OFDM (Orthogonal Frequency Division Multiplexing) 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.

In IEEE 802.16-2004, channels of 3.5, 7 and 10 MHz are defined [1], while pre-WiMAX versions of the equipment of some vendors also supported a bandwidth of 20 MHz. 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 (Quadrature Amplitude Modulation) down to 16-QAM and to QPSK (Quadrature Phase Shift Keying), displaying its ability to overcome QoS (Quality of Service) 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, very useful in the framework of health sciences teaching and learning. Complemented by PtM cellular coverage, a network of this type is justified by the need of creating an Intranet that allows to efficiently exchanging contents within a context of tutorial rooms geographically distributed among different Campus, and an efficient use of e-learning multimedia platforms in a context of mobility.

This paper addresses aspects of design of WiMAX Wireless networks to establish a PtP link with Alvarion BreezeNET B equipment, from FCS (Health Sciences Faculty) of UBI (University of Beira Interior) to HAL (Hospital Amato Lusitano) in Castelo Branco, Portugal. For the PtP component, the dimensioning of 5.8 GHz WiMAX links with relays was addressed. Field trials were held by using 5.4 GHz pre-WiMAX equipment.

The remaining of this paper has the following structure. Section 2 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 II also presents the scenario for the PtP field trials and measurements, and discusses the achieved results, and their impact in the dimensioning process. Section 3 presents two practical installations, and discusses the way the link performance was optimized by tuning up antenna tilts and by choosing the appropriate QoS parameters and the turbo-mode of the equipment. Finally, Section 4 presents the conclusions of the work.

2. Design of Pre-WiMAX Links

A. Models

From the conception work performed previously in the MobileMAN project, an internal project from Instituto de Telecomunicações [2], the existence of LoS (line-of-sight) between the transmitters at FCS/UBI, Covilhã, and HAL was verified, as well as the absence of obstructions to the respective first Fresnel ellipsoids. This dimensioning process lead us to the choice for the placement of two repeaters, one at Gardunha (a mountain) and another at the Castle hill in Castelo Branco, approximately one kilometre away from the Hospital.

Therefore, the link is formed by three hops, the first one, with approximately 21-22 km, from Covilhã to Gardunha, the second, with approximately 26-27 km, from Gardunha to the castle, while the last one, shorter than 1 km, is between the castle and HAL, Figs. 1-3. Last hop is needed because the Hospital height is very low relatively to the surrounding terrain and the castle obstructs direct LoS from the Gardunha mountain to the final destination, Fig. 4.

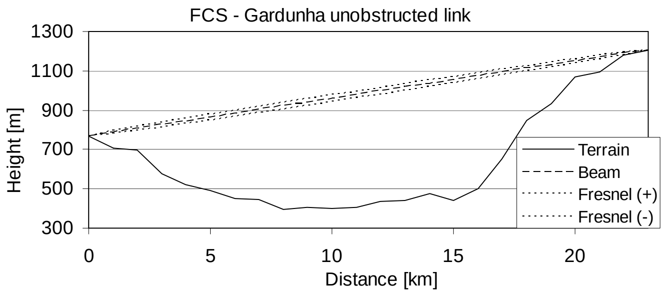

Figure 1: Link between FCS/UBI and Gardunha.

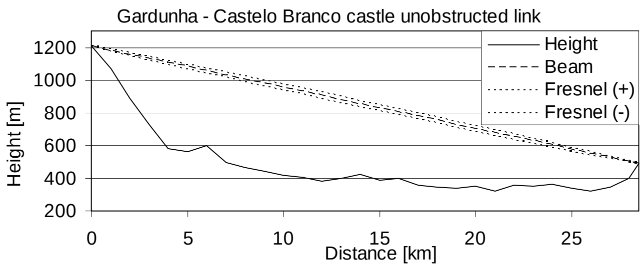

Figure 2: Link between Gardunha and Castelo Branco castle.

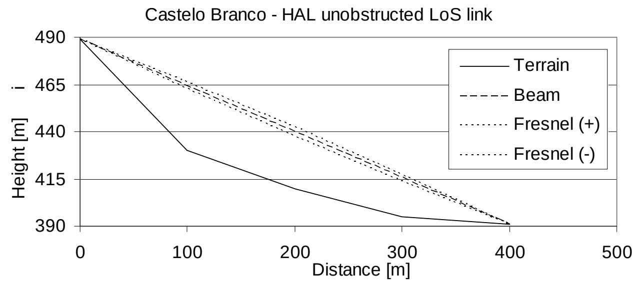

Figure 3: Link between the castle tower and the Hospital.

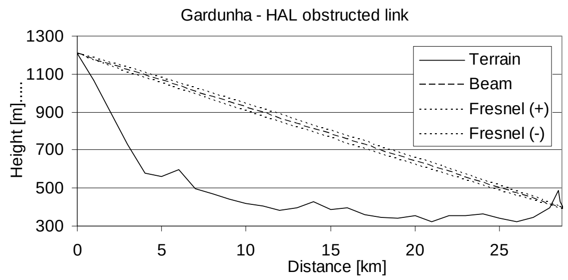

Figure 4: Obstructed link between Gardunha and the Hospital.

For our model, the simplified 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 27 km, and f = 5.8 GHz.

To compute P_r it the following values were considered for the 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, the power of noise is given by [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, two values for the bit error, *ber* (bit error), 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 1. The variation of C/N with the distance, d, is presented in Figs. 5-7, for the QPSK, 16-QAM and 64-QAM modulations. By analyzing these curves it is possible to evaluate the viability of the links for the three types of modulations.

Table 1: 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

The links are considered viable when C/N is higher than C/N_{min_fad}, i.e., for higher distances, with the considered parameters, links are still viable when the QPSK modulation is considered. In Fig. 6, for the 16-QAM modulation, the use of the SUI (Stanford University Interim) model is also highlighted. However, as it is excessively pessimistic, the results are worst.

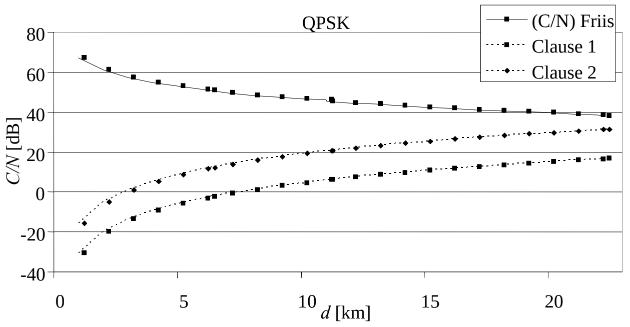

Figure 5: C/N_{min_fad} and C/N for the QPSK modulation.

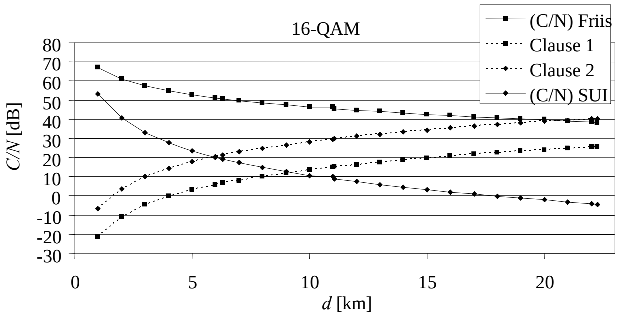

Figure 6: C/N_{min_fad} and C/N for the 16-QAM modulation.

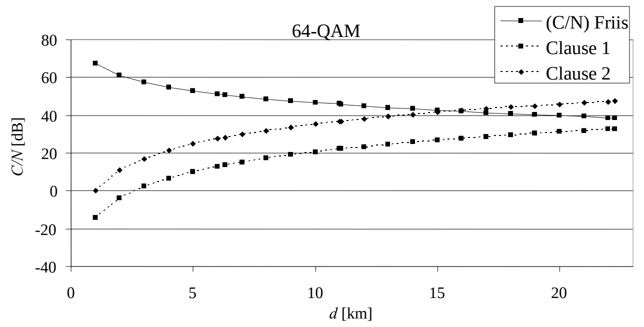

Figure 7: C/N_{min_fad} and C/N for the 64-QAM modulation.

B. Field Trials

Although the actual three-hop installation was performed with the Alvarion BreezeNET B100 equipment, we used the Alvarion BreezeNET B14 in the field trials that helped us in the dimensioning proccess. It presented the following characteristics [6]: f = 5.4 GHz [6], b_{rf} = 20 MHz [6], $G_e = G_r$ = 21 dBi [6], and P_e = 9 dBm, the maximum output power [6], Fig. 8. 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.

Figure 8: 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. 9;
- 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.

Figure 9: 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.

C. Results

According to the topology from Figure 8, 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 40 MB 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 2. Table 3 presents the correspondence among values of C/N, the maximum order of modulation, and the modulation type.

Fig. 10 presents a comparison between the C/N curve by using the Friis formula and the trend line obtained from the field trials results. 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.

Table 2: Field trials results.

Distance to FCS	Data rate, R_b [kbps]		Site Survey		Time
	40MB	100 Files	$C/N_{[dB]}$	Modulation	40 MB
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 3: 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

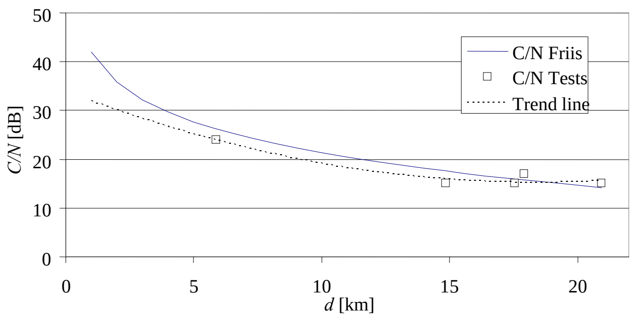

Figure 10: Comparison between theoretical and practical *C/N*.

D. 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.

3. Practical Installations

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 2 km, Fig. 11.

Figure 11: Pilot BreezeNET B installation.

Afterwards, equipment was made available to test the Gardunha-Castelo Branco link with a relay (Covilhã-Gardunha, 21-22 km, and Gardunha-Castelo Branco, 26-27 km), Fig. 12. The optimistic results we achieved in the filed trials lead to an actual installation according to the dimensioning presented before. One terminal station was installed in the Health Sciences Faculty rooftop, two back-to-back relay stations at the tower in Gardunha, Fig. 12, other two back-to-back ones at the tower in the castle, in Castelo Branco, and another one in the Hospital.

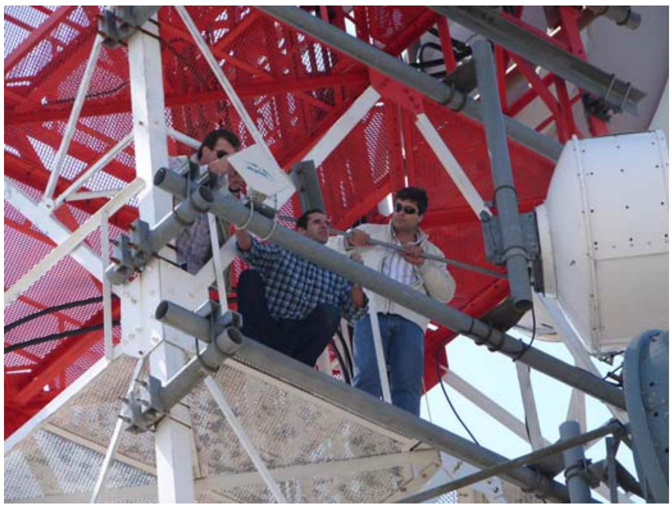

Figure 12: BreezeNET B equipment at the repeater station (in the Gardunha back-to-back relay).

One station has the following hardware: the antenna (radio module), the IDU (indoor unit), power inverter and PoE (Power over Ethernet) unit, and the Ethernet cable (RJ-45 connector), Fig. 13, where one can also see the following items: 1) Crossed Ethernet cable, from the laptop to the IDU, 2) Ethernet cable between the IDU and the antenna, and 3) the IDU power cable). For the configuration of the equipment, after establishing the laptop IP address (10.0.0.xxx), the operator has to click onto the Local Auto-Discovery button in the BreezeCONFIG menu.

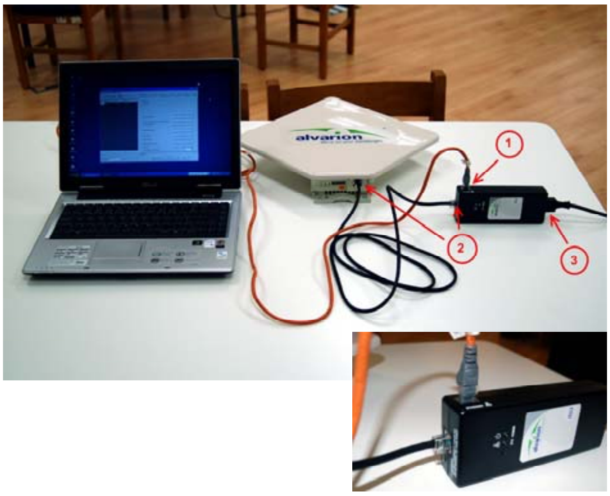

Figure 13: Hardware components of BreezeNET B.

To allow for communication between stations, one station is set as the RB (Remote Bridge) while the other is defined as BU (Base Unit). This is performed in the Unit control tab. In the Air Interface tab, the same ESSID (Extended Service Set ID) needs to be set for both stations. Finally, he IP addresses needs to be set in the IP parameter tab for both stations, e.g., 10.0.0.1 for the RB and 10.0.0.2 for the BU, Fig. 14. Alternatively, these functionalities can be remotely accessed via Telnet in DOS.

After being installed, the antenna tilts were finely tuned by measuring the signal-to-noise ratio, *SNR*, while changing the antenna angle, Figs. 15-16. The simpler approach consisted of observing the LEDs (light emitting diode) at the bottom part of the stations, Fig. 17, but the precise reading of the values of the *C/N* ratio in the configuration software lead to substantial improvements.

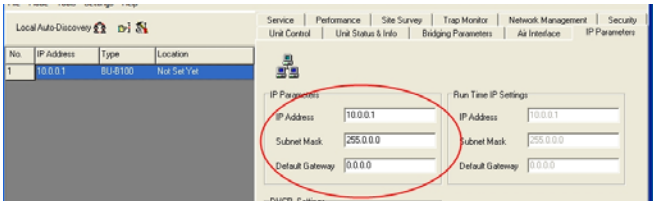

Figure 14: Station IP address configuration.

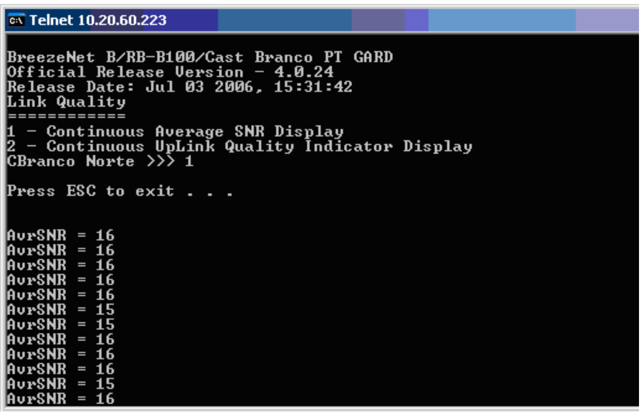

Figure 15: *SNR* monitoring for the link Gardunha-castle.

Figure 16: Fine tuning of the antenna tilt.

Figure 17: RB LEDs for the received power.

Together with the choice of optimum QoS parameters and the selection of the turbo-mode for BreezeNET B, substantial improvements were achieved in the quality of the links by using this experimental procedure.

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 relaying tower 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 in the shorter links.

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.

The actual installation of the three hop link was successfully achieved, followed by a tune up of the tilt of the antennas, to optimize the received power, and by the choice of the best QoS parameters and of the turbo-mode for the equipment, which allowed for obtaining higher values of the throughput.

Acknowledgment

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