

Design and Implementation of IEEE 802.16 Radio Links with Relays

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Abstract: This paper addresses aspects of design and planning of a Wireless network WiMAX (IEEE 802.16) to establish a point-to-point, PTP, link from the Health Sciences Faculty of University of Beira Interior (FCS/UBI) to Hospital Sousa Martins (Guarda), and also presents a field trial where we tested point-to-point links with pre-WiMAX equipment. The design of the link had into consideration the carrier to noise ratio, C/N , and the minimum carrier to noise ratio with fading, $C/N_{min,fad}$. 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 conclusions were achieved.

I. INTRODUCTION

This work presents the results of the design and planning of WiMAX (World Interoperability will be Microwave Access) wireless networks, point-to-point, PTP, 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. Besides it addresses the development of a link point-to-multipoint, PTM, network that covers the whole district of Covilhã. A network of this type justified by the need of creating an Intranet that allows to efficiently exchange of contents and an efficient use of e-learning.

WiMAX is the commercial name of IEEE 802.16. For its creation some work groups were organized, of which detach IEEE 802.16-2004, which is dedicated to PTP and PTM networks (without mobility support), and the IEEE 802.16e, which is dedicated to PTM networks with mobility support [1]. WiMAX uses a kind of dynamic modulation scaling, i. e., it is capable to adapt to the best modulation considering carrier-to-noise-plus-interference versus data rate, Table I.

Table I
Channels characteristics for IEEE 802.16-2004 standard [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

Channels of 3.5, 7 and 10 MHz are defined for the IEEE 802.16-2004 [1]. As the links distances are of the order of tens kilometres, WiMAX appears as a good solution; as it offers 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).

Besides WiMAX allows some forms of 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. 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. On the other hand it allows to accessing to e-contents while students are at home or moving through the city; it will be enough that they own a laptop or multimedia notebook device with a WiMAX card.

This work is addressing the PTP component, in particular the dimensioning of 5.8 GHz WiMAX links, and field trials which 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 field trial and measurements. Finally, Section IV presents the conclusions of the work.

II. DESIGN OF WiMAX LINKS

For the link between FCS/UBI and HAL a hypothesis for the placement of the repeater was already known, hence it was only necessary to verify the existence of line of sight, LoS, and that 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 FCS/UBI 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 the other in Barracão. The first link is between Reitoria and Alto da Malhoeira, with 11.05 km length, while the second one is between Alto da Malhoeira and Barracão, 22.25 km, and finally the third link is between Barracão and HSM, 6.3 km.

For dimensioning purpose, the attenuation, L , is computed according to the modified Friis formula; our approach

considers as parameters 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} . The attenuation L itself is given by the following equation [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: $\gamma=2$ [3], $\gamma_{rain} = 0.0811$ dB/km [5], $\gamma_{fog} = 0.01$ 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

$$\frac{C}{N} = P_r - N, \quad (3)$$

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 calculated by [4]

$$\frac{C}{N_{min_fad}} = \frac{C}{N_{min}} + M_u + M_{ext} \quad (5)$$

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} . Besides its variation with ber , C/N_{min} varies with the type of modulation.

Table II

C/N_{min} as a function of the type of modulation and ber [5].

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

Results for C/N are presented in Figs. 1-3. It is possible to analyze the viability of the proposed links for these three types of modulations supported by WiMAX, as a function of the distance, of C/N , and C/N_{min_fad} . The links are considered viable when C/N is higher than C/N_{min_fad} . In the case of the 16-QAM modulation, the use of the SUI model is also highlighted.

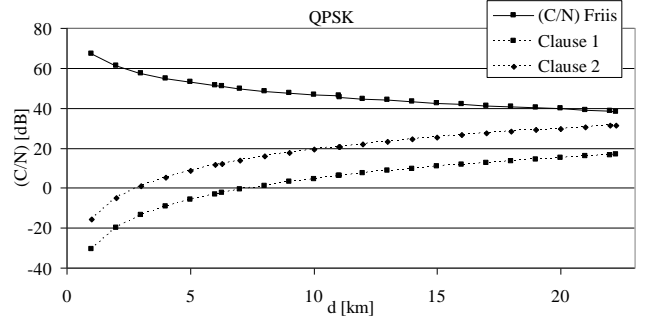


Fig. 1. C/N_{min_fad} and C/N for the QPSK modulation.

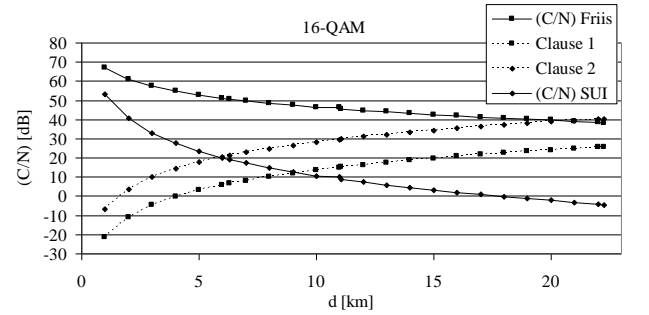


Fig. 2. C/N_{min_fad} and C/N for the 16-QAM modulation.

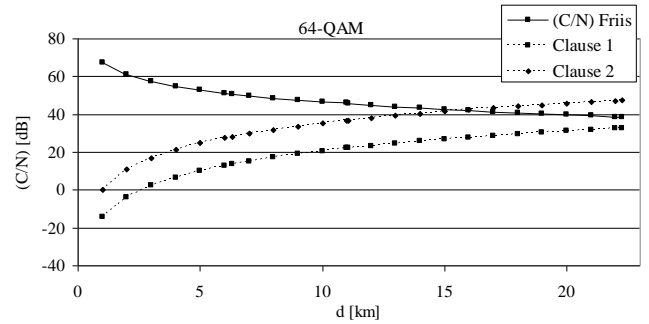


Fig. 3. C/N_{min_fad} and C/N for the 64-QAM modulation.

III. FIELD TRIALS

A. Scenario

Alvarion BreezeNET B14 equipment was used, which presents 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, maximum output power [6], Fig. 4. Beyond the Alvarion equipment, we still used two computers, one as a server and another as client, two UTP cables, and two 12- 220 V invertors. With this equipment, it was possible to create a complete PTP network for the field trials.

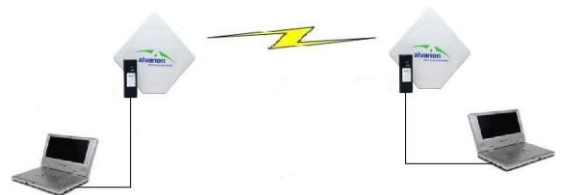


Fig. 4. Topology of PTP network used in the field work.

The tests were made for five different distances. The BS was always located at FCS/UBI, which has an altitude of 490 m. The subscriber station, SS, 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 links 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

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

Table III
Field trials results.

Distance to FCS	Data rate, R_b [kbps]		Site Survey		Time
	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 $> C/N > 21$ dB	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 $> C/N > 7$ dB	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 have very similar values.

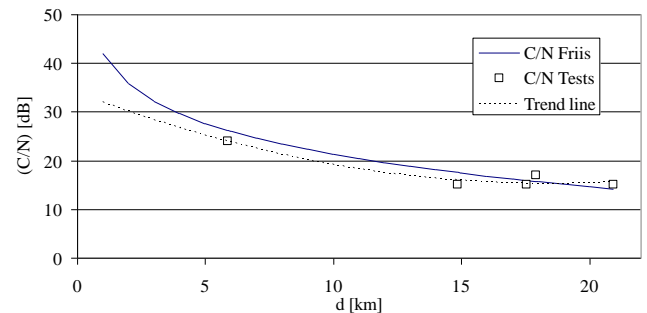


Fig. 6. Comparison between theoretical and practical C/N .

C. Analyses of the Results

The data rate and C/N decreased with the increase of the distance between the antennas. The exception happens in the FCS/UBI-Posto de Vigia link, where the data rate and C/N , are higher relatively to the link with (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. Another equipment was made available more recently 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 will lead to a practical installation, Fig. 9.



Fig. 7. Pilot BreezeNET B installation.



Fig. 8. BreezeNET B equipment for additional tests.

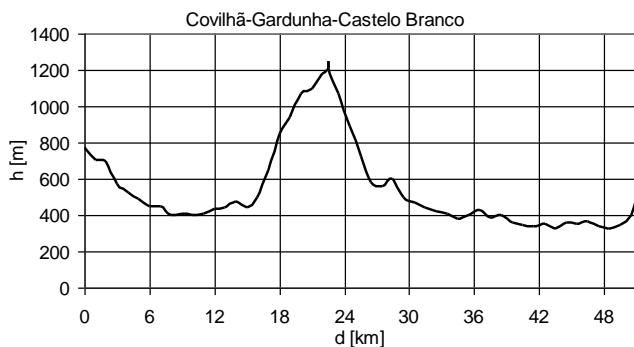


Fig. 9. Obstructed path with a relay (in a tower with 40m).

Besides their usefulness for demonstration and research purposes, 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.

IV. CONCLUSIONS

For the design of the FCS/UBI-HAL WiMAX link, computations were performed to confirm the absence of obstructions to the 1st Fresnel. 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.

V. REFERENCES

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