Applications of 2.4 GHz Microwaves to WLAN Development at the University of Beira Interior Campus

José A. R. Pacheco de Carvalho[1], Hugo Veiga[2], Paulo A. J. Gomes[3], António D. Reis[4], and Cláudia F. F. P. R. Pacheco[5]

Abstract – **Wireless communications are developed and WLAN's created at the University Campus, including point-to-point and point-to-multipoint links to interconnect the Poles and buildings. Microwaves in the 2.4 GHz band and the IEEE 802.11b and 802.11g standards are used. The SNR quality of the links has been tested. It is shown how it can be experimentally improved. Several results are presented and discussed.**

Keywords – **Microwaves, antennas, SNR, WLAN, point-to-point links, point-to-multipoint links.**

I. Introduction

The Beira Interior University (UBI), located at Covilhã city, comprises four main Poles (I, II, III and IV), as well as medical pedagogical spaces at the regional Hospitals. The University network is a MAN. All the Poles, Faculties, Departments, Centres, Services, including all pedagogical spaces, are interconnected through the Informatics Centre (at Pole I) in a star topology for ~6000 users. Access is provided to the national academic network RCCN-RCTS/Internet at 20 Mbps, using IP over ATM. The Poles have been interconnected through dedicated circuits at low speeds up to 2 Mbps and IP routers. The e-UBI Project [1] has been developed, within the national initiative e-U Virtual Campus, to give users access to information in any place of the University Campus. WLAN's (Wireless LAN's) were created using the IEEE 802.11b and IEEE 802.11g standards, where microwaves in the 2.4 GHz band permit speeds up to 11 Mbps and 54 Mbps, respectively [2]. The LAN has been improved [3] to permit the required quality of the wireless network, enabling electronic devices to communicate along the whole University. The main networking equipments are Smart Switch Routers 8600, Matrix E7 and Matrix E1 level 2/3/4 switches with routing capabilities, from Enterasys Networks [4]. The main access networking equipments are level 2 Vertical Horizon switches and ~220 level 2/3/4 RoamAbout R2 Access Points (AP's) [4]. Both out-door and in-door WLAN's were developed for outside and inside of buildings, respectively. Two types of out-door WLAN's were necessary: point-to-point configurations, using two out-door directional antennas (and AP's in LAN-to-LAN endpoint bridge mode), and point-to-multipoint arrangements using an out-door omni directional antenna (for a central AP in LAN-to-LAN multipoint bridge mode) and out-door directional antennas (for AP's in endpoint bridge mode). Out-door point-to-point links were intended to interconnect the four main Poles, over medium distances (up to 5.5 km for the Pole II-Pole IV link, with a repeater), and buildings within the same Pole at 11 Mbps and 54 Mbps, for shorter distances. Out-door directional antennas of various types and manufacturers (14 dBi Yagi [4], 18 dBi planar [5], 21 dBi parabolic grid [5], 23 dBi parabolic grid with 2300-2600 MHz band pass [6]) were used (Table II). Fig.1 shows the general scheme of the links. Out-door point-to-multipoint links were established at Pole II to permit communications of the Staff Residence, the Old Residence, the Sports Building and the Yellow Residence with the Rectory Building, which was the Pole II central point for communications. The relative positions of these buildings are visible in Fig. 2. A 7 dBi omni directional out-door antenna [4] was mounted at the Staff Residence to communicate at 11 Mbps with out-door directional antennas of the 14 dBi Yagi type [4], located in each of the other buildings. The distances involved were 52-108 m. The in-door WLAN's, developed to complement the LAN's, covered the interior of the buildings. AP's were set to workgroup bridge mode. In-door omni directional antennas were useful for improving coverage. Starting from topography of the buildings, site surveys were made to optimize the locations of antennas, using a portable computer having an 802.11 a/b/g wireless card and Network Stumbler software [7] to measure signal to noise ratios SNR.

[1]José Pacheco de Carvalho is with the Informatics Centre and the Remote Detection Unit at the University of Beira Interior, R. Marquês d'Ávila e Bolama, 6201-001 Covilhã, Portugal, E-mail: pacheco@ubi.pt.

[2]Hugo Veiga, and [3]Paulo Gomes are with the Informatics Centre and the Remote Detection Unit at the University of Beira Interior, R. Marquês d'Ávila e Bolama, 6201-001 Covilhã, Portugal, E-mails: hveiga@ubi.pt, pgomes@ubi.pt.

[4]António Reis is with the Remote Detection Unit at the University of Beira Interior, and with the Department of Electronics and Telecommunications/Institute of Telecommunications, at the University of Aveiro, 3810 Aveiro, Portugal,E-mail: adreis@ubi.pt.

[5]Cláudia Pacheco is with the Remote Detection Unit at the University of Beira Interior, R. Marquês d'Ávila e Bolama, 6201-001 Covilhã, Portugal, E-mail: a17597@ubi.pt.

II. Experimental Development and Results

A. Out-door Links

A communications channel has an important dependence of capacity per unit bandwidth, this is the channel capacity (C, in bps) to channel bandwidth (W, in Hz) ratio, on signal to noise ratio (S/N, power of the signal over power of noise). Shannon's formula gives an upper limit for this dependence, $C/W=\log_2(1+S/N)$, which represents channel efficiency [8].

TABLE I

1ST FRESNEL ZONE MAXIMUM DIAMETERS FOR THE LINKS BETWEEN POLES

Link	Distance (m)	1st Fresnel zone maximum diameter (m)
Pole I-Pole II	350	6.6
Pole II-Pole III	1500	13.7
Pole II-Repeater	2500	17.7
Repeater-Pole IV	3000	19.4

TABLE II

CHARACTERISTICS OF THE DIRECTIONAL AND OMNI DIRECTIONAL ANTENNAS

Parameters	Yagi, 14dBi (Enterasys)	Planar, 18 dBi, PW9618 (Phasak)	Parabolic grid, 21 dBi, PW9321 (Phasak)	Parabolic grid, 23 dBi, band pass, GD24BP-23 (Pacific Wireless)	Omni directional, 7 dBi, Roam About (Enterasys)
Frequency Range	2400-2485 MHz	2400-~2500 MHz	2400-~2500 MHz	2400-2485 MHz	2400-2485 MHz
Gain	14dBi	18 dBi	21 dBi	23 dBi	7 dBi
3 dB beam width, V or H	30.8°, 31.4°H	17 ° V, 22 ° H	13 °	8 ° V, 10 ° H	---
Front to back ratio	> 20 dB	>= 25 dB	28 dB	>= 25 dB	---
VSWR	1.5	<1.5	<=1.4	1.5	<2
Max. Input Power	~5 W	50 W	100 W	100 W	---
Impedance	50 Ω	50 Ω	50 Ω	50 Ω	50 Ω
Dimensions	45.7 cm	37 x 25.2 x 4.2 cm	68 cm diameter	72.4 x 91.4 cm	45.7 cm

Therefore it was essential for the quality of wireless communications, to guarantee high *S/N* ratios. Point-to-point wireless links between two LAN's were set through a pair of equipments of the type switch/router, access point (AP) and out-door directional antenna. They were dimensioned so as to obtain clear, unobstructed line-of-sight paths between emitters and receivers. The Fresnel zones are ellipsoids whose foci are located at these points, having maximum diameters d_n at half the way. For a distance d along the link, d_n for the nth Fresnel zone is [9] $d_n = (n\lambda d)^{1/2}$, with $d >> d_n$, where $\lambda = 0.125$ m for $f = 2.4$ GHz. It was taken into account the recommended clearance factor of at least 0.6 of the first Fresnel zone radius [10]. Given the topography of Covilhã city, which is very mountainous and has several valleys, strategically located buildings were chosen for installing the out-door antennas, considering the calculated values of Table I [11]. It was decisive to identify and minimize causes of electromagnetic interferences. The presence of various 2.4 GHz beams, existing in the urban and surrounding areas of Covilhã city, was detected through a portable computer having a 802.11 a/b/g wireless card, a directional out-door antenna and Network Stumbler software [7]. For the 13 ETSI frequency channels in the 2400-2485 MHz band, spacing of at least 3 channels were chosen to minimize interferences.

TABLE III

SNR RATIO FOR THE LINKS BETWEEN POLES AND POLE II BUILDINGS VERSUS TECHNOLOGY AND ANTENNA TYPE

Link	Distance (m)	Technology	Antenna type	(SNR) dB
Pole I-Pole II	350	IEEE 802.11b, 11 Mbps	Yagi, 14 dBi	11-26
Pole I-Pole II	350	IEEE 802.11g, 54 Mbps	Yagi, 14 dBi	0-18
Pole I-Pole II	350	IEEE 802.11b, 11 Mbps	Parabolic grid, 23 dBi, band pass	38-42
Pole I-Pole II	350	IEEE 802.11g, 54 Mbps	Parabolic grid, 23 dBi, band pass	37-38
Pole II-Pole III	1500	IEEE 802.11b, 2 Mbps	Yagi, 14 dBi	19-26
Pole II-Repeater	2500	IEEE 802.11b, 11 Mbps	Parabolic grid, 21 dBi + planar 18 dBi	22-28
Repeater-Pole IV	3000	IEEE 802.11b, 11 Mbps	Planar 18 dBi + parabolic grid, 21 dBi	20-35
Pole II-Repeater (with 2 x 1W amp.)	2500	IEEE 802.11b, 11 Mbps	Parabolic grid, 21 dBi + planar 18 dBi	45-51
Repeater-Pole IV (with 2 x 1W amp.)	3000	IEEE 802.11b, 11 Mbps	Planar 18 dBi + parabolic grid, 21 dBi	43-55
Pole II-Repeater (with 2 x 1W amp.)	2500	IEEE 802.11g, 24 Mbps	Parabolic grid, 21 dBi + planar 18 dBi	38-44
Rectory Building - Staff Residence	97	IEEE 802.11b, 11 Mbps	Yagi, 14 dBi + Omni directional, 7dBi	33
Staff Residence-Yellow Residence	52	IEEE 802.11b, 11 Mbps	Omni directional, 7dBi + Yagi, 14 dBi	30
Staff Residence- Old Residence	75	IEEE 802.11b, 11 Mbps	Omni directional, 7dBi + Yagi, 14 dBi	39
Staff Residence-Sports Building	108	IEEE 802.11b, 11 Mbps	Omni directional, 7dBi + Yagi, 14 dBi	30

Polarization matching was implemented and verified in detail. Other precautions were also taken in setting up the necessary equipments, including the construction of a repeater station at a relatively isolated location of the Cova da Beira valley, as the Poles II and IV were not in line-of sight [12]. The backbone of the LAN is Gigabit Ethernet over optical fibre (full duplex 1000-Base-SX and 1000-Base-LX). The WLAN uses Enterasys RoamAbout R2 AP's having RoamAbout 802.11b and 802.11 a/b/g 15 dBm radio cards. The AP's are connected through 100-Base-TX to level 2/3/4 switches capable of IPv4 routing, Enterasys Matrix E1 [4]. For reasons of performance, WEP (Wireless Equivalent Privacy) was not activated in the AP's. Initial measurements of signal to noise ratio SNR, have shown that long distances (determined by locations of buildings) and electromagnetic interferences in urban areas (where the 2.4 GHz band is increasingly used) are particularly critical. Table II shows the characteristics of the directional antenna types chosen to overcome this problem and improve SNR [11]. The main SNR results, obtained by using the Enterasys RoamAbout AP Manager software [4], are presented in Table III. The best quality was for the 350 m Pole I-Pole II link at 54 Mbps and parabolic grid, 23 dBi, band pass antennas. Thus, a second link of this type was implemented to support the considerable traffic existing between both Poles. For long distance 2.5 km (Pole II-Repeater) and 3.0 km (Repeater-Pole IV) links, 14 dBi Yagi antennas and 11 Mbps did not give the required quality. The combination of 21 dBi parabolic grid and planar 18 dBi antennas at 11 Mbps, for these links, was essential and proved as very efficient. As shown later, its quality was further improved. Table II contains the characteristics of the 7 dBi omni directional antenna used for the Pole II point-to-multipoint wireless links. Again, the AP's were set without WEP activation. The same software as for the point-to-point links was used to measure SNR for every link. Table III shows good results at 11 Mbps, given the relatively short distances and antenna types. All the links mentioned have been additionally monitored through the MRTG (Multi Router Traffic Grapher) traffic measurement software tool [13]. Further tests over the links have been made [14]. They have improved quality of WLAN and LAN communications at the University.

B. Further developments for the Pole II-Pole IV link

In order to improve quality of the Pole II-Pole IV communications, each link Pole II-Repeater and Repeater-Pole IV was equipped with a pair of 1W (30 dBm) out-door, professional, bi-directional Wi-Fi 802.11b/g compatible amplifiers, available from Hyperlink Technologies [15]. They had a receive band pass filter, a low-noise receiver amplifier and a transmit power amplifier. Active power control was available for monitoring output power and providing maximum output power regardless of cable length. The amplifiers operated in bi-directional, half-duplex, time division duplex mode, having been designed for burst half-duplex operation. The aim was to achieve better SNR ratios for the links. The receive band pass characteristic eliminated the unwanted frequency band. Thus, the amplification acted on the band of interest. Figs. 3 and 4 show details of the new arrangement for the Pole II-Pole IV link. Table III shows the new results obtained at 11 Mbps and 24 Mbps, using 1W amplifiers. Details are given in Figs. 5 and 7. It is clear that the results are much better than those obtained without amplifiers. Figs. 5 and 6 permit comparison at 11 Mbps with and without amplifiers, respectively. Fig. 7 shows that 802.11g-24 Mbps is possible at high SNR values. It was also the case, not shown, of the Repeater-Pole IV link. The slight difference is that at 24 Mbps this link is not so stable, compared with the Pole II-Repeater link given the larger distance (3 km versus 2.5 km) and electromagnetic interference. Further tests over the links have been made [14].

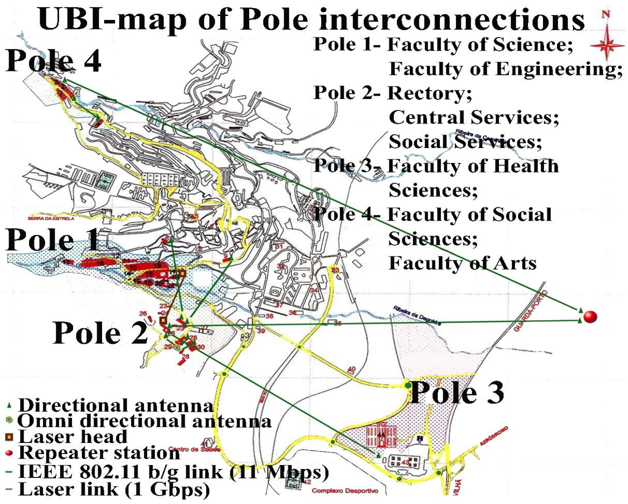

Fig. 1- Scheme of the wireless links between Poles and buildings of the University Campus.

Fig.2- Point-to-multipoint wireless links for Pole II buildings.

Health safety conditions in relation to Wi-Fi have been discussed [16]. The reference safety limit for long term exposure to 2.4 GHz electromagnetic fields is 61 V/m [17], which corresponds, in free-space, to a power density of 9.9 W/m2. This value, for free-space and far-field conditions, would be reached at 1 m and 0.71 m distances from the Pole II (and Pole IV) and the Repeater antennas, respectively. Still, these values are less than the corresponding Fraunhofer distances [9]. As power density varies with inverse square distance, for 10 m and 7.1 m (in the Fraunhofer regions) 0.1 W/m2 arise, which are 1% of the reference safety limit. The newly implemented link has permitted the flow of the increasingly growing traffic between Pole IV and Pole I.

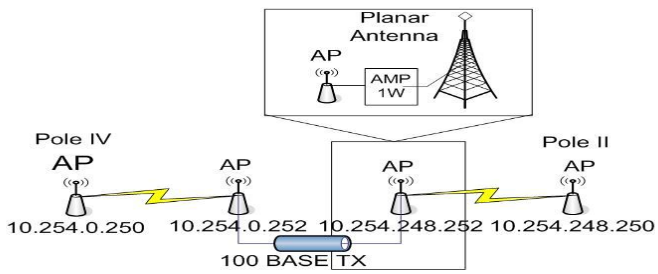

Fig.3- Scheme of the Pole II-Pole IV link, with 1W out-door amplifiers.

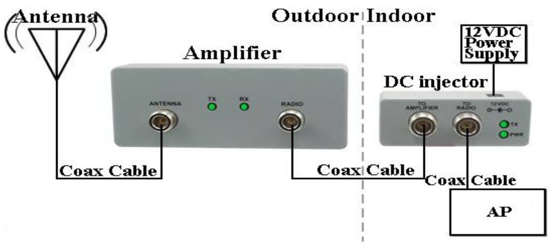

Fig.4- Out-door amplifier connection diagram [15].

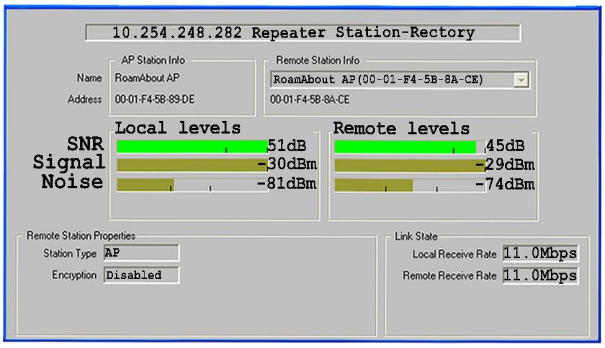

Fig.5- Pole II-Repeater link with 21 dBi parabolic grid and 18 dBi planar antennas, 2x1W amplifiers, 802.11b – 11 Mbps.

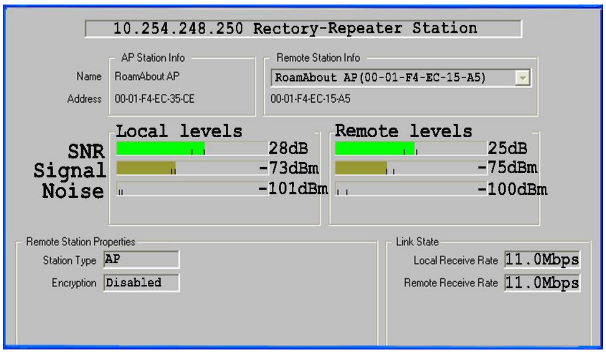

Fig.6- Pole II-Repeater link with 21 dBi parabolic grid and 18 dBi planar antennas, no amplifiers, 802.11b – 11 Mbps.

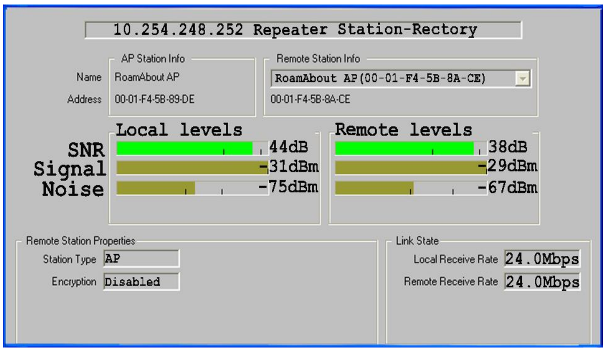

Fig.7- Pole II-Repeater link with 21 dBi parabolic grid and 18 dBi planar antennas, 2x1W amplifiers, 802.11g – 24 Mbps.

III. CONCLUSION

New wireless links, both point-to-point (including long distances) and point-to-multipoint have been developed and successfully tested at the University Campus. The new developed wireless infrastructure has been important for complementing the wired network. It has been important for electronic devices to communicate along the whole University Campus. Further work is in progress to further improve the University communications.

ACKNOWLEDGEMENT

Supports from University of Beira Interior, POSC, UMIC and FCT/POCI2010 are acknowledged.

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