Hybrid WiMAX and Wi-Fi networks for the support of b-Learning and Telemedicine

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Abstract — **This paper addresses the deployment of hybrid WiMAX and Wi-Fi networks for the support of always best connected telemedicine and health sciences education applications. The available services include a LMS (Learning Management System) and several structured functionalities for b-Learning. For the support of these services, fixed and wireless LANs have been deployed, as well as an experimental point-to-multipoint IEEE 802.16-2004 network covering part of the city of Covilhã. The FCS (Health Sciences Faculty) Campus as well as the tutorial rooms of the Faculty spread at the different Hospitals of the region of Beira Interior, Portugal, are benefiting from WLAN coverage, whose backhaul is supported by WiMAX point-to-point links with relays. Field trials results were compared with the ones arising from the WiMAX radio links design, and very similar results were achieved. Service quality was guaranteed by adjusting QoS parameters.**

I. Introduction

The flexibility of the learning process holding high level of scientific and pedagogical quality has become a priority to FCS (The Health Sciences Faculty) of UBI (University of Beira Interior), Covilhã, Portugal. In the international organization resulting from the Bologna Declaration, the integration of the Portuguese Higher Education infers that most of the study must be centred into the individual work of the students, supervised by a tutor, without loss of quality of acquired knowledge. The Faculty IT (Information and Technology) team, together with other relevant players, has developed several projects in the area of b-Learning (blended Learning) and video conference systems implemented with wireless networks. These types of technologies have a considerable impact on excellence for the support of tasks execution and working tools. Despite helping to avoid distances and other obstacles, such as scarcity of time and availability, they are also important to foment Self-Learning, taking the best advantage of the existing resources.

This paper addresses the deployment of hybrid WiMAX and Wi-Fi networks for the support of always best connected telemedicine and health sciences education applications. For the support of these services, fixed and wireless LANs have been deployed, as well as an experimental point-to-multipoint WiMAX network covering part of the city of Covilhã. The backhaul for these networks can be supported by WiMAX point-to-point links with relays.

The remaining of this paper is organized as follows. In Section II, the objectives are discussed and the network architecture, topology and services (e.g., b-Learning) are presented. The need for supporting mobility in the support of applications is also explored. Section III presents the models for the design of WiMAX links with relays and details on its installation. Furthermore, the performance measurement in the developed links is evaluated and the advantages of the developed solution are discussed. Finally, Section IV presents the conclusions.

II. Network Implementation and Services

A. Objectives

The main objective is to focus the learning process into the student, and turn this interactive process into a more attractive and effective task by using multimedia tools to improve his/her permanent actualization and motivation for study. This answers to the need of students who ask for more and more access to learning materials at any place, anyway and anytime, promoting the expansion of teaching in universities.

In the past, Intranet and e-Learning systems, Figure 1, were not made available, and the only opportunity most students had to speak with their professors occurred during scheduled class sessions or office hours. However, nowadays, more professors can be in touch with students at any time, seven days a week. This is especially true in the FCS plan of studies, which is organized to allow for students studying at their convenience. Because of that, it has been noticed that students spend more time with Faculty members than traditional students do.

To support such e-Learning environment, a network infrastructure is required that can handle traffic volumes considerably higher than those usually associated with the traditional universities, Figure 2.

Therefore, and to face these challenges FCS/UBI has deployed the latest generation of computer networks that can simultaneously handle high volumes of video-conference, email, Self-Learning material, and video images over secure, reliable, easy-to-use and highly flexible LAN (Local Area Networks) and MAN (Metropolitan Area Networks).

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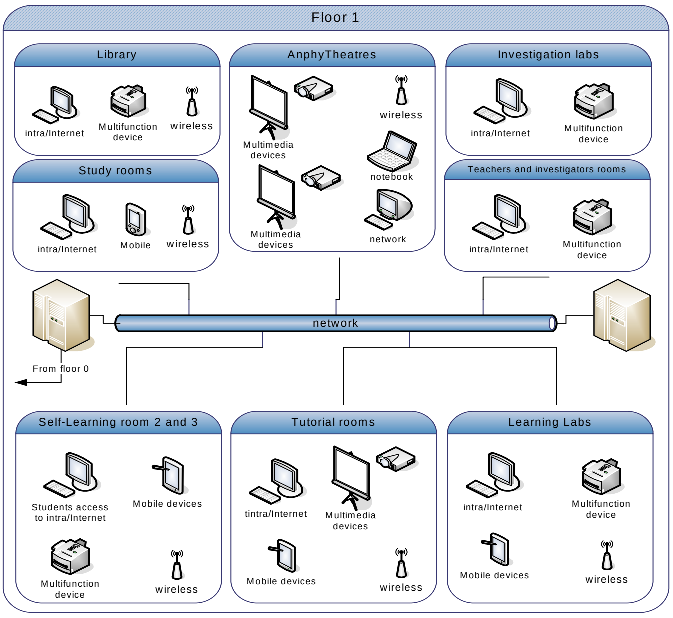

Fig. 1. Scheme for the contemporary Intranet at FCS.

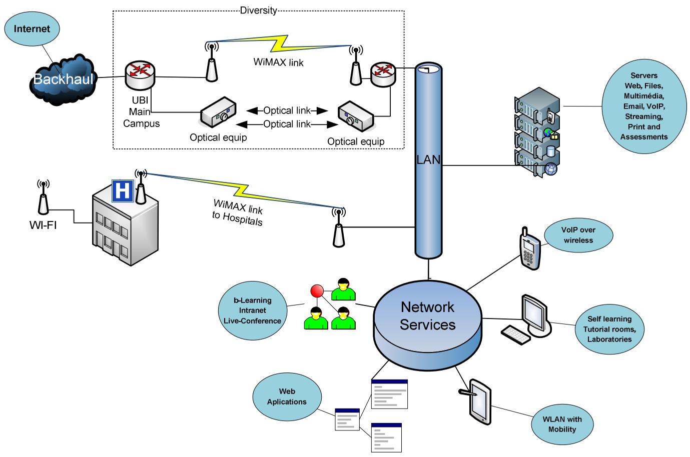

Fig. 2. Network architecture, topology and services.

B. Wireless Networks Infrastructure

The educational model of the FCS was built on close collaboration with health units. According to protocols with the faculty and three Hospitals – Centro Hospitalar Cova da Beira (Covilhã and Fundão), Hospital Sousa Martins (Guarda) and Hospital Amato Lusitano (Castelo Branco) – structures and equipment have been allocated to teaching activities, as detailed in Figure 2, showing the actual Faculty IT network and services. Besides, the link between the main University Campus and the local Hospital Centre, at Covilhã, is supported by a short PTP IEEE 802.11g Wi-Fi (Wireless Fidelity) link.

Also, between the Faculty and the Hospitals, in Castelo Branco, Guarda and Fundão, B3G (beyond 3G) wireless communications are being used, based on WiMAX, the latest standard to be used for WMANs (wireless metropolitan area networks). In order to establish the PTP (Point-to-Point) communication between Covilhã and Castelo Branco (51Km), WiMAX antenna relay was placed at the Gardunha mountain, as can be observed in Figure 3. This is a secure and cheap solution.

The backhaul for the FCS is provided by an atmospheric infrared link (optical link) with a distance of approximately 1.3 km. For this link diversity is guaranteed by WiMAX. When the optical link is not available, e.g., owing to fog, solar positioning, beam variation, temporary link obstructions or transmitter or receiver faults, the FCS incoming router switches to the alternative WiMAX link.

Fig. 3. Square-shaped WiMAX antenna at the Gardunha relay tower (relay stations are mounted back-to-back).

C. WEB and b-Learning Applications

The whole network provides access to a LMS (Learning Management System) platform in the context of the Faculty Intranet, developed within the FCS IT team context. The LMS supports the typical tools for b-Learning, where the pedagogical materials are added and accessed through individual WEB pages of the platform with written, audio and video capabilities, together with multimedia content and interactivity support, Figure 4.

The Intranet platform is an integrated e-Learning system, an association of technology components that facilitates user interaction. In fact, the FCS Intranet has a WEB-based Management System for its plan of studies. It enables GEM (Medical Education Office) to create and manage the learning website through a WEB browser. On the Intranet, a "teacher" only needs to be familiar with his/her preferred WEB browser. On his/her own computer, he/she is able to locally prepare high quality documents and contents.

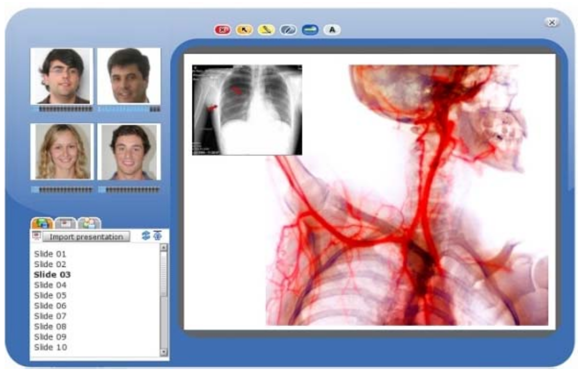

Fig. 4. Tele-medicine application.

D. Multimedia Contents and Mobility

FCS has been giving special attention to the structure and quality of e-contents, as well as their efficacy for the e-Learning objectives. Internet technologies and associated resources are assumed themselves as a crucial instrument to the evolution of learning and share of knowledge processes. As FCS is aware of this reality, the option was for a well-structured computer network with advanced solutions and for information and communication technologies. The aim is to help students and tutors in achieving success in the learning and research processes. An always best connected philosophy was implemented from the beginning, allowing for access independently of users localization within the Campus.

A Wi-Fi network, Figure 5, was therefore conceived and deployed to provide the Wireless LAN inside the Faculty building, its gardens, and also at the associated Hospitals. This network allows for user access to applications, content, services and communications facilities, including Internet and UBI network access. Students can access the learning contents and even teachers can evaluate students in real time using mobile equipment, like UMPCs (Ultra Mobile PCs).

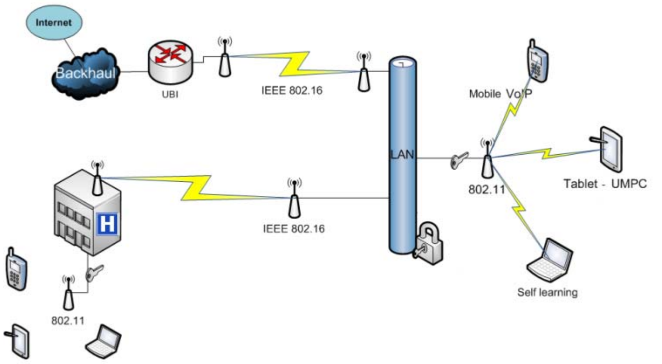

Fig. 5. Wi-Fi (IEEE 802.11) network and Wi-Fi islands.

Besides, an experimental point-to-multipoint IEEE 802.16-2004 WMAN, covering part of the city of Covilhã, allows for users to roam and benefit from some degree of mobility.

III. DESIGN OF WIMAX LINKS WITH RELAYS

A. Models

From the work on design of WiMAX links with relays previously performed in the MobileMAN project [1], an internal project from Instituto de Telecomunicações, the existence of LoS (Line-of-Sight), between the transmitters at FCS/UBI, Covilhã, and HAL, Castelo Branco, was verified. The absence of obstructions to the respective first Fresnel ellipsoids was a design goal (any obstacle should not obstruct this ellipsoid ensuring appropriate radio communication conditions). This dimensioning process lead us to the choice for the placement of two repeaters, one at Gardunha (a mountain near Fundão) and another at the Castle hill in Castelo Branco, approximately one kilometre away from the Hospital [2]. Some practical tests were performed on the support of several applications (e.g., VoIP, video-conference and FTP – and the transfer of a large file was compared with the transfer of several smaller files [2]). The differences on the specifications among the equipments from several manufacturers were compared and the analysis of similar tests, available from the manufacturers, was considered.

As a consequence of the detailed dimensioning process, the PTP link is formed by three hops. The first one, with approximately 21-22km, is from Covilhã to Gardunha, the second, with approximately 26-27 km, is from Gardunha to the castle in Castelo Branco while the last one, shorter than 1 km, is between the castle and HAL. For our model, a 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 Friis formula [3], and the propagation exponent is $\gamma = 2$.

The specific attenuation of fog is negligible as well as the specific attenuation of snow. The specific attenuation of rain is 0.0811 dB/km. The distance d varies between 1 and 27 km, and f = 5.8 GHz (this value is different from 5.4 GHz, the central frequency for the equipment then used).

In order to compute the received power, P_r (in dBW), the following equation is used

$$P_r = P_e + G_e + G_r - L\,, \tag{1}$$

where P_e=-9dBW (maximum output power), and G_e=G_r=28dBi (the transmitter and receiver gains, respectively) [2].

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

$$C/N = P_r - N\,, \tag{2}$$

where the power of the noise is given by [3], [4]

$$N = N_0 + N_f\,. \tag{3}$$

N_0 is the white Gaussian noise power [3], and N_f is the noise figure (N_f=3 dB). The minimum carrier to noise ratio with fading, C/N_{min_fad}, in dB, is obtained (for each clause) by [3]

$$C/N_{\min\_fad} = C/N_{\min} + M_u + M_{ext}\,, \tag{4}$$

where M_u is the uniform margin in dB, and M_{ext} is an extra margin of 3 dB [3], [4]. To determine C/N_{min_fad}, according to the old ITU-R clauses of the ITU-R, two values for the *ber* (bit error ratio) have to be considered, 10^{-6} and 10^{-3} [2], [4]. As OFDM (Orthogonal Frequency Division Multiplexing), is used, the effect of selective fading is negligible [5]. The variation of C/N with the distance, d, is presented in Figure 6, by considering the 16-QAM modulation.

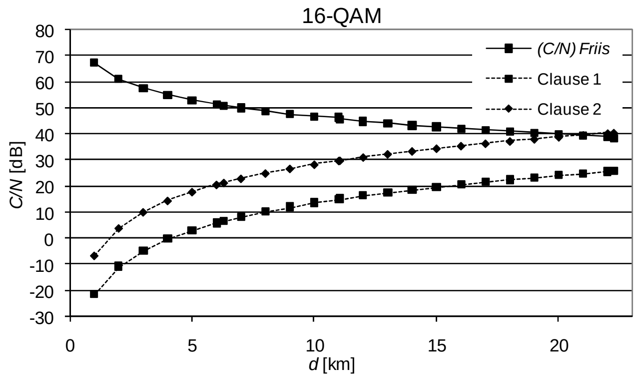

Fig. 6. Curves for C/N_{min_fad} (for clauses 1 and 2) and C/N.

By analyzing the curves it is possible to evaluate the viability of the links. The links are considered viable when *C/N* is higher than C/N_{min_fad}. For higher distances, with the considered parameters, by adapting the MCS (modulation and coding scheme), links are still viable when the QPSK modulation is used instead.

B. Practical Installation

After being installed, the antenna tilts were finely tuned by measuring the signal-to-noise ratio, SNR, while changing the antenna tilt, Figures 7-8. The simpler approach consisted of observing the LEDs (light emitting diodes) at the bottom part of the stations. However, the precise reading of the values of the *C/N* ratio in the Breeze NET B configuration software leads to substantial improvements. This way, it was possible to get a more stable link for a MCS of the same order, the one that adapts to channel quality conditions. As a consequence, lower packet loss and possibly lower delays occur.

Together with the choice of optimum QoS (Quality of Service) parameters, substantial improvements in link quality were achieved by using this experimental procedure. Besides, QoS support is achieved by using DSCP (Differentiated Services Code Point), the RFC2474 prioritization. It marks packets with higher priority, which will be differentiated in this way, reducing the latency. The IP precedence threshold was set to 4 while the DSCP threshold was set to 32 [6]. These values correspond to the real-time interactive/tele-presence application, and are the most suitable for the types of traffic that are supported in the network. It was verified that the comparison between the theoretical and measurement results leads to a perfect agreement [2]. Audio and video services are perfectly supported on top of VoIP and http traffic whenever high loads of FTP traffic are not present.

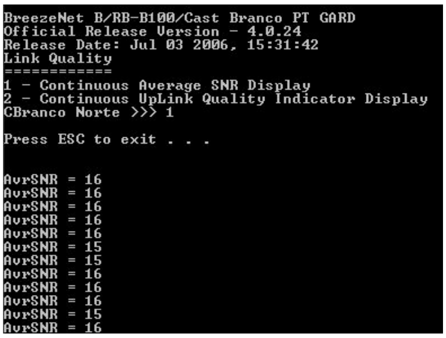

Fig. 7. *SNR* monitoring for the link Gardunha - Castle.

Fig. 8. Fine tuning of the WiMAX antenna tilt.

C. Network and link performance

Latency and packet loss were measured for the three hop link, Figure 5. The considered traffic types are simultaneous http, ftp, streaming and VoIP. The supported MCS were QPSK ¾ for the FCS – Gardunha link, (16-QAM ¾ for the Gardunha - Castle one, and 64-QAM ¾ for the Castle - Hospital one. When the throughput increases the packet loss increases and the delay decreases (for the two values of the packet sizes used in the tests, i.e., 32 and 2048 B). For throughputs up to ~5 Mb/s there is no packet loss while delay is lower than 24ms. Then, both delay and packet loss starts to increase. For a throughput of 7 290 kb/s the packet losses are equal or lower than 15% while the delay is lower than 385ms.

The most limitative link is the FCS - Gardunha one (which is not, however, the longest one) since 28 dBi antennas were not used there. A proposal to improve the overall link performance will be to replace the 21 dBi antenna installed there by 28 dBi ones while decreasing the transmitted power (in order to have an effective isotropic radiated power lower than 1 W, the maximum allowed in Portugal at 5.4 GHz).

IV. Conclusions

The learning system and tutorial rooms of the Faculty, placed on the different Hospitals of the region of Beira Interior, Portugal, support various Web services, VoIP, streaming, and data applications. The network is benefiting from WLAN islands, whose backhaul is supported by WiMAX PTP links with relays. The use of two relaying tower is needed to guarantee LoS conditions.

Field trials results were compared with the theoretical model, and very similar results were achieved. The actual installation of the three hop link was successfully obtained, followed by the choice of the best QoS parameters. Stable values of the throughput, low packet losses and moderate delays were obtained, leading to the guarantee of service quality in these hybrid WiMAX and Wi-Fi networks.

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