VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

FACULTY OF ELECTRONICS

DEPARTMENT OF TELECOMMUNICATION ENGINEERING

Daniel Vaquero Romero

DESIGN OF A RURAL WIRELESS BROADBAND NETWORK

Final bachelor‘s work

Vilnius, 2011

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Defended on 28th of January, 2011, Vilnius, Lithuania

for my parents, of course ¬

CONTENTS

1. INTRODUCTION

There are rural areas where the population is distributed in a dispersed manner and whose per capita income level is low. Communication networks for broadband will not often come to these areas, because these conditions lead to high costs and reduced earnings per customer, becoming economically unattractive investment. This leads to unequal access to information and communication technologies (ICTs) among the inhabitants of these areas and the inhabitants of nuclei that do exist broadband access, leading to the so-called digital divide.

Providing high capacity access is very important because Internet is one of the most important innovations of our time, bringing substantial benefits to economies and societies. The ability to communicate information at high speeds and through different platforms is essential for the development of new services, such as telemedicine in places where it is not possible to have a normal service, education to offer access to alternative educational resources, administration to improve efficiency, and rural development that increases the tourist attraction.

Actually Spain has several plans designed to bring broadband to all towns. These plans include several types of approaches such as programs of grants, loans or municipal initiatives. Broadband services are delivered using various combinations of communications network technologies. Technologies rely on infrastructure of fixed or radio transmission and can substitute or complement each other according to the case. Each technology has distinct characteristics and impact differently on overall capacity and capability of the network.

This project include the design of a wireless network that will provide broadband interconnection between the main buildings in a rural area and also provide Internet access to residents of the town and tourists. We will study the different options available and choose the best according to certain criteria of quality and price. We will develop a proposal for a network, analyze the equipment to use and present a budget report.

2. THEORICAL FOUNDATIONS

2.1 - Wireless technologies

Thanks to the emergence and success of wireless communication protocols has been widespread in the use of such networks, mainly due to the interoperability of equipment from different manufacturers. This has led to develop products so fast, and prices have been decreased because of the volume of production.

The basic difference with wired networks is how to connect nodes, because with wireless network we do not need physical connection, the produce is through electromagnetic waves. So we find certain advantages that make them one of the most promising technologies.

This technique is very flexible, allowing us to interconnect locations complicated, plus it can quickly adapt and extend the qualities of the network as far as coverage and bandwidth concerns. Their deployment is often usually quite fast, especially if there is an equipment and infrastructure upon as communication towers, street lamps, etc. that can be exploited. This must be added that either prior or no infrastructure, the cost will be much slower than a wired network.

However, not all are benefits. Among the problems that arise are the interference between waves, making it necessary to legislate the use of radio spectrum in terms of frequency and power used allowed in each of these frequencies. Using air as physical propagation, radio links vary greatly, because they are subject to instabilities own environment such as weather, noise or uncontrolled interference. All this causes the lower data rates and delays are greater than using wired networks. Also, the transmitted data are likely to be heard by anyone with appropriate resources, necessitating the use of authentication and encryption mechanisms.

A simple way of classification is based on their range, where we can distinguish different groups from largest to smallest area of work:

Wireless Wide Area Network WWAN, the networks have greater coverage, and are known by the UMTS or IEEE 802.20 standard.

Wireless Metropolitan Area Network WMAN, its coverage range is about 20 Km, and the standard that stands out is the WiMAX or IEEE 802.16.

Wireless Local Area Network WLAN, cover only a few hundred meters, but are most popular, especially for Wi-Fi or IEEE 802.11 standard and its family.

Wireless Personal Area Network WPAN, its coverage includes a few tens of meters, and its best known standard is Bluetooth or IEEE 802.15.1.

Wireless Body Area Network WBAN, their range of action is very limited, typically used by sensors attached to the human body to monitor vital parameters or even home automation, highlighting the IEEE 802.15.4 standard or Zigbee. [1]

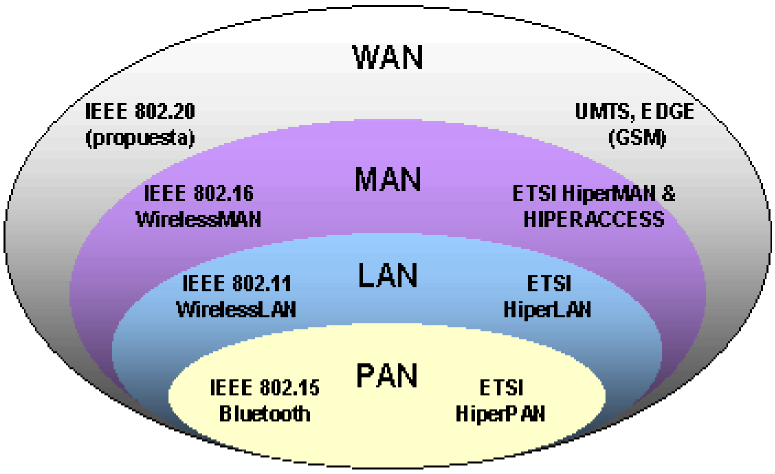


Figure 1: Classification of wireless technologies

Among the most important features of the major wireless technologies are the wireless local loop systems. Involve the application of wireless technologies for fixed telecommunications networks. They are primarily used by customers who are not mobile. Its development has been facilitated by the preparation of the WiMAX standard and the emergence of so-called pre-WiMAX equipment, which emerged due to late approval of the 802.16 standard, which implemented proprietary protocols based on the developments made for WiMAX, so equipment have a very high benefits, able to use unlicensed bands, although there is not interoperability between different manufacturers.

Wireless LANs offer high-speed advantages of network connectivity without the constraints of the physical interconnection through cable. If we add the speed of technological development in recent years because the possibility of using equipment in commonly bands such as ISM or UNII (homogeneous in most of the world) and use of standards based on Wi-Fi is getting more and more interesting performance with installation costs and, especially, reduced operating.

Mobile networks based on GPRS, with its evolution EGPRS, and UMTS, with HSDPA and HSUPA evolutions, provide data services to mobile users at different speeds. The main disadvantage of these networks is that coverage is not complete, and especially in the high price charged to end users.

As for satellite communications, they have proved a key element in the development of communications and information technologies, because to be located in an outer orbit to Earth, it get a wide geographical coverage and has ability to establish multipoint links, so the cost is independent of transmission distance and it has a down bandwidth considerably. However, it has a high initial cost and maintenance, high latency and it needs a terrestrial return channel for interactive services to offer, so that is not usually choose when to implement residential broadband.

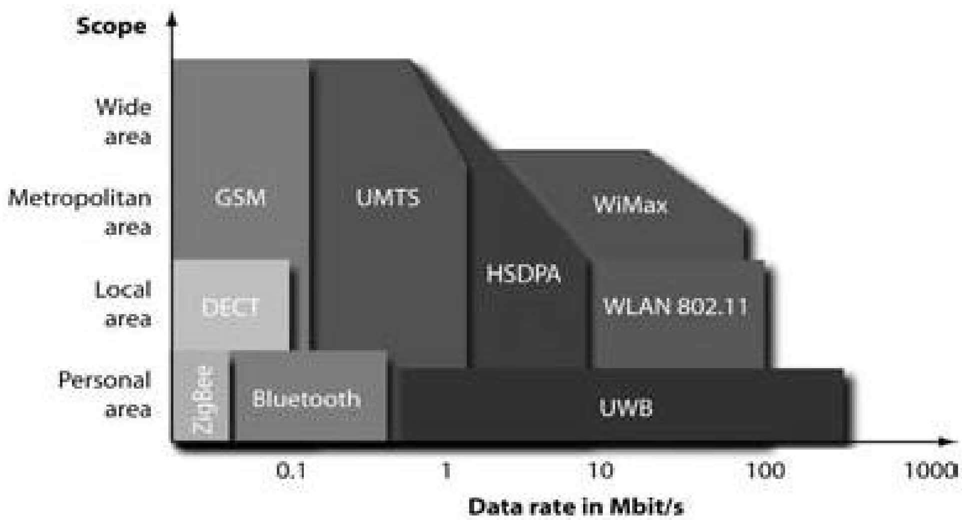


Figure 2: Classifications of wireless communication technologies

2.2 - Technological alternatives

Without prior analysis, it is interesting to consider the 802.11 technology standard for the design of the network due to its high popularity and competitive prices. However, as seen previously, there are some alternatives to consider, each with advantages and disadvantages. We must select the choice that best suits our needs and resources, so we will evaluate the technologies used in other development projects in rural networks, such as VHF technology which has been used successfully, as well as WiMAX technology.

VHF

The VHF or Very High Frequency, is a technology that works in the band 150 MHz and allows voice and data communications with a range of 60 Km. Its main advantage is that it is able to overcome obstacles and establish link without line of sight, due to the diffraction of waves. Also saving money because their towers are lower than Wi-Fi towers, it uses a lower frequency reaches remote locations, reducing the number of repeaters required. The atmospheric phenomena such as rain or clouds have almost no impact, including the de-targeting of the antennas due to wind is not as vital as Wi-Fi.

However, the use of the VHF band requires a license, unlike in Wi-Fi range, which is free. Its transmission rate is lower, using a higher energy, implying a need to deploy more solar panels or power supplies, which together with the higher prices of their equipment, making its cost higher.

VHF option might be more comfortable because the height of the towers required is much lower and the whole process of pointing the antennas is much simpler. But because we do not only decides on technological basis, and considering the history of the evolution of Wi-Fi, and every time you get better performance with more interesting installation costs, expanding the range of companies that can offer their services of installation and maintenance, we discard the VHF for the moment for being the most expensive option.

WiMAX

WiMAX or Worldwide Interoperability for Microwave Access is the name of IEEE 802.16 standar and although it provides wireless connectivity, its applications are different than Wi-Fi. It provides access to areas about 80 Km radius, with highly directional antennas and high gain, and speeds up to 70 Mbps if the spectrum is completely clean. In addition, this technology does not require line of sight with the base stations from other stations. It uses radio waves at frequencies of 2.3/2.5, 3.5 or 5 Ghz, the latter for non-standard or interoperable equipment.

Its main advantages over Wi-Fi is a better performance over long distances, more coverage with a consequent reduction of repeaters, improved data transmission rates and link quality. It also has free frequencies, as well as private. However, the technology is almost new, so there is not much variety of equipment available in the market, being more expensive than those used in Wi-Fi, and in some countries, the frequencies used are subject to change and require further licensing.

Because in the framework of a project developed in the area the cost is a decisive factor, the option is ruled out WiMAX, but it is becoming a popular option to consider for future projects. In the case of a scenario in which we count with enough people spread over a large area, we might think about developing a Wi-Fi/WiMAX mixed network, where rural areas would be implemented with WiMAX, while the more urbanized centers with Wi-Fi. As we shall see, despite to development of wireless network in a rural environment, we know that most people live in two well defined small areas, making WiMAX unnecessary for the moment.

2.3 – 802.11g technology

Overview standard

The IEEE 802.11g standard is a variant of the 802.11 family, designed for data communication local area in the 2.4 GHz frequency band, and belongs to the family of IEEE 802.2, a series of specifications for LAN technologies. [2]

The emergence of 802.11 happen from the proliferation of wireless networking needs. These networks have to adapt to standards that Ethernet networks were already met, and to add the particular specifications of the wired networks do not like the use of radio resources.

The original standard is the basis of all of the following standards because it provides the media to authenticate and authorize devices connections to wired LAN ports and wireless. The following standards change the definition of the physical layer to adapt to the frequencies used and the speeds they get.

802.11 network standards					
802.11 Protocol	-	a	b	g	n
Release	June 1997	September 1999	September 1999	June 2003	October 2009
Maximum data rate		54 Mbps	11 Mbps	54 Mbps	600 Mbps
Different data rate configurations		8	4	12	576
Approximate indoor range	20 m	35 m	38 m	38 m	70 m
	66 ft	115 ft	125 ft	125 ft	230 ft
Approximate Outdoor range	100 m	120 m	140 m	140 m	250 m
	330 ft	390 ft	460 ft	460 ft	820 ft
Modulation	DSSS, FHSS	OFDM	DSSS	DSSS, OFDM	OFDM+
RF band	2.4 GHz	5 GHz	2.4 GHz	2.4 GHz	2.4 and 5 GHz
Number of spatial streams and antennas	1	1	1	1	Up to 4
Bandwidth	20 MHz	20 MHz	20 MHz	20 MHz	20 or 40 MHz
Number of channel		23	3	3	26

Figure 3: Summary of different IEEE standards for WLAN [2]

Many rural WLAN uses 802.11b standar, whose theoretical maximum speed is 11 Mbps, but has a real average performance of between 6 and 8 Mbps. 802.11b disadvantage is that any device that operates on the the 2.4 GHz band is a potential source of interference, such as a home wireless phone, Bluetooth devices or even microwave ovens, resulting in injury in the performance of the WLAN.

Over time, different standards have been developed keeping them compatibility and improving different features. One of the latest is the IEEE 802.11n standard, which is built based on previous standards of the 802.11 family, adding Multiple-Input Multiple-Output (MIMO) and binding network interface and Channel Bonding, as well as add frames to the MAC layer. MIMO uses multiple transmitter and receiver antennas to improve system performance. In addition, another advantage is the Space Division Multiplexing (SDM), which spatially multiplexes multiple independent data streams, transferred simultaneously with a spectral channel bandwidth.

In recent years, the IEEE is working on Bluetooth wireless technology to bring a piece of its specifications as a base material for the new IEEE 802.15 standard, in order to turn the Wi-Fi future fully compatible with Bluethooth, coexisting WPANs and WLANs in the same band of 2.4 Ghz. The interest in this technology is adapting to small devices and low cost, and therefore is widespread in PDAs, laptops and mobile phones.

802.11g

In June 2003, Wi-Fi Alliance (previously WECA: Wireless Ethernet Compatibility Alliance) ratified the third modulation standard: 802.11g. [2]

Although the 802.11n standard is the most recent and promises better performance, it was decided to deploy the network based on standard 802.11g because of being the most popular and mature. Though at first sight it seems that wireless access points could be faster with the latest technology, however, the speed of a Wi-Fi wireless network is set by the slower user, and it is useless to have a very fast access point if the majority of users are slow. Nowadays in Spain, the acquisition of a laptop is usually with embedded Wi-Fi 802.11g, or in some cases alse 802.11b. In addition, we want to continue using of different computers that are available at key points town, as the town hall, the municipal library, the tourist office, highschool, etc. which accept only those standards, compatible with each other, and also because the useful life of such equipment will be about five years, the 802.11g is the solution.

Frequency bands

IEEE 802.11g systems use pipes of 20 MHz of a set of overlapping channels centered at different frequencies. The allocation of channels is fixed to each Access Point.

Channel	Frequency (MHz)
1	2412
2	2417
3	2422
4	2427
5	2432
6	2437
7	2442
8	2447
9	2452
10	2457
11	2462
12	2467
13	2472

Figure 4: 802.11g channels.

Levels

If we model with the Open System Interconnection (OSI), we can describe a standardized protocol architecture decomposed the different functions in seven hierarchical levels. The standard specifications focus on the two lower layers of the model because they incorporate physical details and data and information networking. All 802 networks have components of the PHY layer or physical level and MAC or link level. The physical level deals with the electrical and electromagnetic waves, while the link level is responsible for the physical level is safe, and provide tools to initiate, maintain, and terminate the link.

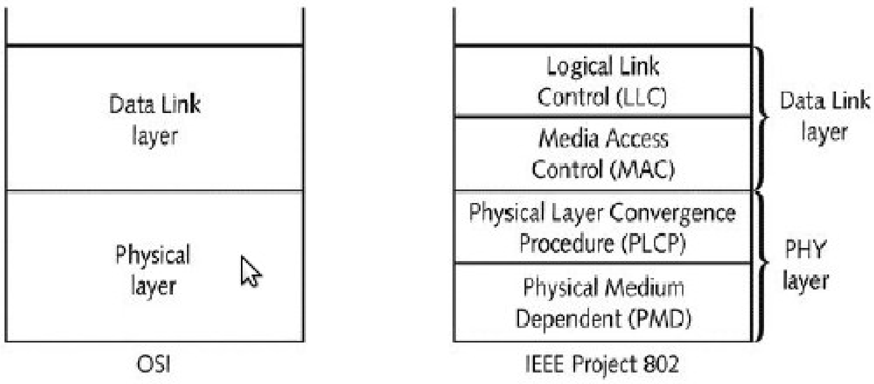


Figure 5: Comparison between OSI – IEEE 802.11 layers [1]

Design

To get a general idea of the standard by which we are working we must know what are its components. Although the standard does not specify how to implement each of the components, it specifies the services to be provided by this technology, so the choices of manufacturers, although they are not limited, they should allow their product to meet these services.

First we have the Station or STA, is the basic element of a wireless network because the network is built to transmit information. It may be a computer, a laptop or a PDA. The Access Point or AP, is responsible for the connection of wired and wireless interfaces, acting as a bridge between them. The Distribution System to connect different AP, or join our network to other more larger network. And finally, we have the wireless medium, which is the material media by which the frames are sent between stations through the AP. It was initially identified two substrates, radiofrequency (RF) or infrared (IR) although the latter has never been used. [1]

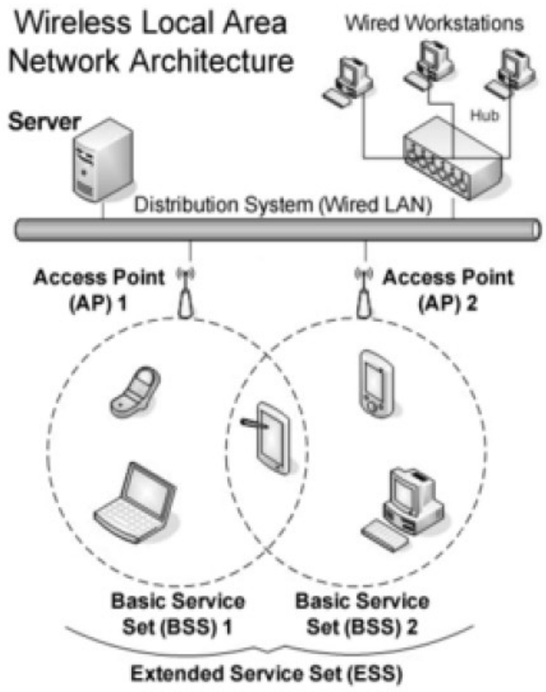


Figure 6: WLAN architecture

Operating Modes

The IEEE 802.11 standard and its variants, with the components seen before, can build two types of network configurations. Ad-hoc networks or networks with customers, in which each client communicates with the other without the intervention of common elements, so the customers can only be connected to the general network if there are any device that acts as a gateway. Secondly, infrastructure networks, where the units are connected to each client and to the network by AP, which acts as a bridge between wireless and wired network, commonly known as Master and Slave. Usually we tend to prefer the use of infrastructure mode, because it has better safety features and connectivity to the wired network.

Services

The services offered can be divided in two categories, Service Station or SS and Distributie Sevice System or DSS. [1]

The SS are common services to all network stations, including AP that must be included in any device that offers Wi-Fi support. They make the frame delivery MSDU (MAC Service Data Unit) to the receiver, encryp for increased security frames, identify the identity of who accesses the LAN before connection is established and deauthentication to terminate an authentication service above.

The DSS are services that are part of a DS and are accessed through an AP. With services such as the distribution in the delivery of frames that determines the destination address in infrastructure networks, integration of frames to another LAN that is outside of our wireless network, association between the gateway AP and the station, reassociation to change the AP and disassociation to remove a network station.

Media access control

Arbitration protocols, FDMA or Frequency Division Multiplexing Access, which is inefficient for use in systems which exhibit a typical behavior of transmission bursts,and TDMA, or Time Division Multiplexing Access, which requires precise mechanisms of synchronization between nodes.

Contention protocols, such as CSMA/CA or Carrier-Sense Multiple Access Collision Avoidance, which is the most widely used because it avoids collisions instead of detecting them, CDMA or Code Division Multiple Access, which works by assigning a code to each node and the CSMA/CD collision detection. [1]

Transmission methods

One of its most important features concerning the possibility for the system to determine the most appropriate modulation scheme, because the 802.11g standard transmits signals with different modulations for varying transmission capacity depending of sensitivity to interference and noise.

Data rate (Mbps)	Modulation	Coding rate	Coded bits per subcarrier	Coded bits per OFDM symbol	Data bits per OFDM symbol
6	BPSK	½	1	48	24
9	BPSK	¾	1	48	36
12	QPSK	½	2	96	48
18	QPSK	¾	2	96	72
24	16-QAM	½	4	192	96
36	16-QAM	¾	4	192	144
48	16-QAM	$^2/_3$	6	288	192
54	64-QAM	¾	6	288	216

Figure 7: 802.11g modulation schemes [2]

In the IEEE standard are four possible methods of transmission, however, our 802.11g uses DSSS and OFDM: [2]

DSSS or Direct Sequence Spread Spectrum. Expands the useful signal over the entire range of frequencies available in a channel with an encrypted, so if the signal are high the resistance to interference will also be higher. With DBPSK and DQPSK modulation (Differential Binary/Quadrature Phase Shift Keying) provide a transfer rate of 1 and 2 Mbps respectively.

FHSS or Frequency Hopping Spread Spectrum. Transmits a part of the information on different frequencies during a time interval (dwell) very short.

OFDM or Orthogonal Frequency Multiplexing Multiplexion. Divide the flow of data in multiple parallel streams, transmitted in their carrier frequencies that are orthogonal so they do not affect each other. It is highly resistant to multipath and narrow-band interference signals, by dividing the transmission of data across multiple channels and using error correction.

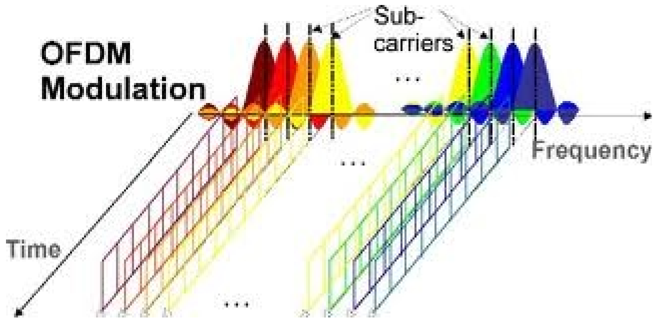


Figure 8: OFDM Modulation

Infrared band technology. It is a very rarely used and hardly defined way, due to their physical characteristics, because it is sensitive to interfering objects and bright light sources, and is applied in localized environments.

Security

The data transmitted in the radio link is protected using a security protocol known as WEP (Wired Equivalent Privacy Algorithm) which only protects the data packet information and not the heading. WEP uses a 64-bit or 128-bit key and RC4 encryption algorithm. To improve the serious security deficiencies that presented, they implemented the WAP (Wi-Fi Protected Access) and finally the WAP2 to modern standards such as 802.11n, who bet for dynamically generated encryption.

Legislation

The FCC (Federal Communications Commission) asigned for IEEE 802.11 family of standards the ISM bands (Industrial, Scientific and Medical) 2.4 and 5.7 GHz that are freely available, so you do not need to purchase licenses for use. [2]

In most countries, any equipment can at any time and almost anywhere emit in these frequency bands, but they must meet standards that vary according to each country. Among the most important restrictions are the limitation of power to avoid damage for being uncontrolled emissions. In this way, users can use their network without interference from others or disturb them interfering unnecessarily communications.

FCC standards are binding on the entire American continent and parts of Asia, while the ETS standards (from ETSI) have to be met essentially in Europe. The most important limitations imposed relates to the transmission power, which ETSI fixed at 20 dBm and FCC requires that the maximum power transmitted will be about 30 dBm with a 6 dBi PIRE antenna, down 1 dBm for each dBi over gain in the antenna. However, current regulations may suffer important changes depending on the laws of each country.

Country	2.4 GHz	5 GHz	Standards
United States, Canada, Group 1	2400-2483.5 2450-483.5 (México)	5725-5850 5725-5850 5725-5850 5725-5850	FCC 15.247 (EE.UU.) RSS 210 (CAN) RSS 139 (CAN) NOM(MÉX)
Austria, United Kingdom, Group 2	2400-2483.6		ETS 300 328-386 ETS 300 440-683
France	2446 - 2483.5		ETS 300 328-386 ETS 300 440-683
Spain	2445 - 2475		ETS 300 328-386 ETS 300 440-683
Israel	2418 - 2475		ETS 300 328-386 ETS 300 440-683
Korea	2400 - 2483.5	5725-5850	
Japan	2471 - 2497		
Australia	2400 - 2483.5	5725-5825	FCC(2.4 Ghz) ETS (2.4 GHz)
New Zealand	2400 - 2483.5	5725-5875	FCC (2.4/5.8)
Saudi Arabia	2413-2439		ETS 300 328 ETS 300 386

Group 1: Argentina, Brazil, Chile, Colombia, Dominican Republic, Ecuador, Panama, Paraguay, Peru, Uruguay, Venezuela, Hong Kong, Indonesia, Mexico, Malaysia, Philippines, Singapore, South Africa, Taiwan, Thailand, Vietnam

Group 2: Belgium, Czech Republic, Denmark, Finland, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovenia, Sweden, Switzerland, Turkey

Figure 9: Standars that devices must be met in each country [2]

3. POPULATION OF STUDY

Navalperal de Tormes is a charming village in the county of Barco de Ávila, Piedrahita, in the province of Ávila, Castilla y León, located in the heart of the Gredos mountain range, just over 80 Km from Madrid, Spain. It is located at 1300 meters altitude, on the banks of the Tormes river, which takes its name. Furthermore, it has a small hamlet/annexed called Ortigosa de Tormes, at 1600 meters, where are the best views of the Gredos mountain range, in fact it is often called "Gredos Balcony". [6]

This is a typical mountain village with its stone and wood constructions, mainly dedicated to the holdings of cattle, sheeps and horses, as well as farming for own consumption. Actually, it is undergoing a sharp change to become the focal point for tourism in the area.

The municipal area is a unique place, and includes, among others, the territory of the Gredos Big Lake, one of the most visited of the highlands and the gateway to the Five Lakes. It is surrounded by forests of oak trees, pines, broom, blackberries, and a variety of aromatic herbs such as thyme, chamomile, oregano, etc.. There is lots of wildlife: vultures, partridges, foxes, wild boar, genets, otters and the representative "Capra Hispanica".

The population density is low, because the territory is relatively long, 60 Km^2, however, most people are concentrated in the village. In the living area and grazing area have been cut down trees and brush, so the land is pasture, while in the surrounding vegetation of trees start rising hundreds of feet above the ground. The tree height is a factor to consider because it can interfere with the line of sight between antennas, in addition to the difference of 300 meters level between the two areas of the town.

In the last 10 years is undergoing a crucial change, because the population has been duplicated, especially during the summer and holiday periods, mainly due to the wide variety of tourism packages available.

More and more people come to know the village and stay in one of the cottages. Mainly come for hiking routes that start from there, whether on foot or horseback, as hiking route Gredos Balcony, so named because you can enjoy a spectacular view over the Almanzor's peak and northern Gredos mountain range. The vision of the whole snow mountain range is an unforgettable experience.

One of the strengths that makes it stand out from other towns in the area is its situation, it is ideal for those who like fishing, especially trout from the Tormes river, and for the hunters, who have an extensive reserve for hunting. In addition, you can enjoy activities as cycling and quads, canoeing and paragliding. Do not forget that you have a variety of gastronomic offers, based mainly on horticulture crops, such as the famous potatos, beans, pork pies and delicious shortcakes, that we can enjoy in the village restaurants. We can not forget the pig slaughter, an important tradition in the villages of the area and cause for celebration.

The development plan presented by the town hall is to offer the experience of being in close contact with nature, without forgetting the comfort that offers a modern society. Because of this, in recent years, the town hall and government of Castilla y León, launched a program to provide rural broadband to more than 18,000 people in the province. The program will allow remote areas to be on equal conditions with urban areas in access to services offered by the society of the information, creating opportunities for communication, employment, education and culture for Ávila, resulting in a substantial improvement in their quality of life. An incentive is to facilitate the creation of companies, opening the doors to economic and social development of rural municipalities, promoting rural tourism. [5]

According to recent studies made by the city council, Navalperal has 350 inhabitants, of whom 50 are in the hamlet Ortigosa, and some more scattered in isolated farms. In summer and holiday periods, the population increases because the visitors to 500. Until recent years, the population was devoted exclusively to livestock and cultivation, however, the flourishing tourism industry has given the town of citizens who play a variety of tasks related with the hospitality and tourism.

Navalperal currently has only public wireless municipal infrastructure in the town hall and library, which also offers wireless for users who are there with their laptops and it has five computers available to the public.

It wants to give coverage to the vast majority of people in the two population centers, with a special interest in school and high school found on Navalperal, as well as tourist offices and rural houses. However, the public health center use also a private network, because they can not risk losing the connection in case of failure and for safety reasons for having the network of confidential patient data.

With the help of Government of Castilla and León, the town will offer to connect Internet for free, using the program to provide rural broadband. In a second step is pretended to extend the network to the other towns of the Tormes riverside.

4. EQUIPMENT SPECIFICATIONS

We have different equipments for each part of the network. First of all we will explain the equipment features and then their use. We must distinguish between backbone and local access network.

In backbone we have equipment Motorola PTP 25600. The 600 Series of Point-to-Point wireless Ethernet bridges include for the 2.5 GHz band, is a set of high performance wireless bridge, providing high capacity and highspeed point to point. It offers high performance connectivity and backhaul in challenging non-line-of-sight environments. With carrier-grade reliability, PTP 600 links have class-leading sensitivity and power output which enable links to go farther, while sustaining high throughput regardless of conditions. With data rates up to 300 Mbps and reaching distances up to 200 Km, this Series of high-performance and secure wireless bridges make cost-effective connectivity and backhaul a reality for a wide range of enterprises, service providers and public safety organizations. [9]

Motorola 2.5 GHz Point-to-Point Bridges – PTP 25600	
Radio Technology	
RF band	2.496 – 2.690 GHz
Channel size	Configurable to 5, 10, 15 or 30 MHz
Channel selection	Fixed Frequency (US BRS/EBS Band Plan) Lower Band – 2496 MHz to 2572 MHz Middle Band – 2572 MHz to 2614 MHz Upper Band – 2614 MHz to 2690 MHz
Transmit power	Varies with modulation mode and settings up to 23 dBm
System gain	Integrated: Varies with modulation mode; up to 154 dB using 18 dBi integrated antenna Connectorized: Varies with modulation mode and antenna type
Receiver sensitivity	Adaptive, varying between -95 and -59 dBm
Modulation	Dynamic, adapting between BPSK and 256 QAM
Error correction	FEC
Duplex scheme	Time Division Duplex (TDD) and Half Duplex Frequency Division Duplex (HD-FDD), Dynamic or Fixed ratio

Antenna	Integrated: Integrated flat plate 18 dBi, 20º beam width Connectorized: Can operate with a selection of separately-purchased single and dual polar antennas
Range	Up to 200 km
Security and encryption	Optional FIPS-197 compliant 128-bit and 256-bit AES Encryption; optional FIPS 140-2 Level 2 mode
Ethernet Bridging	
Protocol	IEEE 802.3
User data throughput	Dynamically variable up to 300 Mbps at the Ethernet: 5 MHz Channel: Up to 40 Mbps 10 MHz Channel: Up to 84 Mbps 15 MHz Channel: Up to 126 Mbps 30 MHz Channel: Up to 300 Mbps (not FCC compliant)
QoS	8 Queues
Ethernet interface	10 / 100 / 1000 Base T (RJ-45), auto MDI/MDIX, optional 1000 Base SX
Management & Installation	
LED indicators	Power status, Ethernet link status and activity
System management	Web access via browser or TLS/HTTPS; SNMP v1, v2c and v3, MIB-II and proprietary PTP MIB; Motorola One Point Wireless Suite
Connection	Distance between outdoor unit and primary network connection: up to 100 meters
Physical	
Dimensions	Integrated Outdoor Unit (ODU): 370 x 370 x 95 mm Connectorized ODU: 309 x 309 x 105 mm Powered indoor unit (PIDU Plus): 250 x 40 x 80 mm
Weight	Integrated ODU: 5.5 kg including bracket Connectorized ODU: 4.3 kg PIDU Plus: 864 g
Wind speed survival	325 kph
Operating temperature	-40°C to +60°C, including solar radiation
Power source	90–240 VAC, 50–60 Hz / 36-60V DC
Power consumption	55 W max

Figure 15: Feature table of Motorola PTP 25600 [7]

The local network has the equipment Alvarion BreezeACCESS Wi², which combine the functionality of Wi-Fi, IP router, and access control to Wi-Fi Hotspots. It also supports WiMAX/pre-WiMAX. Comprehensive full solution combining with other products for backhauling with a robust high power and feature rich 802.11b/g access point. It does not require a subscriber unit for its operation, but a Wi² connected t to a subscriber allows connection of four Wi² to it, forming a star. [10]

Alvarion BreezeACCESS Wi²	
Wireless Specification	
Standards	IEEE 802.3 10BASE-T IEEE 802.3 100BASE-TX IEEE 802.11b/g
Data rate	802.11g: 6, 9, 11, 12, 18, 24, 36, 48, 54 Mbps per channel 802.11b: 1, 2, 5.5, 11 Mbps per channel
Maximum channels	FC/IC: 1-11 ETSI: 1-13 Japan: 1-14
Maximum clients	128 for the radio interface to access point mode
Modulation types	802.11g: CCK, BPSK, QPSK, OFDM 802.11b: CCK, BPSK, QPSK
Operating frequency	802.11b/g; 2,4-2,4835 GHz (EEUU, Canada, ETSI); 2,4-2,497 GHz (Japan)
Antenna specifications	2 x 8 dBi Omni directional (2,4 – 2,5 GHz)
Rx power and Sx sensitivity	
802.11g/b	6 Mbps: 20 dBm Tx power, -95 dBm Rx sensitivity 9 Mbps: 20 dBm Tx power, -93 dBm Rx sensitivity 12 Mbps: 20 dBm Tx power, -87 dBm Rx sensitivity 18 Mbps: 20 dBm Tx power, -84 dBm Rx sensitivity 24 Mbps: 20 dBm Tx power, -80 dBm Rx sensitivity 36 Mbps: 19 dBm Tx power, -77 dBm Rx sensitivity 48 Mbps: 19 dBm Tx power, -73 dBm Rx sensitivity 54 Mbps: 19 dBm Tx power, -70 dBm Rx sensitivity
802.11b	1 Mbps: 20 dBm Tx power, -111 dBm Rx sensitivity 2 Mbps: 20 dBm Tx power, -102 dBm Rx sensitivity 5.5 Mbps: 20 dBm Tx power, -92 dBm Rx sensitivity 11 Mbps: 20 dBm Tx power, -91 dBm Rx sensitivity

Software	
Access Control	Integrated HTML login/captive portal Integrated RADIUS authentication Configurable min/max connect speed
Management	SNMP, CLI, web-based, Selectable RF channel and transmit power
Security	802.1x, AES, WPA2, Radius, WEP, Firewall
Physical	
Size	32,9 x 27,8 x 21,11 cm
Weight	7 Kg
Temperature	Operating: -40º to 60º C Storege: -55º to 80º C
Humidity	5 – 95% (non-condensing)

Figure 16: Feature table of BreezeACCESS Wi^2 [7]

In addition, in certain locations will require additional electronics, particularly in the tourist office, local library, school/high school, and the town hall, there will be a D-Link's DGS-2208 8-port Switch which will interconnect the access point and informatic equipment of the locations. While in some places not all ports are used, they are left for future use. [8]

We also use Q-Link TL-ANT24SP Surge Protector, which protects our network from lightning strikes and electrical surges. [7]

As in the implementation of this network the goal was to create a completely wireless network, we will not need additional wiring. It only needs small bits of Ethernet cable to connect some device by others, and electrical wiring necessary for the operation of equipment.

Finally, it needs to put a mast of 10 meters in one of the locations, Communications stand in Ortigosa (we will see later),due to the peculiarity of the ground and to achieve a clear line of sight saving the tree height. Due to the low profile of the town houses it will not need anything more, it will be enough with the antennas placed on the roof.

5. NETWORK DESIGN

5.1 - Description

Navalperal de Tormes has two distinct nuclei. In our general network, we must distinguish between the two subnets that form it, the local network, one at each nuclei, and the backbone network, which will transmit the signal to provide wireless Internet connection between nuclei. Such networks will be independent, using different configurations in its design.

Backbone Network. The two strategic points are connected by point-to-point, like master and slave at the same time. Focal points will be located in the town hall of Navalperal (where is the Internet connection), and the communications stand of Ortigosa. They will use PTP 25600 with directional antennas.

Local Network. The network structure is point-to-multipoint, in order to provide the necessary connections to the neighbors and businesses and potential tourists. Therefore, this network will be a infrastructure network, with the stations connected to an Access Point. The locations are: in Ortigosa, the camping, and in Navalperal, the tourist office, the library and the school/high school. They will use BreezeACCESS Wi^2, with two omnidirectionals antennas (one to service to its costumers, and another for communication with other devices), and from each of the backbone points it is radiated (star way) to local access points, allowing the connection to the Internet by users anywhere on the network.

Also, as we mentioned, it aims to provide wireless coverage of Wi-Fi access to residents of the town. According to the latest study by the city council on its population, there are about 350 inhabitants, of which 200 are in the range of ages between 10 and 60 (potential internet users) and only 60% of them would be willing service. Also, the equipment to connect will be used by an average of 3 persons, so users will finally be 40 potential residents, to which one we must add 10 or 15 potential mobile users. It can connect more users than the previous ones, but the speed will be reduced.

So it should be able to connect at least 10 simultaneous clients at every point, and we have to anticipate further expansions of the network to support more users, so it should be easy.

The minimum aggregate traffic to be shared among users online is 5 Mbps in each point, dividing this capacity equally among users who are associated with access points. In addition, the minimum required in terms of bandwidth will be 512 Kbps, which is the effective bandwidth that a customer gets when connecting.

Point	Location	Latitude	Longitude	Height	Throuhgput
Ortigosa	Communications stand	40º 21' 55.04 N	5º 18' 12.33'' W	1585 m	5 Mbps
	Camping	40º 21' 55.44 N	5º 18' 17.24'' W	1586 m	5 Mbps
	Total Ortigosa: Camping + Communications stand = 10 Mbps				
Navalperal	Town hall	40º 21' 10.44'' N	5º 18' 01.86'' W	1301 m	5 Mbps
	Tourist office	40º 21' 09.51'' N	5º 18' 0.79'' W	1298 m	5 Mbps
	Library	40º 21' 09.04'' N	5º 18' 06.26'' W	1298 m	5 Mbps
	School/High school	40º 21' 07.42'' N	5º 18' 11.44'' W	1298 m	5 Mbps
	Total Navalperal: Total Ortigosa + Town hall + Tourist office + Library + School/High school = 30 Mbps				

Figure 10: Coordinates of the backbone and Wi-Fi points (GPS) and Throughput

The bandwidth that will be contracted to an operator is 30 Mbps, however, the range of the devices we use is a bit more than we need, as seen in their tables of features. So we will work with 6 Mbps at any point in the network, and 40 Mbps in the final link with the router to provide Internet access.

The operators offer broadband options, including balanced ADSL. This type of connection is based on the hiring of a rate that will increase or decrease as required by the network. The router to connecto to Internet and the necessary wiring till the town hall will be provided by the operator.

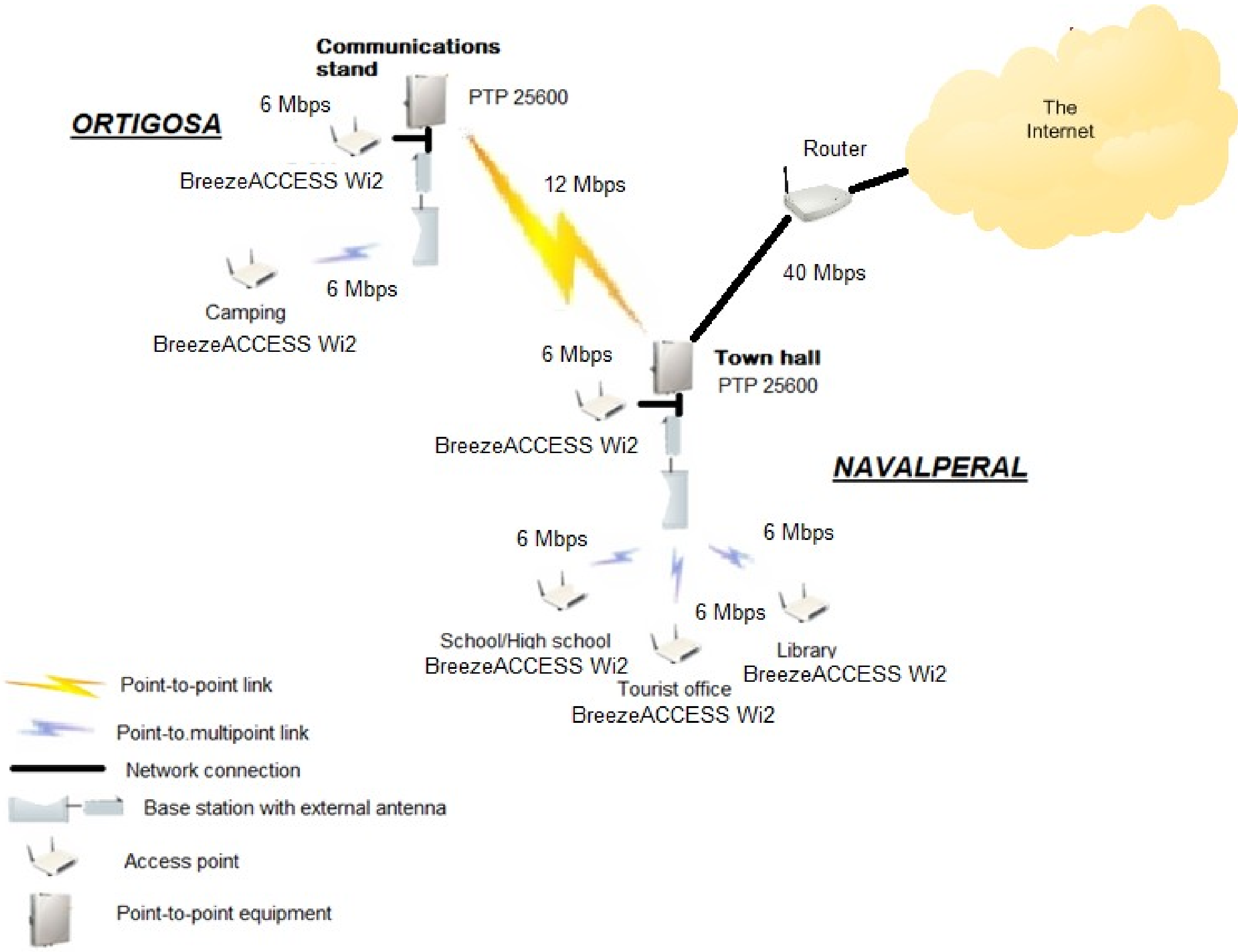


Figure 11: Network scheme

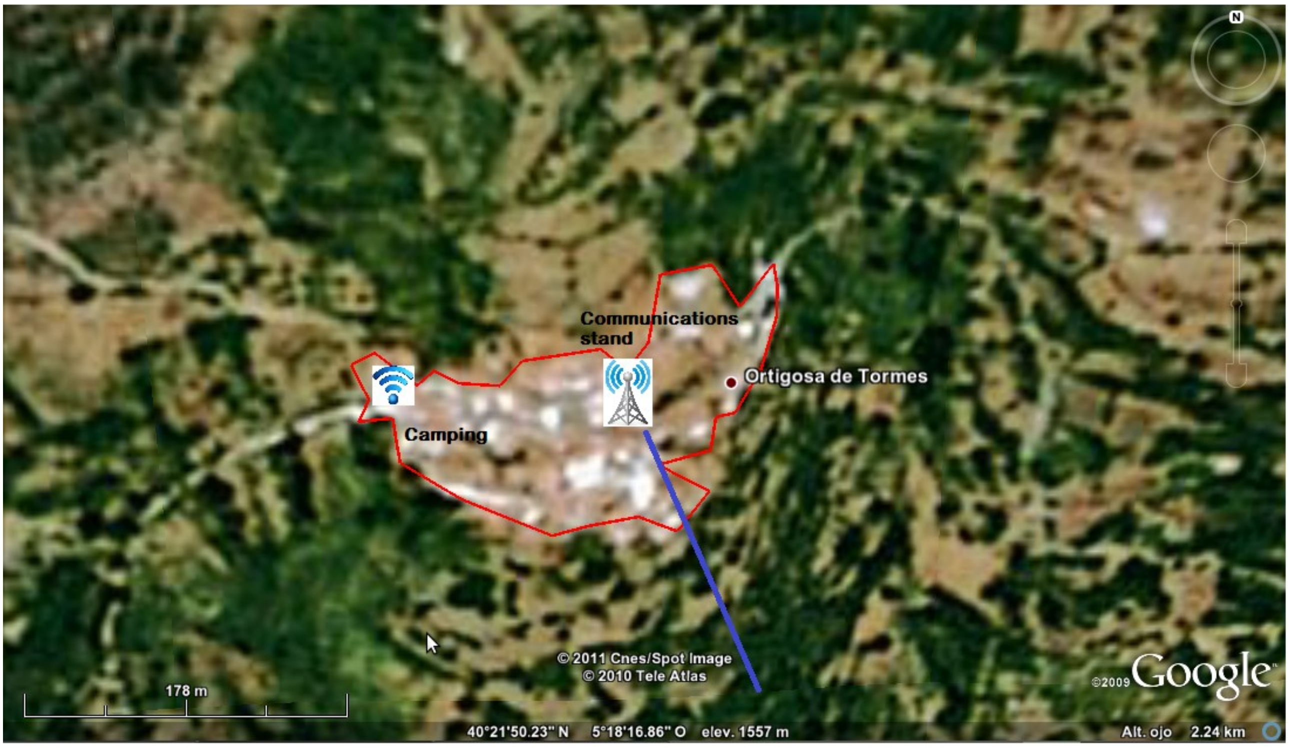


Figure 12: Point locations with Wi-Fi in Ortigosa

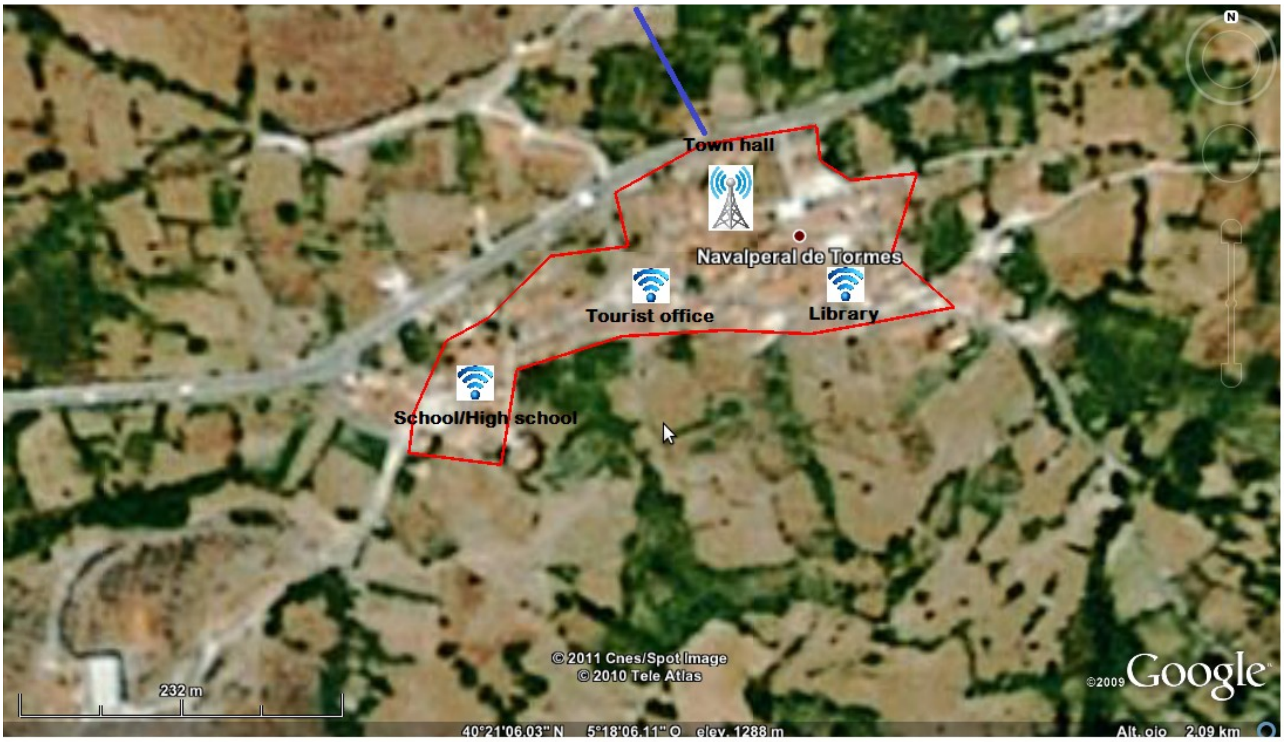


Figure 12: Point locations with Wi-Fi in Navalperal

5.2 - Radio planning

In the backbone network design it has been thought that the locations were connected direct line of sight, to obtain a large bandwidth and low response times. All the access points should be in town hall buildings to be more economical deployment. The network is complemented by the fixed equipment found in the library, tourist office, school/high school, etc.

Access points will install inside buildings, connected to an antenna on the outside, placing it in a way that gets the most coverage.

To calculate the links it has been made an estimate of the expected signal level and fade margin obtained. We must make a balance of power, where PRx is the received power, PTx the transmitted power, GTx the transmitted gain, LcRx and LcTx losses due to the wiring of the transmitter and receiver, Lp propagation loss, and GRx receiver gain.

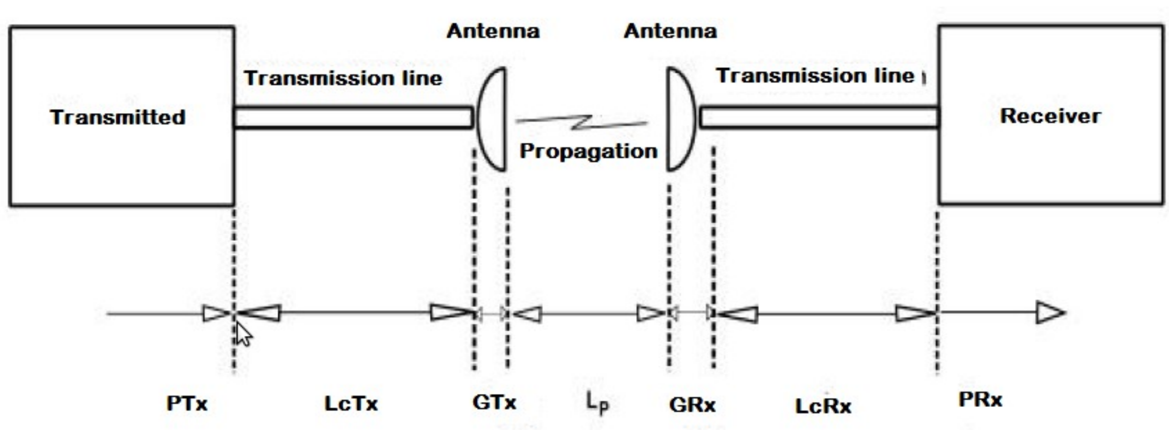


Figure 13: Link balance [3]

$$PRx(dBm) = PTx(dBm) + GTx(dBi) - LcTx(dB) - LcRx(dB) - Lp(dB) + GRx(dBi)$$

To obtain the values, we just have to see the feature table of the equipment participing in the link. In our case, the cable losses are null because the antennas are integrated. Transmitted or received gains are fixed, while the transmitted power will vary.

A key point is the calculation of propagation loss Lp. For this there are several models depending on factors such as terrain, distance, type of environment: rural, urban, etc. In the general case of propagation in free space, the expression is:

$$Lp(dB) = 92,45 + 20\log f(GHz) + 20\log d(Km) \ [3]$$

Likewise, we must verify that at least 60% of the Fresnel zone is free of obstacles to avoid problems with line of sight.

$$\text{First Fresnel zone radius} = 547.723 \cdot \sqrt{\frac{d}{4 \cdot f}}$$

D is the distance the radio link in kilometers, f is frequency in MHz. [3]

The CNAF legislation (UN-85) specifies that equipment working in the 2.4 GHz abroad have to transmit 100 mW (20 dB) PIRE. To have the best radio coverage we have to set the gain of the antennas as maximum, and reduce the transmission power to avoid exceeding the allowable PIRE:

$$PIRE(dB) = PTx(dBm) + GTx(dBi) - LcTx(dB) \ [3]$$

This formula will determine the maximum power transmitted, depending on the transmitted gain, cable losses and the maximum allowable PIRE that is 20 dB.

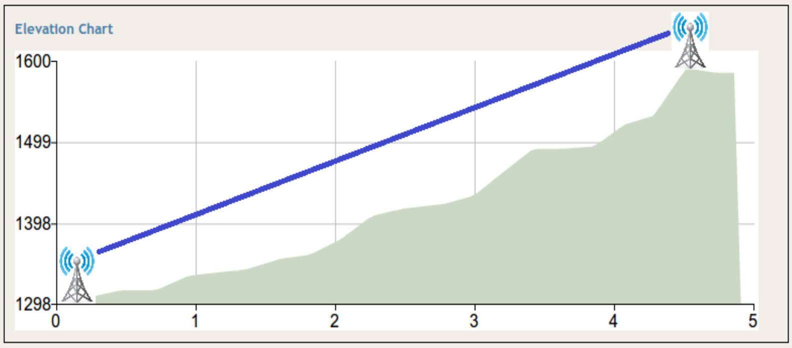
Finally, we must ensure that the received power at the receiver sensitivity is higher than sensitivit for proper operation. We establish a fading margin to operate as a safety margin by which the power must exceed 10 dB sensitivity. Important point we have to check.

$$GRx(dBm) >= S(dBm) + 10 \ [3]$$

Navalperal - Ortigosa link

Location: Navalperal, Town hall
Ortigosa, Communications stand

Side face



Antenna type	Integrated
Antenna gain (dBi)	18
Cable type	UTP
Cable length (m)	0
Cable loss (dB)	0
Connector loss (dB)	0
Other losses (dB)	0
Distance (Km)	1,4
Frequency (GHz)	2,4
Free space attenuation (dB)	102,97
1º Fresnel zone (m)	6,61
60% 1º Fresnel zone (m)	3,96
Radio type	PTP 25600
Transmit power (dBm)	2
Received signal level (dBm)	-64.97
PIRE (dBm)	20
Sensivity (dBm)	-95
Fade margin (dB)	30,03

Figure 14: Navalperal – Ortigosa backbone link

Link	Ortigosa	Navalperal		
Location:	Communications stand Camping	Town hall Library	Town hall Tourist office	Town hall School/High school
Antenna type	Integrated			
Antenna gain (dBi)	8			
Cable type	UTP			
Cable loss (dB)	0			
Connector loss (dB)	0			
Other losses (dB)	0			
Distance (Km)	0,14	0,1	0,1	0,23
Frequency (GHz)	2,4			
Free space attenuation (dB)	82.97	80,05	80,05	87,28
1º Fresnel zone (m)	2,09	1,76	1,76	2,68
60% 1º Fresnel zone (m)	1,25	1,05	1,05	1,6
Radio type	BreezeAccessWi^2			
Transmit power (dBm)	12			
Received signal level (dBm)	-54.97	-52,05	-52,05	-59,28
PIRE (dBm)	20			
Sensivity (dBm)	-95			
Fade margin (dB)	40,03	42,95	42,05	35,72

Figure 15: Access points links

Safety distance

Because the emission in wireless communications is much lower than a mobile device, this exposure to electromagnetic fields do not affect human or animal health. However, in directional antennas the radiated power is concentrated, so you have to play by the rules and deadlines governing by law, making measurements and necessary revisions. Moreover, we can calculate the safety distance, which is the minimum distance that must exist between the radiating element and people.

$$\text{Safety distance (m)} = \sqrt{\frac{M \cdot P_{PIRE}}{4 \cdot \pi \cdot S_{max}}}$$

Where P_{PIRE} is the PIRE power in Watts, M is the factor of reflection (4 if total reflection, 2.56 with reflection, and 1 if not) that we will use 4 for being more resticted, S_{max} is the maximum permitted power density of service in W/m^2 (for computers that emit between 2 and 300 GHz, the reference level is 10 W/m^2). [3]

Our network equipments have antennas with 20 dB (100 mW) PIRE for the local network because CNAF legislation.

Parameter	Value
S_{max} permitted	10 (W/m^2)
PIRE	100 mW
Reflection factor	4
Safety distance	6 cm

Figure16: Safety distance from the radiating elements

The value is small enough to not be a concern, because the equipment will be located on the buildings roofs.

6. ECONOMIC STUDY

After studying the network, is necessary to carry out a budget. The cost of developing and implementing the network, will be pay by the City Council and the government of Castilla y León. The villagers will not have to pay anything, not in the execution or the enjoyment of the project.

This budget will be not exact, because depending on the equipment and the economy and the market when it is made, it will vary.

6.1 - Procurement budget

Equipment	Amount	Price	Total
Motorola PTP 25600 (Point-to-point)	2	6.000,00 €	12.000,00 €
Alvarion BreezeACCESS Wi^2	6	1.800,00 €	10.800,00 €
D-Link's DGS-2208 Switch	4	100,00 €	400,00 €
Dlink ANT24-SP Lightning Protector	6	30,00 €	180,00 €
Cables (UTP CAT 5e, power cable), connectors, other installation materials	1	300,00 €	300,00 €
Total			23.680,00 €

Figure 17: Cost of material implementation [11] [12]

Element	Total
Computer and office material	60,00 €
Binding (four copies)	100,00 €
Total	160,00 €

Figure 18: Cost of consumables

The antennas are placed on the roofs of the buildings described above. They shall be deliberately choosen for belonging to the city council, so their rent will be free. This was an important issue to not increase the price.

Total cost of material implementation: 23.840,00 €.

6.2 - Fees

We consider four hours of installation for each access point, and six for doubles (Town hall and Communications stand) and to book a full working day of eight hours for any contingency, so we have a total of 36 hours of installation. Nowadays in Spain a skilled work is paid at 15 €/hour.

Also, we must pay the engineer to develop the study of the network, and the typist to make the dossier.

People	Time	Cost per hour	Total
Engineer	240 hours	20,00 €	4.800,00 €
Typist	15 hours	10,00 €	150,00 €
Installacion	36	15,00 €	540,00 €
Total			5.490,00 €

Figure 19: Fees

6.3 ISP

The ISP (Internet Service Provider) will be with Telefonica (Movistar), and it will provide the network connection to the Internet. As mentioned earlier, this connection is made through a router that will provide the company, hiring a speed of 40 Mbps through ADSL. In addition, Telefónica also be responsible for periodic checks and required maintenance. [13]

This service will cost 60 €/month with a commitment to stay for 12 months.

6.4 - Total budget

Total budget	
Total procurement budget	23.780,00 €
Total fees	5.490,00 €
SUBTOTAL	29.270,00 €
18% VAT (value-added tax)	5.268,60 €
TOTAL	34.538,60 €

Figure 20: Total budget

The final budget of this project is thirty-four thousand five hundred thirty-eight euros and sixty cents.

It is estimated that the equipment will become obsolete after five years and will be replaced by new technology, so 5-year depreciation (amortization) will be dividing the total budget by 60 months (five years) and adding rents, in this case only the ISP line.

Amortization = 635,64 €

7. CONCLUSIONS

Telecommunications networks can become a tool to promote the development of rural areas. Throughout this project it has designed a wireless network for a village of these characteristics. The possibility of network deployment in these areas has been driven by the recent years momentum due to standartization of the wireless communication protocols for transmission.

Wi-Fi technology, based on the set of IEEE 802.11 standards, has many features which make it appropriate for these environments. On the one hand, it provides powerful features that enable Internet surfing at high speed, data transmission and even voice communications using VoIP. In addition, the investment required for the implementation of the network is very low compared with other networks that offer similar services or wired networks. It has great flexibility that allows easily perform network upgrades once deployed the initial design.

To operate in the ISM frequency band of 2.4 GHz, not require any license, only to be met specific standards of each country. Another advantage is the speed of network deployment, because the equipment are small, easy transportation and installation is not complicated, except in the alignment of directional antennas.

On the other hand, we must consider the distances to be covered by bonds, and the need of sight between the antennas that communicate. Because the terrain or the curvature of the earth, it is sometimes necessary to put the antennas on towers and add intermediate repeaters, although we have seen, it was not necessary for the lenght of our area.

Taking into account all the data we have gathered over our network design for Navelperal de Tormes, we can say that the implementation of a wireless network in the town area serve as a springboard to the village to be situated at the forefront of all area, becoming a point of reference in:

Telemedicine and eHealth: Telemedicine applications allow them to approach people in their own environment, allowing the remote diagnosis, teleconsultation, meetings to get second opinions (teleconference), while the eHealth allows digital storage of data or medical records, purchase of medical supplies, prescriptions online, and even classes at a distance from medical centers (e-learning via videoconferencing).

Education and eLearning: With the eLearning strengthens the learning process and allows students to get in real-time qualified teachers in areas that do not have another option, and they can access alternative educational resources. It also opens the door to videoconferencing and facilitates collaboration between institutions.

Administration and eGovernment: Allows to transform traditional offices, converting paper processes to electronic processes, improving interaction between government and electronically enabled as a new means for the relationship with citizens and businesses. Improve organizational performance by simplifying everyday processes, achieving greater efficiency. Enables interactive communication various municipal buildings, and even the hamlets municipal buildings distant.

Rural development: Increases the attractiveness of rural areas and improving opportunities for marketing products and services such as tourism and recreation, and to connect the farms and companies with national and international markets.

As we have seen, the cost of a wireless network installation in a rural setting, is not considered an overly expensive expenditure for the town council as might be expected, since although it does not handle a lot of money, is an acceptable cost. The network is characterized by its simplicity and its ability to expand as needed.

Also, the proposed design will act as a guide for future plans in other towns in the area.

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[3] Universidad Carlos III de Madrid, "El Medio Radioeléctrico", Tema 2, Fundamentos de Comunicaciones Móbiles, 2010

[4] Boletín oficial del estado: www.boe.es

[5] Junta de Castilla y León: www.jcyl.es

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[7] Online electronic component datassheets: www.alldatasheet.com

[8] Dlink company: www.dlink.com

[9] Motorola company: www.motorolasolutions.com

[10] Alvarion company: www.alvarion.com

[11] Electronics store: www.ciudadwireless.com

[12] Electronics store: www.universalnetwork.com.au

[13] ISP Provider: www.movistar.es

Others links of interest:

ITU: www.itu.int

ETSI: www.etsi.org

WiFi Alliance: www.wi-fi.org

9. ANEXO I – Resumen

1. Introducción

Existe gran cantidad de zonas rurales en las que se distribuye la población de manera dispersa y cuyo nivel de ingreso per cápita es bajo. Las redes de comunicación de banda ancha a menudo no las cubren, debido a que estas condiciones conducen a altos costes y menores ingresos por cliente, convirtiéndose en una inversión económicamente poco atractiva. Esta situación se conoce como “brecha digital”, es decir, la desigualdad en el acceso a las tecnologías de la información y la comunicación (TIC) entre los habitantes de las zonas rurales y los habitantes de otros núcleos urbanos.

El acceso de alta capacidad es muy importante porque Internet es una de las innovaciones más importantes de nuestro tiempo, trayendo beneficios sustanciales para las economías y las sociedades. La capacidad de comunicar información a altas velocidades a través de diferentes plataformas es esencial para el desarrollo de nuevos servicios, tales como la telemedicina en los lugares donde no es posible disponer de un servicio normal, la educación para ofrecer acceso a otros recursos educativos, la administración para mejorar la eficiencia y el desarrollo rural, que aumenta la atracción turística.

Actualmente España cuenta con varios planes destinados a llevar la banda ancha a todos los municipios, que cuentan con diferentes tipos de enfoques, como programas de becas, préstamos o iniciativas municipales. Dichos servicios de banda ancha, se prestan utilizando distintas combinaciones de tecnologías de redes de comunicaciones, basadas en infraestructuras de transmisión fija y radio. Cada tecnología tiene sus propias características e impacto diferente sobre la capacidad total y la capacidad de la red.

Este estudio incluye el diseño de una red inalámbrica que proporcionará una interconexión de banda ancha entre los edificios principales en una zona rural, además de permitir el acceso a Internet a los residentes y turistas.

2. Fundamentos teóricos

En los últimos años, se ha visto incrementado el éxito de los protocolos de comunicación inalámbrica, generalizando este tipo de redes, ya que permiten una interoperabilidad entre equipos de diferentes fabricantes, lo que ha hecho disminuir sus costes. Al no ser necesaria la conexión física entre nodos, encontramos ventajas sustanciales como la conexión en lugares complicados, o un despliegue mucho más rápido que en las redes cableadas.

Sin embargo, no todo son ventajas. Encontramos problemas como las interferencias, por lo que es necesario una legislación el uso del espectro radioeléctrico, inestabilidades en el entorno, como el clima o ruidos, por lo que existen mayores retrasos en las transmisiones que en las redes cableadas. Además, dichos datos son susceptibles de ser captados por cualquier persona con los recursos apropiados, siendo necesario el uso de mecanismos de cifrado.

Existen diferentes tecnologías a considerar, como VHF y WiMAX, sin embargo, se verá que la opción que mejor se adapta a las necesidades y recursos del proyecto resulta ser Wi-Fi.

El VHF o de muy alta frecuencia, funciona en la banda de 150 MHz (más baja que Wi-Fi) y permite comunicaciones de voz y datos con un alcance de 60 km. Su principal ventaja es que es capaz de superar los obstáculos y establecer un enlace sin línea de visión, debido a la difracción de las ondas, con torres más bajas y con menos repetidores que con Wi-Fi. Sin embargo, su uso requiere una licencia. Se descarta esta opción en base a la evolución de la tecnología Wi-Fi, que cada vez consigue un mejor rendimiento con costes más interesantes de instalación.

La interoperabilidad WiMAX proporciona un mejor rendimiento en distancias largas, más cobertura con la consiguiente reducción de repetidores, una mejora de las tasas de transmisión de datos y de calidad del enlace. Debido a que es una tecnología bastante nueva, no hay mucha variedad de equipos disponibles en el mercado, aumentando su coste. Una opción a considerar sería el desarrollo de una red híbrida Wi-Fi/WiMAX, en la que las áreas rurales contarían con WiMAX, mientras que en los centros urbanizados sería Wi-Fi. Sin embargo, en la distribución de la población a considerar, no es la opción óptima.

El estándar IEEE 802.11g es una variante de la familia 802,11, diseñado para comunicación de datos local en la banda de frecuencia de 2,4 GHz, y pertenece a la familia de IEEE 802.2, una serie de especificaciones para tecnologías LAN. [2]

Aunque el estándar 802.11n es el más reciente y promete un mejor rendimiento, se decide desplegar la red basada en el estándar 802.11g, por ser la tecnología más popular y madura. Aunque a primera vista, con otras normas se puede conseguir mayores velocidades, una red Wi-Fi está limitada a la velocidad del usuario más lento, y ya que actualmente la mayoría de los equipos de usuarios disponen de conectividad con este estándar, el 802.11g es la solución.

En un diseño óptimo de una red 802.11g, se distinguen varios elementos. En primer lugar se dispone de la estación o STA, elemento básico de una red inalámbrica ya que está diseñada para transmitir información. Puede ser un ordenador, un ordenador portátil o un PDA. El punto de acceso o PA, es responsable de la conexión de interfaces cableadas e inalámbricas, actuando como un puente entre ellos. Finalmente, se dispone del medio inalámbrico, que es el medio de material con el que las tramas se envían entre estaciones a través de las PA.

Esta tecnología, puede utilizar dos tipos de configuraciones de red. Redes ad hoc o redes de cliente, en el que cada cliente se comunica con el otro sin la intervención de elementos comunes, por lo que sólo pueden ser conectados a la red general si hay existe un dispositivo que actúe como una puerta de enlace. En segundo lugar, redes de infraestructura, donde las unidades están conectadas a cada cliente y a la red por PA, que actúan como puentes, conocidos comúnmente como maestro y esclavo. Por lo general, se prefiere el uso de red de infraestructura, ya que tiene mejores características de seguridad y conectividad a la red cableada.

El estándar, presenta varios medios de control de acceso, como lo protocolos de multiplexación por división por frecuencia o FDMA, ineficientes en las ráfagas de transmisión, y de multiplexación por división de tiempo o TDMA, que requiere de sincronización entre nodos. También utiliza protocolos para evitar la colisión de paquetes como CSMA.

Una característica importante, es la posibilidad de elección de esquema de modulación más adecuado, en función de la sensibilidad en interferencias y ruido. Se disponen de cuatro métodos de transmisión, aunque en 802.11g sólo se usa la expansión del espectro de señal o DSSS y la multiplexación en frecuencia o OFDM.

Los datos transmitidos en el enlace de radio, están protegidos mediante un protocolo de seguridad conocido como WEP (Wired Equivalent Privacy), que sólo protege la información de los paquetes. Para mejorar sus deficiencias, se implementó el WPA (Wi-Fi Protected Access) y, finalmente, el WAP2, que disponen de protocolos de seguridad más robustos.

La FCC (Federal Communications Commission) designó para esta familia de protocolos, las bandas de frecuencia 2,4 y 5,7 GHz, siendo de uso libre, sin necesidad de adquirir licencia de empleo. Sin embargo, impone una restricción de potencia para evitar daños por emisiones no controladas, evitando interferencias y perturbaciones. En Europa, se dispone de una norma ETS (del ETSI) que fija en 20 dBm de potencia radiada.

NOTA: Se pueden consultar las páginas 12, 18 y 20 del presente documento, donde se detallan respectivamente las características del estándar 802.11, los modos de modulación, y las normas que deben cumplir los equipos en cada país, concretamente las figuras 3, 7 y 9.

3. Población de estudio

Navalperal de Tormes es un encantador pueblo de la comarca de El Barco de Ávila, Piedrahita, en la provincia de Ávila, Castilla y León, situado en el corazón de la Sierra de Gredos, a poco más de 80 kilómetros de Madrid, España. Se encuentra a 1300 metros de altitud, a orillas del río Tormes, del que toma nombre. Además, dispone de una pequeña aldea (anejo) llamado Ortigosa de Tormes, a 1600 metros, donde están las mejores vistas de la Sierra de Gredos, de hecho, es a menudo llamado "Balcón de Gredos".

La densidad de población es baja, debido a que el territorio es relativamente largo, 60 Km^2, sin embargo, la mayoría de personas se concentran en la aldea. La altura de los árboles es un factor a considerar ya que puede interferir con la línea de visión entre antenas, además de la diferencia de nivel de 300 metros entre las dos áreas de la ciudad.

El plan de desarrollo presentado por el Ayuntamiento es ofrecer la experiencia de estar en contacto con la naturaleza, sin olvidar la comodidad que ofrece la sociedad moderna. Debido a esto, en los últimos años, el ayuntamiento y el gobierno de Castilla y León, puso en marcha un programa para proporcionar banda ancha rural a más de 18.000 personas en la provincia.

Según estudios recientes realizados por el ayuntamiento, Navalperal cuenta con 350 habitantes, de los cuales 50 se encuentran en la aldea de Ortigosa, y un poco más dispersos en granjas aisladas. En verano y periodos vacacionales, la población aumenta debido a que los visitantes a 500.

Navalperal actualmente sólo tiene infraestructura inalámbrica en el ayuntamiento y la biblioteca. Se quiere dar cobertura a la gran mayoría de personas de los dos centros de población, con especial interés en el colegio y la escuela secundaria de Navalperal, así como las oficinas de turismo y casas rurales, sin olvidar el centro de salud.

4. Especificaciones

Se dispone de diferentes equipos para cada parte de la red: troncal y punto de acceso. En la parte de red troncal, se cuenta con equipos Motorola PTP 25600. Esta serie de accesos inalámbricos punto a punto, son máquinas de un excelente rendimiento, ofreciendo alta capacidad y velocidad. Con una alta fiabilidad, estos enlaces mantienen un alto rendimiento independientemente de las condiciones. Con velocidades de datos de hasta 300 Mbps y alcances de hasta 200 Km, hacen rentable la conectividad para la ubicación dispuesta. [9]

Los puntos de acceso cuentan con equipos Alvarion BreezeACCESS Wi^2, que combinan la funcionalidad Wi-Fi, router IP y control de acceso a redes Wi-Fi Hotspot. También es compatible con WiMAX/pre-WiMAX. Resultan ser una solución integral, con una alta potencia y preparado para accesos 802.11b/g. Es posible configurar los equipos de forma que se conecten cuatro Wi^2 al mismo tiempo, formando una topología de estrella. [10]

Además, en algunos lugares se requieren equipos adicionales, especialmente en la oficina de turismo, biblioteca, colegio y ayuntamiento. En estas ubicaciones habrá switches D-Link DGS-2208 de 8 puertos, que interconectarán los accesos con los equipos informáticos presentes. [8] También se utilizará Q-Link TL-ANT24SP Surge Protector, que protegerá a la red de rayos y sobretensiones eléctricas. [7]

Como en la implementación de esta red el objetivo es crearla de forma inalámbrica, no se necesitará de cableado adicional. Por último, será necesario un mástil de 10 metros en una de las ubicaciones de la torre de comunicaciones en Ortigosa debido a la inclinación del paisaje, para lograr una línea de visión clara por encima de la altura de los árboles. Debido al perfil bajo de las casas, será suficiente con una instalación de las antenas en los techos de las ubicaciones.

NOTA: Se pueden consultar las páginas 24-27 del presente documento, donde se detallan las características de los equipos, concretamente las figuras 15 y 16.

5. Diseño de la red

Navalperal de Tormes cuenta con dos núcleos distintos. La red global comprende dos subredes: una local, en cada núcleo, y la red troncal, que remitirá la señal para proporcionar una conexión a Internet inalámbrica entre ambos núcleos. Estas redes serán independientes, utilizando diferentes configuraciones en su diseño.

Red Troncal. Las dos localizaciones están conectadas punto a punto. Los puntos focales se encuentra en el Ayuntamiento de Navalperal (donde está la conexión a Internet), y la torre de comunicaciones en Ortigosa. Se usará PTP 25600 con antenas direccionales.

Red Local. La estructura de la red es punto a multipunto, con el fin de proporcionar las conexiones necesarias a los vecinos y empresas de negocios y turistas potenciales. Por tanto, será una red de infraestructura, con estaciones conectadas a un punto de acceso. Las situaciones son: en Ortigosa el camping, y en Navalperal, la oficina de turismo, la biblioteca y la escuela. Usarán BreezeACCESS Wi^2, con dos antenas omnidireccionales (una para dar servicio a los usuarios, y otra para la comunicación con otros dispositivos), conectando cada localización hasta los puntos de acceso local, permitiendo la conexión a Internet por los usuarios .

Según el último estudio realizado por el Ayuntamiento en su población, se estima que el número de usuarios potenciales será de 50 aproximadamente. Se estima que el tráfico mínimo compartido en cada punto será de 5 Mbps, con un mínimo requerido en términos de ancho de banda de 512 Kbps por usuario. Se contratará una conexión total de 40 Mbps (en lugar de 30) para cubrir esta necesidad, ya que la gama de dispositivos elegida lo considera más adecuado.

Para el diseño de la red troncal, se han situado dos localizaciones con línea de visión directa, optimizando el ancho de banda. Los puntos de acceso se han establecido en edificios públicos, y así tener un despliegue más económico.

El cálculo de los enlaces, ha tenido en cuenta una estimación del nivel de señal esperado y de margen de desvanecimiento. Se debe establecer un equilibrio entre la potencia recibida y transmitida, así como las pérdidas y ganancias de del enlace.

Usando los valores de los dispositivos, así como el cálculo de las pérdidas de propagación, donde intervienen factores como la distancia, el tipo de entorno o el terreno, podemos averiguar los valores de ganancia y potencia

También se ha tenido en cuenta la legislación CNAF (UN-85) que especifica que los equipos de trabajo en los 2,4 GHz han de transmitir 100 mW (20 dB) de PIRE. Para obtener el radio de cobertura, se fija la ganancia de las antenas como máximo, y se reduce la potencia de transmisión para evitar exceder el valor de PIRE permitido.

Para un correcto funcionamiento, se ha asegurado que la potencia recibida sea suficientemente alta para superar la sensibilidad de los equipos.

Se estudia la distancia de seguridad de las antenas direccionales, es decir, la distancia mínima de los elementos radiantes en la cual los campos electromagnéticos no afectan a la salud humana o animal. Esa distancia es de 6 centímetros.

Finalmente se estudia el factor de reflexión, que resulta ser de valor 4, lo suficientemente pequeño para no ser una preocupación, ya que los equipos radiantes se encuentran en las azoteas de los edificios.

NOTA: Se pueden consultar las páginas 29-6 del presente documento, donde se detallan respectivamente, las características de la ubicaciones elegidas, el diseño de la red, y los cálculos de los puntos PA en enlaces punto a punto, concretamente las figuras 10, 11, 14, 15 y 16.

6. Estudio económico

El presupuesto del proyecto comprende tanto el desarrollo de la red como su implementación. Como parte del plan de progreso del área, tanto el Ayuntamiento del municipio como el Gobierno de Castilla y León se harán cargo del mismo, permitiendo que los habitantes se dediquen a su disfrute. Cabe destacar que el importe del proyecto puede variar con las fluctuaciones del mercado.

Además del coste de la equipación utilizada en el diseño de la red antes descrito, es importante destacar que las antenas serán ubicadas deliberadamente en las azoteas de edificios municipales, con el fin abaratar en la medida de los posible el presupuesto. El coste total del material asciende a 23.840,00 €.

Para el importe de los honorarios se han estimado cuatro horas de instalación para cada punto de acceso, y seis en los dobles (Ayuntamiento y Torre de comunicaciones) además de reservar tiempo para cualquier contingencia. Teniendo en cuenta los sueldos en España por un trabajo cualificado, y los importes del ingeniero de desarrollo, el coste total de los honorarios asciende a 5.490,00 €.

El proveedor del servicio de Internet se contratará con Telefónica (Movistar) que proporcionara la conexión y también se encargará de las revisiones periódicas y el mantenimiento requerido. Este servicio tendrá un costo de 60 €/mes con un compromiso de permanencia de 12 meses.

El presupuesto definitivo de este proyecto es de 34.538,60 €.

El cálculo de la amortización ha tenido en cuenta la depreciación de los equipos en cinco años, así como el incremento de la línea del ISP, con lo que se obtiene un valor de 635,64 €.

NOTA: Se pueden consultar las páginas 37-39 del presente documento, donde se detallan los desgloses de los importes, concretamente las figuras 17, 18, 19 y 20.

7. Conclusiones

Las redes de telecomunicaciones pueden convertirse en una herramienta muy importante para promover el desarrollo de las zonas rurales. En este estudio se ha diseñado una red inalámbrica para un pueblo de estas características.

La tecnología Wi-Fi tiene muchas propiedades que la hacen apropiada para estos ambientes. Por una parte, proporciona características de gran alcance que permiten la navegación por Internet a alta velocidad de datos y comunicaciones de voz. Además, la inversión requerida para su implementación es muy baja, y cuenta con una gran flexibilidad que permite fácilmente realizar mejoras de la red una vez desplegado el diseño inicial. Al no ser necesaria ninguna licencia para operar en su rango de frecuencias, y teniendo una equipación pequeña y de instalación sencilla, la convierte en idónea para cubrir áreas rurales.

Teniendo en cuenta todos los datos que hemos recogido a través del presente estudio para Navelperal de Tormes, podemos afirmar que la implementación de una red inalámbrica en su área puede servir como trampolín para convertirse en un punto de referencia en *telemedicina* y *eSalud*, permitiendo diagnósticos remotos y teleconsulta, *eLearning*, para un acceso a recursos educativos alternativos, *administración electrónica*, mejorando eficazmente los procesos cotidianos de los ciudadanos, y *desarrollo rural*, ya que mejora las oportunidades para la comercialización de productos y servicios en mercados nacionales e internacionales.

Se ha constatado que el coste de instalación de una red inalámbrica en un entorno rural, no se considera un gasto demasiado caro para el Ayuntamiento de la ciudad, como era de esperar, ya que si bien no maneja una gran cantidad de dinero, es un costo aceptable. La red se caracteriza por su sencillez y su capacidad de ampliación, según sea necesario.

Además, el diseño propuesto servirá de guía para futuros planes en otras localidades de la zona.

10. ANEXO II – Acerca del estudio

El presente trabajo ha sido presentado en el Departamento de Ingeniería de Telecomunicaciones de la Facultad de Electrónica, en la Vilnius Gediminas Technical University (VGTU) de Lituania. Fue defendido el 28 de Febrero de 2011, con un resultado final de la evaluación de 8 (GOOD).

A continuación, se detallan la relación de intervinientes:

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Decano de la Facultad de Electrónica Prof. Dr. Habil. Roma Rinkevičienė

"When you reach the Navalperal de Tormes area, something in the landscape, land and mountains will make you into a strange and homely feel. If it is in winter and you approach the chimneys of the houses after walking the valleys and trails, you will feel transported to other times and places, where the time measurement is different and tasted slowly. If it is summer or spring, the light will make you look and feel differently, as if to breathe the air is filled with good memories and understand that there is another way to live life, although for a few days".

Navarredonda la rica
en Hoyos relamidos;
Collado picoteras;
Navacepeda majos y amigos de andar con yeguas
si son suyas las regalan,
si son de otros las revientan;
Herguijuela
cabras que andan por las barreras;
San Bartolomé
tontos tontos para lo que les tiene cuenta;
Ortigosa la golosa
que en el tiempo las cerezas se comen los pipos
y ni siquiera el rabo dejan;
Navasequilla falsos tiran coces como yeguas;
Horcajo beatos que a menudo se confiesan;
La Lastra y La Lastrilla
tienen una maña buena
no quieren trabajar después de la panza llena;
El Mosillo el tontillo;
lo más alto “La Cabrera”
y desde aquí me vuelvo para atrás a contar los que me quedan;
La Eliseda...
Angostura ojoruchos que se lamen las colmenas;
Zapardiel...
Navalperal
majos majos de toda potencia,
gastan zapato picado y sombrero a media cacheta.

Old song sung from the region