INTERNATIONAL TELECOMMUNICATIONS SOCIETY
ITS 18TH EUROPEAN REGIONAL CONFERENCE
2-4 SEPTEMBER 2007. ISTAMBUL, TURKEY

Technical and Economic Viability of WiMAX-PLC Network Roll-Out to Supply Broadband Access in Rural and Exurban Areas

Madrid, 31th July, 2007

AUTHORS:

Mr. Antolín Moral Caballero
Ph. D. Researcher
Polytechnic University of Madrid

Mr. Arturo Vergara Pardillo
Ph. D. Researcher
Polytechnic University of Madrid

Dr. José Manuel Riera Salis
Professor
Polytechnic University of Madrid

Dr. Sergio Ramos Villaverde
Assistant Professor
Polytechnic University of Madrid

Dr. Jorge Pérez Martínez
Professor
Polytechnic University of Madrid

CONTACT:

e-mail: amoral@gtic.ssr.upm.es
www site: www.gtic.ssr.upm.es
Phone and Fax: +34 91 336 73 20
Mobile: +34 605 66 52 61

ADDRESS:

Escuela Técnica Superior de Ingenieros de Telecomunicación
Office C-431
28040 Madrid
Spain

Topics: policy to reduce broadband gap, cost-effective broadband access solutions for rural and isolated areas

1. Introduction

Broadband based services have become an integral part of nowadays life; the broadband market has experienced a huge growth since the year 2000. During the period between 2000 and 2005[1] the number of broadband subscribers in the OECD countries grew from 13.3M to 156.7M[2]. Traditionally this market had been driven by DSL and cable operators, but as demand grew, both existing and new providers and operators expanded their businesses and looked for new ways to increase their potential.

The opening up of the energy market and the worldwide restructuration and deregulation of electricity production and distribution, made power utilities worldwide to show a major interest in telecommunications market, and in PLC (Power Line Communications) technology in particular. Moreover, since the 90's utilities have rolled out fiber optic networks over medium and high voltage lines in order to sell transmission capacity to new entrants in telecommunication markets. These roll-out costs would be smaller than the faced by new entrant because utilities owned occupation rights of public domain and their own ducts and other civil work elements. The PLC technology started at 2000 as a chance for utilities to diversify into the telecommunications market. During the following years PLC access experienced an important development, both from technological and commercial point of view through multiple initiatives involving PLC trials all around the world and multinational projects like the OPERA project[3]. The PLC technology put power utilities in a unique position for offering advanced communication services on top of their traditional energy offering. Utilities own a widespread optic fiber network used for their internal services, so they could roll out an access network just where they have fiber optic cable with less cost. Moreover, communication services are synergetic to the power utilities services, enabling them to leverage their infrastructure as well as their substantial customer base in creating new significant opportunities yielding significantly higher revenue percentages than the traditional energy trade.

For these reasons several numbers of pre-commercial roll-outs, about some thousands of customers, were launched focused on urban high dense populations in almost all major European countries, although always restricted to determined areas and cities. For rural environments the investment necessary to provide one PLC access outside these dense areas was not affordable due to the medium voltage costs and the lower population, representing a large barrier to develop PLC in isolated settlements [1].

"Broadband for all"

Market dynamics suggest that commercial forces will drive further deployment, although some areas of the EU will suffer delayed coverage or will be excluded altogether from broadband rollout. In fact, a study of PriceWaterhouse Coopers [2] concludes that broadband will be available to more than 95% of urban population in the EU25 by 2010 although coverage in rural areas will be much lower (achieving 75% by 2013 in the wealthier countries but no more than 35% in most of the recent accession countries). And the same study estimates the net present value of benefits to be 69% larger than costs. Under these circumstances, public intervention may be considered desirable or necessary.

---

[1] This paper presents the results of a project delivered between 2005 and 2006, so the introduction reflects different aspects relative to the beginning of the project at 2005.

[2] See OECD Broadband Statistics to June 2006 www.oecd.org/sti/ict/broadband

[3] The OPERA project (Open PLC European Research Alliance) is a R&D Project with funding from the European Commission which started at 2004 beginning and will extend until December 2008. The main objectives of the project are the development and standardization of PLC technology.

The scope for public intervention in under-developed areas was emphasized in *e*Europe 2005. In the eEurope 2005 Action Plan (IP/04/626) set 'widespread availability and use' as its broadband objective and set that Structural Funds can be used to increase broadband coverage in under-served areas if the use is based on competition rules and on the regulatory framework for electronic communications. It aims at minimizing competition distortions due to public support on the basis of a technology-neutral approach. These objectives are shared by the i2010 Initiative.

While implementing *e*Europe 2005, Member States were committed to put in place national broadband strategies. In Spain, the Ministry of Industry, Tourism and Trade launched the "National program for the roll-out of broadband in rural and remote areas" [14] in 2005. With this program co-financed by EU funds (IP/05/398), the Spanish authorities have earmarked a total of €26.4m in direct grants and €111.9m in interest-free loans for the period from 2005 to 2008. Under the program, providers of electronic communications services may submit proposals for providing broadband in specific areas where such services are currently not available. The Commission concluded that the aid was not likely to cause undue distortion of competition within the Single Market and was therefore compatible with EC Treaty state aid rules (Article 87).

The RANGIHD project

The combination of the different elements became the year 2005 into a year of opportunities for the PLC technology and the Spanish utilities. On one hand the technology was in mature state, there were a considerable number of commercial roll-outs in urban areas, and the broadband market continued in a growing process. For the other hand there was an important state aid program to roll out new networks in areas without a broadband supply. Besides, the emergent fixed wireless technology WiMAX (Worldwide Interoperability for Microwave Access) based on the IEEE 802.16-2004 standard could reduce the cost for rural roll-outs by the substitution of the medium voltage segment.

Under this context Iberdrola[4] and the Universidad Politécnica de Madrid[5] launched the RANGIHD project (New Generation Access Network and Digital Home) with the Spanish Ministry of Industry, Tourism and Commerce economic support. The project aims to integrate a WiMAX-PLC access network to supply broadband access in rural and exurban areas. This involved a technical and economic viability analysis for the proposed solution and a pre-sale roll-out which involved real customers. The final objective of the project was the extension of the broadband service to rural and exurban areas in Spain by an utility using PLC technology in combination with WiMAX with the economic support of the "National program for the roll-out of broadband in rural and remote areas"

Paper structure

This paper presents the results and conclusions of a two years project. Chapter 2 describes the network architecture of the proposed solution. Chapter 3 presents the pre-sale roll-out and the technical viability analysis carried out. In chapter 4 the business case analysis that let to this WiMAX-PLC operator to make a profit is made. Chapter 5 does emphasis in the study of the sensibility of the model to those factors that are more difficultly predictable like market forecasts, and introduce the state aid effect in the business plans. Finally, chapter 6 presents a summary and the paper conclusions.

[4] One of the biggest Spanish utility http://www.iberdrola.es/

[5] http://www.upm.es

2. Architecture description

The proposed solution aims to extend broadband access to exurban and rural areas by an utility that own a widespread optic fiber network. The last mile access network is composed of a WiMAX (IEE 802.16-2004) and PLC 2.0 combination which fits to the demographic and housing structure of the target areas. WiMAX allows a low cost connectivity with dispersed households, and the PLC technology could exploit the electricity grid that reaches almost 100% of population and the possibility of in-home distribution.

Exurban areas are primarily residential and compared to suburban areas are further from the urban center and characterized by lower household densities, moderate population dispersion and grouping of households into residential communities of single family dwellings. DSL availability is limited due to the distance between the end-user and the switching center and cable in many cases is simply too expensive.

Rural areas are small cities or towns that are located far from a metropolitan area. They are characterized by low percentage of households in apartment blocks and an important dispersion of the population among the territory. Customer densities can be fairly high in these areas but they tend to be underserved due to their remote location and population dispersion.

Overall network architecture

The network roll-out combines multiple technologies efficiently to supply broadband access to the final customers. The network architecture is composed of the following elements:

- Core transmission network (CTN): Composed by a fiber optic network and systems to manage and operate the network and the interconnection with ISPs and PSTN. The CTN reaches almost every utility's electrical substation allowing a widespread coverage over the national territory.
- Backhaul link (BL): The WiMAX base station is sited at a fiber node, usually at an electrical substation. In the case of rural or exurban communities, where sometimes there is no nearby CTN network (>5 km), a wireless point to point backhaul link is needed to extend the coverage to the specific area. The backhaul link can be a WiMAX-compliant point-to-point solution or another commercial off-the-shelf point-to-point radio in any frequency band licensed for fixed microwave applications.
- Access network: Composed by point-to-multipoint WiMAX links and a final PLC segment which architectures depend on the kind of customer. The following sections describe the WiMAX and PLC access network characteristics and the different architectures

WiMAX access network

The WiMAX access network links the fiber optic with different buildings or transformer centers to distribute the connectivity at low cost. For this purpose a set of WiMAX base stations are deployed at electrical substations to get coverage over the area with point-to-multipoint links, and a set of outdoor WiMAX CPE[6]s are distributed among different buildings or transformer centers depending on the zone's structure. These CPEs are connected with PLC head-end equipment to allow the final access network and in-building distribution.

The availability of spectrum depends on the every country regulation, but generally there are three primary frequency bands with today's prevailing regulations:

---

[6] Customer Premises Equipment

- The 5.8 GHz unlicensed band
- The 3.5 GHz licensed band
- The 2.5 GHz licensed band

For this access solution, the 3.5 GHz licensed band was selected due to its availability in many countries for fixed broadband wireless access, better propagation than the 5.8 GHz band, and the obvious advantage of providing protection against interferences from other wireless operators. In many countries this band has about 200 MHz of total available spectrum between 3.4 and 3.8 GHz, with different canalizations FDD[7] or TDD [8] [1]. In the Spanish case the regulation determines 20 MHz for upstream and 20 MHz for downstream per license FDD in the 3.5 GHz band, with 3.5MHz or 7MHz channel bandwidth [6]. The 3.5 MHz channel bandwidth was selected.

For the development of the project we consider a deployment scenario based on the deployment of a minimum set of base stations to get ubiquitous coverage at the outset and only add additional capacity as the need arises to serve a growing number of customers [5]. The added capacity can be achieved by adding more channels to the base stations up the bandwidth limits[9], or by deploying additional base stations. The capacity and range assumptions for WiMAX channels are presented in the following table.

Assumption per channel	Exurban	Rural
Range	4.7 Km	<5Km
Area	69.4 Km^2	<78.54 Km^2
Capacity	12.7 Mbps	12.7 Mbps

Table 1: Assumptions per WiMAX channel [5],[7]

PLC access network

The PLC technology is used for get broadband[10] connectivity access between the WiMAX CPE and the end customers, allowing the in-building distribution in apartment blocks and the connectivity distribution among a group of single family dwellings at residential communities.

The main electrical infrastructures reused for the PLC access network are those of the low voltage segment:

- Transformer Centers (TC): Electrical infrastructure that transform electrical power from medium voltage to low voltage. The PLC head-end equipment is sited in the low voltage segment
- Power Protection Cabinets (PPC): Interconnection point protected by fuses which represents an edge point between the utility power grid and the community electrical installation. The PPC allows the deployment of intermediate repeaters to extend the coverage and to inject or extract the signals.
- Electricity Meters Room (EMR): Infrastructure that centralizes the electricity meters of a building and the point where the in-building electrical distribution begins. A PLC repeater is needed for the signal distribution.
- Customer household: The electrical household installation becomes into an indoor access network with coverage in every room of the house, when every socket is an interconnection point with telecommunication services.

[7] Frequency Division Duplex
[8] Time Division Duplex
[9] For the project's assumptions the maximum number of channels is four in each sense (4x3.5MHz)
[10] Also known as BPL (Broadband over Power Line)

The architecture of the PLC access network depends on the customer distribution and the WiMAX links. For high buildings or apartment blocks, the WiMAX base station is sited at the roof, and the PLC head-end equipment is sited at electricity meters room. For residential communities of single family dwellings the WiMAX CPE and PLC head-end are sited at the transformer center which serves this community. An example of PLC architecture is presented in the Figure 1 to represent the different infrastructures and equipments that are needed for the deployment of a PLC access network.

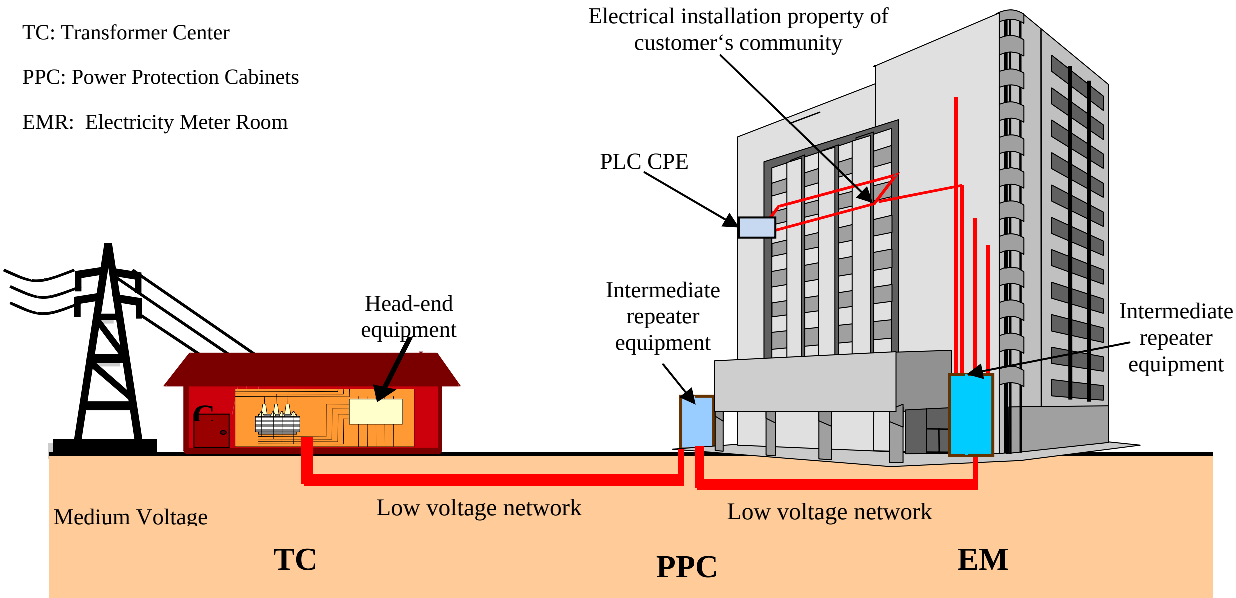

Figure 1: PLC Access network architecture [8]

Customer's equipment and access network architecture

The customer's equipment and access network architecture depends on the kind of customer. The proposed solution considers four different kinds of customer with different access networks architectures, their characteristics are summarized in Table 2.

Customer	Access network architecture
Small and medium enterprises (SME)	Use outdoor WiMAX CPE sited in the business dependencies. SME customers don't use any PLC segment or equipment.
Residential customers at apartment blocks	Use outdoor WiMAX CPE sited at the building's roof. The in-building distribution is made by a PLC segment over the low voltages lines of the building with the PLC head-end equipment sited at the electricity meter room of the building. A PLC CPE is needed for each customer.
Customers in residential communities of single family dwellings	The WiMAX link reaches the electrical transformer centers that supply electrical power to the community, where outdoor WiMAX CPEs are installed. The connectivity is distributed by a PLC segment over the low voltages lines. PLC repeaters are installed on power protection cabinets to extend the coverage and on electricity meter rooms to allow the in-door distribution. A PLC CPE is needed for each customer.
Other residential customers	Other customer not included in the last two types, generally isolated houses far from other population centers. They use an outdoor WiMAX CPE. These customers don't use any PLC segment or equipment.

Table 2: Access network architecture and equipment per kind of customer

The next figure represents the network architecture for the different customers.

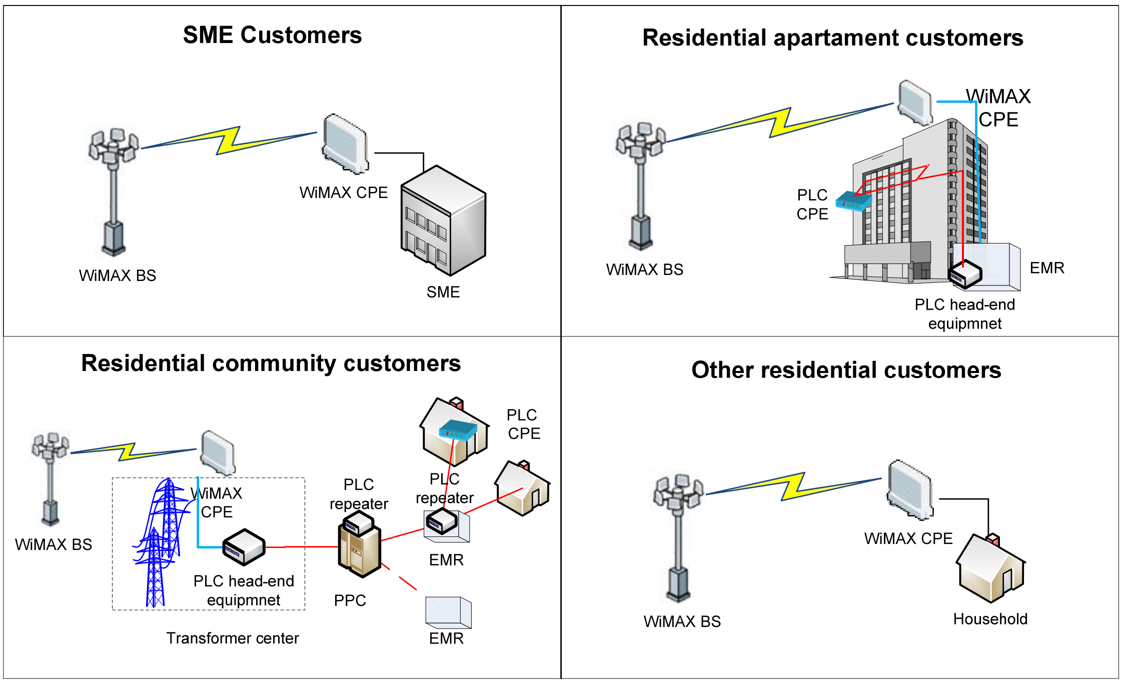

Figure 2: Access network architecture and equipment per kind of customer

3. Analysis of technical viability

This section presents the results of the technical viability of the proposed solution. This analysis is based on a pilot network rolled out into the project context in 2006 in the surroundings of the city of *Soria*. The pilot infrastructure involved a new residential community called *Las Camaretas* of about 250 chalets, a small town called *Golmayo* of about 800 inhabitants and a services platform sited in *Madrid*. The pilot had a pre-sale character with 20 customers in the *Las Camaretas* residential community and a public center for internet access in the *Golmayo* town. The following sections describe the pilot infrastructure, the services provided, and the conclusions of the technical viability.

Pre-sale roll-out

The pilot network deployment was carried out by Iberdrola and NeoSky[11]. The combination of the optical fiber transmission network of the first and the core network of the second perform the TCN functions, allowing a real service in a widespread area determined by the utility's fiber coverage. In order to test the network response to QoS[12] based services a services platform was implemented at Iberdrola's network management center in *Madrid*. This platform supplied to the customers VoIP[13] and VoD[14] services, both are described in the next section.

[11] A LMDS Spanish operator http://www.neo-sky.com/Neo-sky/neo-skyhome.htm
[12] Quality of Service
[13] Voice over IP
[14] Video on Demand

The connectivity and value-added services were extended to *Las Camaretas* residential community and to *Gomayo* town by the use of a WiMAX-PLC access network as described in chapter 2. The WiMAX segment was a point-to-multipoint wireless network which linked the WiMAX base station sited at the electrical substation near *Soria* with two WiMAX CPEs, one sited at the main transformation center of *Las Camaretas*, and the other sited at the public center in *Golmayo*. Both links had direct line of sight and were about 500 meters and 2500 meters long respectively. Each link used one different channel of 3.5 MHz (in each sense) at the 3.5GHz licensed band provided by NeoSky who has a license to operate at this band.

The services distribution at *Las Camaretas* was carried out by a two level PLC infrastructure. The main level distributed the services using a point-to-multipoint network over the medium voltage[15] among the main transformation center and other 3 transformation centers. The second level implemented a point-to-multipoint network over the low voltage grid as presented in chapter 2 for the residential communities of single family dwellings, extending the coverage over the zone, and providing telecommunications services to 20 customers. The public center in *Golmayo* didn't use any PLC infrastructure; it supplied the services to the users via a public computer room and a WiFi open network.

Provided services

During the 2006 the pilot infrastructure was providing telecommunications services to 20 customers in the *Las Camaretas* residential community and a public center in *Golmayo*, the main services were:

- A symmetric internet access service of 2 Mbps with an oversubscription 30:1
- Voice over IP service based on ITU-T H.323 recommendation, G.711 codifier and RTP and RTCP internet protocols. This service needs 110 Kbps and strong QoS requirements.
- Video on Demand service based on Windows Media Platform and MMS and RTSP protocols. This service was implemented as a web site where the content was displayed on demand. It had two different qualities, 100 and 700 kbps with different QoS requirements.

Technical viability

In order to ensure the technical viability of the proposed solution two characteristics need to be defined and ensured: the end to end capacity of the system and the end to end quality of service management.

The capacities supported by the three used technologies are very different. The optical fiber practically offers a limitless capacity. The PLC 2.0 can reach 100 Mbps up to 1000 meters in medium voltage and 200 meters in low voltage. Finally the WiMAX link reaches 12.7 Mbps for a 3.5MHz channel, and the lack of available licensed spectrum in the 3.5GHz band makes the WiMAX connection the bottleneck of the system keeping the WiMAX-PLC network from offering a real triple play service.

In order to be able to offer services with important temporary requirements like VoIP or video, it is necessary to have mechanisms that guarantee the end to end quality of service. The use of

[15] The solution presented in chapter 2 doesn't consider the medium voltage line for communications due to the high cost of the equipments. However the pilot implements this technology for other reasons that are out of the scope of this paper

different technologies with different QoS mechanisms requires their integration to be able to ensure the global QoS management mechanism.

With regard to PLC technology, it allows the definition of different class of services (CoS) [9] according to the standard IEEE 802.1p [10] in order to establish different parameters and priorities. On the other hand, the standard WiMAX 802.16-2004 offers more possibilities to implement the services differentiation which allows the QoS ensuring [11]. The common mechanism to both technologies that allows the implementation of a global QoS management mechanism is the VLANs definition as described in [10]. The pilot network implemented different CoS and showed how the end to end QoS could be managed and ensured by the WiMAX and PLC combination.

4. Analysis of the economic viability

In this section, a financial analysis of the proposed solution is carried out for a period of five years to analyze its economic viability. The results are undertaken on the basis of market forecasts (of potential clients and penetration rates). Earnings come from sale of broadband internet access. Other services like VoIP or video on demand are not taken into account but could be provided as the trial showed in chapter 3. The network model proposed in chapter 2 is used to establish how the resulting target clients are served. Finally, investment and operating costs are calculated.

Market

The target market segments are the residential market and the small and medium enterprise (SME). These SME could be segmented into two different kinds: SME-a that demand higher speed internet access and SME-b that demand lower speed.

In this paper the analysis is centered in two different demographic areas: exurban and rural areas. Demographic aspects play a key role in determining the business viability of any telecommunication network, a fact that makes it necessary to adequately characterize the different areas. In this paper it is used the areas proposed by the WiMAX Forum (WiMAX Forum 2004) but they are adapted to the characteristics of Spain.

Exurban areas are primarily residential and compared to suburban areas are further from the urban center with lower household densities. So, for the purpose of the business case, it is used a population density of 300 inhabitants per sq-km (inhab/km2) with the following distribution of households: 35% buildings and 65% houses. Finally, we consider a deployment area of 125 sq-km that represent a target population of 37500 inhabitants (~12700 households).

With regard to market penetration and the adoption rate of the services we can expect that cable and/or DSL are not universally available in this area. The reasons are that DSL is limited due to the distance between the end-user and the switching center and cable in many cases is simply too expensive. However, they are interesting zones for traditional operators for the medium-high purchasing power of population so we could expect that these operators roll-out their network in these areas. For that, in the business case we will assume a four year adoption rate [1] for this area where competition is likely to be strong and an expected market penetration of 12% of households that represents 18% of the total market [12]. However, chapter 5 includes the analysis of sensibility of the model for these two variables that are highly dependent on the competition.

Rural areas are defined as small cities or towns that are located far from a metropolitan area. The low population, their remote location and the lower market penetration that could be expected for social and cultural reasons do that this areas tend to be underserved. However, the limited competition and the existence of public politics that cover part of the investment needed could help to the economic viability of the network roll-out. For all these reasons, these areas could be good candidates to extend the network roll-out of operators like the case that it's being analyzed in this paper. For the purpose of the business case we are going to consider towns with a total population below 10000 inhabitants that could be covered with an only WiMAX base station (5 km base station radio that represents 78.45 sq-km). These towns consist of mainly houses (85% houses and 15% buildings). Moreover, we consider that we count with a direct state aid equal to 30% of total investment in this area as part of the Spanish program "National program for broadband roll-out in rural and remote areas (EBA)" [14]. And it is assumed an expected market penetration of 16% of households and a three year adoption curve due to the lack of competition and the high pent-up demand.

Table 3 summarizes all the market characteristics assumed for the two demographic areas proposed. So as to calculate the number of households, SME-a and SME-b, it is supposed that there are 2.9 inhabitants per households in addition to 12 PIME-b and 0.7 PIME-a for each 100 households[16].

		Exurban area	Rural area
Geographical Area Description		Metropolitan area but primarily residential and with lower household densities	Small rurally located city or town
Market Segment		Residential & SME	Residential & SME
Residential Density		300 inhab/km2	<125 inhab/km2
Size		125 km2	78.54 km2
Population		37500	<10000
Total Households		12500	<3390
Distribution of Households	**% building**	35%	15%
	% houses	65%	85%
Total SME-a		89	<24
Total SME-b		1530	<4115
Adoption rate		4 years	3 years
Expected Market Penetration		12%	16%
State aid		--	30% total investment

Table 3: Summary of market characteristics for the two demographic areas[17]

Service and revenue

Table 4 describes the characteristics of the broadband internet access and the prices used in the business case for the different kinds of users.

End customer	Service Description	Monthly Fee	Activation Fee
Residential	Symmetric 512 Kbps with 30:1 over subscription	39 €	39 €
SME-b	Symmetric 300 Kbps CIR[18] ,1024 Kbps PIR[19]	50 €	100 €

[16] Source: Spanish National Institute of Statistics http://www.ine.es/en/welcome_en.htm
[17] Adapted from [1] to the Spanish market and State aids
[18] CIR: *Committed Information Rate*
[19] PIR: *Peak Information Rate*

End customer	Service Description	Monthly Fee	Activation Fee
SME-a	Symmetric 600 Kbps CIR ,2048 Kbps PIR	75 €	200 €

Table 4: Characteristics of services and prices

The service and price of the broadband service for the residential market in the rural area has to carry out with the requirements established for the EBA program. In fact, the requirements that this program establishes are the followings:

- Service: 256 Kilobits per second downwards connection and 128 Kilobits per second upwards connection in the least favorable cases
- Price: a maximum monthly fee and a maximum activation fee of 39€ (in the three first years)

The fees in Table 4 are assumed to stay constant over the business case period.

In this paper, it is only taken into account the broadband internet access service but the operator could also provide voice services to residential and SME customers and other value-added services like video on demand as it is showed in the chapter 3. This new services will be very important to encourage customer loyalty and to increase the ARPU (*Average Revenue Per User).* However, as it is showed in chapter 3, television service has to be provided by means of agreements with other agents due to the lack of available spectrum to accommodate this service in the WiMAX link.

Investment and expenses

The paper analyses the economic viability of a WiMAX-PLC network roll out by an electrical company that own a widespread optic fiber network. So it is assumed that the core network exists and it only has to been paid a monthly fee for the connection to this optic fiber network and internet (see Table 6, variable Core Network Connection). This fee lets to this operator to pay network's amortization and to add the capacity needed to the additional customers that will be covered by the new WiMAX-PLC access network.

In the analysis it is assumed that a single hop point-to-point microwave link will be necessary to connect every WiMAX base station to a distant fiber node and that this link will have capacity enough to transport all the traffic of this base station. In the business case it is not taken into account the case of install a multiple hop microwave link because it is assumed that the optic fiber network is enough widespread to reach a lot of rural towns with a single hop link and because this multi-hop link would introduce too high fixed costs to make the model viable.

With regard to WiMAX base stations, they need not be installed in totality at the outset, but can be deployed over a period of time to address the new customers. However, as it is used operator-installed outdoor CPEs with directional antennas, is desirable to locate and deploy a number of base stations enough to cover the target customers and to minimize the possibility of having to insert other base stations within the same coverage area to add capacity.

The network architecture was described in chapter 4. Table 5 includes the cost of each element of the network. In addition it is assumed a progressive price reduction for the network equipment up to the 15% for the WiMAX and PLC CPEs and up to the 10% for the rest of equipment in the fifth year. Finally, it is assumed that the 20 MHz in the licensed 3.5 GHz band needed is obtained through an auction process at a cost of 0.0363 € per population.

CAPEX Item	Business Case Assumptions
Site Acquisition, Civil Works and other Equipment	€ 20k/BS Site, Civil Works and other Equipment in exurban areas € 10k/BS Site, Civil Works and other Equipment in rural areas
Channel Base Station WiMAX	€ 6 K per channel for additional channels
Wireless Point to Point Backhaul	€15 K /BS
WiMAX – PLC equipments in TC and in buildings	1000 €
PLC Repeaters in PPC	380 €
CPE PLC	288 €
CPE SME-b	350 €
CPE SME-a	400 €
Spectrum License	0.0363 € per population

Table 5: Investment for Network Infrastructure and CPE[20]

With regard to the expenses, table 4 summarizes the OPEX items that are used in the business case analysis.

OPEX Item	Business Case Assumptions	Comments
Indirect costs	15% of gross revenue	Include sales and marketing expense and offices, consumables, etc.
Equipment Maintenance	5% of CAPEX in Network Equipment 7% of CAPEX in CPEs	Reflects higher maintenance costs associated with maintaining remotely located equipment
Staff	35% of gross revenue in year 1 dropping to 10% in year 5	Customer technical support with company personnel and the rest with outsourced personnel
Base Station Site Lease Expense	€ 1500 per month per BS in exurban areas €1000 per month per BS in rural areas	
Radio Backhaul Tax	€ 1600 per year	
Core Network Connection	€ 400 per month per E1	Connection to the fiber optic core network and internet

Table 6: OPEX summary

Financial analysis

In this section, a financial summary for the two target areas is presented. In order to calculate EBITDA (Earnings Before Interests, Tax, Depreciation and Amortization), Cash Flow, NPV (Net Present Value) and IRR (Internal Rate of Return), a growth factor of 2% and a discount rate of 15% have been assumed.

Exurban areas

A market summary for the exurban areas business case is provided in Table 7. The financial details are provided in the graphs shown in Figure 3. The spectrum available to the operator is assumed to be limited to 40 MHz (2x20 MHz) and it is used 3.5 MHz channels with frequency division multiplexing. So a 4-sector base station is deployed using one channel pair per sector. The two base stations needed to meet the capacity requirements for the five years are deployed in the first year.

[20] Based on [1] and our own and project´s partner experience acquired with the trial

The IRR obtained from this business model is 17.7% so, in the market condition assumed, the network roll-out would be viable. However, in chapter 5 a study of the sensibility of the model to market conditions is done.

Year	1	2	3	4	5
Residential subscribers at Yr end	202	377	808	1212	1346
Business subscribers at Yr end	31	79	127	159	191
Total subscriber at Yr end	233	456	935	1371	1537

Table 7: Market summary for the case of exurban areas

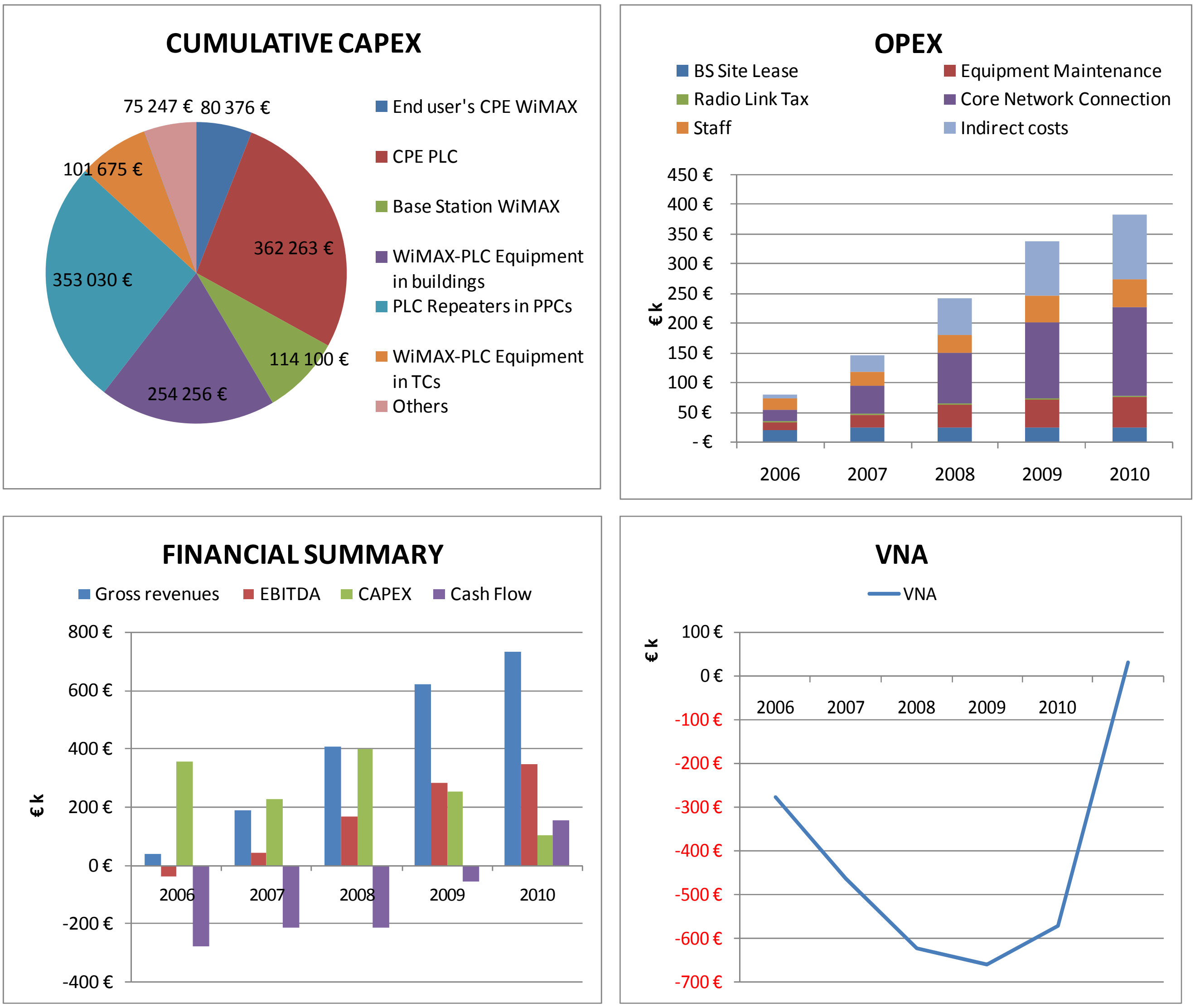

Figure 3: Financial summary for the case of exurban areas

Rural areas

A market summary for the rural areas business case is provided in Table 8. The financial details are provided in the graphs shown in Figure 4. These results are obtained for a rural town of

5000 inhabitants. A single base station with a unidirectional sector and a 3.5 MHz channel pair per sector is deployed in the first year. Then one channel is added in year 5 to increase capacity.

The IRR obtained in this case is 10.97% so, in the market condition assumed, the network roll-out would not be viable. However, in chapter 5 a study of the sensibility of the model to several conditions is done.

Year	1	2	3	4	5
Residential subscribers at Yr end	44	97	219	234	243
Business subscribers at Yr end	4	11	17	22	26
Total subscriber at Yr end	48	108	236	255	269

Table 8: Market summary for the case of rural areas

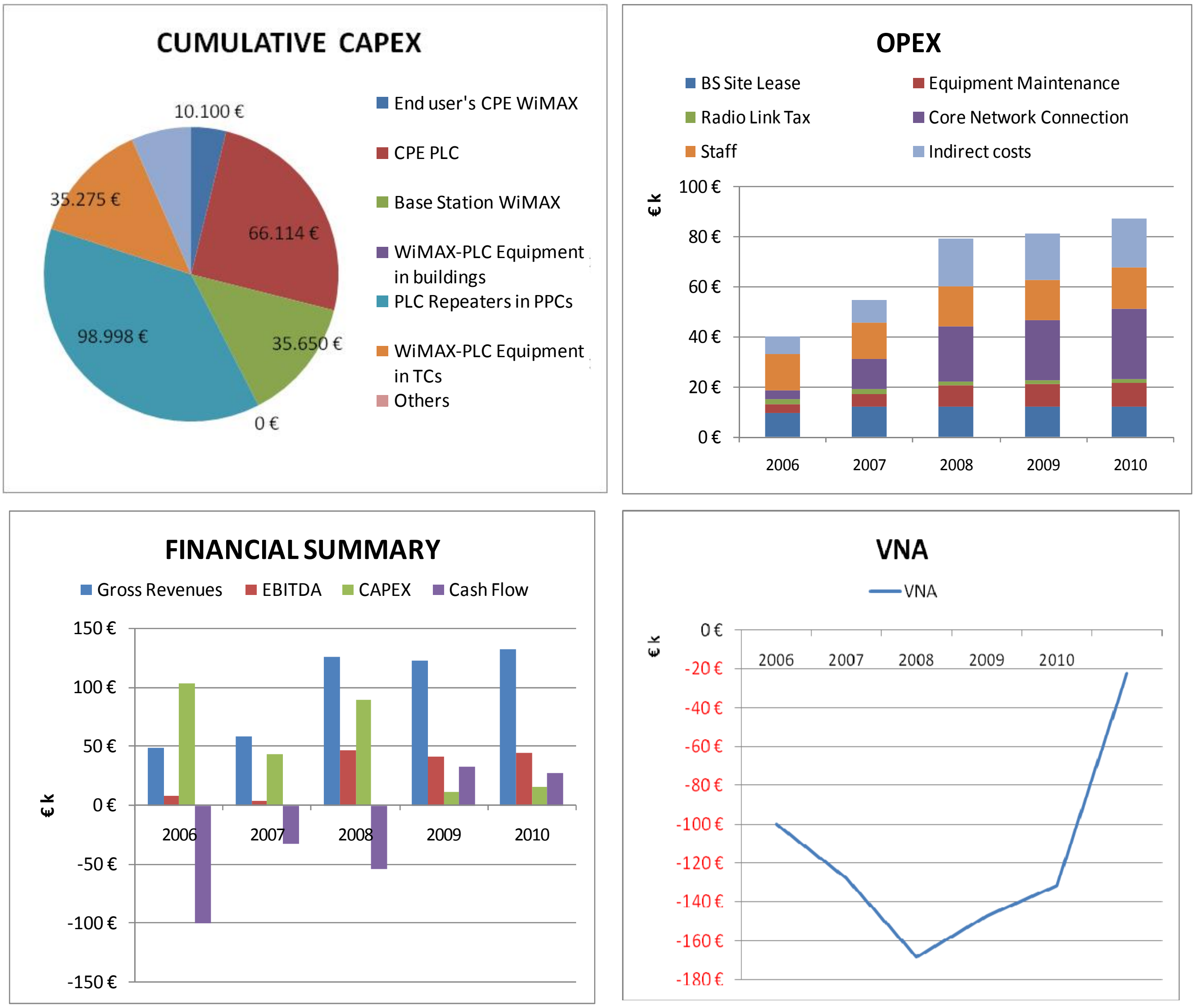

Figure 4: Financial summary for rural areas

5. Sensitivity analysis

In this chapter, a study of the sensibility of the business models to several factors is done in order to determine conditions needed to ensure the economic viability of the WiMAX-PLC solution proposed.

Exurban areas

In chapter 4 it is mentioned that cable and DSL are not universally available in these areas. However, these areas are too interesting for traditional operators due to the medium-high purchasing power of population. So it could be expected that these operators roll-out their networks in these areas and that, so as to avoid the limitations of DSL and cable, they use new access networks based on fiber optic like VDSL and DOCSIS 2.0.

The competition of these operators would affect importantly the WiMAX-PLC network business success due to their high scale economies and their "triple-play" offers. It could decrease the expected market penetration or delay the year of adoption. So it is interesting to analyze the economic viability of the solution proposed with these different situations (Table 9).

Penetration rate	Year of adoption		
	5	4	3
16%	11.89%	23.49%	35.71%
12%	6.17%	17.7%	29.18%
8%	-14.90%	5.10%	21.09%

Table 9: Analysis of sensitivity of the business case in exurban areas for different market conditions

The market conditions situated below the main diagonal represent situations that could be expected in case of strong competition of traditional DSL and cable operators. As it is shown in Table 9, in that case, the business case is no longer viable.

Moreover, Table 10 presents the results that it would be obtained if the operator could receive the state aid from the Spanish program EBA. It would happen if this operator is the first in roll out his network in an underserved area but then it appear other operators in the market.

Penetration rate	Year of adoption		
	5	4	3
16%	27.00%	35.65%	46.34%
12%	20.47%	**28.41%**	39.46%
8%	3.85%	16.47%	30.35%

Table 10: Analysis of sensitivity of the business case in exurban areas for different market conditions in case of the operator could receive the state aid from the program EBA

As Table 10 shows, the state aid helps the viability of the business case in case of competition.

Rural areas

The analysis of sensibility in rural areas is going to focus in determine conditions needed to ensure the economic viability of this WiMAX-PLC solution. For that, it is used three variables for the analysis: the total population of the rural town in which the network is deployed, the expected market penetration and the availability or not of the state aid (Table 11).

Penetration rate	State aid	Total population				
		3000	4000	5000	6000	7000
12%	Yes	-16.66%	0.11%	5.85%	10.58%	17.86%
	No	-23.72%	-7.62%	-0.63%	4.18%	10.37%
16%	Yes	-4.73%	9.37%	**10.97%**	19.13%	23.63%
	No	-12.12%	3.05%	4.97%	12.03%	17.67%
20%	Yes	7.85%	18.46%	20.92%	25.42%	29.48%
	No	1.37%	12.54%	13.97%	19.55%	23.72%

Table 11: Analysis of sensitivity of the business case in rural areas for different target population, market penetration and with and without public state aids

As Table 11 shows, the economic viability is quite sure in towns with population over 6000 inhabitants.

6. Summary and conclusions

The paper analyses the technical and economic viability of WiMAX-PLC network roll out to supply broadband access in underserved areas in Spain. This analysis is part of a project made by Iberdrola and Universidad Politécnica de Madrid.

This project started in 2005 when the availability of PLC technology, the increase of the broadband market and the Spanish broadband strategy that tried to extend broadband access everywhere in the country, made of the broadband market a great opportunity for some utilities that own a widespread optic fiber network. By that time, these companies had already carried out some trials of their PLC broadband service and the service was been offering in some urban areas.

One of the objectives of the project was to analyze the viability of combining a wireless technology like WiMAX with PLC to extend the broadband service to underserved areas in Spain. Due to these areas are primarily residential and there are a lower household densities, WiMAX could be more interesting than medium voltage PLC link to extend the connectivity with a low cost.

The technical viability was carried out by the roll-out of a pre-sale trial. The trial shows that this both technologies could be combined to offer broadband access, voice over IP and other value-added services with an end to end quality of service management. However, the lack of available spectrum in bands that can be used to NLOS[21] broadband communications keeping the WiMAX-PLC network from offering a real triple play service.

The analysis of economic viability of WiMAX-PLC network roll out is presented in this paper for exurban and rural areas. The business case in exurban areas is viable in general but it is sensitive to competition from other DSL and cable operators. In rural areas the business case is only viable when the deployment takes place in town with a population over 6000 inhabitants. As these business cases show, PLC is still an expensive technology and, despite the cost reduction that represents the WiMAX introduction instead of the medium voltage PLC link, the combination of WiMAX and low voltage PLC is not a competitive solution from an economic point of view nowadays. So it would be necessary to substitute PLC for another technology like DSL or Wi-Fi to make sure the economic viability of the roll out.

So almost three years after the beginning of the project, the situation is quite different. The PLC broadband service has not able to compete with the services of the traditional cable and DSL operators, so utilities have already started to stop their broadband service offering.

[21] Non Line Of Sight

Moreover, the coverage of the broadband service now is quite bigger mainly based on DSL so the underserved areas are smaller. Despite the viability of the solution in exurban and certain rural areas, the roll out in these areas, that was contemplated as a natural extension of their network, make no sense after that they have left the broadband market in urban areas.

Acknowledgements

The authors would like to thank Iberdrola for its leadership in the project, the Ministry of Industry, Tourism and Commerce for the economic support through the PROFIT program, Alcatel for the WiMAX technology and equipment support and NeoSky for the authorization to use its 3,5GHz licensed band.

A. Moral would like to thank the support of the Ministry of Education and Science through its FPU program and the support of the Chair on Information Society Development of Red.es at Universidad Politécnica de Madrid.

A. Vergara would like to thank the support of the Universidad Politécnica de Madrid through its FPI program and the support of the Chair on Information Society Development of Red.es at Universidad Politécnica de Madrid.

References

[1] OPERA project. D63 Report of new business model. December 2004

[2] Price Waterhouse Coopers et al, "Technical assistance in bridging the digital divide – A Cost Benefit Analysis for broadband connectivity in Europe", October 2004.

[3] WiMAX FORUM, WiMAX: Business Case Models for Fixed Broadband Wireless Access based on WiMAX Technology and the 802.16 Standard. October 2004

[4] WiMAX FORUM, WiMAX: The Business for Fixed Wireless Access in Emerging Markets. June 2005

[5] WiMAX FORUM, WiMAX Deployment Considerations for Fixed Wireless Access in the 2.5 GHz and 3.5 GHz Licensed Bands. June 2005

[6] CNAF, Cuadro Nacional de Atribución de Frecuencias, ORDEN ITC/1998/2005, de 22 de junio, BOE 28-06-2005.

[7] EURESCOM, WIBAN Project: WiMAX in Backhaul and Access Networks http://www.eurescom.de/public/projects/P1400-series/p1446/ February 2005

[8] Electric Power Research Institute: *Broadband over Power Line 2004: Technology and Prospects*. White Paper. October 2004.

[9] M.K. Lee, R. E. Newman, H. A. Latchman, S. Katar and L. Yonge, HomePlug 1.0 Powerline Communications LANs- Protocol Description and Performance Results version 5.4, International Journal of communication systems, 2000; 00: 1-6, September 2002.

[10] E. Niclas, IEEE 802.1p ,Q - QoS on the MAC level, April 1999

[11] IEEE Std 802.16™-2004, IEEE Standard for Local and metropolitan area networks: Part 16: Air Interface for Fixed Broadband Wireless Access Systems, October 2004.

[12] CMT, Annual report. 2006

[13] European Commission Press Release: *State aid: Commission endorses public funding for broadband communications in rural and remote areas of Spain*. IP/06/284. 7th April 2005.

[14] Ministerio de Industria, Turismo y Comercio: *Programa de extensión de la banda ancha en zonas rurales y aisladas*. ORDEN ITC/701/2005 (BOE 22-03-2005). March 2005.

ABOUT THE AUTHORS

Mr. Antolín Moral gained his BSc degree and his MSc degree in Telecommunication Engineering both form the Universidad Politécnica de Madrid and he is currently working on his Ph. D. His research interests are focused on the development of New Generation Network (NGN) and the new advanced telecommunications services from a technical, economic and regulatory point of view and on telecommunications policy and regulation.

Mr. Arturo Vergara gained his Telecommunications Engineering Master degree in 2006 from the Universidad Politécnica de Madrid. Since 2007 he enjoys a research grant from the Universidad Politécnica de Madrid to develop his Ph.D activities in the Research Group of Communications and Information Technologies. His research interests are focused on technological, economic and regulatory aspects of NGN development and new advanced telecommunications services.

Dr. José Manuel Riera received his MSc degree in Telecommunication Engineering in 1987, and his PhD in 1991, both from the Universidad Politécnica de Madrid. Since 1993 he has been an Assistant Professor of radio communications at this University. His research interests are in the areas of radiowave propagation and wireless communication systems. He has directed research projects in these fields with private and public funds. He is the author of more than 30 technical papers, published in international journals and conference proceedings or as book chapters.

Dr. Sergio Ramos gained his Ph.D. in Telecommunications Engineering from the Universidad Politécnica de Madrid, and he has an MBA from the Stockholm School of Economics. He worked for the European Commission as Resident Twinning Adviser of a PHARE Twinning Project for the Public Utilities Commission of Latvia, to design and monitor the transposition process of EU framework into Latvian legislation. Sergio is an expert on mobile and wireless communications, his research interests being the technological, economic, regulatory and social aspects of 3G and Beyond communications systems and mobile Internet. He is currently Deputy Coordinator of the Telecom Operators Group at the Spanish ICT Industry Association (AETIC) and Associate Professor at the Universidad Politécnica de Madrid.

Dr. Jorge Pérez gained his Ph.D. in Telecommunication Engineering from the Universidad Politécnica de Madrid, and his Master in Social and Political Science from the Universidad Complutense de Madrid. He is a professor in the Signals, Systems and Radiocommunications Department of the E.T.S.I. de Telecomunicación. Dr. Jorge Pérez leads the Research Group in Communications and Information Technologies (GTIC-SSR-UPM). His research interests are focused on new advanced telecommunications services and telecommunications policy and regulation. From 1990 to 1999, Dr. Pérez was President of the Spanish Professional Association of Telecommunications Engineers and Dean of Spanish Telecommunications Engineers. He currently holds the Chair on Information Society Development of Red.es, where he coordinates the Spanish Experts Group on Analysis and Prospective on Telecommunications. In addition, he is adviser on Industrial Policy on Telecommunications and Sector Regulation for the State Secretary of Telecommunications at the Spanish Ministry of Industry, Tourism and Commerce.