Universidade de Aveiro Departamento de Electrónica, Telecomunicações e Informática

Ano 2014

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Tese apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Doutor, realizada sob a orientação científica do Professor Doutor Manuel Oliveira Duarte, Professor Catedrático do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro e sob a co-orientação da Professora Doutora Raquel Matias-Fonseca, Professora Auxiliar do Departamento de Engenharia e Gestão Industrial da Universidade de Aveiro.

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I dedicate this work to me beloved husband, dearest, supportive, understanding friend and major critic Nuno Borges de Carvalho;

to my mother and pillar Maria Manuela Miranda e Castro who always taught me not to give up in the face of adversity;

to my children part of my being: Rebeca, Sara and Tomás so I can be a role model and an inspiration for their future life.

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"*A recompensa por um bom trabalho, é a oportunidade de fazer mais*."
"*The best reward for good work is the opportunity to do more*"

RAQUEL CASTRO MADUREIRA

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SEPTEMBER, 2013

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Esta tese de doutoramento aborda a questão do serviço universal de telecomunicações no contexto de redes de acesso de próxima geração (RNG). Este trabalho pretende contribuir para a redefinição do desígnio do serviço universal concentrando-se principalmente em estendê-lo a serviços de banda larga como um factor de desenvolvimento nacional e um caminho para atingir os objectivos da agenda digital Europeia 2020.

This doctoral thesis addresses the issue of telecommunications Universal Service under the context of next generation access networks (NGN). This work wants to contribute to the redefinition of the Universal Service scope mainly focusing in extending it to broadband services as a factor of national development and a path to accomplish the Digital European Agenda 2020.

palavras-chave

Telecomunicações, Serviço universal, Redes de acesso de nova geração, Banda larga, Regulação Telecomunicações, Modelos técnico-económicos, Portugal, FTTx, LTE, TDT

resumo

Esta tese aborda a questão do serviço universal de telecomunicações no contexto das redes de acesso de nova geração. Este trabalho pretende contribuir para a redefinição do conceito de Serviço Universal de Telecomunicações concentrando-se principalmente em estendê-lo a serviços de banda larga como factor de desenvolvimento económico e social e tendo em conta o grau de dependência que, actualmente, as sociedades modernas têm em relação aos diferentes serviços de comunicação e informação. De forma complementar pretende-se também ir ao encontro de alguns dos desafios enunciados na Agenda Europeia 2020.

Serviço Universal é aqui definido como o acesso a uma rede de telecomunicações (com obrigações em termos de tipo e qualidade de serviço para o operador), por parte de todos os cidadãos, em qualquer localização geográfica do país, a preços uniformes e acessíveis.

A perspectiva adoptada é a Estatal como mentor da equidade social, respeitador das dinâmicas de mercado liberalizado mas também conhecedor dos requisitos dos modernos serviços de telecomunicações e da sua relação com as diferentes tecnologias disponíveis. A possibilidade de subsidiação é assumida. A prestação de Serviço Universal é sujeita a concurso aberto a todos os operadores, que se assume possuírem outros negócios, que não apenas o Serviço Universal, com rentabilidade e usando tecnologias semelhantes às preconizadas para a respectiva prestação de Serviço Universal.

Embora o trabalho desenvolvido tenha componentes de análise económico-financeira, a abordagem utilizada é a de engenharia, procurando contribuir para a identificação de soluções técnicas e organizacionais que possam oferecer perspectivas sustentáveis para a disseminação e adopção das soluções redes de nova geração.

Como ponto de partida o trabalho apresenta uma visão geral sobre o estado da arte das redes de acesso, procurando identificar quais os diferenciais existentes entre essa realidade e a de possíveis cenários de rede de próxima geração com potencial de acesso para a generalidade dos cidadãos.

O caso da realidade Portuguesa será objecto de uma atenção especial, tendo em consideração as suas especificidades em termos de geografia, demografia, economia e dinâmicas do mercado.

Os principais resultados deste trabalho são os seguintes:

• Identificação de possíveis cenários para a evolução das redes actuais, nomeadamente em áreas com *deficit* de cobertura de rede.

• Identificação de possíveis modelos de operação e negócio para a materialização dos cenários acima desenvolvidos e respectiva análise económica, como tentativa de determinar os factores críticos associados à sua sustentabilidade e /ou necessidade de subsidiação.

• Contributo para o quadro regulatório das Redes de Nova Geração sob o ponto de vista dos constrangimentos das tecnologias e das especificidades do Serviço Universal.

keywords Telecommunications Universal Service, Next generation access networks, Broadband, Telecommunications Regulation, Technical and economic models, Portugal, FTTx, LTE, DTT

abstract

This thesis addresses the issue of Universal Service for telecommunications in the context of the access networks of next generation. This work aims to contribute to the redefinition of the concept of universal telecommunications service focusing primarily on extending it to broadband services as economic and social development factor and taking into account the degree of dependence that currently, modern societies have for the different communication and information services. Complementarily it also intended to meet some of the challenges set out in the European 2020 agenda.

Universal Service is defined here as access to a telecommunications network (with obligations in terms of type and quality of service for the operator), by of all citizens at any country's geographical location, with uniform and accessible price.

The approach adopted is the State as a mentor for social equity, respectful of the liberalized market dynamics but also knowledgeable of the requirements of modern telecommunications services and its relationship with the different technologies available. The possibility of subsidizing is assumed. The Universal Service´s provision is subject to open to all operators, which are assumed to possess other profitability businesses, than the Universal Service, using technologies similar to those prescribed for the respective Universal Service provision contest.

Although the work has components of economic and financial analysis, the approach is the engineering point of view, looking for help to identify technical and organizational solutions which offer prospects for the dissemination and adoption of next generation network solutions.

As a point of departure the work gives an overview on the state of the art access networks , trying to identify which of the differences between this reality and possible scenarios for next-generation network with potential access to the generality of the people .

The case of the Portuguese reality will be given special attention, taking into account their specific characteristics in terms of geography, demography, economics and market dynamics.

The main results of this work are:

• Identification of possible scenarios for the evolution of existing networks, in particular in areas with deficit coverage.

• Identification of possible operating models and business to the materialization of the above scenarios developed and its economic analysis in an attempt to determine the critical factors associated with sustainability and / or need for subsidies.

• Contribution to the regulatory framework of new generation networks from the point of view of the constraints of technology and the specifics of the Universal Service.

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Chapter 1. **INTRODUCTION**

The telecommunications sector has undergone considerable changes during the last two decades and has acquired major importance in present day forms of life. Modern telecommunications consumer´s habits have changed. These transformations are also beign reflected in the work of several international bodies, as is the case of OECD "*internet for all"* concept presented in the Seoul declaration in 2008, [1] also complementarily to the challenges set out in the European 2020 agenda, [2].

For that, this work will exploit techno-economic models, per technology, to forecast the cost implications of different types of new generation (NGN) solutions[1] that are potential candidates to support the concept extension of the Universal Service to data rates never got lower than 1Mbps. This knowledge can be used by a state to act as an equal opportunity provider to all citizens in its territory.

1.1 Thesis Objectives

The central objective of this work is to contribute towards the identification of a possible path for the provision of broadband Universal Service in Portugal.

The problems to be discussed related to the extension of the universal service obligations to broadband services to all the citizens in Portugal. With this purpose, several hypotheses were followed, based on currently available new generation network (NGN) technologies such as: Long Term Evolution - LTE, Fiber to the Home Gigabit Passive Optical Network FTTH-GPON and also a close look to Digital Video Broadcast DVB.

The viewpoint followed in the debate of these hypotheses assumes the State (Government) as the prime promoter of the broadband universal service, launching periodically (periods of twenty, twenty five years) tenders for the selection of provider(s) of universal service of electronic communications where an existing private operator will be licensed as Universal Service Provider (USP). So it is the main objective of the thesis ***to provide technical solutions to support political and regulation decisions for short/medium term Portugal 1Mbps Broadband Universal Service implementation, based on a geographical financial analysis***.

In order to achieve this, the secondary objectives are:

[1] In this thesis the following new generation networks were selected: LTE, Long Term Evolution and FTTH-GPON, Fiber to the Home Gigabit Passive Optical Network. DVB, Digital Video Broadcast was also discussed as a potential alternative way to deliver internet access.

- The choice of the technology to implement the broadband universal service, according to the different geographical and social realities in Portugal.
- The definition of technology architecture and network planning based on the identified technologic solutions.
- The quantification of the deployment cost of these technological solutions based in a theoretical business plan using real demographic and geographic data.
- The calculation of a technical economical solution of the network implementation, from a private operator point of view; in order to give directions for the state subsidization policies.
- Directions of a broadband universal service strategy to Portugal.

These objectives will consider that the main client of the universal service is the population where the liberalized market does not invest and also the population with economical needs. This strategy is based in the assumption that broadband access is a matter of economic development and social equity.

This is going to be done assuming that the players are already in the field, with competitive existing networks in several regions of the country. The financial differential between the typical network roll out and the extension of the network deployment to potential non profitable regions is going to be measured.

The research gap implicit in in this research is the adoption of an open concept but also realistic, suitable and affordable for Portugal. In this research are implicit the questions:

- "*How much does it cost the network expansion due to universal service requirements*?", also,
- "*Is affordable for Portugal as a nation to provide/ subsidize universal broadband access*?" and
- "*if so in which conditions*?" (Service definition, technology adopted and business model)

The main key words are therefore: Portugal, Universal Service and New Generation Networks.

1.2 Background and Motivation

The communications history is one of the most impactful and successful sectors, concerning the number of subscribers, economic revenue and intangible development of communities. This path has been done from a simple cientific curiosity until a recognization of its public utility as Universal Service. Figure 1 presents a general overview of some telecommunication milestones, from the invention of the telephone in 1870's by Bell and Gray (*both independently designed devices that could transmit speech electrically*), until nowadays where most of us (readers or players in the sector) are surround of broadband technology, with smart phones, cloud applications and high data throughputsFigure 1.

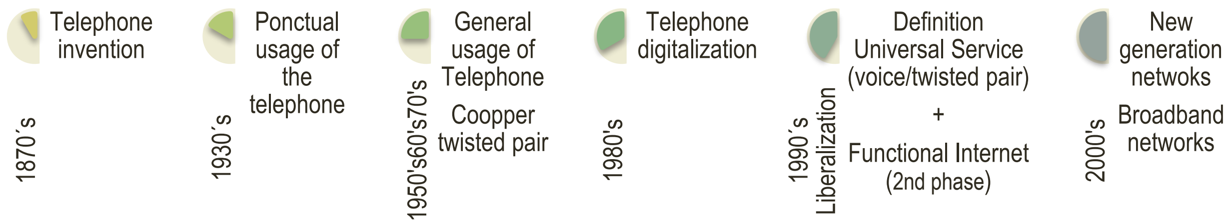


Figure 1 – (Some) communication milestones in the telecommunication sector. From the author.

The decades after the First and Second World War were a fruitful period of evolution and modernization in several countries in the world as the Unites States, along Europe and some countries in Asia. The twenty century war periods were determinant to realize the strategic importance of the telecommunications in the battle field, Figure 2. This convenience was later applied to the common life.

Figure 2 – The telephone at the First World War. Source: http://postaisportugal.canalblog.com.

The peaceful environment between the World Wars, and mainly after the Second War, along with the efforts for rapid development of economy, allowed the introduction of the technology in the ordinary life of citizens: vacuum cleaners, kitchen mixers, washing machines, dishwashers, hair dryers, calculators, portable radios, color televisions and modern telephone handsets. In Figure 3 some examples of Portuguese marketing in the end of the nineteen century and in 1930, concerning the advantages of the communications is shown. As can be seen, the telephone had to be marketed as its usefulness was not initially understood.

Figure 3 – Telephone publicity in the 1887 (in the left) and in the 1930's in Portugal. Source: restosdecoleccao.blogspot.pt , [3].

For more than a century (since 1875) the most common (and barely only) choice for telecommunications was the fixed wired telephone. During this period the technologic evolution was residual as it was an analog transmission based on a twister pair copper cable (some of that infrastructure still remains nowadays) but its penetration kept growing along the decades. Since there are official register statistics from the 60´s, the once "scientific curiosity" (the telephone) began to smoothly enter the consumer´s modern way of life in several countries of the world. In Figure 4 Portuguese statistical data is identified in the picture with a purple arrow. Other countries can be found for qualitative comparison purposes.

Along the twenty century the increasing telephone penetration changed personal and society habits, that less developed countries or countries with severe social inequality (at the bottom of the picture) try to replicate in the beginning of the twenty first century as a development role model.

Until the 90´s of the twenty century the telecommunications sector was characterized as a growing market but dependant from a stagnated technology and business case lead by an unique operator per country, the incumbent, in most cases a state owned company.

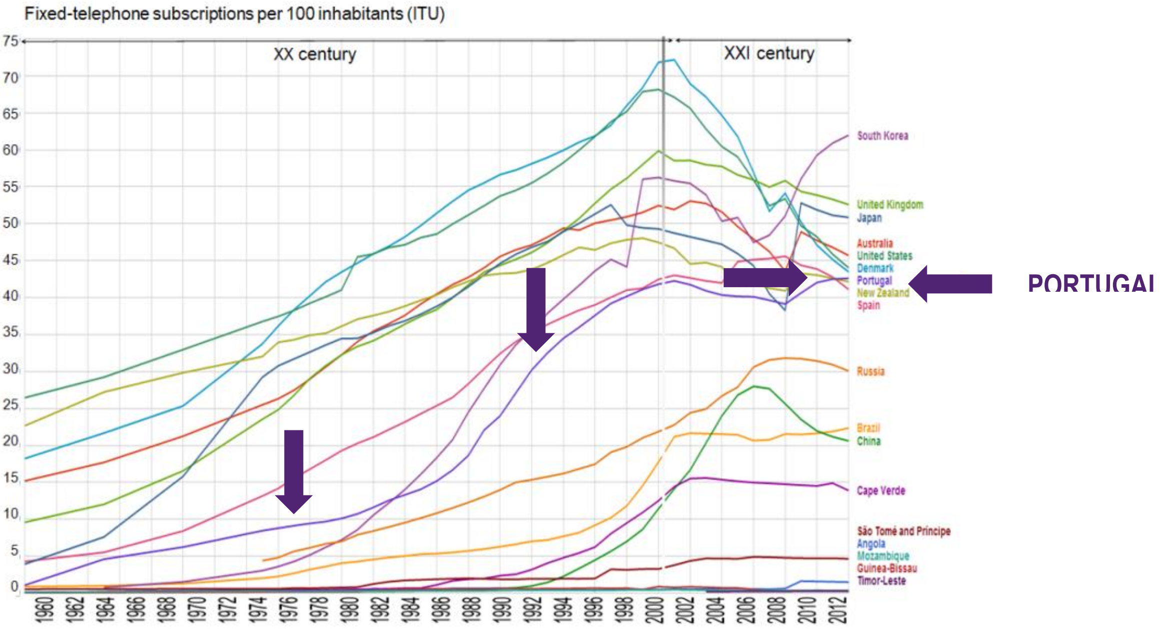


Figure 4 – Fixed telephone subscription per 100 inhabitants since 1960 in several countries of the world. Source ITU, [4].

The end of the century brought several novelties concerning technology with the digitalization and the data transfer and concerning regulation with the market liberalization. The market liberalization and the privatization of the incumbents open the opportunities to several new players to join the sector, [5]. The need for differentiation and the struggle for market share brought technological developments to the existent wireline technologies and turned to daylight the wireless communications. Moreover the opening to a competitive market at late 90's of the twenty century expanded the concept of telecommunications from fixed voice only to mobility and data transfer. The information society was born.

Different types of communications lead to new telecommunications operators and suddently the traditional public switch telephone networks (PSTN) operators started to share the leading role in the sector, where they typically used to have monopoly. The fixed-telephone subscriptions penetration (meaning voice only) stabilized or even decline (also seen in Figure 4) only recovering after 2008 with integrated plans of cable TV and unlimited fixed phone calls, based in cooper or optical fiber networks.

At the same time mobile and data communication started to raise from 2000 forward, as new operator´s start to enter the market with other technologies and services as the mobile cellular technology or fixed internet/broadband access, Figure 5-7. These phenomena's are equitably distributed around the world.

By the end of the first decade of the twenty first century, data communications, mainly driven by the usage of the internet are spread around the world and become an essential service for improving public interest, safety and social welfare. It became such a public interest utility with relevance that was assumed by law (for example in Portugal in 2008 [6]) and the Organization for Economic Co-operation and Development (OECD) create the Seoul declaration for the future of the world economy based on the internet communications [1].

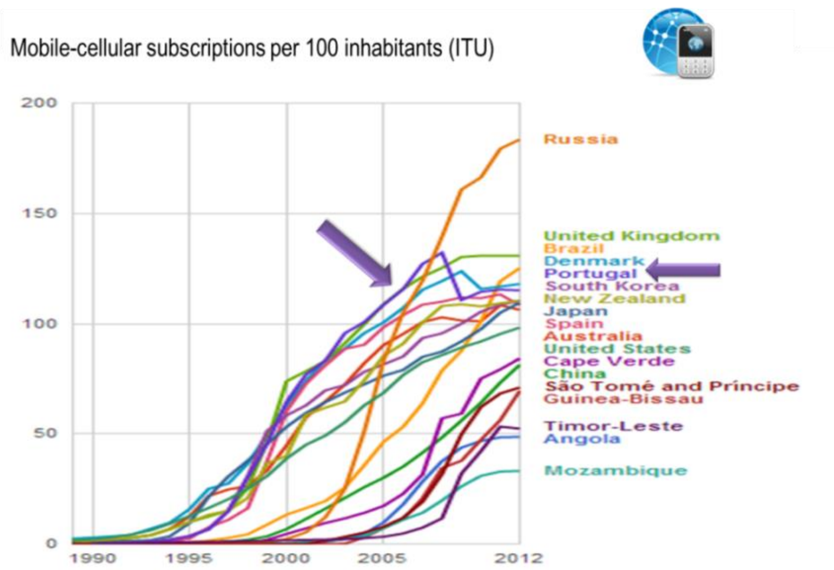


Figure 5 – Mobile-telephone subscriptions per 100 inhabitants in several countries of the world since 2000. Source: ITU, [4]

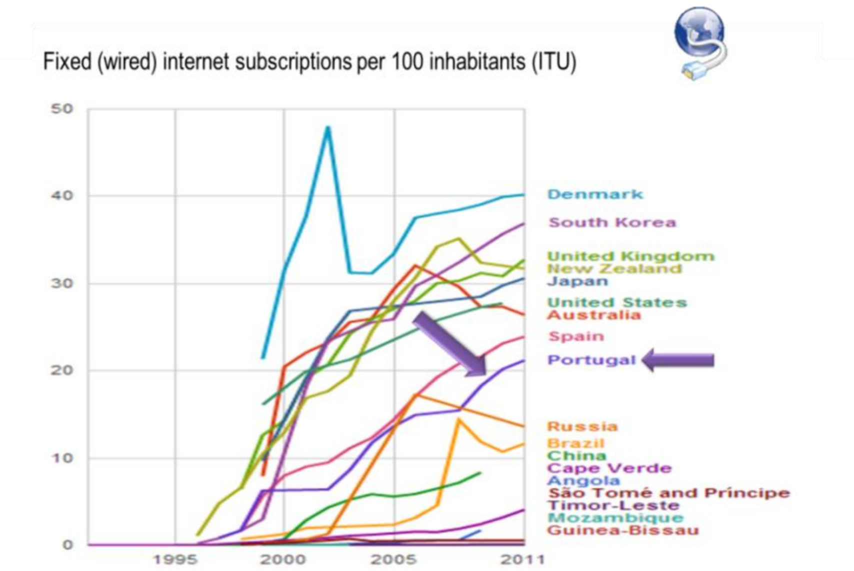


Figure 6 – Fixed wired subscriptions per 100 inhabitants in several countries of the world since 2000. Source: ITU, [4]

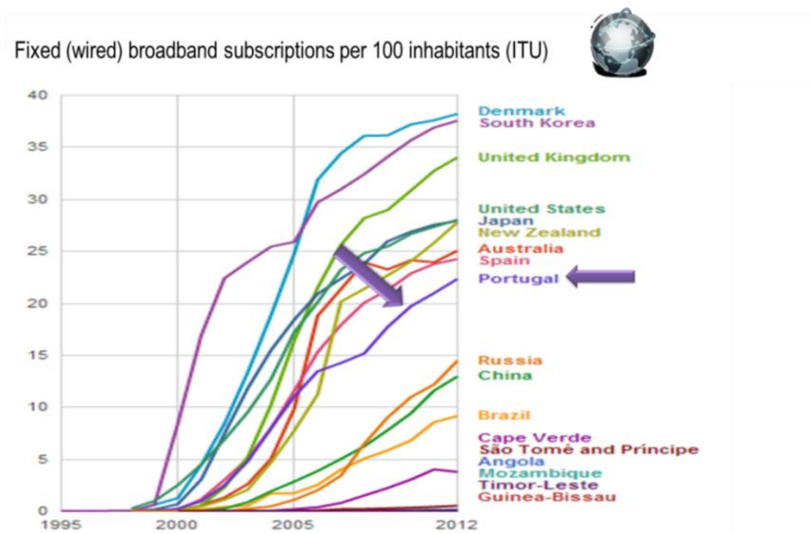


Figure 7 – Fixed broadband subscriptions per 100 inhabitants in several countries of the world since 2000. Source: ITU, [4]

Data communication and internet became such an important way of communication that the United Nations recommended the internet access as a an Human right itself and a key point in which individuals can exercise their right to freedom of opinion and expression, as guaranteed by article 19 of the "Universal Declaration of Human Rights and the International Covenant on Civil and Political Rights", [7]. The seeds of the knowledge society were launched.

At the beginning of the XXI century with the internet boom, a whole new range of applications and services flourished. These new broadband services should provide sufficient performance and wide enough penetration of services, reaching a performance level that will encourage the development of new applications and capture new subscribers. This context drove the telecommunications operator's to reinvent themselves to follow the increasing amount of data transferred due to the consumer´s increase and due to the new applications and services data needs (named broadband applications, due to the wider band needs compared with voice band allocation).

Broadband applications demand broader bandwidth and increasing speed transmissions to satisfied consumer´s impatience. A new performance stands up as throughput response became a key factor for the success of a technology. By the year 2000 the first generation of broadband systems appeared with excellent adoption response from the final users, Figure 7. Some of the most successful technologies are: new coding schemes for the wireless Global System for Mobile Communications General Packet Radio Service (GSM-GPRS), the release 99 of the third mobile generation Universal Mobile Telecommunications System (UMTS- R99), [8], new families of wireline Digital Subscriber Line (xDSL) technologies and the first specifications of Data Over Cable Service Interface Specification (DOCSIS), [9]. This topic will be described in detail in Chapter 3.

For the first time, the general subscriber is aware of the type of technology beyond its communications network and it is not rare to see non-technical people discussing for e.g. about advantages or disadvantages of a certain wireline connections versus a wireless one in a particularly location. The technology is now widely spread and incorporated as part of everyday common citizen and vocabulary.

New systems, new solutions and new infra-structures appeared in order to respond to the new costumers' bandwidth and throughput needs. As an answer to growing public demand, the telecommunications market is still providing newly developed alternative broadband systems. The New Generation Networks (NGN) wireless and wireline emerged from this context. The NGN access network can be defined as the part of a telecommunications network which connects subscribers to their immediate service provider, usually referred as the "*last mile*" (not in the literary sense, but indicating the network segment closest to the customer – the access network).

The access network should reach each one of the subscriber's using its own telecommunications subsystem and due to that is sensitive to investment (capital expenditures, CAPEX and operational expenditures, OPEX) and to the average return per user (ARPU). The more throughput´s demanding the higher deployment cost is expected.

The NGN's do not appear in a sterile environment; they are part of a natural evolution and will co-exist with the existing networks. Some of them will still be active for several years and that means that the most reuse or co-location with existent networks implies more profitable new networks. It is also an auspicious time for the introduction of new planning practices for network and telecommunications services, so planning decisions took in the past will not be repeated and infra-structures won´t be duplicate or even triplicate in the same geographical area. Each one of the existing networks have their own limitations but also some good advantages and is quite relevant to understand them, so that hybrid systems can be built complementing the NGN roll out, mainly in non-profitable geographic areas. The impact of the business plan of a network deployment will be developed in 4.8.

In summary, the natural evolution leads to a far new level of communications where (potential) expensive new generation architectures and systems are needed. Due to this context, the new generation networks have become part of new economic plans for many operators and governments as a path to economic growth and society welfare. At this point, it is relevant to analyze the geographic reach of existent successful technologies and infra-structures.

Each operator´s roll out depend on their own license targets based on their own deployment plans, based on successful business plans where the investment is done in places where the return is warranted in medium and/or short term. It is exactly at this point that the wishes of global and ubiquitous network society access might not be assured to be transpose into the reality. Despite special NGN plans for rural zones (in Europe [1] an in Portugal [2]) there are no absolute guarantees that 100% of citizens will have access to broadband networks.

This scenario may lead to the increase of the digital gap among regions and citizens, e.g. those residing in rural and remote areas as well as citizens with economic constraints will be unable to benefit from online education, e-health and e-government services. This gap is significantly bigger between developed and non-developed countries, but it is also a common reality inside developing countries, [10]. Previewing this potential asymmetry, some countries implemented in the last years national broadband plans, financing part of the operator´s investments. As it can be seen from ITU data and Figure 8, some developing countries apply a complementary way to counter balance the broadband expansion with the inclusion of broadband communications in the Universal Service definition.

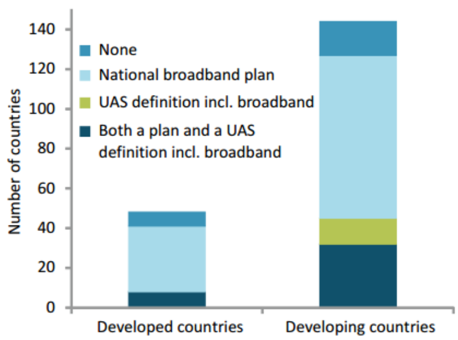


Figure 8 - National policy instruments in place to promote broadband, 2011. Source :ITU, [10]

Beside the NGN plans for deployment geographic penetration a problem remains associated to the digital gap issue. From the subscriber point of view it is necessary that the network exists in the places where he/she lives or works, but is also important to guarantee that the access has an affordable price for the average citizen. The geographical expansion of the networks comparing broadband prices in countries around the world, published by the International Telecommunication Union (ITU), highlighted that there are 17 countries with prices equal to 100% or more of average monthly income, while 25 countries have a price equal to 1% or less of average monthly income, [10].

The next graph intends to compare the average prices inside Portugal with the average income, which when compared with the other European Union countries is one of the highest, representing from 3.3% to 5.5% of the average local income (color lines, left axis), Figure 9. The percentage of households with at least one person aged between 16 and 74 years old and with broadband connection to Internet at home is also added in the vertical right axis. The average broadband price is constant in all country. As expected in the Lisboa region, where the average income is bigger and the broadband cost have less impact in the monthly income, the percentage of subscriber is bigger than the rest of the country. On the other side areas where the average income is lower the broadband penetration is directly proportional.

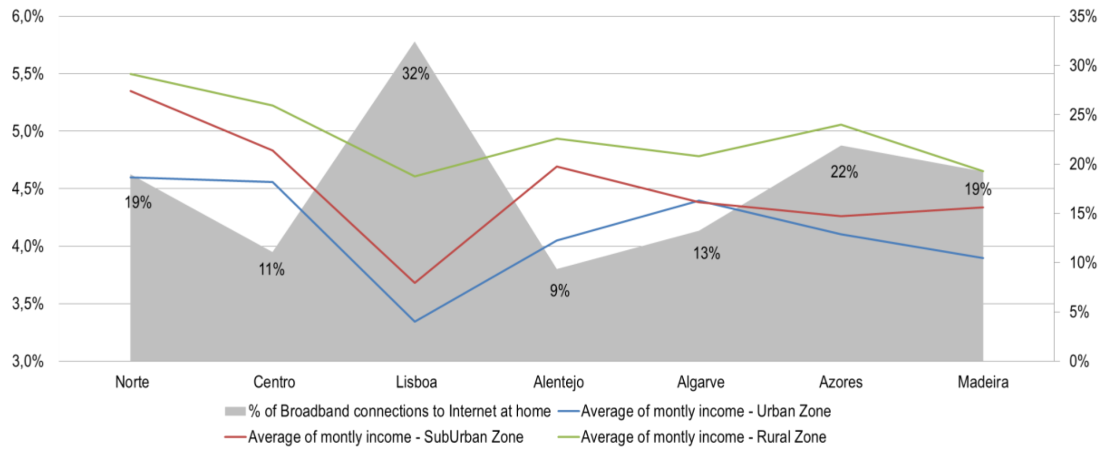


Figure 9 – Broadband average price compared with average income in urban suburban and rural areas in Portugal. Source: ANACOM[2] and INE[3] adapted by the author.

As a summary, at this point it is relevant to retain the impact that communications have in the modern societies life's and how the regulation changes of the late twenty century were determinant for new player´s to enter the sector leading to the technological and services diversification.

In parallel to this history of success some geographical regions without any economic attractiveness are apart from this development. In some cases governments adopted national broadband plans in another they adopt an update version of the universal service instrument.

That was not the case in Portugal until the moment.

The new technologic developments and their social impact propose the revision of the traditional telecommunications Universal Service concept, usually associated with the fixed voice communications and defined as the communication service access availability for all citizens in any geographically region in the country at affordable prices. The Universal Service in the context of the NGN´s acts as the counterpoint of a vicious business model cycle towards a successful end, Figure 10.

Figure 10 schematically represents the liberalization model adopted in the telecommunication sector in the late 1990's. This opportunity led to the appearance of a relevant number of new operators in most countries of the world in several areas as fixed wired communications, mobile communication, internet providers and broadband services providers. This boom of available services brought the concept "always connected" to daily life which itself led to a new generation of consumers much more aware of the quality of the service. Mean time between failures, drop calls, data throughput and service availability are constantly motorized by thousands of alert customers.

All these dynamics promote the economic virtuous business cycle leading to enhancing investments in existing infrastructure and promote densification in new geographical regions, leading to new subscribers and feeding the loop in a positive feedback.

[2] http://www.anacom.pt/render.jsp?categoryId=345174, Access September 2013 (in Portuguese)
[3] http://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0002509&contexto=bd&selTab=tab2&xlang=en, Access September 2013

Despite this reality that has been observed for this last two decades, another reality emerged in parallel. The continuous demand in more sophisticated networks involve each time bigger investments unbearable to support in case of investments without short term guaranties of return. Without any legal instrument to regulate the areas to invest, the market naturally led to exclusion country zones with low income, geographically apart from urban centers as rural or insular areas. This side of the same virtuous reality is the vicious business cycle.

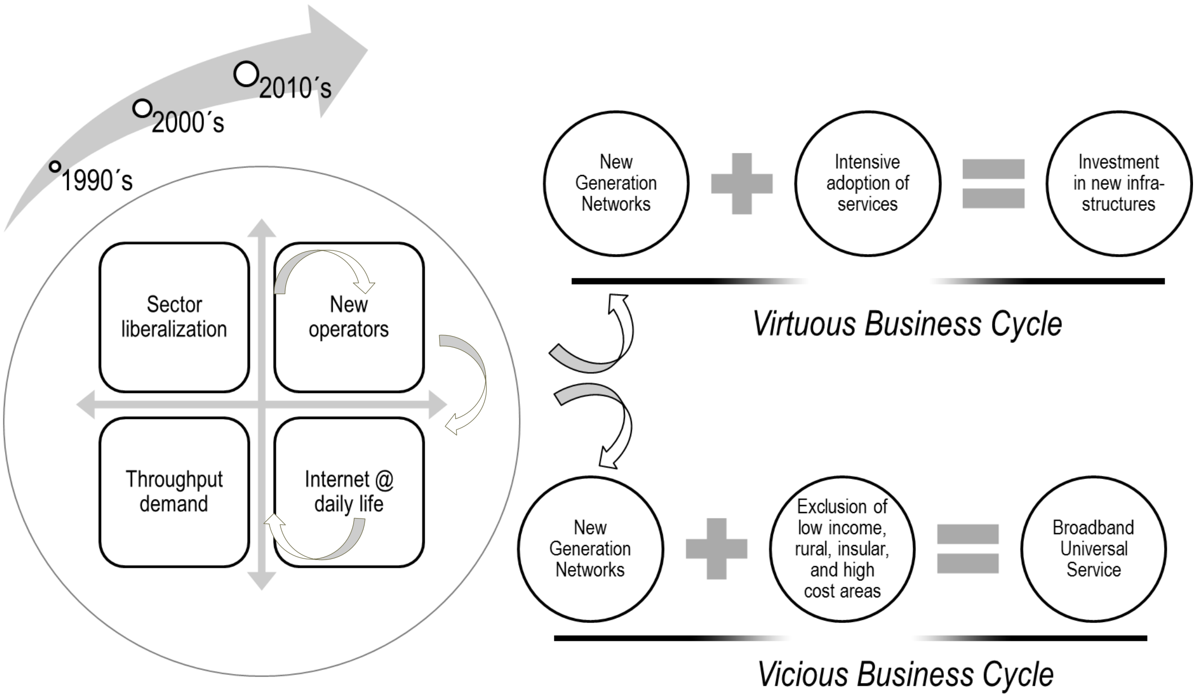


Figure 10 – Virtuous and Vicious business cycle.-The path for Broadband Universal Service. Adapted by the author from [11]

The Universal Service concept seemed outdated during the 1990's by the time of liberalization of the telecommunications sector which provided the appearance of new networks which apparently provided global coverage. (*As an example, mobile communications connections in Portugal had risen from 81 to 158.4 connections per 100 inhabitants by 2002/ 2013,[12] with coverage reaching more than 90 percent of the territory and a 92.1 percent of residents customers of the mobile telephone services*.).

The adaptation of the Universal Service concept to the current environment can lead to the restoration of the virtuous business cycle towards an equality access to new ways of communications and therefore to global and equitable country development.

1.3 Defining Broadband

The new generation networks enable the broadband communications, which means wider bandwidth usage than the previous communication networks. Bandwidth refers to the throughput capacity of a given communications network. Historically the term bandwidth was used by radio communication engineers to refer to the amount of radio communications spectrum available or necessary for carrying an (often analog) signal, for example a telephone call uses four KHz of bandwidth while a television signal uses eight KHz.

In relation to digital transmission of data, the amount of bandwidth between the sender and the recipient determines how much data can be transmitted per unit of time. It's measured in bits per second (bps) or Kbps, Mbps, Gbps, etc. Broadband is a transmission capacity to high-speed Internet access that is always on and faster than the traditional dial-up access and its ability to transport multiple signals and traffic types simultaneously.

All of a sudden the available band is not broad enough. And as it can be illustrated by the well-known FTTH Council figure above, [13] the usage trends are both symmetrical and asymmetrical links and exponential increase of capacity needs, Figure 11.

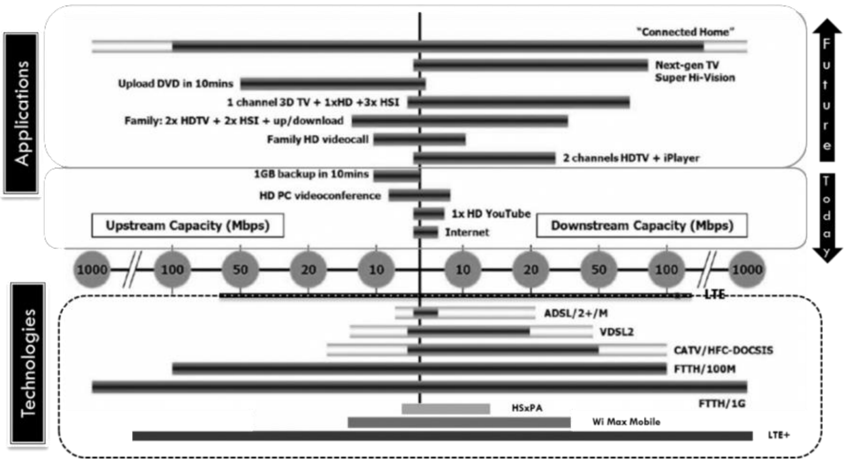


Figure 11 - Bandwidth needs for today and forthcoming future applications. Source: FTTH Council.

This subject became so relevant and intrinsic in the modern way of life, that even Politian turn their attention to a subject traditionally reserved to technicians and engineers. In November 2008, the European Parliament states: "*that equipping Europe with high-speed internet connections is as important as building the railways in the nineteenth century*", and declares it the key of modern development [14]. The global average connection speed continued to grow in the first quarter of 2013, increasing 4.0% to 3.1 Mbps, [15].

Broadband and high-speed are not objective concepts and are used freely according to circumstances. Typically systems with the throughput above 1Mbps are considered broadband networks. It is this value that was adopted by Finland, Spain and Korea as the broadband Universal Service, Section 2.2. France aimed internet access with at least 512 Kbps to every citizen by 2012; the United Kingdom plans access with 2 Mbps by 2012 and Canada with 5 Mb/s by 2015. In Germany, some parties purpose internet access with 16 Mb/s by January 2012 and 50 Mb/s by January 2016.

The European Commission has proposed extending broadband access to the entire EU by 2013 and providing the whole region with access to speeds of at least 30Mbps by 2020. The targets form part of its 'Digital Agenda for Europe', DAE, [16].

The next figure presents the progress 2009-2012 of all the EC members concerning the execution of the DAE plan considering the internet speed, percentage of households, increase in public spending and some e-government indicators, Figure 12. It is a very optimist graph to improve confidence in all state members to pursuit the path of broadband for all (target 95, 5% of population with broadband coverage for all with date rates higher than 30Mbps).

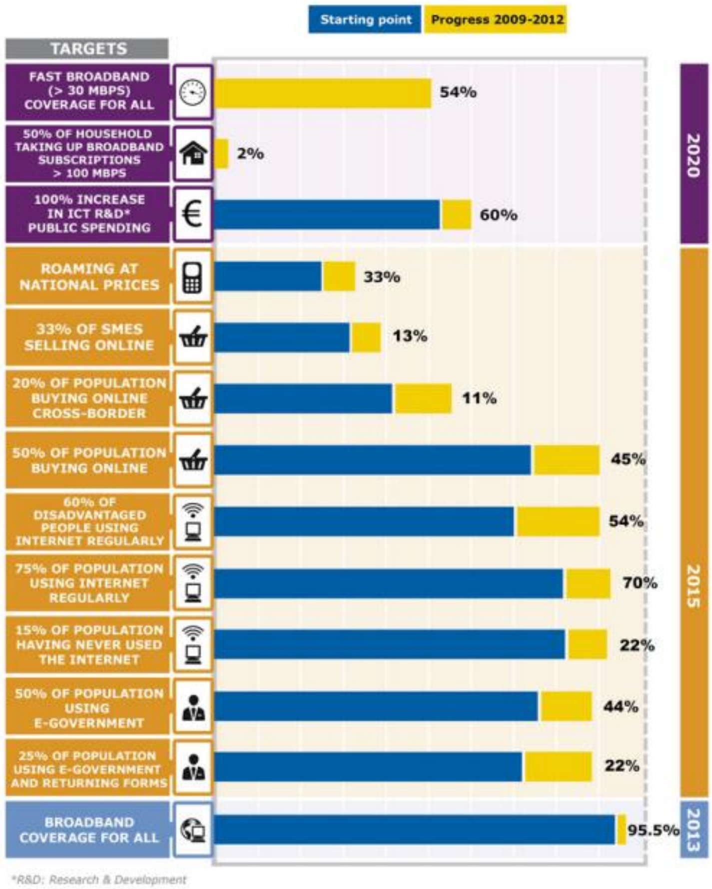


Figure 12 - Digital Agenda Scoreboard assesses progress. Source: European Commission, [16].

The next section will mention the first data transfer networks, their evolution to the present broadband networks and the technological trends to the new generation broadband networks towards the DAE targets and the IMT-2000 specifications, [17].

1.4 Context: Why Portugal?

Portugal is an European Community country in south-western Europe. In addition to its continental territory (892.000 km^2) the country includes also two archipelagos in Atlantic North: Madeira and Azores [18] and an Ocean platform of 200 miles from continental shelf[4]. Its current population is around 10.5million citizens who are mostly concentrated near the coast with special predominance between the two major cities: metropolitan area of Lisbon, in the center of the country and metropolitan area of Porto in the north. Along this location the population density is relatively balanced but in the interior and south of the country the population is sparse and concentrated in smaller villages, Figure 13.

[4] The Portuguese outer limits are under revision for extend by the United Nations Oceans´ law of sea, 19. (CPLP), C.d.L.d.P.C. and G.d. Portugal, *Continental Shelf Submition of Portugal* 2009..

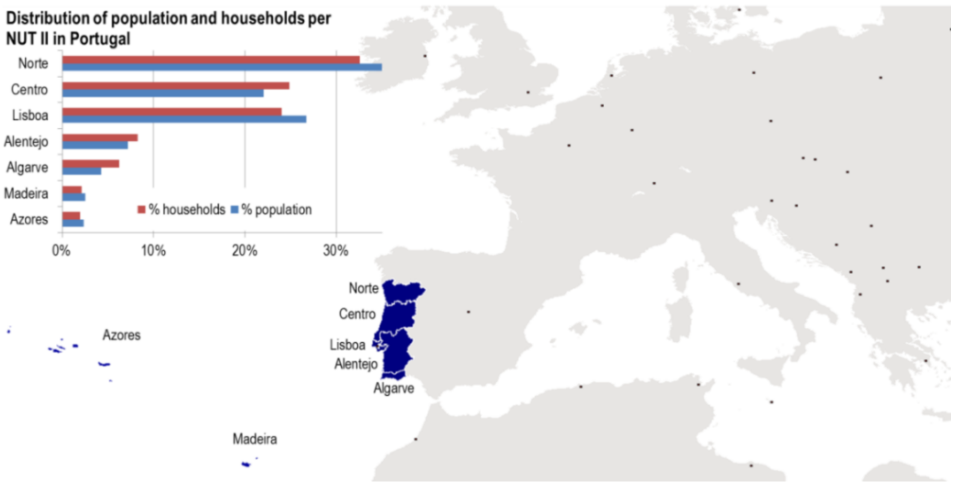


Figure 13 – Portugal in Europe and the Portuguese distribution of population and households by NUTS II regions

Since the 15th century with the discovering of the new world, (America) and the conquest of the seas, the Portuguese are known by their technological developments mainly in navy instruments and efforts for world globalization. From the early communication systems towards today´s massive technology use, life´s quality has been improved and the continuously progression of the country´s Gross Domestic Product (GDP) can be correlated with the telecommunications technical developments and customer´s growth as illustrate in Figure 14.

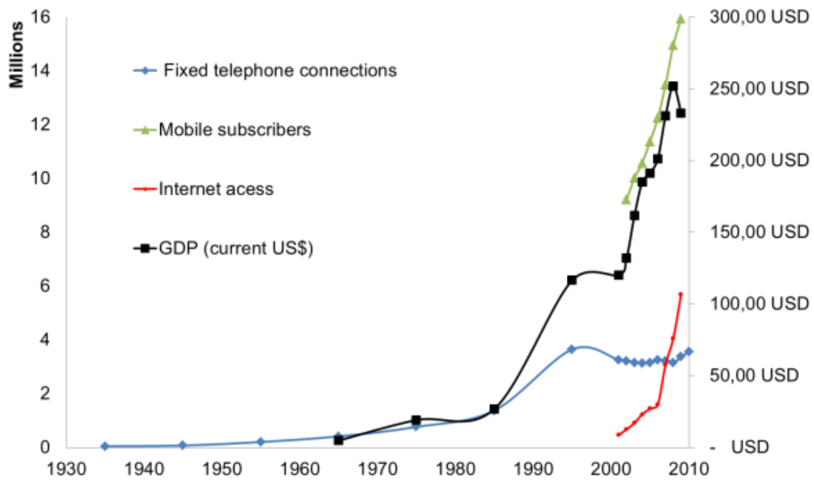


Figure 14 –Portuguese communication´s customer growth vs. GDP(USD),data processed by authors based on [20, 21].

To understand the Portuguese consumer's behavior and the telecommunication sector, Chapter 3 describes the current Portuguese telecommunication market and ends with the current framework and scope of Universal Service of telecommunications. Even though it is a small country concerning territorial platform and inhabitants, it has a very dynamic telecommunication sector regarding number of operator´s, technology diversity and consumer penetration in some areas.

Portuguese consumers are well known for their open disposition to new technologies and to new means of communications. In a 10.5 million inhabitants market, there are thirty-three telecommunication service providers, and some of them use more than one access technology. Also, according to the telecommunications regulator, ANACOM, fixed telephony subscribers penetration in terms of residential direct access customers was reported at 56.2 per 100 conventional dwellings, [22]. and mobile subscribers are around 16 051 044 (151.4 percent of total population), [12]. Portugal is in the top five of UE27 countries with highest mobile penetration per 100 inhabitants.

All providers of fixed access Internet offer broadband access. Among these, eighteen companies use ADSL, while modem cable is used by seven and optical fiber by ten. There are seventeen companies providing the service through other means (e.g. leased lines). Moreover, four of the providers of mobile telephone service, also provide 3rd and 4th generation mobile broadband Internet access. New markets in high density areas are now being captured due to the new triple/tetra play offers: the triple play includes low prices for voice fixed telephony, high-speed Internet and high definition TV/Video on demand by fiber. At the end of the quarter of 2013, there were around 2.4 million fixed Internet accesses in Portugal (more 1.4 percent compared to the 4th quarter of 2012) with an year-on-year, growth reported at 6.1 percent, [23].

According to national statistical in 2011, 98% of Portuguese households with internet access have broadband connection, [24] and the total new generation access broadband coverage in percentage of households is quite impressive when compared with other countries. The coverage indicator is defined as the percentage of households living in areas served by NGN and includes the following technologies: fiber to the home, FTTH, fibber to the building, FTTB, cable DOCSIS 3.0, VDSL and other superfast broadband, at least 30 Mbps download, [25]. Internet access based on wireless technologies is done only by 9% of the subscribers, [24].

All these data reveals the attractiveness of the internet consumers for the new broadband systems as well the country´s efforts to fulfill the path for the European Agenda 2020, [16] for fast broadband (>30Mbps) coverage for all, Figure 15.

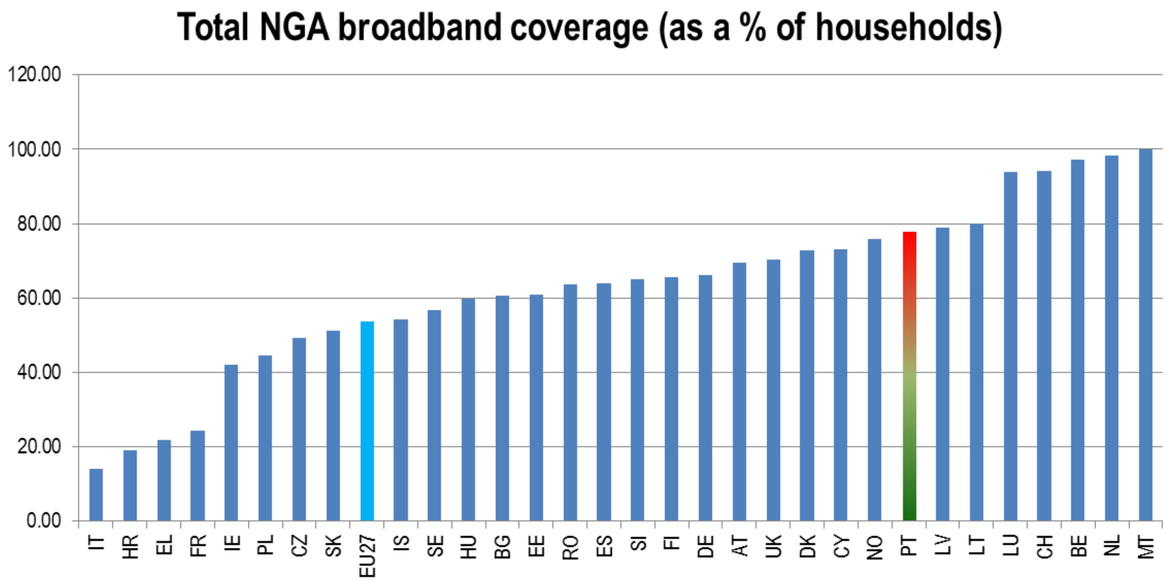
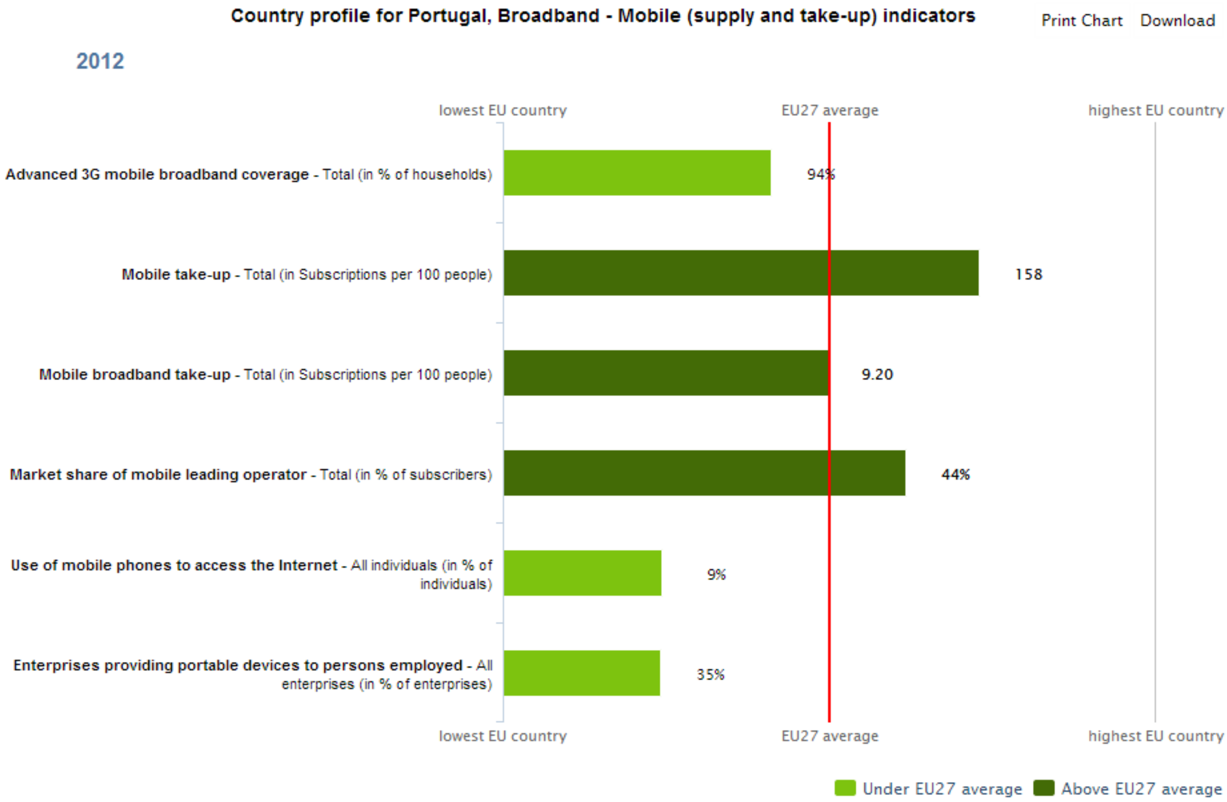


Figure 15 - Total new generation access wireline broadband coverage in percent of households in Europe. Source: Europe Digital Agenda, [25].

Despite this encouraging scenario, Portugal is still in a modest place compared to its counterparts in Europe, [26] and the world, [27] when the subject is the usage and subscriptions of that same technologies, Figure 16 and Figure 17.

PORTUGAL COUNTRY PROFILE (2012)



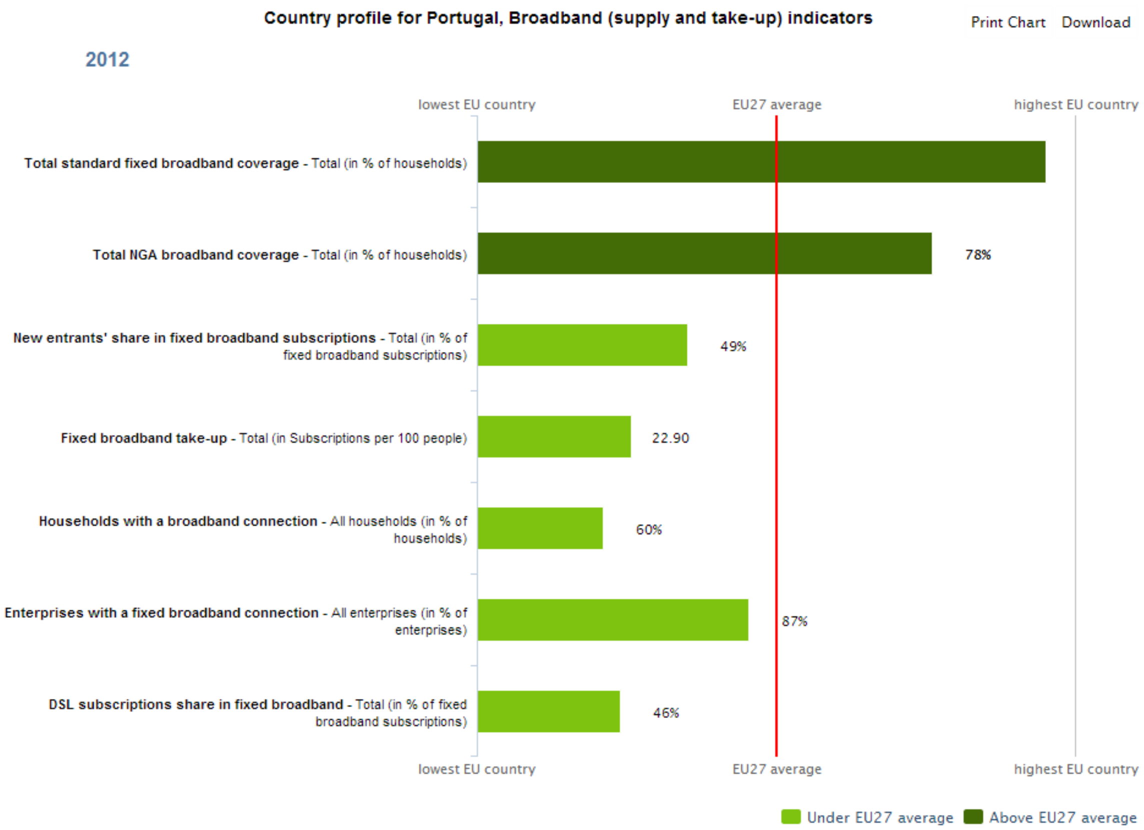


Figure 16 – Country profile for Portugal broadband supply and take-up indicator for mobile (above) and wireline (at the bottom. Source: Digital European Agenda, [26].

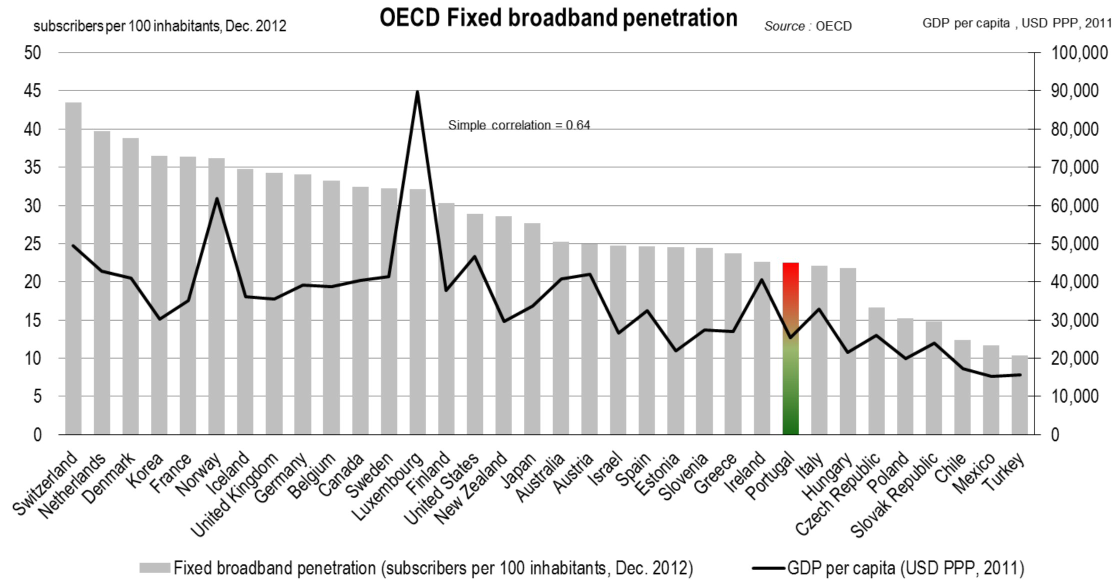


Figure 17 - OECD fixed (wired) broadband penetration and GDP per capita. Source OECD, [27].

The interpretation of these data leads to the conclusion that Portugal is an interesting choice for the analysis of the future of the penetration of the "internet of the future" due to:

- It is representative of the group of countries with lower GDP but with relevant fixed broadband penetration;
- Part of the society has big attractiveness and adoption for new systems and services;
- Part of society might lead to a widening digital literacy gap if measures are not taken;
- A self-regulated market might lead to broadband deployment only at geographical zones with guarantee of return, which might lead to a country at two speeds;
- The efforts to expand the broadband deployment to low income zones can lead to a price discrepancy among users depending on their location.

In this context, the update of the Universal Service to broadband would function as an instrument of agglomeration of the nation according to the spirit of the original concept of the Universal Service at the 20th century. The route towards this goal should be done depending on the socio economics characteristics of each country. In this work that reflection is done for Portugal.

1.5 Document Overview

As referred above this doctoral thesis aims to present economic feasible technological scenarios for telecommunications networks architectures of the emerging broadband networks, in the context of the Telecommunication Universal Service, in the particular case of Portugal. This type of work involves a multidisciplinary overview among several issues such as the telecommunications engineering, finance, regulatory issues and social behavior This work is divided in 7 chapters and subsequent sections to complement the main goals, Figure 18.

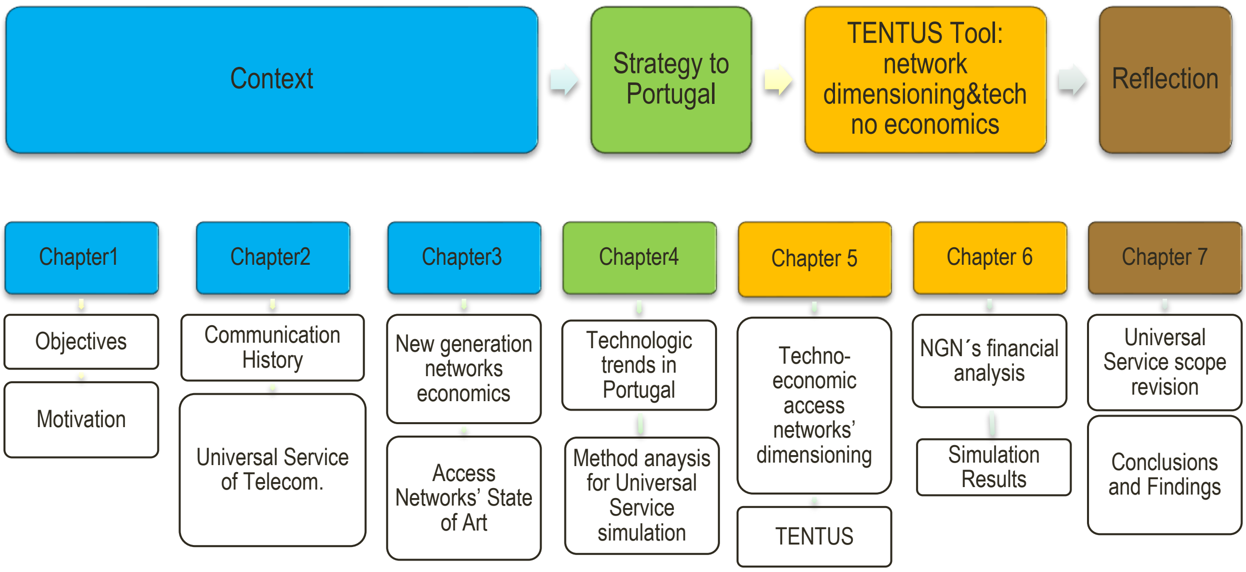


Figure 18 – Thesis methodology overview and chapter organization.

In detail:

Chapter 1 : The introduction chapter aims to give a full perspective of the global motivation and context of this work as well as the document organization. It also summarizes the main contributions achieved in the thesis.

Chapter 2 : Chapter two is intended to make a historical review and to consider what could be the function of technological development in relation to the extension of the scope of Universal Service around several regions of the world.

Chapter 3 : In this chapter the identification of technical solutions and technology trends to NGN will be presented. The current access networks will be analyzed in detail, in order to find the underlying factors, technical, financial or social, to support its success before this evolutionary path for some and disruptive to others. Further, the chapter aim is to identify their architecture and roll out details to foreseen their deployment constrains and complementarily with the existing networks in a Universal service scenario.

Chapter 4 : This chapter is focused in examining Portuguese current status of the telecommunications´ sector as well the Universal Service´s historical development. It will start with an analysis of some country´s indicators in order to define a characterization method to identify socio-demographic common areas. It is followed by an historical overview of the telecommunications sector and a description of the existing and widely used telecommunications technologies in Portugal This chapter intent to position the reader in the present context of Portugal to understand the challenges for implementation of broadband Universal Service and define a strategy to be followed in geographic regions that are potential described as non-profitable regions.

Chapter 5 : A simulation tool was designed by the author for design planning and financial-economic analysis of different NGN scenarios. This tool (the Techno-Economic access Networks' dimensioning Tool for Universal Service, TENTUS) was developed in order to achieve an answer to an financial feasible scenario for broadband for all. This study is being followed by a line of research with an analytical approach, making a comprehensive survey of existing quantitative tools [60] of technical and financial analysis applied to telecommunications.

Chapter 6 : This chapter presents the results of the TENTUS tool per technology. The equipment and management investments per year are compared to the income during the twenty five year project studied. The cashflow is compared with and without Universal Service obligations.

Chapter 7 : In this chapter based on the previous analysis and results, the future of the Universal Service Portugal is debated.

The last pages of the document are reserved to the publications and deliveries of this work as well as the lists of references, acronyms, equations, figures and tables.

Due to the multi-disciplinary aspect of this work, combined to the study of a concrete reality, several statistical have to be combined to adapt the impact of that data to the focus of the study. These factors lead to a big number of references (224 references) that were deliberately enumerated at the end of the document. The regulation aspects implied the description of several laws and recommendation, both national and European – 34% of the references; the description of the state of the art implied to list in detail several standards and equipment suppliers – 21% of the references; and the statistical analysis involved the consultation of several sources that are around 15%. The list of authors represents 30% (67) of the global value, Figure 19.

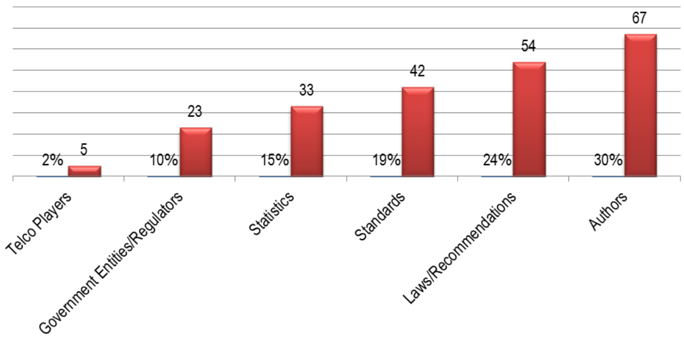


Figure 19 – Reference analysis per type of data.

1.6 Contributions

The main contributions of this work are the answers to the following questions (problems). These questions should be able to be answered at the final of this work, depending on the initial assumptions and hypothesis.

- Which should be the new obligations of the Universal Service?
- Who should provide the Universal Service?
- How to finance the Universal Service?

The inclusion of broadband service in the scope of Universal Service obligations is currently a core issue and there is no common position on the subject. The work presented in this thesis made several contributions related to the implementation of broadband Universal Service in Portugal, those include:

The state of the art study of the telecommunications sector and the universal service in Portugal

The state of the art of the Universal Service in Portugal was presented in the paper "133 years of Telecommunications Universal Service in Portugal", [28] and describes the history of the Portuguese telecommunication sector. The challenges for the Portuguese Universal service were described in paper "The Challenge of Universal Service in 21st Century Portugal", [29]. This work was fundamental to understand the Portuguese telecommunications sector, the socio-demographic context and the technology and behavior evolutions.

Identification on the potential technologies for broadband Universal Service

To picture the Portuguese telecommunications reality a state of the art review concerning the most representative technologies implemented in Portugal at the time of the time of writing this thesis. Also, a carefully study was made referring to the potential technologies that are available now for broadband Universal Service implementation, those include GPON, LTE and DVB-T, but future technologies have also been addressed with new trends as white spaces technologies.

TENTUS Simulator

A simulator was developed to simulate the roll out deployment of both a wireline GPON and a wireless LTE networks, with several degrees of freedom. The tool, named TENTUS, is based on several inputs given by the user, from the technical specifications of the network equipment to the subscriber´s forecast. The algorithm takes into account the number of subscriptions, the geographical distribution, the equipment efficiency and time life, and calculates the bill of material per year as well as other financial indicators as CAPEX, OPEX. ARPU, Earnings Before Interest, Taxes, Depreciation and Amortization- EBITDA, Cash-flow and Net Present Value - NPV.

DVB-T and DVB-S solutions for the rural areas

Beside the study of the wireline GPON and the wireless LTE technologies as the main short term candidates for Universal Service, other solutions were evaluate mainly for non-profitable zones. The analyzed solutions for Universal Service distributions in rural zones are based on Satellite and Terrestrial Digital Video Broadcasting. This contributions result after the answer to the ANACOM public consultation on the future of the digital television in Portugal, [30] and was presented in the paper "Digital terrestrial television: a golden or a missing opportunity?- A reflection on the introduction of DTT in Portugal", [31].

Portuguese Universal Service proposals

A technological solution combined with a strong techno-financial analysis was made for Portugal; this is believed to be a step forward to the implementation of a broadband Universal Service in Portugal.

Several papers, conferences, book chapter and invited talks were published throughout this thesis, those include:

1. Raquel Castro Madureira, A. Manuel de Oliveira Duarte, Raquel Matias-Fonseca, "*Digital terrestrial television: a golden or a missing opportunity? A reflection on the introduction of DTT in Portugal*", Journal of Telecommunications, Volume 15, Issue 2, August 2012, [31].
2. Raquel Castro Madureira, A. Manuel de Oliveira Duarte, Raquel Matias-Fonseca, "*The Challenge of Universal Service in 21st Century Portugal*", Technology and Society Magazine, IEEE, Volume: 31, Issue: 3 , Fall 2012, Page(s): 27 – 33, [29].
3. Raquel Castro Madureira, A. Manuel de Oliveira Duarte, Raquel Matias da Fonseca, "*133 anos de História das Comunicações em Portugal*", Revista do DETUA, Vol. 5, Issue 3, July 2011, [32].
4. Raquel Castro Madureira, A. Manuel de Oliveira Duarte, Raquel Matias-Fonseca, Carina Pais, Jorge Carvalho, "*The impact of geography and demography on the economics of fibre optic*

access networks", ICSNC 2012, The Seventh International Conference on Systems and Networks Communications, Lisbon, Portugal, [33].

5. Raquel Castro Madureira, A.M.d.O.D., Raquel Matias-Fonseca. "*133 years of Telecommunications Universal Service in Portugal*". A Century of Broadcasting. Proceedings IEEE HISTELCON'10, Madrid, Spain, 3-5 Nov. 2010, Page(s). 203-208, [28].
6. Jorge Carvalho, et all, Book Chapter "*Custos e Benefícios, à Escala Local, de uma Ocupação Dispersa*", ISBN: 978-989-98156-0-5, Direção-Geral do Território, 2013, [34].
7. Raquel Castro Madureira, "*Resposta à Consulta Pública ANACOM sobre o futuro da televisão digital*", Mar2013, [30].
8. Raquel Castro Madureira, IV Fórum Lusófono das Comunicações, "*Que serviço para o Serviço Universal para o séc. XXI?*" invited by ARCTEL-CPLP, 11 a 12 de Abril 2013, ISCTE-IUL, Lisboa, Portugal, [35].
9. Raquel Castro Madureira, "*Serviço Universal em Portugal*", invited by Ordem dos Engenheiros de Aveiro, Delegação da OE em Aveiro, Aveiro, Portugal, 28 January 2011, [36].

Chapter 2. **UNIVERSAL SERVICE OF TELECOMMUNICATIONS**

2.1 General Concept

Universal access (UA) and Universal Service (US) can largely be characterized by the availability, accessibility and affordability of telephony and the Internet, with increasing consideration of the inclusion of broadband and broadcasting. The following definitions are used, [37]:

- Universal access (UA): ubiquitous access to the service e.g., at a public place, thus also called public, community or shared access.
- Universal service (US): every individual or household can have service, using it privately e.g., either at home or increasingly, carried with the individual through wireless devices such as mobile phones or pad's.
- Universal access and service (UAS): the generic term when referring to both Universal Access and Universal Service or the general concept.

The three hallmarks of Universal Access and Universal Service are:

- Availability: the service is available to inhabited parts of the country through public, community, shared or personal devices;
- Accessibility: all citizens can use the service, regardless of location, gender, disabilities and other personal characteristics; and
- Affordability: the service is affordable to all citizens.

In the context of the information and communications technologies (ICTs) the concepts of Universal Access and Universal Service are applicable to the following services: Telephony (voice calls and text messages); narrowband and broadband Internet and radio and television broadcasting.

The context of this thesis is the transition of the usage of the today´s Universal Service concept in the fixed telephony and narrowband internet to a broader concept with broadband internet and all IP services and applications, including voice.

Universal Service concept was designed in the 1990's (in Europe [38], in Portugal, [39]) to complement the new sector´s regulation based on the market liberalization and public operator's privatization. Its mission is to safeguard reasonable access to all citizens with affordable price and protecting those with special needs, financial and physical limitations. The Universal Service acts as a legal instrument to ensure social benefits through technology to all citizens without discrimination, with a Universal Service provider (USP) chosen by public contest and with several predefined obligations (USO), with or without public funds, Figure 20.

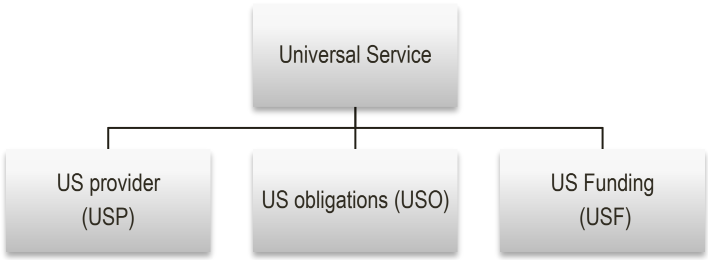


Figure 20 – Universal Service fundamentals.

In most countries of the world with Universal Service and for historical reasons the Universal Service provider was the incumbent operator but also that is changing.

The Universal Service obligations might lead to huge investments in infra-structure in places without assurance of financial return. The intangible returns, like social benefits and population well-being are difficult make worth the investment of private companies, Figure 21. The Universal Service provider (USP) should find metrics to measure the intangible benefits returns and balance them with the network deployment investments. If the social benefits cannot be correctly measured or understood, the swing pends to the investment side and the Universal Service is considered as a burden. In the European Union, a Universal Service fund may be established by a member state if it is concluded that the incumbent would be significantly competitively disadvantaged by being designated the Universal Service provider. So far only France, Italy and Spain have decided to establish such a Universal Service fund. With the transition to broadband Universal Service it is expectable that this fund has to increase enormously.

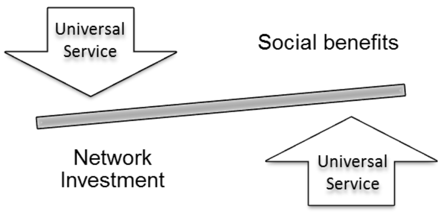


Figure 21 - The Universal Service swing concept: intangibles versus investment.

Today´s Universal Service obligations (USO) depend from country to country in combinations of several services as:

- Provide a connection to the fixed telephone network at a uniform reasonable price
- Request, and provide a connection that allows functional Internet access.
- Provide at least one scheme for consumers with special social needs who have difficulty affording telephone services.
- Provide reasonable geographic coverage of public call box services.
- Provide Universal Services at geographically uniform prices.
- Ensure that tariffs for Universal Services do not entail payment for additional unnecessary services.

- Provide a basic level of itemized billing at no extra charge.
- Provide Universal Services that accord with defined quality thresholds.
- Provide funds for a relay service for text phone users.
- Supply and maintain directories and databases for the provision of directory services.

2.2 Universal Service concept around the world

In this walk along the telecommunications history the present time is reached with two different types of reality: from one side, there is the diversification of the technological offerings along with the set of the consumer's communications needs. On the other side there are the Universal Service obligations based on a certain technology and a well-defined service. Many countries in the world already adopted a Universal service or access. Figure 22 picture the number of ITU countries with or without Universal Service/UA, [40]. Note that the fact that a country does not have the legal mechanism for Universal Service does not mean there is not a concern about the subject. In Europe, that is the case of Finland, Denmark, Estonia, France and Romania where the Universal Service obligations are allocated on a competitive basis.

With the opening of the market and the emergence of new operators, governments began to address the issue of quality assurance, so national regulatory authorities (NRAs) were born around most countries of Europe and governments legislated to a universal access communications law. This new concept makes sense only in a competitive environment, in others, where there are serious risks of investments abandonment in low income geographic areas, leading to serious gaps of development inside the same country. During the process of incumbent´s privatization the statutes of the Universal Service obligations were also included and thus access to funds for compensation. Elissen and From, [21] claim the resurgence of the debate on the Universal Service is a political response to the deregulatory process in the previous decade to strengthen the role of the state. Examples of countries with this course are for example the case of Portugal, Spain, France, and Belgium.

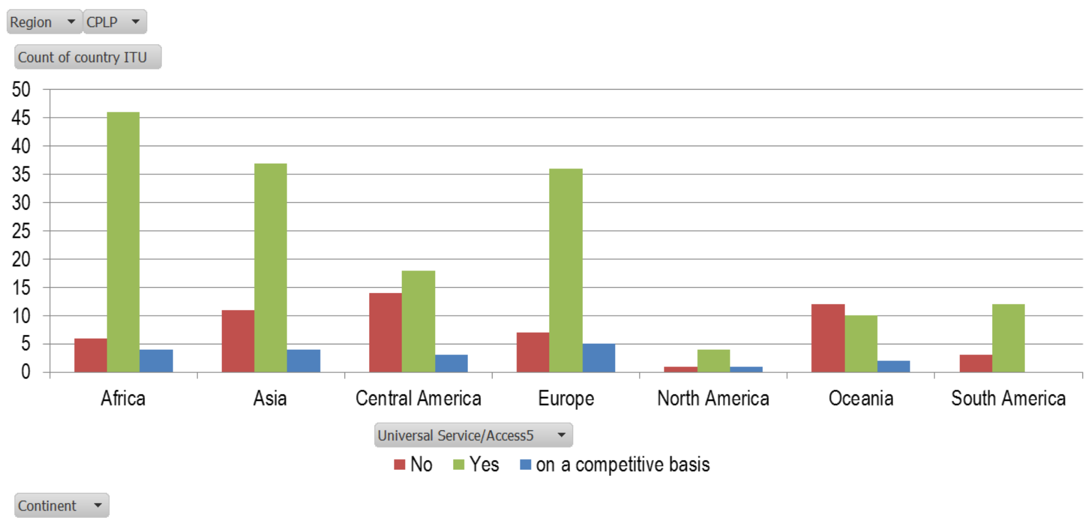


Figure 22 – Universal Service or Access adoption in ITU countries. Source: ITU, [40].

As the broadband became more essential in the daily life comparing to dial up internet access, some countries move forward to the next level adopting the broadband obligations to their USO, Figure 23. Other countries adopt national ultra-fast broadband plans where local authorities are already involved in broadband or FTTH rollouts, national schemes are offering financing, following a call for proposals at the local level. Such is the case in both the United States and France where the State acts as more of a lever. National projects that involve a high level of expenditure per capita are naturally those that have opted to build a neutral, national FTTH network – Australia being a prime example here, along with Singapore, Greece and, in a different form, New Zealand, [41].

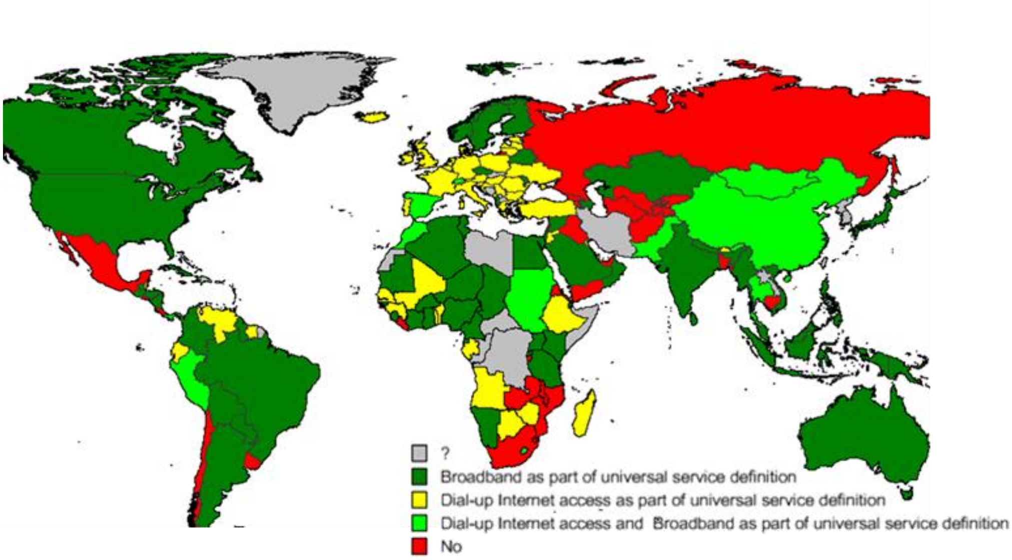


Figure 23 – Broad band adoption as part of Universal Service obligations. Source: ITU, [4].

The European Commission conducts a review of the scope of the EU Universal Service rules every three years, in particular to examine whether mobile telecommunications services or broadband should be included (in 2005/2006 and 2008). In November 2011, the Commission adopted a Communication on Universal Service in e-communications reporting on the outcome of the public consultation held in 2010 and its third periodic review of the scope of Universal Service, [42]. It concluded that there was no need to change the basic principles or scope of EU rules on Universal Service concerning the inclusion of the mobile telecommunications services and the inclusion of broadband connections at EU level. The main arguments are that the first ones are already in a mature and widely expansion level and the second ones (broadband subscriptions) are not.

In 2007 [43], the national Finnish regulator FICORA "*determined explicit permission for splitting Universal Service´s requirements between two different services with different underlying technologies*", opening room for diversity of technologies and embracement of broadband for Universal Services. Also in European Union, Spain introduce the redefinition of the universals service supporting technology allowing the broadband 1Mbps networks. Other countries as Switzerland, Canada, the United States, Taiwan and Japan also introduced broadband to the Universal Service concept.

The current status for some countries for their relevance or proximity to Portugal is described in detail next. Some realities through Europe are described to illustrate the diversity scenarios.

European Union (EU)

Portugal: Portugal is the focus of this work. The detailed description of the Universal Service framework is done in Section 4.5 when an historical review of the Portuguese telecommunications is done.

At this point it is presented a summary of the services and obligations available in Portugal.

The Universal Service was defined in Portugal by law in 1997 [39] and put in practice in 1999 ,[44]. The obligations until June 2014 are in Figure 24:

Figure 24 – Some of the Universal Service obligations (left to right): Fixed twisted cooper, emergency number, paper directories and public payphones.

- Fixed twisted cooper voice communications for all citizens at a uniform reasonable price;
- Data rates sufficient to permit functional Internet access
- Emergency number access;
- Paper directories;
- Public payphones;
- Special fares for low incoming citizens, disabled and elder citizens (special fares might raise as maintenance costs rises);
- Adequate equipment's for disable citizens.

By the time of the Universal Service implementation, in 1999, the Universal Service provider was the incumbent, Portugal Telecom (PT), with a direct contract assignment until 2025 where the government kept a golden share. In 2013 and due to pressure of the European Commission for incorrect implementation of the EU´s directives [45] a public contest for Universal Service provider was done and the golden share removed. The contest split the obligations in three different contests: connection to a public communications network at a fixed location (voice and data provision for functional internet – 56kbps), public payphones and subscriber's directories, [46].

Spain: In Spain the incumbent Telefónica is the Universal Service supplier. The Royal Decree 424/2005 transcribes the Regulation Act 2003 on the conditions for "the provision of electronic communications services, Universal Service and protection of subscribers", [47]. The provision of telecommunications services to all citizens at affordable prices are guaranteed, cost limits are set and Universal Service provider nominations are defined. In 2008 the Spanish regulator, CMT, determined the cost of Universal Service and thus enabled the compensation fund for financing of Telefónica for the years 2003 to 2005. In 2010 Spanish EU Presidency presented a program, [48] referring the extension of Universal Service requirements to broadband Internet, making it compulsory for member states to make the service available in every corner of their territory. The move is aimed at improving Web access in rural areas but has raised a number of concerns for the telecoms industry. The broadband Su was adopted in

2011 with 1Mbps for all citizens at an affordable price, based on several technologies including satellite communications[5].

France: The case of France is quite unique as since King Louis XVI, Napoleon in the XIX century and Mitterrand in the 1980's, there has always been a strong state intervention in the economy, including the telecommunications market. Hence, even if there has always been applied a certain concept of public service, with access to fixed telephone line moderately priced, European directives have only been treated in 1996, after the (forced) opening of the sector to competition, in a clear rejection of the American concept of market economy. The Universal Service in France includes the possibility to apply the Integrated Digital Network (ISDN) and make free emergency calls, access telex, data service, public telephone pole, telephone directory printed or in electronic form and offers special conditions of access to people with physical or financial limitations. The French authority, ARCEP, also determined a price for Universal Service in which a compensation for France Telecom exists, paid 3 times a year, [49] [50]. France aimed to guaranteeing Internet access with at least 512 Kb/s to every citizen by 2012[6].


Greece: The proper functioning of the regulation of Greece is of paramount importance to EC due Greece strategic geographical in south-east Europe, characterized by the confluence of 3 continents, dozens of languages, ethnicities and cultures. Greece was the last EU country to transpose the Universal Service to its legislation in 2006, although the Greek regulator EETT referred Universal Service as early as 2002, [51]. The incumbent OTE is the Universal Service provider and offers universal access to dial-up limited to narrowband services (not extend to ISDN), access to public cabinets, paper telephone directories and special services for disabled people.


United Kingdom: In the United Kingdom, UK, besides the incumbent British Telecom, BT there is an alternative operator providing Universal Service, Kingston. The UK was the first European country to open the telecommunications sector to competition in 1982. The Universal Service in the UK includes the access to fixed phone voice services and Functional internet access (FIA) in a minimum of 28.8kbps. Public telephone cabinets, a free emergency call and special rates for special cases are also included in the Universal Service provisioning. Both operators offer financial and technical solutions to deaf subscribers. There is provision for a compensation fund, but has not been activated either by BT or the operator Kingston. The paper directory service is not included, [52].

Finland: Finland is a special case in Europe with its specific characteristic of greater geographical dispersion, there has never been a monopoly and the number of operators was never lower than 50 regionally divided that can be interpreted as the incumbents, [43]. Until 2008 the Universal Service was never mentioned in the legislation and then it was decided by each municipality the need to incorporate or not a legislative requirement. Two-thirds of the Finnish municipalities said they did not need to define any operator as Universal Service provider and in the 135 municipalities that have accepted a Universal Service provider (about 55% of the area of Finland) have chosen to define an access service technologically neutral. In October 2009, Finland was the first European country to guarantee public access to enter the Internet at 1Mbps to 1 July 2010.

There are, however, EC countries with alternative routes to incumbent as the Universal Service provider. In Germany and Luxembourg any Universal Service provider was appointed. In Estonia the Universal

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[5] On line @ http://www.itu.int/ITU-D/ict/newslog/Spain+Introduces+1+Mbps+Broadband+Universal+Service.aspx, Available September 2013.

[6] On line @ http://www.itu.int/ITU-D/ict/newslog/France+Launches+Broadband+For+All+Certification.aspx Available September 2013.

Service is provided by a non-incumbent operator and in Hungary 5 operators were designated to provide Universal Service.

The paper directory service is not included in Ireland, Sweden, Slovenia and Estonia. In the last three, public pay phones are also not included.

Until 2011 only three countries triggered the compensation fund for the provision of Universal Service: Italy, France and Spain, while in Austria the operators agreed upon the compensation due. By June 16, 2009, , there were still exist some Universal Service infringement proceedings transcription (for different reasons) of the "Direct Universal Service, or of the "Electronic Communications", by the following countries: Germany, Belgium, Bulgaria, Greece, Slovakia, Spain, France, Holland, Italy, Lithuania, Luxembourg, Portugal, Poland, Finland and Sweden, [45].

European, not EU countries

European countries such as ***Albania, Bosnia Herzegovina, Croatia, Macedonia, Cyprus, Serbia-Montenegro and Turkey***, with more than 130 million residents are in the process of transition to democratic systems of a free market economy. They are also gearing up to implement the liberalization of the telecommunications sector, creating regulatory bodies, or even advancing their own Universal Service standards. Turkey was ahead of this process with the sector´s liberalization in 1998 keeping a governmental golden share in the incumbent operator. Turkey is on the process to enter EC since 1987. Other countries are still under internal organization such as Serbia-Montenegro and Albania that still confront some political instability due to the Kosovo crisis and the peculiar case of the dual structures of Bosnia and Herzegovina with 2 regulators, 2 Departments of Transport and Communications reporting to one Ministry of Affairs and Communications.

 *United States of America*

Another inevitable reality is the **United States of America** (USA). Since 1934 there was never been such a change in the USA law as large as the President Bill Clinton´s Act of 1996, [53]. These laws consider the Universal Service of all relevant sectors in society such as health, education or telecommunications. The primary objective of this law, regarding communications, allowed an open market promoting among others learning and work over long distances. This law created a new commission, the "*Federal-State Joint Board*", which defines the services and obligations of the Universal Service. Their recommendations are absorbed by the regulator and guarantee the ability to make and receive telephonic voice calls, sound associated with typing, access to emergency line, access to operator services, access to long distance calls and paper phone books.

All telecommunication operators can apply to became Universal Service providers and can apply to public compensation funds as the: "*Universal Service Fund*" (USF) [54]. These funds are paid quarterly by the earnings of inter-statues and international calls from all telecom operators in the country. There are senators who argue that all communication service operators as Internet Service Providers (ISP's) or voice over IP (VoIP) should also be included in the USF to promote broadband services in the more rural and lower income. However, forces in Congress are opposed to claiming disorders free market competition. Moreover IP service providers do not contribute to USF even if they provide voice communications. The funds allocation is also questioned showing some proposals for the allocation of Universal Service provider became based on public auction to the highest bidder. These processes are under evaluation.

In 2010, the National Broadband Plan (NBP) articulated a Universal Service goal of providing access to broadband service to all people in the United States.

Australia and New Zealand

In another corner of the world in **Australia**, the Article 7 of the "Telecommunications Act of 1997" transcripts on the obligations of Universal Service and regulates the Universal Service obligations and ensures voice telephone services, functional internet access – 64kbps and payphones at affordable prices. Note the Digital Data Service Obligation (DDSO), on the obligations of digital services and ensuring fair access of the resident or business to service data, are apart from this document. Australia´s incumbent, Telstra is the only provider of Universal Service and DDS and Universal Service funding is determined by the Ministry based on the instructions given by the regulators ACMA (Australian Communications and Media Authority). In 1991, the government created two pilot areas based on 52 areas of regional governments. This project aimed to evaluate various ways to provide Universal Service, manly considering the introduction of additional operators, [54-56]. Since 2009, Australia is committed to the roll out of the national broadband network (NBN), a wholesale-only, open access network delivering broadband to all Australian premises.

In **New Zealand**, the telecommunications service obligations (TSO) for local residence telephone service was defined in 2001 as the telecommunications act, [57, 58]. Package include the definition of fours principles: local free-calling option for local residential telephone service will be maintained for all Telecom (USP) residential customers; it will charge no more than the standard residential rental for local residential telephone service; customers in rural areas will be no higher than the standard residential rental and Directory assistance is to be continued.

China

As one of the fastest growing developing economies with 1/7 of the world population, **China** has a telecommunications systems and policies that caught the attention from the world. The telecommunications reforms of the last two decades enabled the sector to play a leading strategic economic role and to deliver economic benefits to the Chinese people. China is the largest telecommunications market in the world but with huge asymmetries. From one hand the big cities are highly developed and in the other hand its rural hinterland begins to wake up from centuries of stagnation.

The 1993 telecommunications reform opened to competition for non-essential services and in less than a decade swap from communications monopoly to about three thousands operators, including paging or very small aperture terminal satellite, VSAT. By 1995 China Telecom and a new operator China Unicom were born. The market was opening although all operators are necessarily Chinese. Measures for a telecommunications Universal Service were started in 1993 and by the end of 1997, among China's 27 provinces, the average telephone penetration of the top five provinces was only 15 percent, meaning in a global observation a penetration average of 5.2 per 100 inhabitants, [4, 59]. The fixed telephone subscriptions reach the peak in 2006 with 27.98/100. The decline to 20 in 100 inhabitants in 2012 is due to the immense penetration of the mobile phones with 81.2 in 100 inhabitants in 2012. Both dial-up Internet access and broadband are part of Universal Service definition, [60].

Africa and Latin America

In many more countries in **Africa and in Latin America** [61] there are visible efforts and trends to reorganize the telecommunications sector leading to the adoption of a similar concept of Universal Service.

 *CPLP (Community of Portuguese Speaking Countries)*

The association of communications and telecommunications regulators of **CPLP**, ARCTEL-CPLP is a permanent Forum for exchanging information and sharing experiences in the scope of the communications sector regulation of the Portuguese speaking States. It is the forum for exchanging information in the scope of the National Regulatory Authorities (NRA) for communications and telecommunications of **Angola, Brazil, Cape Verde, Guinea-Bissau, Mozambique, Portugal, São Tomé and Príncipe** and **East Timor**, Instituto Angolano das Comunicações (INACOM), Agência Nacional de Telecomunicações (ANATEL), Agência Nacional das Comunicações (ANAC), Instituto das Comunicações da Guiné-Bissau (ICGB), Instituto Nacional das Comunicações de Moçambique (INCM), Autoridade Nacional de Comunicações (ANACOM), Autoridade Geral de Regulação (AGER) and Autoridade Reguladora das Comunicações (ARCOM), East Timor respectively.

In the sense for adoption of best practices and the standardization of the regulation in the communications sector; the states members tend to adopt the main concepts by adapt them to each country´s reality. Table 1 presents a deep look in the Community of Portuguese Speaking Countries (*Comunidade dos Países de Língua Portuguesa* – CPLP), and their respective Universal Service providers, [62]. Except Timor-Leste all of them provide universal telecommunication service, most often accepting technology neutrality. In 2013 Mozambique and Angola just closed the tender for Universal Service provision.

Brazil adopted a national fixed broadband plan (Plano Nacional de Banda Larga, or PNBL) to reach 4,424 cities by 2017. Several operator´s provide low-cost services as TNL (Oi), Telefonica Brazil and Sercomtel (Algar Telecom).

The next table summarized the answers reported to ITU in 2012 by those countries, Table 1. Most of them reported they have digital broadband plans expansions. In Africa the main constrains are the geographical isolated settlements but also the frequent power black outs that also affect the communications!

In Brazil one of the main constrains for broadband Universal Service implementation is the fact that any operator answered the Universal Service tender. This happens because in Brazil the USP have to leave all the infra-structure to the state at the end of the license time period.

As a summary Table 1 can be built based on the previous descriptions:

Continent	***Country***	***Universal Service Regulator***	***Voice services***	***Other services***	***Broadband in Universal Service***
European Union	Portugal	Regulatory Authority	Fixed line private residential Telephone booth Paper Directories	Functional internet access 56kbps	No
	Spain	Regulatory Authority	Fixed line private residential Telephone booth Paper Directories		1Mbps (complement with satellite)
	France	Regulatory Authority	Fixed line private residential Telephone booth Paper Directories ISDN		No
	Greece	Regulatory Authority	Fixed line private residential Telephone booth Paper Directories		No

	United Kingdom	Regulatory Authority	Fixed line private residential Telephone booth	Functional internet access 28kbps	No
	Finland	Regulatory Authority	Fixed line private residential		1Mbps
Non EU members	Albania Bosnia&Hez Croatia Macedonia Cyprus Serbia-Mont Turkey	Regulatory Authority	Fixed line private residential Telephone booth		No
North America	United States of America	Regulatory Authority	Fixed line private residential Telephone booth		4Mbps
South America	Brazil	Government body & Regulatory Authority	Fixed line private residential Telephone booth	Schools (primary, secondary post-secondary) Health centers Emergency services Services for impaired/ elderly Telecenters	No
Oceania	*Australia*	Regulatory Authority	Fixed line private residential Telephone booth	Functional internet access 64kbps	No
	New Zealand	Regulatory Authority	Fixed line private residential Telephone booth Paper Directories		No
Africa	Angola	Government body	Fixed line private residential Telephone booth Individual mobile cellular service		No
	Cape Verde	Regulatory Authority	Fixed line private residential Telephone booth	Emergency services	No
	Guinea-Bissau	Government body & Regulatory Authority	Telephone booth	Telecenters Others approved by the government	No
	Mozambique	Regulatory Authority	Fixed line private residential Telephone booth	Internet public access Emergency services	No
	Sao Tome and Principe	Government body & Regulatory Authority	Fixed line private residential Telephone booth Individual mobile cellular service Mobile Telephone booth	Telecenters Emergency services	No
Asia	Timor-Leste (East Timor)	Not regulated			
	China	Government body	Telephone in "Every Village Plan"	Dial up internet	Yes (the "12th Five-Year")

Table 1– Universal Service at some countries in the world. Source: ITU, [62].

2.3 Measuring the Universal Service Benefits

Measuring the benefits of intangible goods is quite hard task to do, due to its subjectivity. It is now widely accepted that access to the basic telephone provides a basic support to social and economic participation in modern Western society, [63] as modern economies rely on a communication basis. The "always on line" is a reality for some of the business and part of urban consumers and associated to an idea of success and modernity.

The new forms of communication, such as the mobility, and data applications as for example video calls, lay down barriers in segments of the population that were traditionally the "*unphoned*" as older people and people with mental and physical disabilities contributing as new form of integration. Unfortunately it was not possible to get some statistics concerning the subscribers profile to corroborate this statement that derived from the author´s experience with senior "universities" in suburban areas.

As new forms of communicate evolve and more countries adopt the broadband new generation networks taking into account their welfares, one approach for measuring the benefits of a broadband Universal Service is to understand the impact of the NGN in the society.

For the society as a whole

NGN are part of the technological evolution of the telecommunications world as it responds to the demands of consumers. The aging population is one of the megatrends that are shaping today's economic and social understanding. There are growing concerns about health, entertainment sports and fitness. A NGN can reply to most of the consumer needs by providing long distance services as tele-medicine, video-conference classes and tele-work.

Several studies [40-42] have already been done and focus on various facets of NGN´s deployment in access networks. Studies specific to Portugal such as the Boston Consulting Group, BCG´s study [40], quantify the potential impact of services to be offered by NGN based on fiber to the home in specific areas.

Eight areas of economic and social impact were identified as priority benefits to new NGN based services: health and social work, security & justice, education, public administration, mobility & logistics, commerce & retail, tourism and media, entertainment & culture. According to this study, NGN service deployment in Portugal will result in a significant increase in public good, including approximately a 1.8% increase in GDP. The measure of this impact is the sum of the contributions of three major areas: economical, environmental and social impact. The direct impact will come in three different waves, Figure 25:

- - The first wave, valued at 900 million Euros, will come through improved services for faster connections and reliable Internet, such as virtual classrooms, sharing of criminal intelligence, virtualization, utility or tele-presence.
- - The second wave of impacts, valued at 700 million Euros, will come from e-working, interactive advertising, virtual tourism and shopping by television.
- - The third wave, which involves the widespread use of virtual consultations or surgery, for example, is valued at 300 million Euros.

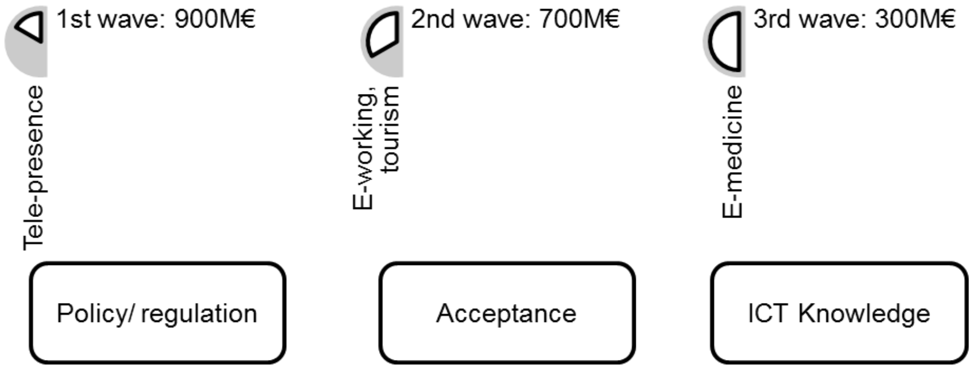


Figure 25 -- NGN´s economic impact in Portugal, adapted from BCG [40]

According to the European Commission model [41], considering the actual adoption rate, broadband development is likely to contribute to the creation of 1,076,000 jobs in Europe and a broadband-related growth of the economic activity of €849 billion between 2006 and 2015. According to the model, in the worst case, broadband development will result in a creation of 345,000 jobs in Europe between 2006 and 2015; while in the best case, 2,112,000 jobs could be created.

The perspectives demonstrated by some of the recognized studies are quite optimist and predict a brighter future concerning the population welfare and the economy of the countries involved.

Other studies however are not as optimistic [42], different models suggest that civil engineering costs (among other costs) for the fiber networks deployment will limit the deployment of the FTTH to high density areas, leaving other zones, mainly rural areas, out of the NGN wave. This would, in turn, limits prospects for economic development.

For the consumer individually

Beside the whole intangible benefits of the Universal Service that also affect each one of the citizens individually it is relevant to highlight the two main advantages of this instrument that intend to give equal opportunities to all citizens regardless their geographic location and economic background:

- The access at the comfort of his home of the main trends of communication;
- The cost control of that access.

One main drawback of this cost control is that sometimes this same instrument may be used to finance communications for isolated farms to who may have economic power to do it without any type of subsidization.

For the Universal Service provider

There is also another component on the benefits measuring beside the socio-economic benefits of a universal telephone/broadband network.

Several times the question of the Universal Service burden is raised concerning a financial perspective of the business plan. However there are also intangible earns for a Universal Service provider, [64]. Those are corporate reputation and brand image; life cycle effects; ubiquity; subscribers data base; extra publicity at public payphone; mailing; rate regulation; access to Universal Service funds and access to new segment fringes that derive in the network subscriber effect.

2.4 Universal Service literature´s challenges

The concept of "universal service obligation" (USO) has been around for decades; however, its definition continues to change. The main challenge of the Universal telecommunications Service in the beginning of the 21st century is to find a concept that can achieve the reliability and social relevance of its predecessor, the twisted copper pair, but also can move towards a wider definition of communications utility that can help to deliver equal opportunities to all consumers in a modern life concept of "always connected" at moderated prices.

The telecommunication sector is one of the most active in the modern economy and the explicit reference to fixed system architecture and limited services, as the current Universal Service definition can confine the public target. This might lead to a serious problem for the Universal Service provider that suddenly finds out that there is no demand on the Universal Service. The ITU indicators for developed and developing countries of the world report a trend to decrease the number of fixed telephone subscribers, Figure 26, while other forms of communication are in great expansion, [65].

Mobility and broadband become essential services for improving public interest and safety, social welfare and the information society plan challenging the status quo of what was thinking as the minimum services required for development. The current model revolving around the provision of well-defined services as fixed voice, appears in need of fundamental re-thinking A universal telecommunication service associated with the fixed voice service has been be challenged by authors for the last two decades.

The attractiveness and reasonable prices of other communication forms and the detriment of fixed telephone lead to an embranchment in the Universal Service history.

From the technological point of view, there are several technologies that are candidates to become both new generation networks and Universal Service providers. Alternative policies of broadband programs might fulfill all the subscribers' needs with adequate regulation. In this case, there is no need for a legal instrument as Universal Service as already in some countries (Section 2.2).

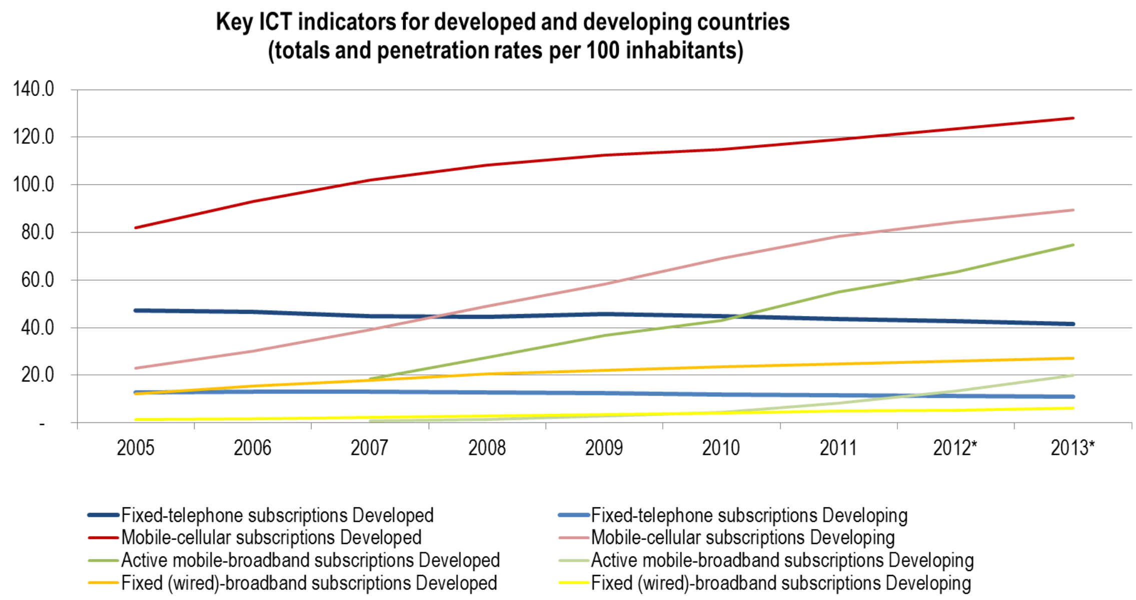


Figure 26 – Key ICT indicators for developed and developing countries. Source: ITU, [65].

Even in a healthy open market with several players in competition covering most part of the territory, it is also a reality that the studies and plans for expansion of communications networks are typically confined to geographical areas associated with greater and faster return on investment. These scenarios may lead to increase the digital gap among regions and citizens, e.g. those residing in rural and remote areas will be unable to benefit from online education, health and government services.

If market mechanisms are insufficient to ensure services are available and affordable for those without service then the option of imposing a Universal Service obligation should be defined. The guidelines to reappraise the scope of Universal Service should be the definition of specific features of the service under consideration and the determination whether the service is essential for full participation in society and in the public interest.

In the last two decades the scientific literature has been approaching this subject concerning the network neutrality and the broadband inclusion as part of a modern Universal Service concept.

The inclusion of mobile networks to the Universal Service does not focus only on the question of voice telephony. The paradigm of fixed phone at home has expired. Increasingly, the public uses tablets, multifunction phones, computers and smart digital televisions with web access. The extent of the requirements for inclusion of new interfaces by the user and the inclusion of broadband services deserve consideration by several authors. This matter has been analyzed by several authors as Xavier [66],[67] and Cave and Hatta [68], challenging the fixed network paradigm.

In 1997 after the liberalization, Xavier [66] raised several questions on emerging technologies and services and how they should or not be absorbed by the universal concept of interconnected companies. The paper provides rules for strategy development of Universal Service and it's financing under NGN. In 2006 Xavier alerted for another issue "*of how to keep some of the obligations in a universal technology of Next Generation Networks (NGN)", [69].* As an example, in the short term it will be mandatory to associate geographic location to the emergency call, in a situation where the call is done by VoIP is not possible for the present situation, unless there is a location equipment associated..

In 2008 Cave and Hatta broke the myth of the fixed telephone network and reinforce the possibility of inclusion of wireless systems (wireless) as part of the Universal Service, [68]. Defend the existence of a Universal Service technologically neutral and multiple suppliers. They warn, however, for the need of spectrum regulators to not run the risk of an inefficient use of this scarce resource.

Also Goggin shares this idea of extending the Universal Service with mobile communications, which corroborates with the current high number of users distributed worldwide regardless of the region lives, habits, social or economic stratum, [70]. Further argues that this fact goes against the OECD in 1991, intended to be a future service and universal access, [71]. Their main concern focuses on economically disadvantaged groups and/or physically disabled.

The analysis of Calvo in 2012 [72] confirm that while NGN are rolled out and technologies evolve there is a need to review Universal Service regimes so that they continue to fulfill their role. Whereas each country try to fulfill the commitments adopted in the Seoul Declaration, [1], each country has developed national goals that vary in scope and timing, and smoothly the broadband concept is incorporated in universals service definition.

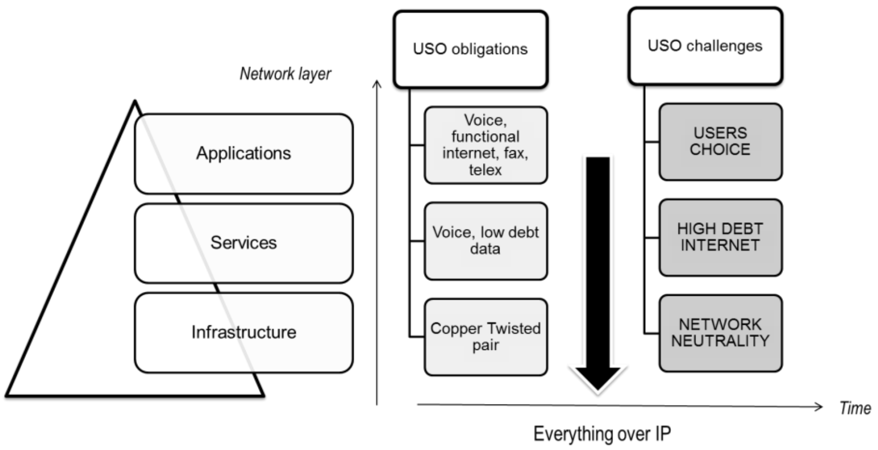


Figure 27 - The Universal Service challenges forecast after the "everything over IP" milestone. From the author.

As focus by Crandall and Waterman, each user does not internalize the benefit that its consumption generates service to others, [73] and therefore in some cases the demand is not the promoter of the network upgrade. For this reason several countries have defined the existence of universal service funds to help to subsidizer operator´s in those areas.

Financing the costs of universal obligations can be done either through public funds, either by creating a specific fund to which all operators contribute. In Portugal the existence of a fund is also contemplated, however this fund has not yet been created and it is justified by the "*mismatch between the accounts of PT and analysis that ANACOM has made of these calculations*", and the incumbent keeps referring the obligation as a burden as it has been self-financing it along the years.

In some EU countries the fund has been created and activated, as in Italy, France and Spain. In fact most of the cases observed are based on models of financing of operators by operators mostly from international communications revenues (with higher profit margins). It seems a fair system yet and in particular the USA some questions are raised by fixed voice operator's taxpayers. They claim that other operators including mobile operators or VoIP provide the same type of voice service is not considered as contributors. They argue this is a contradiction to the original concept of equitable distribution of burdens.

The 2009 Nobel laureate in economics, Ostrom [74] was recognized for her work dedicated to the observation of an emerging form of business management relations - the organization by the municipalities. Her analysis focused on water and forest resources and how this management is much more productive if managed as a microcosm of what geographical cross and following directives often inadequate power ethereal and distant central government. Eventually the case for new forms of management may spread to other sectors of the economy and can be applied to telecommunications with enhanced power and autonomy of municipalities in relation to infrastructure in their region. This can be the path to achieve a fiber broadband Universal Service, sharing the cost per region and among the operators.

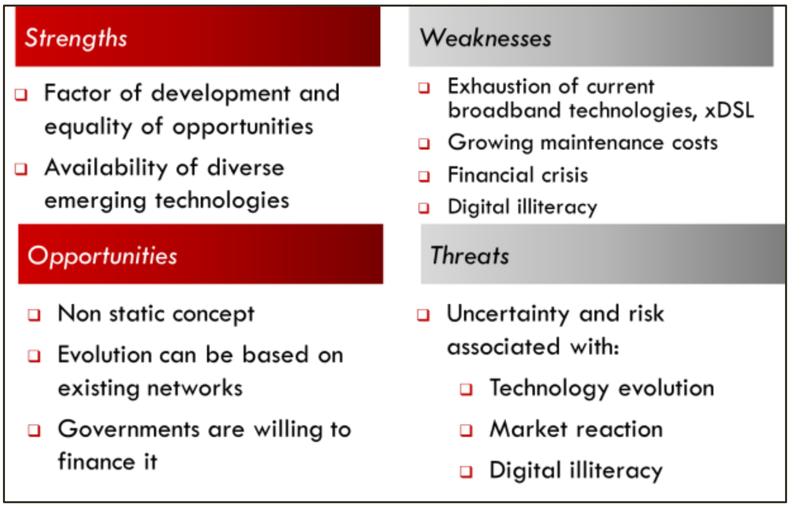
Meanwhile in Portugal and in Europe several funds from the National Strategic Reference Framework (NSRF, "QREN" in Portuguese) [75] are been allocated by contest to regions in order to implement the broadband network in geographic areas usually economically disadvantaged. It is a requirement of these competitions a minimum coverage of 50% of the population, it is a relevant effort to reduce asymmetric development but it does not guaranteed the universal access.

Concerning the question of financing the Universal Service is also the subject of study and among others, Falch and Hensen, [76-78] seek to examine the real extent of NGN investment in terms of Universal Service, proposing public-private partnerships (PPP)

2.5 Summary

This chapter provides an overview of the Universal Service´s concepts from the technological, regulation and political point of view in the modern societies. It presents the concept of Universal Service as it is interpreted by some countries, namely in Portugal, EU and non EU members as well as other countries around the world. And also presents a literature´s glimpse from several author´s in the field of study.

A SWOT analysis finds as Strengths of the Universal Service: Factor of development and equality of opportunities and in parallel the availability of diverse emerging technologies; Opportunities: defined as a non-static concept, the evolution can be based on existing networks and governments might be willing to finance it. As Weaknesses: the apparent exhaustion of current mature technologies and its growing maintenance costs; and as Threats: uncertainty and risk associated with technology evolution and the market reaction/unprepared.



Chapter 3. **ACCESS NETWORKS' STATE OF ART**

Communications are currently present in everyday life and are currently taken as a commodity. This has been the result of deep transformations that went along with the emergence of the web, and later the explosion of broadband, the interactivity of social networks and the massive traffic generated by user-generated content as video sites and blogs. With more than 4 billion users of mobile communications subscriptions in 2008 [79] and more than 2 billion active Internet users [3, 80], ever more people demand access to their personalized digital services while on the move or at their homes, at leisure, at work leading to an extremely load stress to the telecommunications networks.

The telecom network segment that connects the end user with the core network is called the access network. As time and technology goes by, the way the telecommunication networks approaches the final users evolved in such a way that allows the increase of data transfer per user. The way it carries the sign of telecommunications between the core and the user can varied and depends on the service carried, the infrastructure and the technology chosen, involving multiple access modes and signal modulation.

Different technologies and means of transmission can be used in the various sub-segments in which they can share the access network, Figure 28. The access network can be defined as the part of a telecommunications network which connects subscribers to their immediate service provider, usually referred as the "*last mile*", even though nowadays is just an expression that most of the time does not correspond to the exact measure of a mile but with some technologies can correspond to several miles. It is also the telecommunications subsystem more sensitive to investment and for that more controversial and target of several analysis.

In this thesis special attention is given to this network segment as it is more and more a relevant factor for budget allocation especially in broadband network operators. The main focus of this work is the emergent broadband access network techno analysis as broadband is the way for achieving digital inclusion for all. To introduce the path to these emergent technologies is relevant to analyze the existent technologies that are the state of the art at the current time.

The search for telecommunications systems that can provide broadband access anytime, anywhere has led to the development of various innovative communication systems both Wireless and Wireline sectors of activity. History shows that in the telecommunication industry there has been a constant competition between fixed and wireless operators [81]. More recently the digitalization of the contents, the emergence of IP and the increasing need of high speed broadband by end-users has enable the convergence of networks, services and devices. This convergence is taking place in different segments of the network.

Because the aim of this work is reaching the end-user, the focus in the technological trends will remain in the access network.

Since the introduction of the plain old telephone service (POTS), the conceptual approach of the access network is more or less the same (unless the technology involved), in the sense that at a certain geographical point towards the final users it is placed a central office as a physical node (most of the time the municipality center) to gather all the connection from all parts of a certain municipality. From there several flexibility points are introduced whenever there is the need of a physical separation due to a road intersection or junction, until the house of the user. Figure 28 intend to show the evolution of this approach concerning both the physical infrastructure and the technology involved.

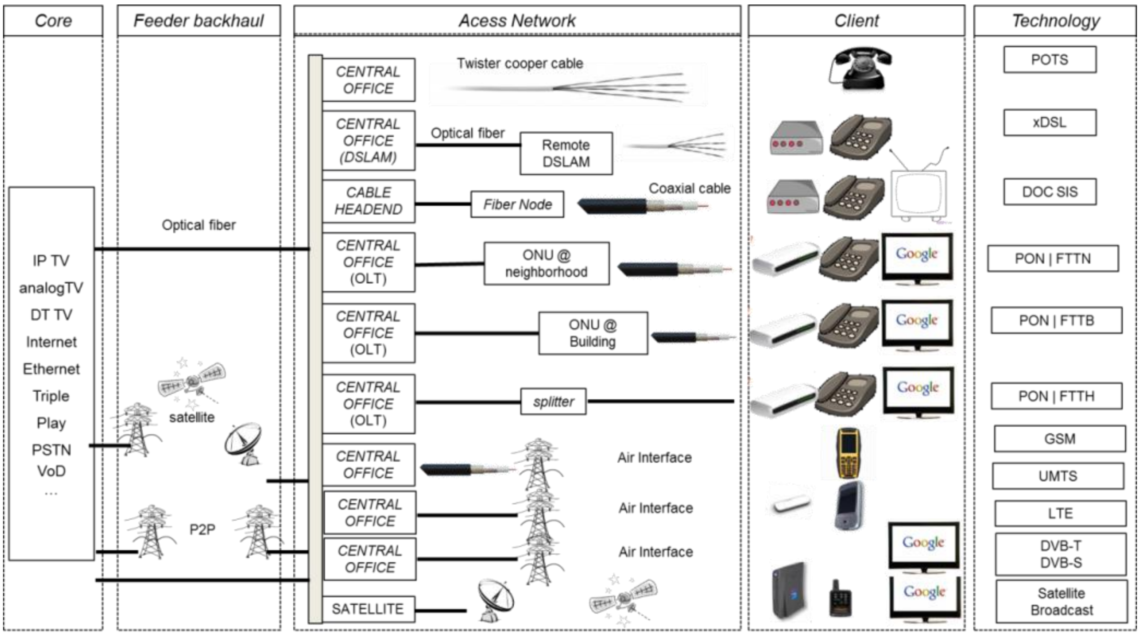


Figure 28–Technology scenarios for telecommunications access networks. From the author.

The overview of the New Generation Networks, (NGN´s) and trends are particularly pertinent and actual. It is important to understand what it will be the path that NGN´s will follow in the near future and even most important is to understand the roll out investment models to avoid the knowledge gap between regions and therefore citizens. To move forward the future a small step backwards to picture the existing ambience, where the NGN will emerge and coexist.

Consumer traffic also has changed significantly since triple play services emerged in the 1990s. It started as highly asymmetrical traffic with downstream volume 10 times greater than upstream. Then it became less imbalanced with the growth of peer-to-peer and interactive services. Currently, upstream services, such as picture and video storage in the cloud, social media and video chatting, are being rapidly adopted, turning the GPON a desirable mean of data transport due to its symmetrical characteristics, [82], Figure 29.

Monthly Consumption - Europe, Fixed Access			Monthly Consumption - Europe, Mobile Access		
	Median	Mean		Median	Mean
Upstream	485.7 MB	2.5 GB	Upstream	2.0 MB	41.1 MB
Downstream	5.3 GB	10.9 GB	Downstream	10.5 MB	269.9 MB
Aggregate	6.0 GB	13.4 GB	Aggregate	13.2 MB	311.0 MB

Figure 29 – 2013 Europe monthly consumption comparison on upstream and downstream services (fixed access on the left, mobile access on the right). Source: [82].

In this study it is consider and evaluate NGA architectures which meet the anticipatable in short terms, future bandwidth demand and allow for highest bandwidth with a tendency to symmetry and quality for end-users and which no longer rely on copper cable elements. These are the present time, fiber to the home, FTTx architectures only.

Next-generation fiber and the remain copper technologies will continue to enhance capacity in both directions, as shown in with keen attention to cost to expedite deployments and adoption, [83], Figure 30.

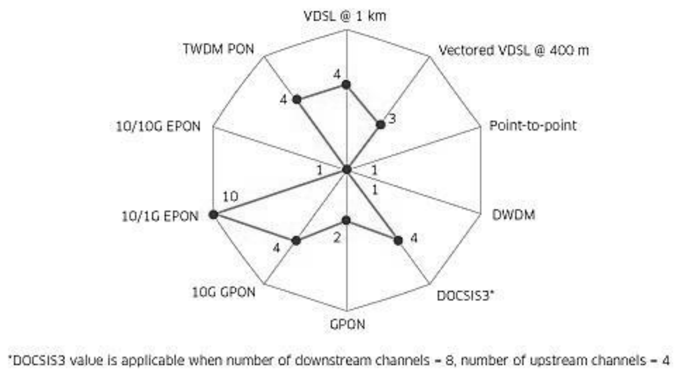


Figure 30 - Overview of downstream-upstream capacity ratio per different technologies. Source: [83]

The evolution of GPON technology offers a good example. It has been standardized to have four times more capacity downstream than upstream, striking a smart balance between investment and bandwidth demand. The evolution of GPON technology offers a good example. It has been standardized to have four times more capacity downstream than upstream, striking a smart balance between investment and bandwidth demand.

The next sections present a description of different transmission technologies represented in the previous figure. Some references to the Portuguese context of each one are also mention along the text description.

3.1 Wireless Cellular Network Technologies

Wireless cellular networks are characterized by the ability of approaching multiple users simultaneously. This diffusion can be for all users (not addressed, point to multi-point or broadcast such as radio and television) or to a restricted group of users (broadcast or addressed point to point as for example the conversation by phone).

The wireless communications are deployed with a cellular concept architecture, where base stations are spaced by inter-site distance that determines the coverage area of each station, (as it will described in detail at Section 0)

The radio communication systems consist of two basic components: the transmitter which is composed of a modulator for transforming the digital signals into radio analog variations, a transceiver to convert the signal from base-band to an intermediate frequency and an up converter to convert the signal to the RF frequency of interest and finally an antenna. The receiver, is composed by the receiving antenna, which most of the time is the same as the transmitter antenna, this element is used to gather the electromagnetic waves and convert them into electrical signals; the receiver transceiver that converts the RF signal back to IF, and a demodulator to recover the information signal back again.

The wireless access networks are part of an evolution that began in the 80´s of the latest century, with the analog mobile systems with heavy handset not easy to carry. Since then several systems appear to provide lighter handsets, more mobility, higher voice and data quality and high debt data transfer. Some of them were more successful than others, but the fact is that some of them still coexist. And in the path for even more complex systems the decision maker cannot forget that already existent field solutions should be exploited before deploy and invest in a new system from the root, Figure 31.

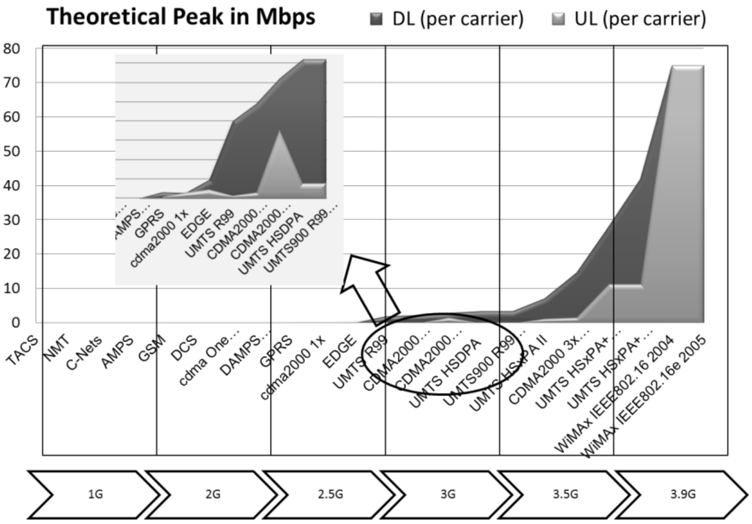
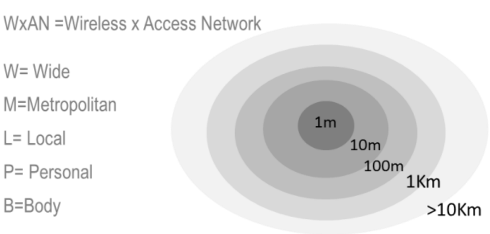


Figure 31 – Theoretical deliverer peaks in Mbps comparison for current wireless technologies (DL and UL). From the author.

The range achieved by a wireless network and its capability to deliver higher or less quantities of information per second depends on the technology used. The technologies are divided in families each one with its type of specifications in such a way that sometimes they can co-exist but not inter-communicate. It is the case for example of a GSM network and a Wi-Fi network, they use different types of transceivers and it is not possible to handover from one to the other even if they co-exist. On the other hand in the case of a GSM network one can switch to an UMTS network, even though the transceivers are different, most of the receivers are dual band and therefore can commute in the two technologies no matter the different frequency band and the differences in modulation techniques.

The current wireless networks can be organized in families, according to the average coverage area. The wireless systems used for the wider ranges, as Wireless Wide Area Network (WWAN) and Wireless Metropolitan Area Network (WMAN) are typically GSM/UMTS, WiMAX, and LTE. In the Wireless Local Area Network (WLAN) category there are low range networks with high throughput such as Wi-Fi, Figure 32.



WWAN	•GSM/UMTS •LTE;WiMAX
WMAN	•GSM/UMTS •LTE;WiMAX
WLAN	•Wi-Fi 802.11
WPAN	•UWB •ZigBee •Bluetooth
WBAN	•RFID •ZigBee

Figure 32 –Wireless networks families according theoretical coverage radius. From the author.

In October 2009 [84], ITU had received six candidate technology submissions for the global 4G mobile wireless broadband technology. The selected technologies are expected to be accorded the official designation of IMT-Advanced - to qualify as true 4G technologies, Figure 33.

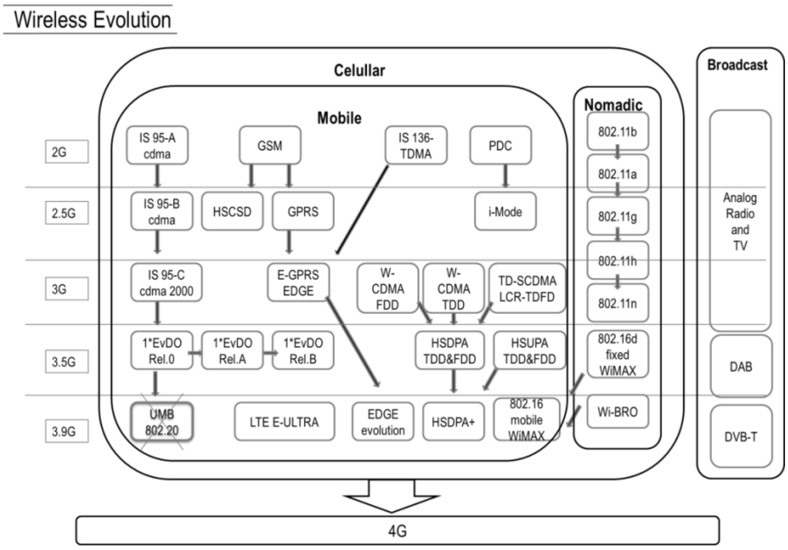


Figure 33- Wireless Evolution towards the NGN. From the author.

The next sections will describe some of the most used wireless technologies, and the best positioned to be Universal Service candidate technologies at short and medium term.

3.1.1 Local Area Networks: Wi-Fi IEEE802.11

The emerging 802.11n standard is still in the development form. At the time of this report the latest draft of this standard is Draft 4; WIFI Alliance created a certification program for the WIFI devices, including 802.11n, which are certified as per Draft 2 of this standard. Currently, the 802.11n vendors have already created an industry. Both chipset and platform manufacturers are working hard to reach the 802.11n evolving market.

Since 1996 [85], several industry leaders came together to form a global, non-profit organization with the goal of driving the adoption of a single worldwide-accepted standard for high-speed wireless local area networking. Since the beginning of this project, IEEE built a standard based on the work done by the Alliance [86] called IEEE802.11. In 1999 the first standard was published as IEEE802.11.b [87], nowadays the IEEE802.11.n is appearing after several appends and amends. Major improvements are waited in next release 802.11ac, Figure 34.

Release	***Date***	***Frequency (GHz)***	***Throughput (Mbps)***	***Net bit rate (max)***	***Range indoor appx. (m)***
802.11a	Oct99	5	23	54	35
802.11b	Oct99	2.4	4.5	11	38
802.11g	Jun03	2.4	19	54	38
802.11n	2009	2.4	150	600	70
802.11ac	2009	2.4 & 5	866	1000	70

Figure 34 - The Wi-Fi standardization evolution. Source: IEEE 822.11.

The major obstacle to Wi-Fi is to reach a wider spread area. New developments are continuing to evolve in this segment as the so-called Wi-Gig, which is a Wi-Fi working at 60GHs with peak bit rates of 7Gbps.

3.1.2 WiMAX

WiMAX has become synonymous to IEEE 802.16 [88] standards-based technologies enabling the delivery of last mile wireless broadband access as an alternative to wired broadband like cable and DSL (and also to High Speed Packet Access). More recently (2007) ITU announce [89]: "*The specific terminology of the IEEE 802.16 standard in ITU-R M.1457 Recommendation is 'IMT-2000 OFDMA TDD WMAN'*". WiMAX became most used after the hurricane Katrina in 2005 and the Tsunami in Indonesia in 2004, where it was used to restore the communications.

WiMAX provides different types of connectivity, fixed e.g. in a private home, nomadic as connectivity is available but only within the limited range of the local antennas, portable available in public hot spots with no interaction and soon, mobile wireless broadband connectivity without the need for directs line-of-sight with a base station. Originally it was licensed for the 10 to 66 GHz frequency range. Subsequent upgrades extended the 802.16 air interface standard to cover non-line of sight (NLOS) applications in licensed and unlicensed bands in the sub 11 GHz frequency range

WiMAX fills the gap between the wireless LANS and the wide area networks, WAN´s previously described, in open concurrency to wire-line DSL and cable reaching higher overage areas at an attractive cost. Theoretically a typical cell radius deployment goes from 3 to 10 kilometers, real live measurements show 1Km of cover area in urban areas with 4.5Mbps DL and up to 30Km with 1.5Mbps, DL and 550kbps for the UL. WiMAX Forum Certified systems can be expected to deliver capacity of up to 40 Mbps per channel, for fixed and portable access applications. This is enough bandwidth to simultaneously support hundreds of businesses and thousands of customer-premises equipment (CPE) at each household, Figure 35.

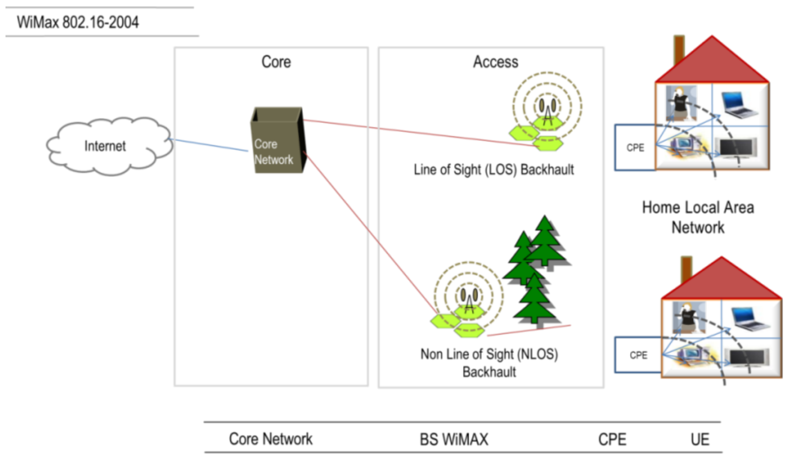


Figure 35 - WiMAX Architecture. From the author.

Mobile network deployments are expected to provide up to 15 Mbps DL of capacity within a typical cell radius deployment of up to three kilometers. WiMAX technology is nowadays incorporated into the majority of notebook computers and PDAs.

Typically each cell has a whole 100 Mbit/s backhaul so there is no contention here. In practice, many users will have a range of 2-, 4-, 6-, 8- or 10 Mbit/s services and the bandwidth can be shared. If the network becomes busy the business model is more like GSM or UMTS than DSL. It is easy to predict capacity requirements as you add customers. Additional capacity can be added on the same sector to increase the simultaneous number of users.

The main competitor of LTE to reach IMT-Advanced 4G is the Wi-Max evolution IEE802.16m. As 3GPP LTE, WiMAX-m is concentrating much effort on MIMO, mobile multi-hop relay networking and related developments needed to deliver 10X higher throughputs. In the specifications the WiMAX mobile pretends to achieve more than 225Mbps DL and 33Mbps UL, TDD. Unfortunately the strong effort of the main manufacturers in LTE approaches is moving faster to the elimination of WiMAX technology.

3.1.3 Cellular networks or mobile networks

Some of the most successful wireless systems implemented in Portugal are described in the following section: GSM, EDGE, UMTS R99, UMTS 900, UMTS HSDPA and LTE. The wireless cellular networks were rapidly and widely accepted in Portugal since their entrance in the market. Low prices (both in service pricing with low rates per minute and high subsidized handsets) and wide range coverage were factor of success of such technologies.

GSM- Global System for Mobile Communications

In the mid-80s of the twentieth century, the ECPTA (European Conference of Postal and Telecommunications Administrations, [90]) has created an international working group called *Groupe Spécial Mobile*, which evolved over cellular communications. In 1992 the standard moved to ETSI. About ten years after the first-generation, GSM Phase1 was in the market. It was an analog technology, and only allowed the transmission of voice, but that allowed a breakthrough that would change the way of living that have adopted this system: the mobility and the feeling of being contactable anywhere, anytime. It was an unexpensive and reliable technology but the equipment was large and the quality of service was average, with little immune to noise.

Wireless systems Phase 2, or more commonly called the 2nd generation systems already had digital technology, with increased noise immunity, higher transmission quality and greater security and confidentiality, [91]. In terms of services provides the voice call and data from low speed up to 9.6 kbps. It uses a modulation Gaussian Minimum Shift Keying (GMSK) a variant of the technique Phase Shift Keying (PSK) technique with temporal approach, Time Division Multiple Access (TDMA) carrier on Frequency Division Duplex (FDD). That is the same frequency serves multiple users "simultaneously".

Given the modulation technique used the bit rate offered by GSM is somewhat limited. Phase 2+ arises with increasing transmission rates, by aggregating multiple channels or new channel coding schemes. New services for data transmission appear as: HSCSD (High Speed Circuit-Switched Data), in 1998, GPRS (General Packet Radio Service) in 1999 and EDGE (Enhanced Data rates for GSM Evolution or Enhanced GPRS) in 2003 [92]. The services themselves are not modified but enhanced by offering a new physical layer; some modifications were introduced to initial GSM system to support packet switching communications.

GSM-GPRS - General Packet Radio Service

The GPRS service requires an average investment for the operator because it keeps most of the equipment of the GSM network but requires some changes to the BSC and the Core Network, Figure 36. It works as a complement to providing you with GSM data services, starting to exist in two parallel networks: GSM network responsible for voice traffic (circuit) and responsible for GPRS data traffic (packet). GPRS uses up to eight timeslots delivering from a total bandwidth of 9.6kbps up to 72.4Kb or 107.2Kbps DL and

42.8kbps in the UL, allowing the operator to provide mobile video and picture, requiring new phone equipment than GSM only.

EDGE - Enhanced Data Rates for GSM Evolution

EDGE has been introduced into GSM networks since 2003, initially in Cingular in North America. It appears as an evolutionary standard on the way to the Universal Mobile Telecommunications Service (UMTS). Although the cost versus time to market were no enough to bring it as a very successful system it was the solution for operators that did not win the UMTS licenses contest.

It is a digital mobile phone technology that allows increasing data transmission rate and improving data transmission reliability .It is also based in the GSM architecture allowing the use of the existing spectrum 800/900/1800 and 1900MHz. It is classified by ITU as a 3G network technology, but most people call it 2.75G as in reality the data rates that EDGE offers is not of the range of other 3G technologies and can be used for any packet switched application such as an internet connection, high-speed data applications such as video services and other multimedia can benefit from EGPRS' increased data capacity. With EDGE, data network improves the overall user experience when accessing data and rich content. It delivers throughput speeds on the network for end users with EDGE-enabled devices up to 4 times the current rate, by packing up to 69.2Kbps into eight timeslots, for a total theoretical DL of 473.6Kbps and 237kbps in the UL. As a GSM based system can support up to seven simultaneously users per carrier and a coverage range up to 30Km.

EDGE Evolution improves EDGE in a number of ways. Latencies are reduced by lowering the Time Transmission interval (TTI) by half (from 20 ms to 10 ms). Bit rates are increased using dual carriers, higher symbol rate and higher-order modulation (32 Quadrature Amplitude Modulation, QAM and 16QAM instead of 8-Phase Shift Keying, PSK), and "Turbo Codes" to improve error correction. Finally signal quality is improved using dual antennas. An EDGE Evolution terminal or network can support only some of these improvements, or roll them out in stages.

A driver for evolution in the telecommunication world is the paradigm shift from circuit-switch to packet switch. Both GPRS and EDGE radio access networks require modifications to support packet switching, so this is the next step for evolution, Figure 36, [93].

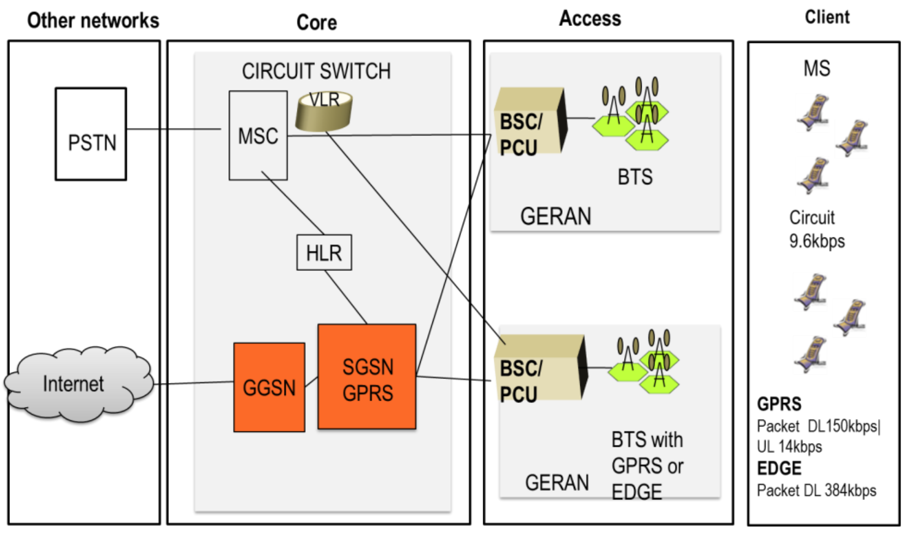


Figure 36 - GSM and GPRS network architecture, Adapted by the authors from ETSI [93]. From the author.

The main elements in the GSM network are described next.

Mobile station, MS or User Equipment, UE

- *SIM card* –Card located in the mobile phone that identify each subscriber and terminal (International Mobile Subscriber Identity)
- Mobile phone – Refers to the terminal equipment used by the user. It may be of the following categories, Table 2.

Class	***Type***	***Transmission Power [W]***	***Transmission Power [dBm]***
Class 2	Car Kit	8	39
Class 3	Transportable mobile unit (discontinued);	5	37
Class 4	Mobile phone	2	33
Class 5	Dual mobile phone	0,8	31

Table 2– Mobile classes. Source ETSI, [94].

Base Station Subsystem- BSS

- BTS: Base Transceiver System: is the connection through the radio channel between the UE and the network BSS. It has no processing capability. Also commonly referred to as site or base station consists of antennas; cables (feeders, top and bottom jumpers); combiners and the radio frequency transmitters and receivers.

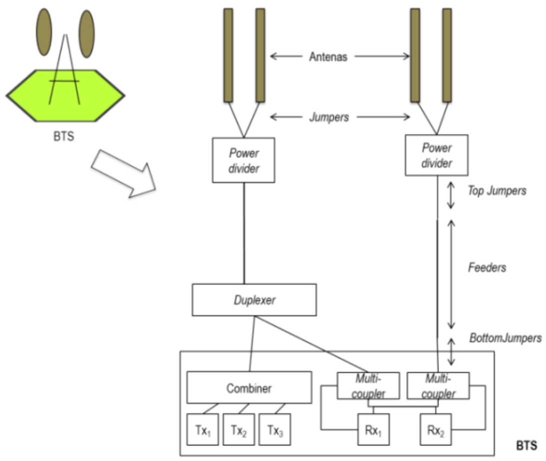


Figure 37 – Inside a GSM base station, BTS. Adapted by the author from manufacture datasheets.

- BSC: Base Station Controller: Receives the data sent by the MS and BTS in order to make the decisions that were necessary. It has a switching capacity and performs all processing of data concerning the radio interface. Only a limited number of base stations can be connected to one BSC, even though in the last BSC generations this capacity has increase enormously (e.g. in the beginning of the 90's only 12 to 15 BTS could be connected per BSC, in the 10's can reach to 100.).

MSC: Mobile Switching Centre

- MSC: It is an intelligent switching node with all the functionality of a circuit-switched network. Is interconnected to the public network (PSTN) via a Gateway MSC (GMSC) to ensure the routing of calls that have a fixed number of such addressee or originator. The MSC is responsible for checking the authentication of MS who wish to make calls in their service area and management of mobility. An MSC can support multiple BSCs connected to each other.

- *G-MSC:Gateway* Mobile Switching Centre: Connects the network to public network PSTN and internet cloud.

Operation and Support Subsystem - OSS

- HLR: Home Location Register*: Contains the records for all clients belonging to the network operator. The HLR also contains information about the current location of each of its registers on the information that is sent whenever a customer enters the service area of a different VLR.*
- VLR: Visited Location Register*: Keeps track of all the MS that are in every moment, in the service area of that VLR. It also includes registration and customers of other networks that have roaming agreement with the network operator.*
- OMC: Operation & Maintenance Centre*: It is the command center and supervising the entire system under the supervision of alarms: power failures, cuts the lines of leased lines 2Mb/s or optical fibers or problems in BTS .From this spot one can extract statistics from the operating system elements as e.g. traffic, dropped calls, congestion. Also here is the loading of new versions of network software.*
- EIR: Equipment Identity Register*: It is a database containing an identification of all the MS allowed to operate on the network. It is a security measure to ensure that equipment stolen or having problems, after detected from IMEI (International Mobile Equipment Identity), are not authorized to access the network. Most operators, even at international level, share their data to prevent theft of equipment and later reactivation in a different operator.*
- AUC: Authentication Centre*: It's another element of the security system of the GSM. Is intrinsically linked to the VLR containing all information concerning the security authentication of a client. In particular all the billing information or some other impediment threatens the client in question.*

The changes introduced by the GPRS are the introduction of the following blocks:

BSC: Base Station Controller

- PCU (Packet Control Unit): GPRS radio management functions;

OSS: Operation and Support Subsystem

- SGSN (Serving GPRS Supporting Node): routing, charging, interworking with GSM network;
- GGSN (Gateway GPRS Supporting Node): gateway and firewall, routing and roaming.

The numbering in GSM is an international ISDN number assigned to each user. The number assigned to each user of the mobile network is called MSISDN (Mobile Subscriber ISDN number) is basically a country code, country code (CC), a national destination code national destination code (NDC) and subscriber number (SN). The MSISDN number is used to call another user over the public network PSTN / ISDN, being used to route the call to the GMSC the GSM network. The GMSC then uses the MSISDN to interrogate the HLR for that user if everything is correct, in order to forward information to the MSC visited.

UMTS R99 - Universal Mobile Telecommunications System

International Mobile Telecommunications-2000 (IMT-2000), [95] is the global standard for third generation (3G) wireless communications, defined by a set of interdependent ITU Recommendations. ITU Recommendation ITU-R M.1457, [8] specifies five types of 3G radio interfaces:

- IMT-2000 CDMA Direct Spread, also known as UTRA FDD including WCDMA in Japan, ARIB / DoCoMo recommendation. UMTS is developed by 3GPP.

- IMT-2000 CDMA Multi-carrier, also known as Cdma2000 (3X) developed by 3GPP2. IMT-2000 CDMA2000 includes 1X components, like cdma2000 1X EV-DO.
- IMT-2000 CDMA TDD, also known as UTRA TDD and TD-SCDMA. TD-SCDMA is developed in China and supported by TD-SCDMA Forum
- IMT-2000 TDMA Single Carrier, also known as UWC-136 (Edge) supported by UWCC
- IMT-2000 DECT supported by DECT Forum.

The vision of an international and uniform telecommunication´s standard became a step ahead with the GSM evolution and first deployable release of the third generation: the UMTS release 99, also known as W-CDMA, developed within 3GPP (www.3gpp.org) and ITU (www.itu.int). The architecture is most similar to GSM/GPRS and in the generally of the cases if the operators have the two licenses for both 2G and 3G, the sites and antennas are co-located. Most of Europe regulators reserved the band around 2GHz exclusively for UMTS mobile service.

UMTS R99 (Release 1999) includes the original W-CDMA scheme using paired or unpaired 5 MHz wide channels bandwidth around 2 GHz and the radio access provide for Frequency Division Duplex (FDD) and Time Division Duplex (TDD), allowing UMTS Terrestrial Radio Access (UTRA) technology to operate in a wide range of bands and co-exist with other radio access technologies. The modulation used is W-CDMA (*Wide-Band Code-Division Multiple Access*) or CDMA2000 (*Code Division Multiple Access*) to provide the transport of bigger quantities of data, it did not exceed the theoretical 2Mbps in the downlink and 384kps in the uplink both in excellent coverage conditions and unloaded network. Even if it hasn´t the exponential growth as GSM had previously, there was a rapid growth of UMTS market led to a focus on its next significant evolutionary phase, namely Release 5 [96], to achieve higher data transfer speeds and capacity.

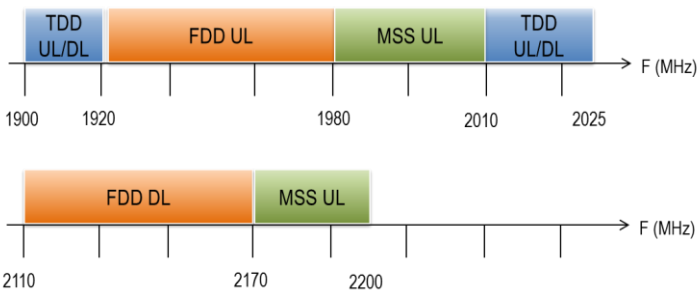


Figure 38 – Spectrum allocation for UMTS.

With UMTS system the output values mobile for data communications started to become a reality. New services of Internet access and video telephony rose to offer to subscribers a new range of services in addition to voice such as the first access terminal data to a PC via USB thumb drive.

The main differences for the R99 UMTS and the previous generation GSM/GPRS are the frequencies band that are higher and uniform worldwide, 2GHz; the modulation QPSK BPSK in DL and UL; the multiple access technique CDMA; the Radio Interface; the complexity of cell design; the maximum bit rate up to 2Mbps; the type packet- oriented network (IP and ATM) instead of Circuit Switch only (CS) and it is an IMT2000 is the first mobile system a standard accepted worldwide.

The architecture of the UMTS mobile phone and is often co-located with pre-existing GSM network. This means that many poles and towers can be used to install new antennas and the space leased to the BTS can be renegotiated to accommodate the new 3G device, Node B. Yet all the equipment is new because it works at a different frequency, like the Core undergo major changes. Compared to GSM it was necessary to change to new mobile phones; new BTS, from BTS to Node B; new network control, from BSC to RNC (Radio Network Controller); new transmitter antennas and oblige to major changes at Core Network.

The access network on the GSM and GPRS is called GERAN (GSM EDGE Radio Access Network) and network access for the UMTS is called UTRAN (UMTS Terrestrial Radio Access Network), Figure 39.

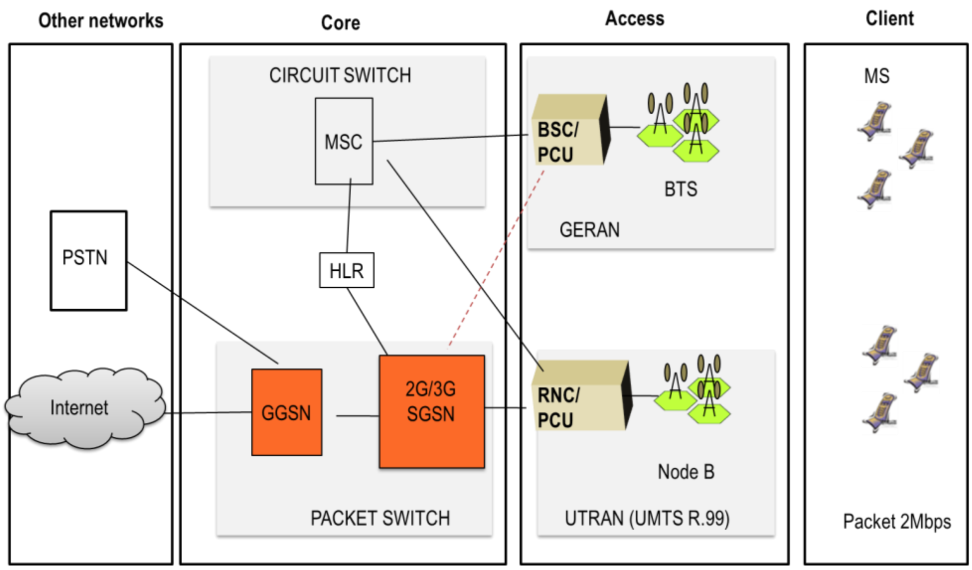


Figure 39- GSM and UMTS R99 architecture´s, Source: Adapted from 3GPP [97]. From the author.

The described modifications allowed new services to end users for example faster access to Internet, availability of higher bandwidth and use of Non-real time services such as e-mail. Services may be available via Circuit Switch as voice and data services without time constraints with multiple debts, LCD (Long Constrained Delay data) 64kbps, 144kbps or 384kbps or service via a packet data (Packet Switch, PS) without time constraint, UDD (Unconstrained Delay date) 64kbps, 144kbps and 384kbps.

The growing usage of mobile internet was the beginning of a new era and a new value chain for operators. The new applications available to the general public gradually guide the operators to extend their field of action once limited to the network itself, to the fields of content and applications, leading to the convergence previous mention (see). The operator´s revenue switch from the network services to the application services and contents.

UMTS 900

Since the emergence of networks of mobile data communications, demand is growing exponentially all over the world being limited expansion in capacity and coverage of UMTS. Thus emerged the idea, as in GSM to use a new frequency band [98], to another area where it could expand and capacity and also increase the penetration and indoor coverage radius of reducing the costs of building more stations basis, not only due to the fact that if you use a lower frequency as the possibility of co-located with the GSM sites[99]. Therefore UMTS uses the 900MHz band and it is called UMTS900. Figure 40 presents the coverage radius of the same UMTS system at two different frequencies: 2GHz and 900MHz, and also for two different case circuit switch 64kbps (CS64) and packet switch at 384kbps (PS384).

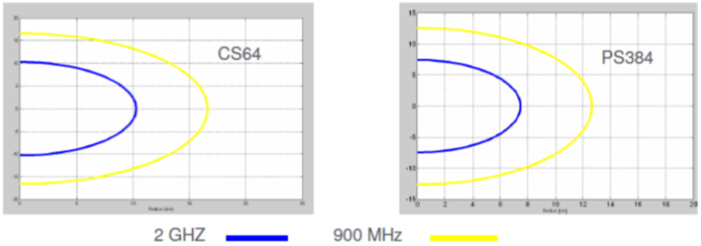


Figure 40 – Comparison of the coverage radius UMTS at different frequency bands and for different service types. Source: Nortel [99].

<u>*UMTS HSxPA*</u>

The next standard evolution at the 3GPP family concerning high speed communications is High-Speed x Packet Access. The x equals to D means downlink (Release 5, [100]) and x equals to U means uplink (Release 6, [101]). From this point forward the aim is to get rid of the circuit switch core network and create an all IP based network, but remaining the real time services, Figure 42.

The issue with the real time services required that a connection is actually made between the points of communication while in a data communication, for example a mail is sent by client to server protocol, which means the mail is sent to a server and then the mail client will later download the mail to its own computer.

To solve the problem of real time services in all IP solutions, 3GPP adopted the SIP – Session Initiation Protocol. Because this process is difficult to control a new platform was added IMS IP Multimedia Subsystem which allows the control of the SIP, for example to billing. IMS is also relevant to QoS control, specifically the delay which is the most sensitivity problem in real time services. The IMS is also relevant to application developers to allow the network behavior to be completely transparent.

Beside the introduction of the IMS, the other changes from the previous release 99, were at the level of software updates at the SGSN, RNC and Node B and several hardware changes where it is relevant to mention new power amplifiers; the review of the capacity of the links RNC / SGSN and ATM / PDH due to the increased volume of data transported and also new RF cards at the Node B from the operator point of view. From the subscriber point of view, the need of new mobile devices: mobile phones and pen drives were required.

At Release 6 the circuit switch is implemented again, as IMS is open to other wireless technologies that are not 3GPP standards as WiMAX (**Error! Reference source not found.**), Figure 42.

In UMTS the most important control is the power control both in downlink and in uplink channels. The total amount of transmitted power is divided among all the users. In the DL sometime there is non-used power leading to waste of capacity. The protocol High-Speed Downlink Packet Access (HSDPA) was the first in the 3G mobile telephony protocol in the HSxPA family that reuses this unused power and allows the usage of higher modulation schemes, leading to high speed communications, Figure 41.

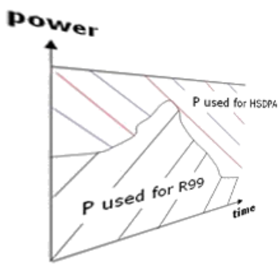


Figure 41 – Power usage by UMTS R.99 and UMTS HSDPA. Source: 3GPP, http://www.3gpp.org/HSPA.

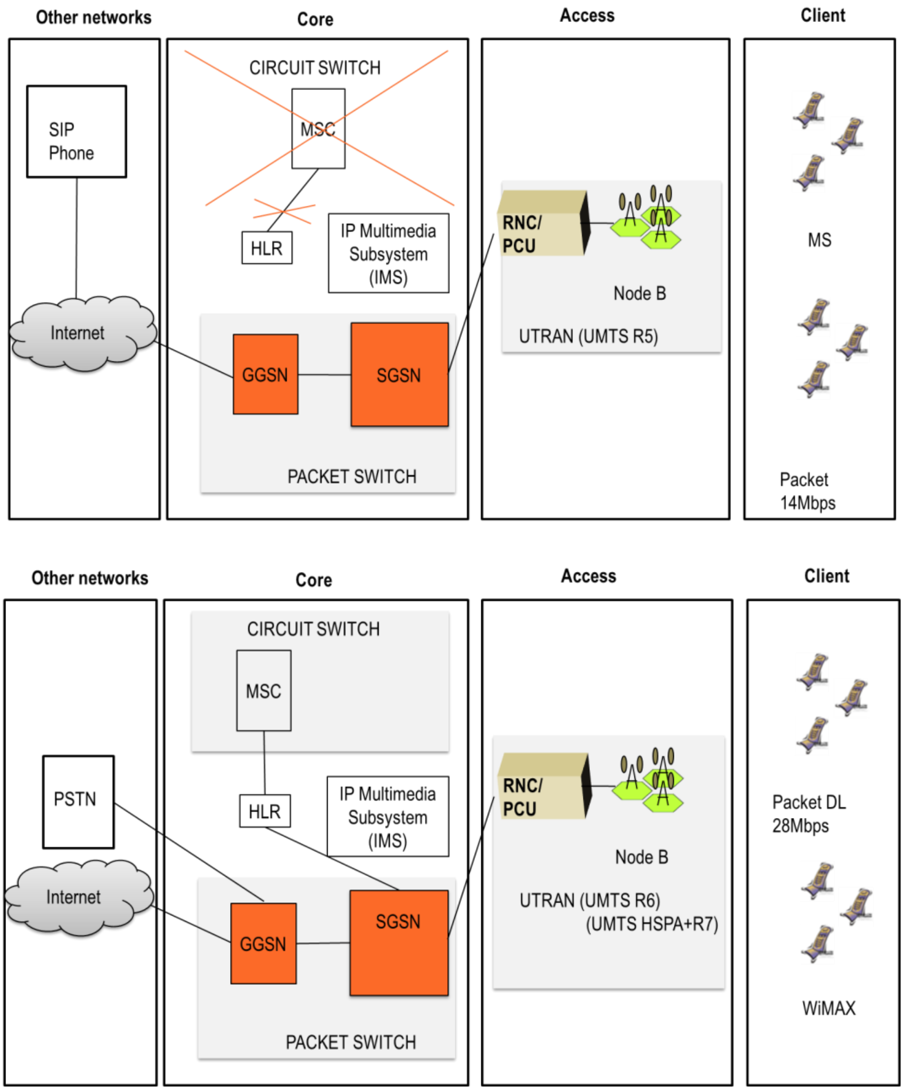


Figure 42 - UMTS Release 5 (up) and 6 (down) architecture´s, Source: Adapted from 3GPP, www.3gpp.org. From the author.

A plain UMTS network and an HSxPA UMTS network can be planned separately even though they might coexist at the same site. As an operator strategy, HSxPA implies typically the use of a second frequency to off load the UMTS traffic and the HSDPA UMTS site can be co-located with the UMTS existent network, [102]. This strategy is use in hotspots and keeps the CAPEX investment minimum, reducing the deployment of new sites and infrastructures rental.

Soon an identical protocol in uplink appears, the HSUPA. A current HSDPA/HSUPA supports up to 14.4Mbps in the DL and 5.76Mbps in the UL and represents the fastest 3G wide range wireless Internet access protocol. It is IP-based transport instead of ATM in Core. Releases 7 and 8, allow radio enhancements including 64 QAM that will reach the 28/42Mbps in the DL and 11.5Mbps in the UL. The available bandwidth is shared between the users each radio sector covers. So these numbers concerns theoretically limits that depend on the distance to the cell and on the number of simultaneously users.

With the evolution HSDPA or HSDPA + and with the introduction of MIMO (Multi-Input Multi-Output) described in the IEEE 802.16e standard is expected to double the bit rate of 14Mbps to 28Mbps per site, making way for the new generation of high-output radio system. The MIMO systems are a set of transmission techniques for wireless communication systems with multiple antennas in transmission and reception, Figure 43.

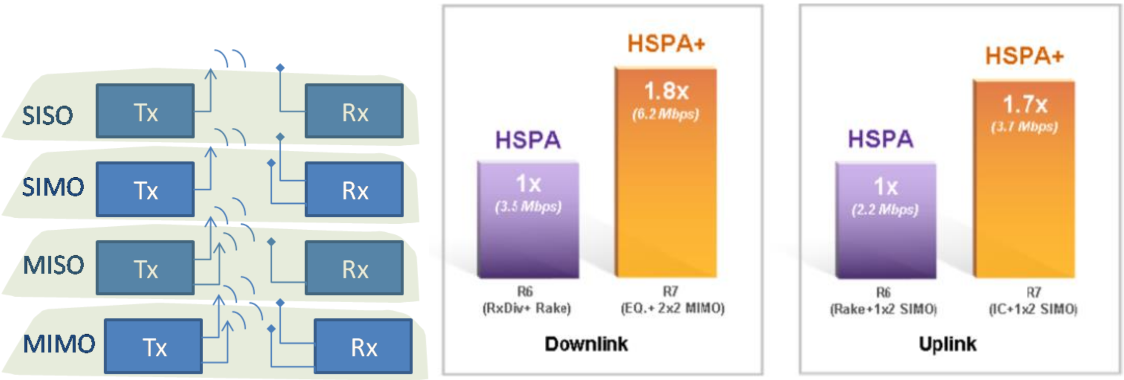


Figure 43 –SISO, SIMO, MISO, MIMO and impact at HSDPA+, [103].

<u>LTE – Long Term Evolution</u>

Third generation mobile systems enabled access to broadband in day-to-day and impacts the way of life of societies and organizations. As the penetration spreads worldwide the emergence of more and more applications, such as online games, mobile TV, and Web 2.0, demand new requirements of the infrastructure of mobile networks as traffic access to the Internet and e-mail exceeds the GSM / UMTS capacity.

Political power is aware of the evolution of telecommunications networks and their implications as a development factor of the population and the economy, and the sector uses its power to mobilize all actors in the sector to move forward quickly to new technology generations, either within the fixed networks ([104]) as mobile. In 2009 the European Commission (EC) published the Long Term Evolution (LTE) as the next step in the transformation of mobile networks in mobile broadband networks, in what will be the fourth generation mobile, [105], contributing for the convergence in the same technology of equipment suppliers and operators, over IP.

LTE [106] (3GPP Long Term Evolution), is the natural evolution of 3GPP GSM and UMTS WCDMA networks. LTE will only allow Packet switch, and voice will be driven by IP, will continue to maintain SMS as well as emergency calls including location support. It will enables fixed to mobile migrations of Internet applications such as Voice over IP (VoIP), video streaming, music downloading, mobile TV and many others, LTE networks and will also provide the capacity to support the increasing demand for connectivity from a new generation of consumer devices tailored to those new mobile applications. The LTE specifications, 3GPP *release* 8/9 [7], aim to lower the cost per bit, simplify the architecture, decreasing the consumption of the terminal equipment and optimizing the use of bandwidth previously used and even other bands.

To reach higher debts in transmission a new technique is used the OFDM (Orthogonal Frequency Division Multiplex) and new antenna technology MIMO (Multiple Input Multiple Output) is mandatory. LTE, combining OFDM and MIMO, will provide 2 to 5 times greater spectral efficiency than the most advanced 3G networks reducing the cost per bit and allowing better economics for operators and end users, [107].

The main features and enhancement of LTE to UMTS/HSPA include increasing the bit rate of 3 to 4 times at release 6, DL throughput of 100 Mbps (20 MHz spectrum) and UL 50 Mbps (20 MHz spectrum), a better latency (<5ms), at least 200 users per site, mobility at 5-15 km/h, it is packet switch only and eliminates redundancy of functions between the access network and the core, [108]:

[7] *In http://www.3gpp.org/LTE*

The main e-UTRAN characteristics are: a "flat" architecture where there is no RNC; control & data scheduling; simplified RRC; QoS aware; IP Transport; PS only network with VoIP and SON – Self-Organizing Network. The eNodeB has replaced the functions of the UMTS RNC, connecting directly to the Mobility Management Entity , MME in the Evolved Packet Core, EPC, [109] [110], Figure 44.

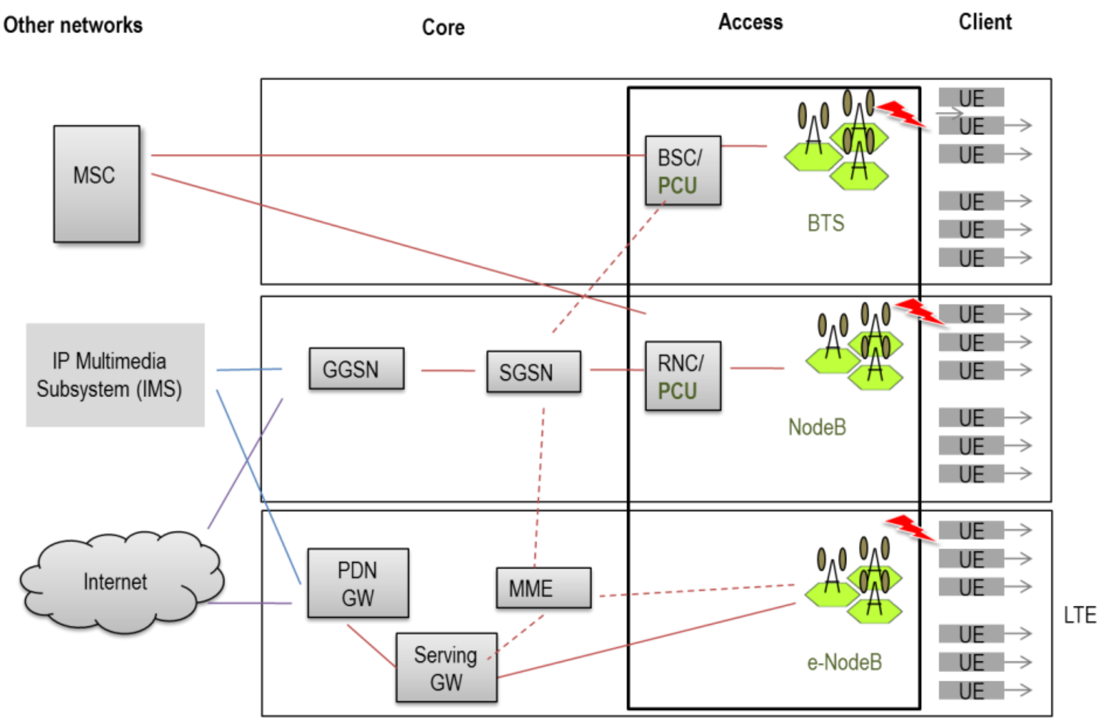


Figure 44 – Mobile architecture evolution, from GSM to LTE. Source: Adapted from 3GPP.

The following table aims to present the improvements debit in different stages of evolution of 3G network, [111], Table 3 and Figure 45.

Parameters	***WCDMA (UMTS)***	***HSxPA (HSDPA / HSUPA)***	***HSxPA+***	***LTE***
Max DL(bps)	384 k	14 M	28 M	100M
Max UL(bps)	128 k	5.7 M	11 M	50 M
Latency, round trip	150 ms	100 ms	50ms (max)	~10 ms
3GPP releases	Rel 99/4	Rel 5 / 6	Rel 7	Rel 8
Modulation	CDMA	CDMA	CDMA	OFDMA / SC-FDMA

Table 3– Comparison bit rate among 3GPP releases, [111]

A new standard called LTE-Advanced, LTE Release10 is already giving its first step. In LTE-Advanced focus is on higher capacity: with an increased peak data rate, DL 3 Gbps and UL 1.5 Gbps. The new standard presents higher spectral efficiency from a maximum of 16bps/Hz in R8 to 30 bps/Hz in R10 and also an increase number of simultaneously active subscribers. The main new functionalities introduced in LTE-Advanced are Carrier Aggregation (CA), enhanced use of multi-antenna techniques and support for Relay Nodes (RN), Figure 45, [112].

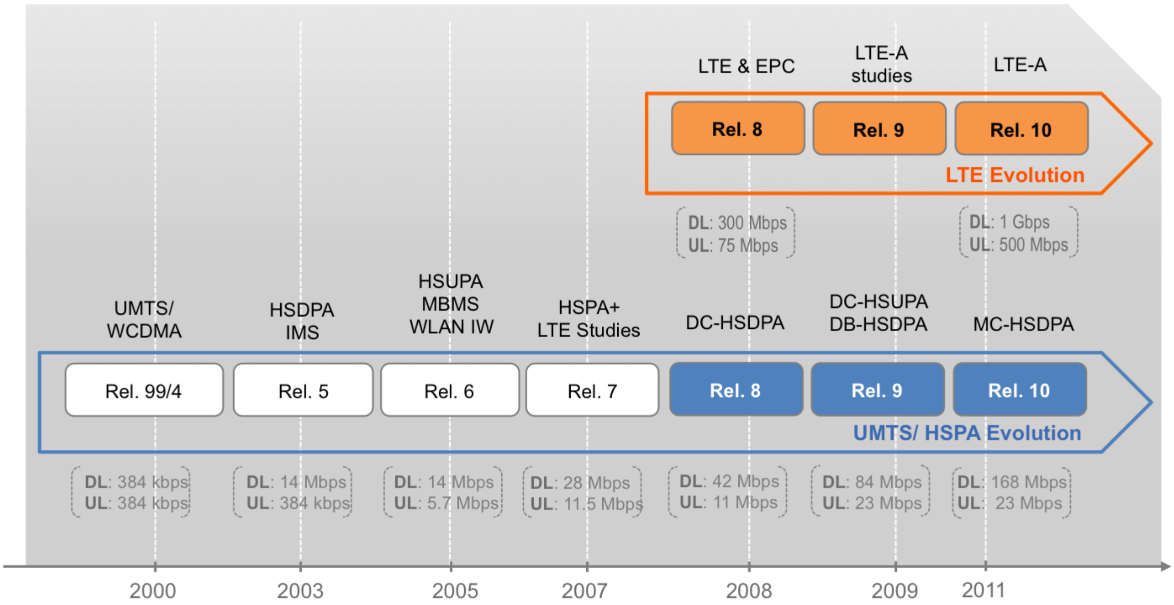


Figure 45 – 3GPP specs evolution. Source: IKUAL courtesy.

LTE itself is a new model in the access standard, , Fig.21. Conceptually the architecture is not quite different from the previous generations and savings can be achieved in base stations renting by co-locating the sites with existing GSM or UMTS sites and also by the elimination of the RNCs as part of its intelligence and decisions will pass to the evolved- Node B [113]. To achieve and guarantee high transmissions debts it is predict that the sites inter-.distance should be lower than GSM (typically 750m in an urban area) or even UMTS (typically 350 to 400m in high traffic density) so more base stations will be needed considering the same costumer penetration rate.

3.2 Broadcasting

Radio

The transmission medium used in the radio services is the free space, where carriers are modulated in amplitude or frequency, AM and FM. When the amplitude of the carrier wave varies according to variations in the frequency and intensity of a sound signal is called modulation AM. When the frequency of the carrier wave varies within a level set at a rate equal to the frequency of a sound signal, called FM modulation. These systems have evolved to present a better quality, which led to the emergence of digital audio broadcasting (DAB - Digital Broadcasting Audio, *[114]*). The digital broadcasting supports between 6 to 17 radio stations, enabling transmission speeds of around 1.5 Mbps.

In Portugal in 2011, it was revoked the right of use of frequencies associated with the service TDAB [115]. No country has so far set a date to "switch-off" FM. So far, in a limited number of countries, in Western Europe and Australia, DAB systems are operational, but still FM networks are running as before.

Television

Technological developments in television distribution is the gateway to the digitalization of broadcasting (DTT - Digital Terrestrial Television), based on DVB-T [116] which will replace the current analogue terrestrial. Digital television is transmitted using radio frequency signals, just like traditional television, but allowing reception of multiple channels on a single frequency range. Digital TV is the designation that means the technology that enables digital transmission of television signals, offering considerably better - given, among others, greater immunity to disturbances in the picture - and providing room for more television channels. The advantage with digital transmission replaces analogue transmission, in various types of media such as cable, satellite and terrestrial broadcasting.

The digital broadcast technologies adopted by the European Union, EU, are based on the digital video broadcast (DVB) standards issued by ETSI, [117, 118]. The most common standards are respectively DVB-T for terrestrial broadcast architectures and DVB-S2 for broadcast by satellite, usually named Direct-to-Home (home). Recently DVB-T2 [119] is also appearing in some networks with the main target to provide HDTV using MPEG4 encoding for fixed rooftop reception [120] offering significant benefits concerning spectral efficiency, increased number of broadcast programmes to be accommodate in the same multiplexer and increasing coverage area due to new guard intervals reducing interference from distant sites.

The terrestrial deployment is supported most of the time by a transport network within optical fibers or occasionally by microwave links. Some of the DTT licenses´ mention the possibility of a country's coverage with a mixture of DVB-T, terrestrial broadcast for a certain percentage of the population and DVB-S, satellite broadcast as a complementary for zones without adequate terrestrial broadcasting infrastructures, called shadow zones.

Figure 46 and Figure 47 illustrate the overall architecture of a digital television network, considering the case of a single frequency network (SFN). From left to right, it is shown that each TV channel or radio operator sends their contents to the broadcast operator´s digital broadcast center, DBC, to be multiplexed and converted in the DVB transport stream, TS. Then this DVB frame can be broadcast by different access means: by terrestrial or by satellite transmission, until the viewer´s TV set.

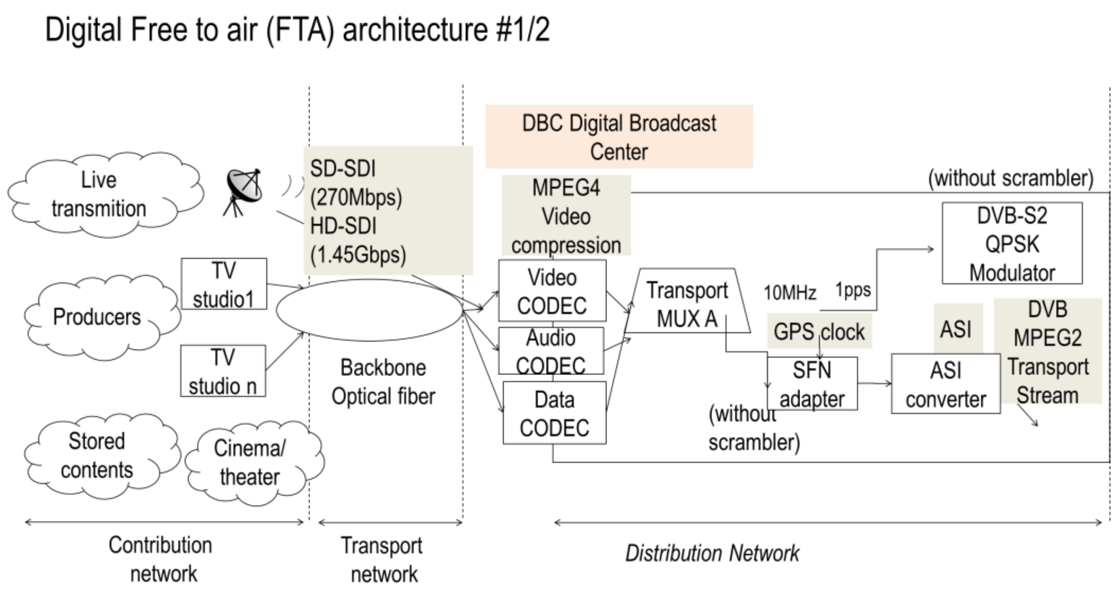


Figure 46- Broadcast free to air system´s architecture part 1. Adapted by the authors from [117, 118].

A terrestrial broadcast network operator's roll-out of a digital terrestrial TV broadcast (DTTB), network will have the following key cost categories taking into account in this study.

Contribution network: The net contribution starts at the beginning of the value chain of the audiovisual sector, in content production. These may come from different locations and arrive at television or radio studios in various formats: by radio, by satellite or via optical fiber networks. In each studio, the post-production "*creates*" the programmatic channel with the delivered contents and send it to the broadcaster at the DBC, digital broadcast center, Figure 46.

Transport network: The programmatic channel at this phase is an uncompressed signal that is send via a fiber optic network. One of the most common interfaces used in television studio is the Serial Digital Interface (SDI). This is an interface in which the bits of a data word are sent consecutively via a single transmission channel with debts of 270Mbps in standard mode (SD-SDI). In case it is a signal with higher quality the HD-SDI signal has a debt of 1.45 Gbps. The serial interface is capable of carrying audio, video, and can also be used to transport data packets in accordance with ITU-R BT.1364, [121], [122, 123], Figure 46.

Distribution network: The Digital Broadcast Center receives all the programmatic channels for encoding and multiplexing. Each signal, corresponding to a programmatic channel, arrives at the DBC as a signal SDI, without any type of compression. Each video or audio signal is then encoded with more or less compression (MPEG 2 or 4) and all the channels are combined in an aggregator stream with multiple inputs ASI, to different multiplexers (in case of more than one multiplexer). At each multiplexer the DVB MPEG 2, transport stream (TS) is built and encapsulated in an ASI (Asynchronous Serial Interface), which will carry one or more programmatic channels (in HD or in SD). In case it is a free to air network (FTA) the signal does not requires additional coding, in the case of a pay TV broadcast channel, it is at this point where the codification of the signal takes place. In the case of a single frequency network, the TS pass by a single frequency adapter to ensure synchronization between the network and each of DTT stations. Synchronization failures result in loss of frames and mutual interference, originating quality loss or failure with the total absence of signal reception, Figure 46.

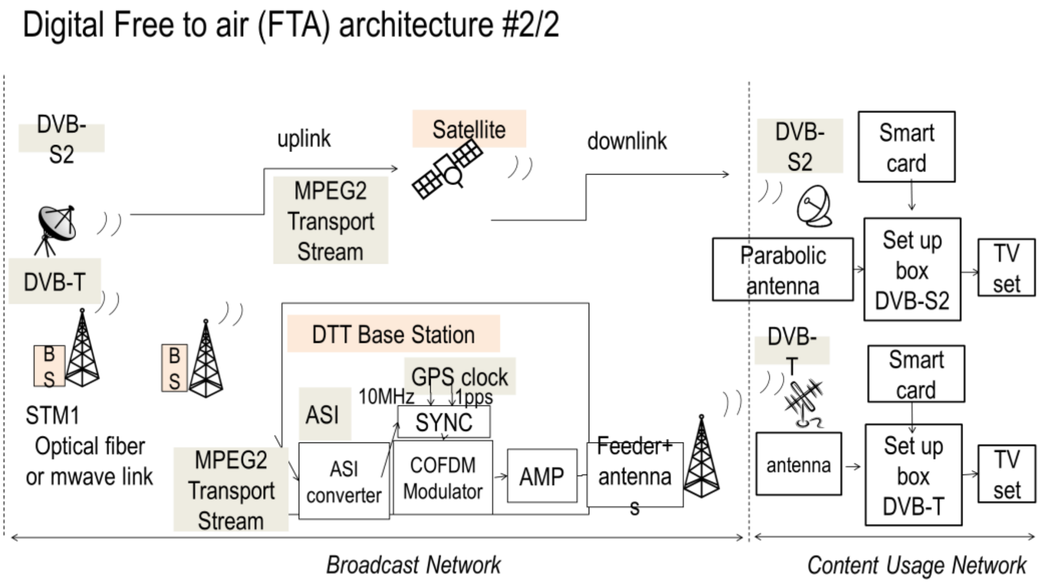


Figure 47 - Broadcast free to air system´s architecture part 2. Adapted by the authors from [117, 118].

Satellite broadcast network: The satellite broadcast is characterized by a rough propagation scenario, so it is necessary to have robust codification and noise immunity to avoid high bit error rate. In this case the signal is modulated as quadrature phase shift keying (QPSK) which is different from the DVB-T based scheme. The most common standard is DVB-S2 that has around 36% of performance gain of useful bitrate (Mbit/s) over the previous standard DVB-S, [124], [125], Figure 47.

The output signal, uplink, leaves the Earth station to a geostationary satellite, which will later be received individually in each home via a satellite dish (downlink). The broadcast network does not depend on any telecom infrastructure on the ground as is made by a user receiver if located inside a satellite's footprint coverage area. This type of solution is most of the time a turnkey lease solution chosen by the TV broadcaster leasing the full transport service to a satellite operator. The DVB-S2 system can be used with single carrier per transponder or multi-carrier per transponder, [116], Figure 47.

Terrestrial broadcast network: In the case of the transmission of terrestrial digital TV, the signal leaves the broadcast center in DVB-ASI mode towards the transmission sites, the terrestrial base stations by point to point radio connections or through a fiber optics infrastructure (dense wavelength division multiplexing, DWDM and synchronous digital hierarchy, SDH networks, at national or regional level). In each one of the base stations, the signal is encoded as coded orthogonal frequency-division multiplexing (COFDM[8]) and its synchronization is made with a GPS clock, in parallel. The signal is amplified and sent to a tower or elevated structure (buildings or water towers) and broadcast in panel arrays with four or five antennas which together simulate an omnidirectional radiation pattern.

Client network: This network segment corresponds to the equipment necessary to receive digital television at each home. The cost of this system is supported by the client, or sometimes subsidized by the operator. At the time of analog-digital transition, viewers in the proximity of the base station were able to maintain the same receiving antennas, others had to reorient them and others had to acquired higher gain antennas or switch to parabolic dishes. All of them needed to acquire either a digital television either a digital set-up box (DVB-T or DVB-S2). The DTH solution is technically complex requiring most of the times an expert intervention for a correct installation, Figure 47.

3.3 Wireline Networks Technologies

For several decades the fixed networks were confined to the twister pair of copper which delivered the traditionally voice communications also known as the Plain Old Telephone Service (POTS). The twisted pair wire consists in two 1mm copper wires in parallel towards each one of the subscribers. It is with this physical support that the Universal Service obligations are imposed in most of the European countries. Soon it became possible to use different technologies as ISDN and DSLx and became possible also transport data and allow internet access.

In parallel the coaxial cable appears initially to deliver TV but nowadays also offers fixed telephone and internet access. Like twisted pair, coaxial cable also consists in two copper wires, but concentric to each other. With this type of cable construction, data can travel at higher rates. In coaxial cables there are also different technologies in use as ADSL, ADSL2+, DOC SIS1 and DOC SIS3 that allows up to 100Mbps per user.

Until the late 90's of the previous century the optical fiber path was used only for the core network (both for wireline and wireless networks) as it allows huge amount for bandwidth and so far no other application seems suitable for this expensive physical support. However with the increase of internet traffic and broadband applications, the fiber passed the barrier to reach subscriber's homes leading to the new generation networks, the so called "Fibber to the Home", (FTTH). Optical fiber is a flexible, thin medium that lead light pulses, where each represent a bit. Because it carries nothing more than light, it is immune to electromagnetic interference, thus allowing the signal integration several kilometers without attenuation. It supports tremendous bit rates, up to hundreds of GHz and allows symmetric traffic in DL and UL without band sharing among users as in wireless systems.

[8] High-performance DVB-T COFDM. Available on line, access January 2013: www.realtek.com.tw/products/productsView.aspx?Langid=1&PNid=22&PFid=35&Level=4&Conn=3&ProdID=146

3.3.1 Copper Twisted pair

PSTN - Public Switched Telephone Network

The existing twisted pair infrastructure in the access network has been installed in the past for the public switched telephone network (PSTN), and it provides the traditional voice service POTS (Plain Old Telephone Service). The system was originally known as the Post Office Telephone Service, Figure 48.

Although it is called old it does not mean it is old fashion or obsolete, it is still one of the most reliable systems ever build and provides extensive connectivity of world´s population. It is regularly updated and restored here and there. Portugal Telecom invests every year around 250 million Euros in the cooper network in restoring and maintenance as some parts of the network dated the 30´s of the previous century

Individual houses and businesses were connected to their central telephone office via individual cables at, by today's standard, very slow speeds. Central offices, on the other hand, were connected to each other with what would become known as a T1 or E1 line which provides 1.544Mbps and 2.048Mbps respectively. Originally by using Frequency Division Multiplexing (FDM) channel multiplexers costumer were constrained to a 4KHz bandwidth for the voice channel and modems operated at 9.6, 19.2, 28.8 and 33kbits/s , [126].

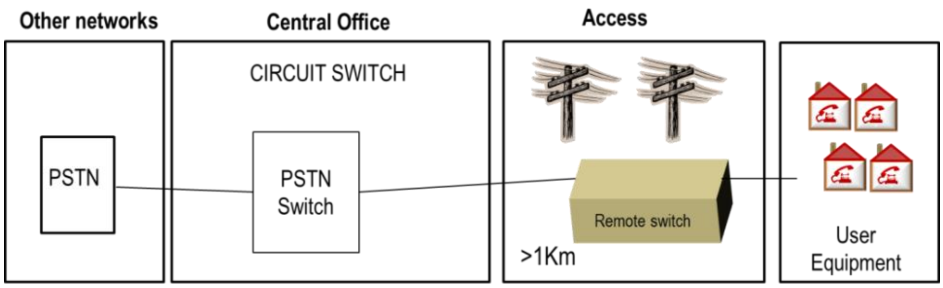


Figure 48 - POTS basic architecture. From the author.

As technology evolved with time, the path became utilized for more functions than just transmitting voice communications. Today, the path is used to transmit voice, data, voice and data, fax, and inter-channel signaling to invoke custom features, and much, much more. In some applications, the "twisted pairs" are double to create a four-wire communications path, which is capable of bearing even greater amounts of signals. ´

In the early 1980s, T1/E1 migrated to the local loop-also known as the last mile. The local loop is the distance between the local office and the end user, usually about 4 km. The use of digital modulation codes as Pulse Code Modulation (PCM) allowed the narrow-band data transport of 64kb/s.

By the time optical fibre began to raise in the beginning of the XXI century, some announced the end of twisted pair due to its low bit rates. But twisted pair did not give up. Modern copper wires technology relatively recently called Copper Distributed Data Interface (CDDI) [127] is the implementation of FDDI protocols over twisted-pair copper wire and can provide 100-Mbps service over copper.

ISDN - Integrated Services Digital Network

ISDN, which stands for Integrated Services Digital Network, is a system of digital phone connections which allows voice and data to be transmitted simultaneously across the world using end-to-end digital connectivity by using frequencies above the voice band. Roughly is like the telephone line has virtually "double", and in one wired pair line there is the voice channel and in the other the data channel.

In most countries ISDN uses a frequency range of 80 kHz. The ISDN-BRI (Basic Rate Interface) is also known as 2B+D. This is because it consists of 2 B Channels with a speed of 64 Kbps, and 1 D Channel with a speed of 16 Kbps. Since ISDN BRI has 2*64 Kbps B Channels, it has a 128 Kbps maximum data rate. ISDN BRI was developed for Internet connections used in small businesses and homes the ISDN PRI is designed for industrial and large-scale users and can combine up to 23 (T1) or 30(E1) B channels to achieve up to 2048 bps.

ISDN owes its success to its integrated services and multiple user channels in a single line, high quality and supplementary services such as call holding, automatic call-back, calling line identification; fast call set-up and quite reasonable data communication prices. In some European countries as France ISDN is included as a Universal Service obligation, [49].

3.3.2 The Digital Subscriber Line, DSL family

As xDSL reuses the existing copper infrastructure (both coaxial and twisted pair) enabled far faster data transmission it is a cost-effective solution and a 50 times faster transmitting data path. A DSL connection is always on and due to the different frequency used it works in parallel with standard telephone service, just by adding a small line filter in the wall jack. Although it uses the telephone lines it differs from dial-up internet that only allows 56kps, by using digital transmission that can reach the 256kps, downloading.

There are several DSL technologies, among them and chronologically: HDSL- Higher Rate Digital Subscriber Line; ADSL- Asymmetric Digital Subscriber Line and VDSL- Very high bit-rate Digital Line Subscriber. The throughput of this type of connection depends on the distance between the end user and the Digital Subscriber Line Access Multiplexer (DSLAM), so the commitment distance / transmission rate is one of the most important factors to take into account. In order to reach distances between the subscriber house and the central office (CO) bigger than 5500Km a remote DSLAM is simply a DSALM that is placed in a Remote Terminal instead of a CO. Usually the remote terminal is fed by fiber and then copper is used from there to the residence.

HSDL decreases the cost of installing T1/E1 lines, and significantly decreases the amount of time required to install them. With certain hardware enhancements or heavier gauge copper it can facilitate connectivity over distances up to 7 km and delivers up to 1.544 Mbps of bandwidth each way (DL and UL) over the two existing copper twisted pairs. The operating range of HDSL is limited to 3658.5 meters, so signal repeaters are installed to extend the service.

ADSL is the most popular xDSL technology. Due to its asymmetric nature, it is well suited for web browsing, rather than traditional DSL. It delivers higher downstream speeds (8Mbps) than upstream speeds (640kbps). ADSL2 and ADSL2+ are improved version of ADSL, which can reach 24Mbps in the DL for 2Km range, Figure 49.

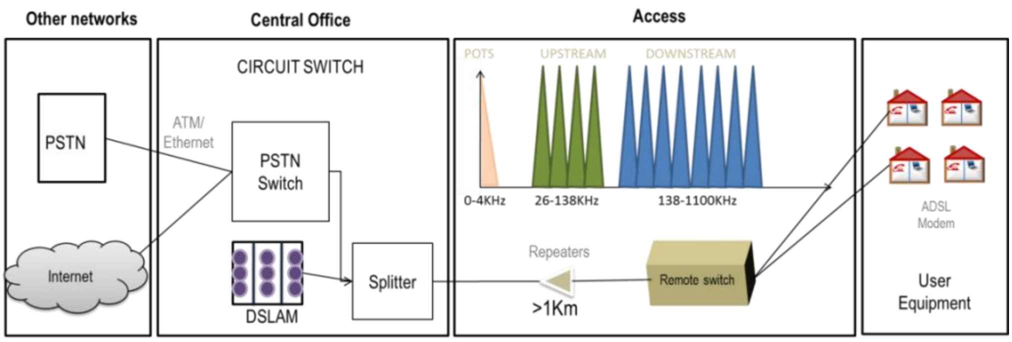


Figure 49- ADSL architecture. From the author.

Since the bandwidth available in coaxial cable is quite high; at a frequency around 450MHz it has been exploited to provide data network with maximum debts of 4Gbps. However this amount of bandwidth is not at all available to each costumer. In opposite to the ADSL, cable is a resource shared among all the users. In consequence depending on the number of users, the typical debt per internet coaxial cable client is between 500kbps and 1.5Mbps, downstream and 256kps for upload. As it is highly dependent from the charge of the network internet cable providers cannot guarantee a fixed throughput.

The Distribution Area (DA) of an ADSL coaxial network can have in some cases a loop length of 3,6Km. But the introduction of VDSL or ADSL2/ADSL2+ is limiting the DA loop length distances to between 900m and 1,5Km. In the CO fed distribution area of a cooper outside plant (OSP) is around 5,5Km.

Very-high-bit-rate digital subscriber line, VDSL was the next generation DSL at accelerated rates of 52 Mbps in the DL and 12 Mbps in the UL, [128]. The next generation VDSL2 allows a symmetrical throughput of 100Mbps, [129].

3.3.3 Coaxial Cable

Cable operators have been refreshing its commercial offer, from an exclusive TV service, to include voice and video. The technology that allows the video services over the same cable infrastructure used for high-speed data and voice over IP is Data over Cable Service Interface Specification, DOCSIS.

Over just a few short years, the DOCSIS has evolved as the industry standard for ensuring interoperability between cable modems at the subscriber location and Cable Modem Termination System (CMTS) platforms at the operator's headend, [130]. Nowadays the use of the IP protocol on the interface is DOCSIS 3.0 support operators against offering high-speed fiber networks, anytime, anywhere at any device. The associated architecture DOCSIS IPTV Bypass Architecture configures an edge router to forward the repetitive video packets to DOCSIS encapsulation in a substantial cost reduction compared to Cable Modem Termination System (CMTS), [131].

3.3.4 HFC (Hybrid Fiber/Coax) network

The hybrid Fiber/Coax network is a natural evolution of cable TV networks. The adoption of a mixed network consisted of a fiber-optic and coaxial cable in different portions of the network and enables greater interactivity to the system.

Using HFC, a local CATV company installs fiber optic cable from the cable head-end (distribution center) to serving nodes located close to business and residential users and from these nodes uses coaxial cable to individual businesses and homes. An advantage of HFC is that some of the characteristics of fiber optic cable (high bandwidth and low noise and interference susceptibility) can be brought close to the user without having to replace the existing coaxial cable that is installed all the way to the home and business.

3.3.5 Passive Optical Networks

The feasibility of using optical fiber in the access system rises with increasing of broadband services. Since the 90s it has been placed great expectations on network solutions based on optical fiber in the access network, such as being able to permanently solve the problem of getting home each customer with broadband access, allowing access services of voice, video and data with an appropriate level of QoS.

The use of technical and optical passive components (PON) access network has contributed significantly to the implementation of this type of architecture, this standard was normalized by ITU-T, G.984 [132]. For historical registration, following is the list of some of the main standards on this technology in ascending time order:

- ITU-T G.982 (1996), "*Optical access networks to support services up to the ISDN primary rate*", an early STM-PON, [132];
- ITU-T G.983.1 (1998), "*Broadband optical access systems based on Passive Optical Networks (PON)*", the ATM-PON System, [133];
- ITU-T G.983.3 (2001), "*A broadband optical access system with increased service capability by wavelength allocation*", the B-PON system, [134];
- ITU-T G.652 (2003), "*Transmission media and optical systems characteristics – Characteristics of a single-mode optical fiber and cable*", [135];
- ITU-T G.984.1 (2003), "*GPON: General characteristics*", Core G-PON requirements, [136];
- ITU-T G.984.5 (2007),"*G-PON: Enhancement band* ",Ready for XG-PON, [137];
- ITU-T G.984.2 (2008),"*GPON: Physical Media Dependent (PMD) layer specification*", Core G-PON PMD layer, [132];
- ITU-T G.984. 3 (2008)," *GPON Transmission convergence layer specification* ", Core G-PON TC layer, [138];
- ITU-T G.984.4 (2008),"*GPON: ONT management and control interface specification* ", Core G-PON management, [139];
- ITU-T G.984.6 (2008)," *GPON: Reach extension* ", Reach extenders >20Km, [140];
- ITU-T G.984.7 (2010),"GPON: Long reach", Long reach extenders =40Km, [141];
- ITU-T G.987 (2012)," 10-Gigabit-capable passive optical network (XG-PON) systems: Definitions, abbreviations and acronyms", XG-PON is a subclass of NG-PON1, [142].

Technology	*Type*	*Wavelength (down/up)*	*Speed*	*Standard*
EFM fiber	*Active*	*1550/1310*	*100 Mbps*	*802.3ah*
		1490/1310	*1Gbps*	
G.985	*Active*	*1550/1310*	*100 Mbps*	*G.985*
EPON	*Passive*	*1490/1310*	*1Gbps*	*802.3ah*
APON	*Passive*	*1490/1310*	*155Mbps, 622Mbps*	*G.983.1*
		1550/1310		*G.983.3*
GPON	*Passive*	*1490/1310*	*2.5Gbps DS/1.25 Universal Service*	*G.984*
10GE-PON	*Passive*		*10Gbps symmetrical*	*G.987*
XGPON1	*Passive*		*10 Gbps*	
XGPON2	*Passive*		*40Gbps?*	

Table 4 – ITU PON standard evolution. Source: ITU.

APON/BPON (ITU-T G.983)

APON, ATM PON, [143], is the initial PON specifications defined by the FSAN committee used ATM as their layer 2 signaling protocol. It needs active switches at the office center. APON systems are based upon ATM as the bearer protocol. Downstream transmission is a continuous ATM stream at a bit rate of 155.52 Mbps or 622.08 Mbps with dedicated Physical Layer OAM (PLOAM) cells inserted into the data stream.

EPON (IEEE 802.3a)

Ethernet Passive Optical Network (EPON), [143] is a point to multipoint (P2MP) network topology implemented with passive optical splitters, along with optical fiber PMDs that support this topology. EPON is based upon a mechanism named MPCP (Multi-Point Control Protocol), which uses messages, state machines, and timers, to control access to a P2MP topology. It been widely used in Japan, Korea, India, and others as the elected NFN, Fig. 24. (Note that the expression Gigabit EPON is synonymous with EPON.)

GPON (ITU-T G.984)

A PON is a passive optical network architecture that provides a point-to-multipoint and in which use power dividers to which a single optical fiber to serve multiple locations, typically 31, 64 or 128. It consists of a node of a CO called Optical Line Terminal (OLT), one or more client nodes, called Optical Network Units (ONU) or Optical Network Terminals (ONT) and the fibers and splitters between them that make up the network Optical Distribution Network (ODN);

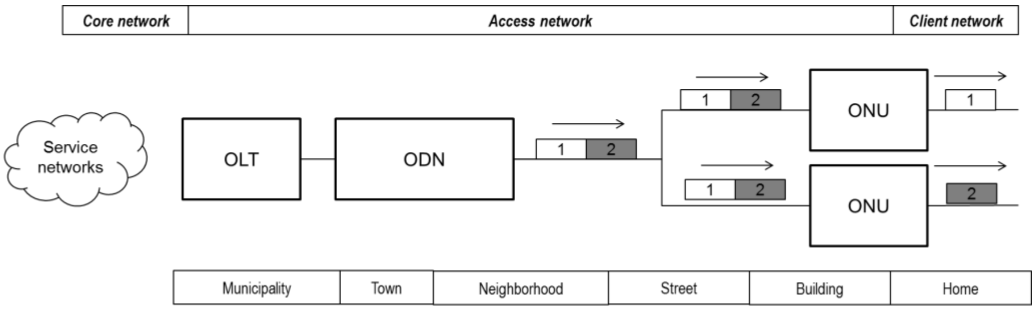


Figure 50 – Block Diagram of a Passive Optical network, Source ITU-T G.983 [133].

Gigabit PON is a PON technology operating at bit rates of above 1 Gbps. Apart from the need to support higher bit rates, the overall protocol has been opened for re-consideration and the sought solution should be the most optimal and efficient in terms of support for multiple services, OAM&P functionality and scalability.

GPON Standard	***ITU G.984***
Bit rates	Downstream: 2.5Gbit/s; Upstream: 1.25/2.5Gbit/s
Optical wavelengths	Downstream: 1490nm; Upstream: 1310nm
Supported ODN classes	A,B and C (15/20/25dB)
Split ratio	1:32/1:64/1:128
Fiber distance	20Km
Transmission Format	Ethernet, ATM, TDM

Table 5 – GPON main characteristics. Source: ITU, [132].

The main GPON requirements are: full service support C including voice (TDM, both SONET and SDH), Ethernet (10/100 BaseT), ATM, leased lines and more. Physical reach at least 20 km. It supports various bit rates options using the same protocol, including symmetrical 622 Mbps, symmetrical 1.25 Gbps, 2.5 Gbps Downstream and 1.25 Gbps Upstream and more. It is being widely chosen by North American and European operators.

The basic diagram of an passive optical network is according the ITU specifications as Figure [133]. This work focuses the dimensioning of a GPON network:

- The optical line termination –OLT is located at the Central office.
- The optical distribution network -ODN) which provides the optical transmission means from the OLT towards the users, and vice versa using passive optical components, The ODN is the main part of the FTTx network; its construction directly affects the total cost, system performance, reliability and the upgrade potential.
- The optical network unit - ONU provides (directly or remotely) the user-side interface. It is expected that there is no change of intermediate ONU is required to upgrade access network capabilities to accommodate future evolution of broadband and multimedia services.

A PON network takes advantage of wavelength division multiplexing (WDM), using one wavelength for downstream traffic and another for upstream traffic on a single non dispersion-shifted fiber [135]. The process of transporting data downstream to end users in GPONs is different from that of transporting data upstream to the OLT. In downstream transmission, data are broadcasted from the OLT to each ONU using the entire bandwidth of the downstream channel, and all the downstream data are carried in one wavelength. ONU´s selectively receive frames by matching the address in the Ethernet frames. The broadcast and select architecture of GPON allows downstream multimedia services like video (IP HDTV) broadcasting. In the upstream direction, multiple

ONU´s share the common upstream channel and send their traffic in the upstream wavelength. Only a single ONU may transmit during a time slot in order to avoid data collisions. It is noteworthy that each ONU transmits directly to the OLT, but not to other ONUs. An ONU buffers the frames from end users until its time slot arrives, where it bursts out their buffered frames to the OLT at full GPON channel speed. [132] [144].

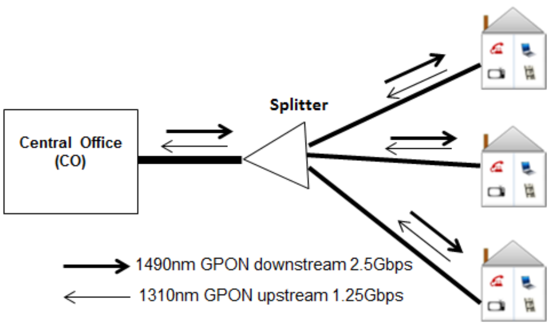


Figure 51 – GPON up and downstream wavelength..

XG-GPON

Although GPON is widely perceived to possess sufficient bandwidth for the next few years, a 10G specification is currently being developed. Although NG-PON1 is as an asymmetric system it reaches rates of 10Gbps downstream and 2.5Gbps upstream. The selected NG-PON1 system is essentially an enhanced TDM PON from GPON.

NG-PON1, as the proposed standard is called, is a natural continuation in the evolution of PON technologies, increasing bandwidth four times to 10Gbps, reach from 20 to 60 km, and split from 64 to 128 – although reach and split maxima are not obtainable simultaneously. Most importantly, these evolutionary technologies will avoid the need for significant upgrades to the installed outside plant.

There are many techniques in play in the industry FSAN has attempted to structure these into “NGA1” and “NGA2”:

- NGA1 = 10G total capacity and compatibility with GPON. 10G serial transmission and CWDM multiplexing
- NGA2 = 40G total capacity and compatibility not necessary and true WDM PON, with 1G per wavelength

A possible evolution roadmap is purposed by Huawei, Figure 52,[145]

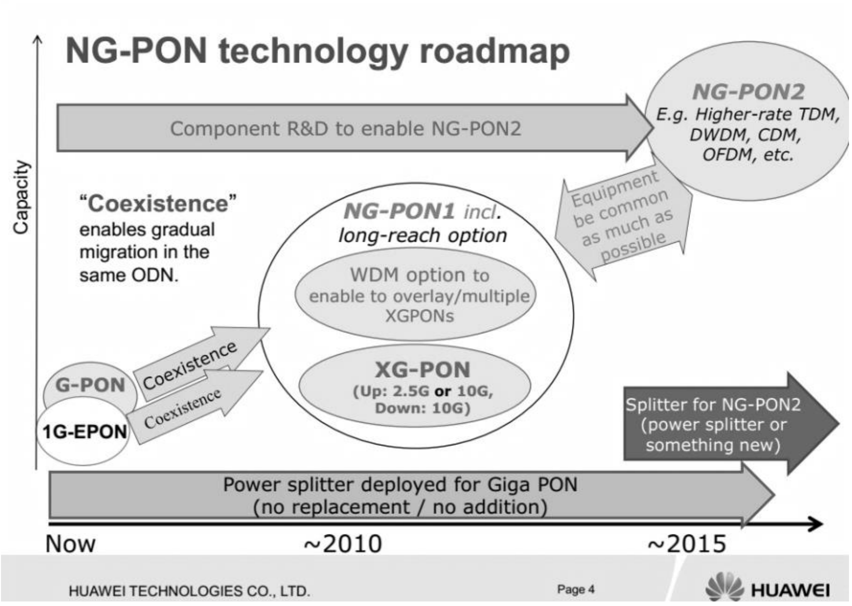


Figure 52 – Huawei vision for NG-PON evolution. Source: HUAWEI.

3.4 The New Generation Networks

The ITU broadband definition include the following characteristics, [146]:

- Packet-based transfer
- Separation of control functions among bearer capabilities, call/session, and application/service
- Decoupling of service provision from transport, and provision of open interfaces
- Support for a wide range of services, applications and mechanisms based on service building blocks (including real time/streaming/non-real time services and multi-media)
- Broadband capabilities with end-to-end QoS and equivalent conveyance of all services with the same QoS
- Interworking with legacy networks via open interfaces
- Generalized mobility
- Unfettered access by users to different service providers
- A variety of identification schemes which can be resolved to IP addresses for the purposes of routing in IP networks
- Unified service characteristics for the same service as perceived by the user
- Converged services between fixed and mobile networks
- Independence of service-related functions from underlying transport technologies
- Support of multiple last mile technologies

- Compliant with all regulatory requirements, for example concerning emergency communications and security/privacy.

The International Mobile Telecommunications-Advanced (IMT-Advanced) systems are mobile systems which include the new capabilities of IMT that go beyond those of IMT-2000. Such systems will provide access to a wide range of telecommunication services (including advanced mobile services), supported by mobile and fixed networks that are increasingly packet-based. In other words, IMT-Advanced (or 4G) will see a progression beyond third-'generation (3G) technology. The 4G target peak data rates agreed upon in ITU-R Working Party 8F [17] are "*up to approximately 100 Mbps for high mobility such as mobile access and up to approximately 1 Gbps for low mobility such as nomadic wireless access*", Figure 53.

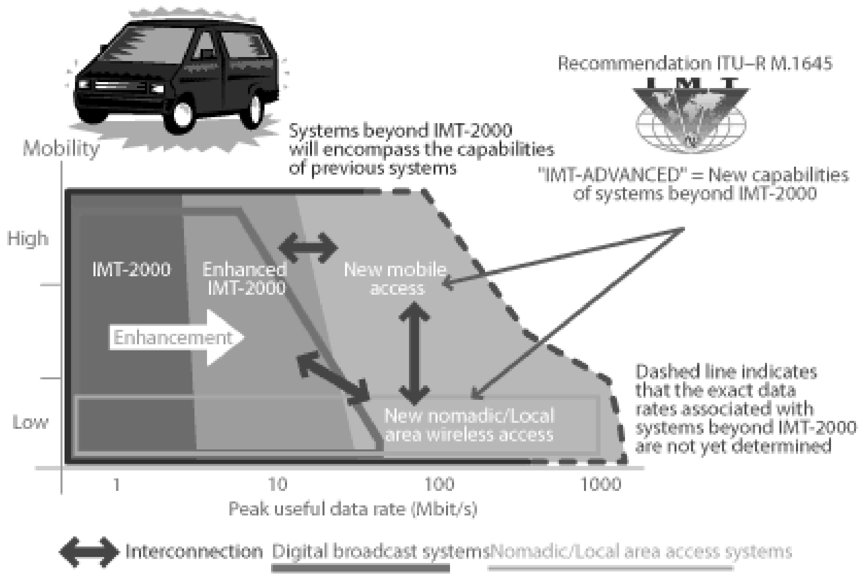


Figure 53–IMT Advanced, the "Van diagram". Source ITU.

In this section new candidates for future broadband communications will be briefly discussed. Those include the concept of cloud-radio access network (CRAN) and white space technology based on cognitive radios.

3.4.1 Cloud Radio Access Networks

The significant increase in data needs from the increasing information society is leading data providers to increase significant the available data rates to the final user. This is creating new ways to address the approach of providers to the distribution data plans. Some of the present ideas include the Wi-Fi offloading concept, where the data is redirected to a Wi-Fi network always when the user is in its coverage area, the Wi-Fi network in this case also belongs to the service provider, so this is in fact transparent for the final user.

With this concept proving a high reliability, data providers start to evaluate the concept of small cells or femtocells approach, where the base station is actually installed in the leaving room of the final user, that is the final user will have a low cost cell in its building that uses a wired connection to the operator itself, this way to distributed network will allow the increase of data throughput availability, the reduction of energy consumption from the operator point of view and the control of the network availability from the operator point of view.

This is driving the industry to a convergence of the radio access networks to a common radio interface, where all the decisions and the network operation are condensed centrally in the operator office, this new approach is called CRAN, that is cloud radio access network, where the radio interface is a very simplistic box, with mainly an antenna and a mixed-signal converter and the core of the protocol network approach is centralized by the operator in the Cloud.

3.4.2 White Space Communications using Cognitive Radio

In 2000 Prof. Mitola, [147] stated a new vision of wireless communication in his PhD thesis: "*The point in which wireless personal digital assistants and the related networks are sufficiently computationally intelligent about radio resources and related computer-to-computer communications to detect user communications needs as a function of use context, and to provide radio resources and wireless services most appropriate to those needs*". The door is now open to a new way of looking to the radio communications, where there were some facts assumed stable as the frequency spectrum attribute for each technology to work it. This idea was so disruptive that IEEE began a new standardization to study the Next Generation Radio and Spectrum Management, [148].

This new concept for radio technology is only possible with the significant increase in information processing using high speed processors. This fact combined with the fact that the DVB-T freed up a significant amount of spectrum, is moving researchers to think in a new technology called white space communications, where the radios will roam freely without any limitation of pre-established rules. In this case the radios should be aware of the interference and the surrounding frequencies been used and should have some form of "intelligence" that will give the hardware the capability to decide when to transmit, where to transmit (frequency) and which waveform to use (that is which modulation). In these futuristic scenarios the data provider will not have to be worried for the planning of the network neither the spectrum regulator should guarantee free part of the spectrum. This of course imposes significant a strong processing capability from the radio the core and the quality service manager.

3.5 Summary

In order to understand the context of the broadband networks, this section describes the most common implemented technologies concerning voice and data transfer. A quick historical overview, architectures, main characteristics and trends are described for the most common telecommunication networks in Portugal and in most countries of the work, technologies such as broadcast, wireless ad wireline communications.

The "after" new generation networks trends are also introduced.

Chapter 4. **TELECOMMUNICATIONS IN PORTUGAL: AN OVERVIEW**

The aim of this work is to evaluate the cost and implications of the Universal Service as a broadband benefactor to all citizens in Portugal. For that, this chapter will reflect on the current reality of the telecommunications sector of the country and evaluates a strategy to apply the developed tool TENTUS (described at Chapter 5) to Portugal.

4.1 Geography

Portugal is one of the oldest countries in Europe (born in the 5th of October 1143) at Iberian Peninsula and a member of the European Community, EC since 1986. It is situated in the south-western Europe with a total area of 92 050 Km^2 [18] and 2330km perimeter divided between the continental land and two archipelagos: Madeira and Azores. Madeira and Azores are two archipelagos in the North Atlantic. At the present time, the Portuguese outer limits are under revision by the United Nations Oceans´ law of sea, [19], to extend the ocean platform to 200 miles from continental shelf.

All the Iberian Peninsula is, overall, an upland area, split by the basins of major rivers. In Portugal it is in the north where there are the highest areas which concentrate 95% of altitudes above 400m and all the high peaks beyond the first 1000m. The South is dominated by lowlands and flattened where, above 500m, only some remaining reliefs are more resistant to erosion, Figure 54.

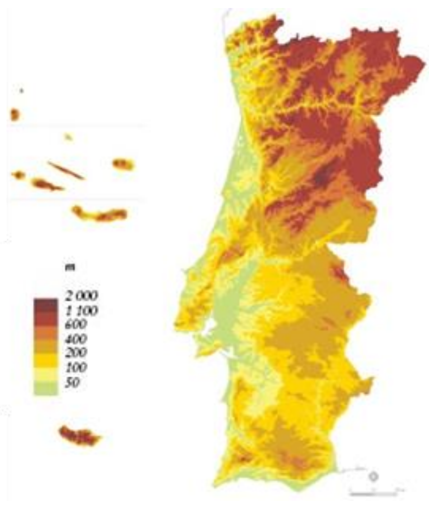


Figure 54 –Portugal´s relief.

4.2 Administrative divisions

The country is divided in administrative areas with the following hierarchy: “distritos” that contain the “concelhos” (municipalities) and the smallest part of the land distribution, “freguesias” (parish). This type of characterization of the territory concerns the geographical land distribution. There are 18 “distritos” in mainland plus the 3 “distrito” in the autonomous regions of Madeira and Azores. Each “distrito” is therefore subdivided in “concelhos” with a City Hall, “Câmara Municipal” and each “concelho” is divided in “freguesias” that are managed by “Junta de Freguesia”, Table 6.

As part of the National plan to reform the administrative divisions, in 2012 the entity Governo Civil (per district) was extinct leading to the reinforcement of the Inter-Municipalities Regions. In 2013 the parishes were grouped in the review of regional planning and were reduced from 4040 to 3091.

Administrative category	**Government Entity**	**Mainland**	**Madeira**	**Azores**
Distritos	*Governo Civil* (until 2012)	18	1	3
Municipalities *(Concelhos)*	City halls and Municipal Assembly	278	11	19
Freguesias	Civil Parishes	2881	54	156

Table 6 - Administrative division of Portugal in 2012.

The territorial unit “*freguesia*” does not match a village or a town. A city or a town can be subdivided in several “*freguesias*”. The following picture shows in detail this type of distribution for Portugal, Figure 55.

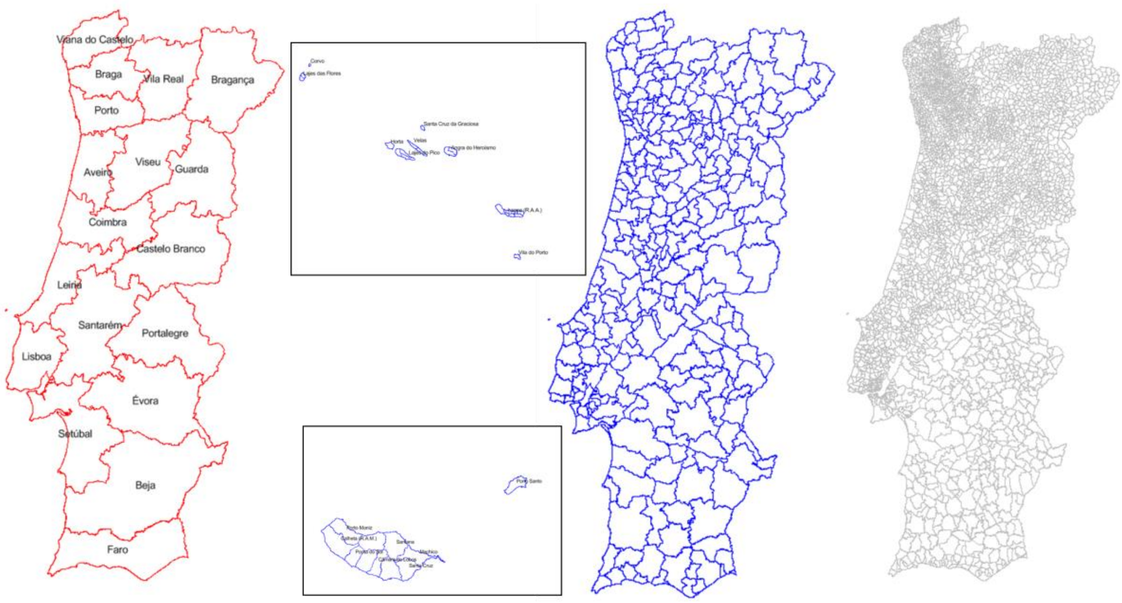


Figure 55-Administrative division of Portugal: “Distrito”, “Concelho” (with Islands) and “Freguesia” (from left to right,).

To become a town (“*vila*”) according to the Portuguese law (Art. 12, law11/82) it is necessary that some conditions are fulfilled, such as: more than 3000 voters, in a continuous agglomeration and at least half of the following equipment’s should be available: Medical assistance; Pharmaceutics; “Casa do Povo, dos Pescadores”, cultural center or other cultural associations; Public Transports; Post office; Shops, stores and hotels; School; Bank. Other reasons such as historical, cultural or architectural can justify the nominee for village without the previous requirements (Art. 12º, 13º and 14 [149]).

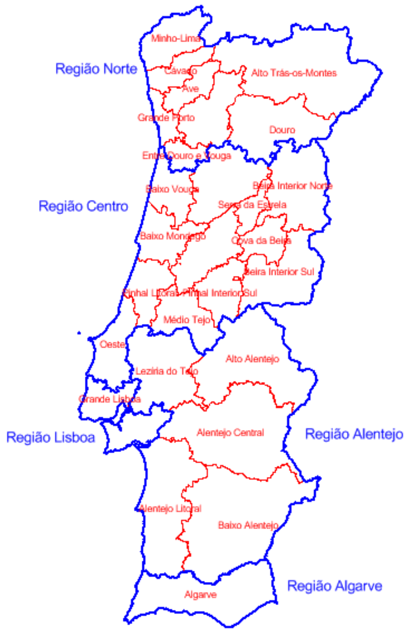
To became a city (”cidade”) it is necessary to fulfill the following requirements: (Art. 13 [149]): more than 8000 voters, in a continuous agglomeration; at least half of the following equipment’s should be available: Hospital or medical assistance 24h per day; Pharmaceutics; Fireman; Theatre and Cultural center; Museum and library; Hotels; Several degrees of schools; Public transports: urban and suburban; Parks and Public gardens. Other reasons such as historical, cultural or architectural can justify the nominee for town without the previous requirements (Art. 12º, 13º and Art. 14 [149]).

In parallel with the geographically distribution, one can find another type of characterization based on the population aggregation. A significant group of people living in the same area is called "*localidade*". The Portuguese population is divided in 15 654 "localidades". Depending on a various factors such as the number of inhabitants, the area and the public services offered that type of catalog lead us to the denominations as "Cidades", "Vilas" or "Populações".

For statics purposes the Nomenclature of Territorial Units for Statistics (NUTS) are adopted, developed and regulated by the European Union, Table 7.

Level	***Subdivisions***	**#**
NUTS I	Continente Portugal Região Autónoma dos Azores Região Autónoma dos Madeira	3
NUTS II *(map blue line)*	Regional Coordination Commissions + Autonomous regions	7
NUTS III *(map red line)*	Groups of Municipalities	30

Table 7– NUTs of Portugal in 2012.



In this study the granularity chosen to work with is the municipality, "concelhos" in a total of 308. They will be classified according some of the many available statistical variables, described in detail in the next sections, named GEOTYPES.

4.3 Demography

In 2011 Portugal total population is approximately 10,562,178 inhabitants. 95% of this population lives in the continental platform and 2.5% in Madeira and 2.3% in Azores. The population is concentrated in the continent along near 1230Km of coast and mainly in two major cities- Lisbon in the south and Porto in the north- and several small towns in the Atlantic West coast and in the Mediterranean Sea (Algarve district in the South). Inland the population is sparse in smaller towns and villages.

The last decade the trend is to stabilized the number of citizens (born and non-born). As it can be seen in detail from Figure 56, the comparison between 2005 and 2010 demonstrate the trend of the reduction of the number of children under 14 years-old and the raise of the population above 65. This data is on line with major countries in Europe where it is predictable that if the demographic evolution continues with this trend in twenty years from now the working age population will also be significantly reduced.

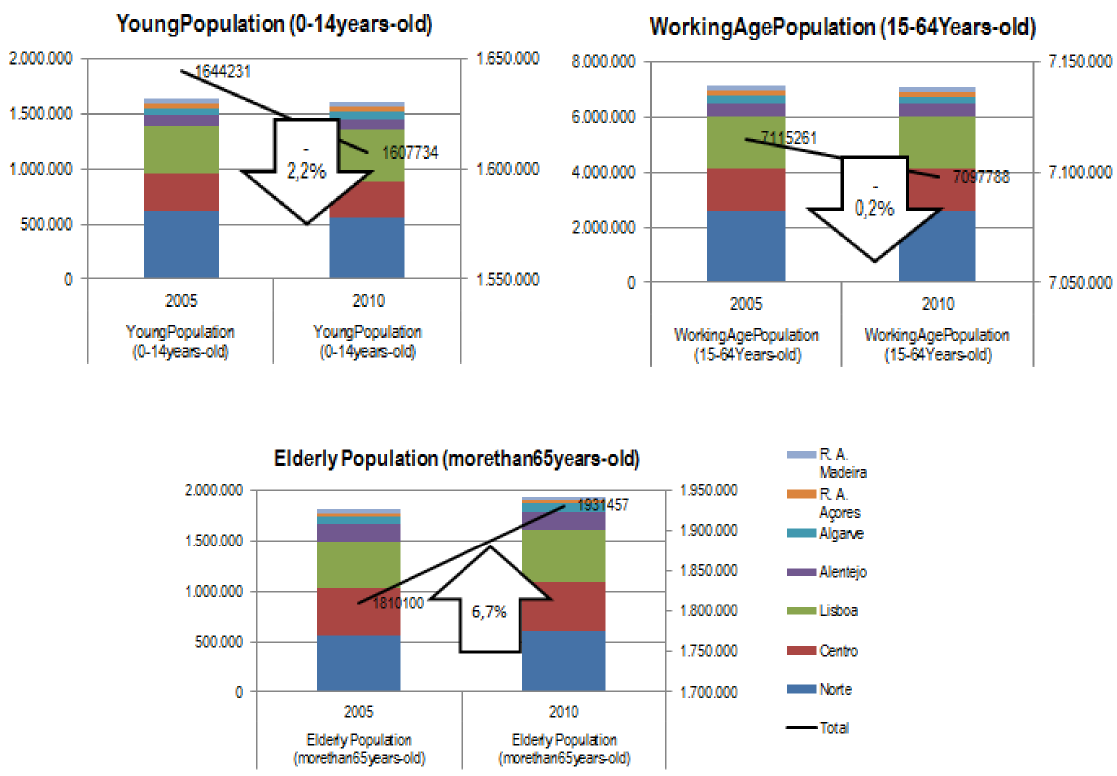


Figure 56 – Age distribution per population segment and per region, 2005 and 2010 comparison. Source: INE.

The children's population decreasing is more dramatic in the Norte region with 7.7% decrease and in the Centro region with -5% variations from 2005 to 2010. The same analysis per region presents that only Algarve and Lisboa regions contradict the less than 14 years-old population decreasing. Regions as Alentejo are suffering a relevant population loss as it can be seen at Figure 57 by the black bar with a negative evolution between 2005 and 2010 of 2.5% approximately.

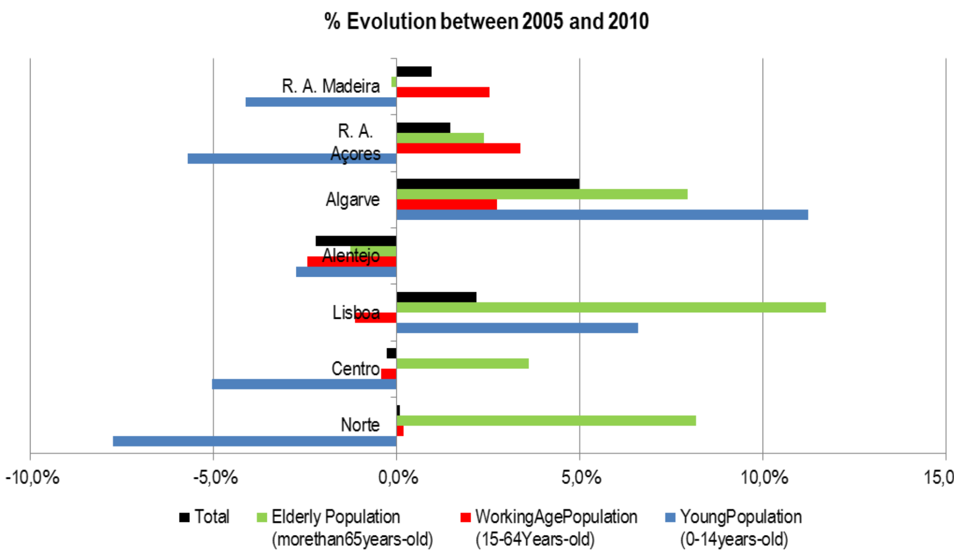


Figure 57- Percentage of population evolution betwwen2005 and 2010 per region.

The average number of households per building is 1.7 in the mainland (3.3 in Lisbon region), 1.4 in the Madeira and 1.1 in Azores. The average Portuguese family has 2.6 elements but this number reaches 2,9 and 3 in Madeira and Azores, [150]. As a note it can be seen that there are more buildings and houses than families. This might indicate that a relevant part of the homes are unoccupied.

	Area (Km^2)	*Families*	*Buildings*	*Houses*	*Inhabitants*
PORTUGAL	92,050	4,048,559	3,544,389	5,878,756	10,562,178
Continent	88,944	3,873,767	3,353,610	5,639,257	10,047,621
Madeira	785	92,936	91,961	129,643	267,785
Azores	2,321	81,856	98,818	109,856	246,772

Table 8 -- General Data of the territory of Portugal: area, perimeter and inhabitants. Source: Census INE 2011.

With the objective of getting an accurate geographical and territorial picture of Portugal, in this chapter the municipalities were classified in Geotypes based on several characteristics of population, area and housing types described in the next sections

4.4 Geotype characterization

In order to accurately characterize the territorial reality of Portugal, a classification method was proposed in this thesis to classify each Municipality using several variables based on socio-demographic items. This method has a starting point the Vergara´s approach in a similar context (developed for fiber deployments) for Spain [11]. The described method differs from Vergara´s in the final choice of variables and values that better pursuit the Portuguese reality as described in the following section.

First of all the municipalities were dived in classes depending on the total number of inhabitants based on 2011 Census. In parallel several variables were defined as the main key indicators of the social-demographic reality per municipality, Table 9. There are is a multiplicity of variables that can be used and several combinations were experimented. The ones chosen, concern some aspects of the socio-demographic characterization, lead to a final result considered suitable to the author´s empirical country knowledge. Those are the total population (POP), the number of dwelling units (DU), the population density per area (DPOP), the percentage of urban are with edification (%U_A); the maximum distance between the urban center and the further point of the municipality (DUC) and the ranges of the incomes in the Urban and Rural areas (UIn and RIn).

Variable	***Description***
POP	Population
DU	(Dwelling Units) "
DPOP	Population density per area (hab/Km2)
%U_A	Percentage of Urban Area with edification
DUC	Max distance of subsections to urban center (Km)
UIn	Urban Income Range (€)
RIn	Average Rural Income Range (€)

Table 9 – Geotype classification variables.

Then next table summarizes the adopted values for each one of the chosen variables to characterize each municipality.

<table>
<tr><th>GEOTYPE</th><th>POP</th><th>DU</th><th>DPOP</th><th>%U_A</th><th>DUC</th><th>UIn</th><th>RIn</th></tr>
<tr><td>10</td><td>>250K</td><td>>250K</td><td>>1200</td><td>UA>25%</td><td>DUC<10</td><td>[1000€, 1400€]</td><td>[600€, 750€]</td></tr>
<tr><td>9</td><td rowspan="2">50K<200K</td><td rowspan="3">50K<200K</td><td rowspan="4"><1200</td><td>5%<UA<25%</td><td rowspan="7">10<DUC<15</td><td rowspan="2">[700€, 1400€]</td><td rowspan="4">[600€, 990€]</td></tr>
<tr><td>8</td><td>UA<2%</td></tr>
<tr><td>7</td><td rowspan="3">10K<50K</td><td rowspan="7">UA<1%</td><td rowspan="2">[700€, 1200€]</td></tr>
<tr><td>6</td><td rowspan="3">10K<50K</td></tr>
<tr><td>5</td><td rowspan="5"><100</td><td rowspan="5">[700€, 1000€]</td><td rowspan="5">[600€, 880€]</td></tr>
<tr><td>4</td><td rowspan="3">1K<10K</td></tr>
<tr><td>3</td><td rowspan="2">1K<10K</td></tr>
<tr><td>2</td><td rowspan="2">DUC>15</td></tr>
<tr><td>1</td><td><1K</td><td><1K</td></tr>
</table>

Table 10 – List of variables values for Geotype characterization.

The final aspect of the Geotype classification is in the following figure. Beside the orange, yellow green scale related to the GEOTYPE classification, it also can be found a blue line concerning the "Distritos" and the Urban, Suburban and Rural agglomerations.

More urban zones contains more number of municipalities with high Geotype level (yellow and orange) as Aveiro, Lisboa and Porto; and more rural zones have more municipalities with low Geotype levels (green) as Évora, Portalegre and Vila Real.. As expected the more urban and dense areas are in the center-north offshore, while the northeast, center interior and part of Madeira and Azores are much more rural.

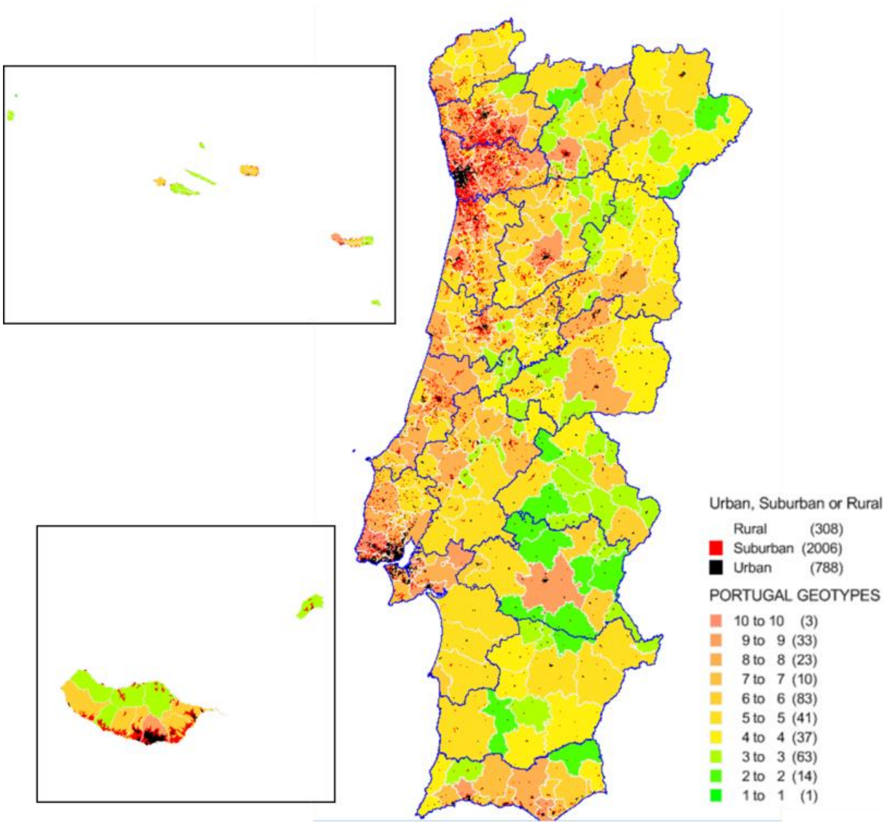


Figure 58 –Geotypes distribution of the municipalities per "Distrito" and with U, Su and Rural identification.

4.5 Brief History of Telecommunications in Portugal

Like many other European countries, the telecommunication history in Portugal can be separated in a two distinct phases: the incumbent monopoly and the market liberalization. Figure 59 illustrates these two phases and also identifies several important stages inside each phase.

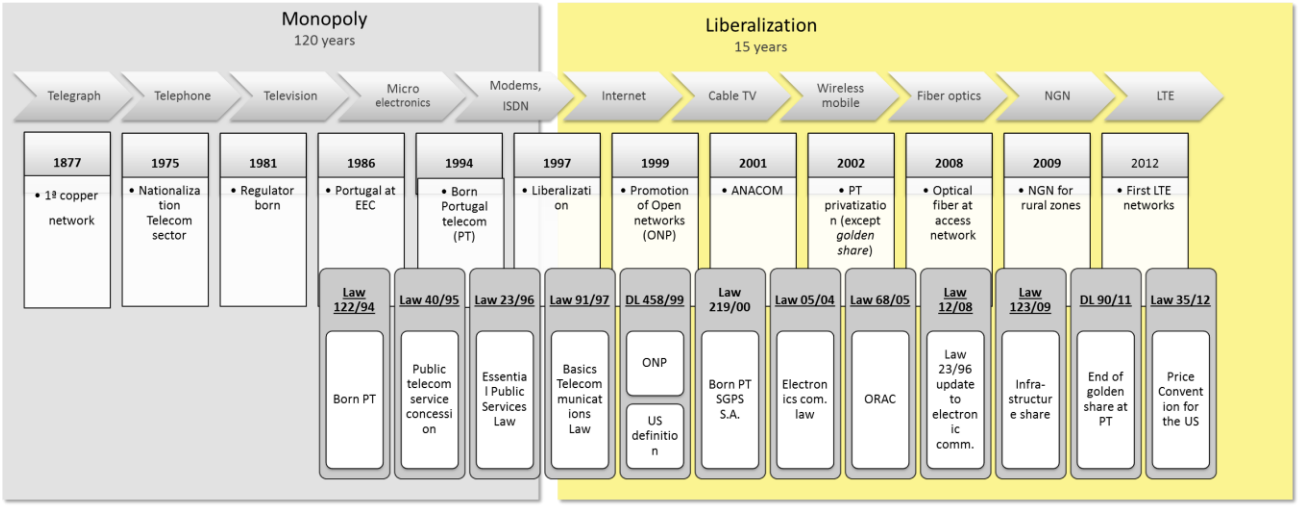


Figure 59 – Portuguese telecommunications history frame.

All these stages were followed in parallel by the technological development and such as the emergence of the Web in the beginning of the 90´s. As an answer to the public growing demand, the telecommunications market is providing alternative broadband infrastructures that are emerging and developing fast.

All around the world and namely in Europe, there is a new era of massive deployment of the New Generation telecommunications Networks (NGN). In this context it is highly relevant to observe how the telecommunications´ market regulatory framework has been evolving along the time in Portugal and to extrapolate the predominant needs of these new infrastructures.

The shape taken by regulation can have a strong impact in the success or the failure of this new stage in the telecommunications sector. This subject is a transversal issue for several countries in the world; however it is also relevant to identify the individual characteristics and constraints of the country reality. For this reason this thesis has its focus on one particular European country- Portugal.

The most relevant legislation concerning the telecommunications sector are presented in Table 11..

Law number	***Law name***	***Impact***
Decree-Law 40/95	Public Telecommunications Service Concession	Basis for the public telecommunications service. Exploitation given to PT as well as Universal Service obligations and financing, until 2025.
Law 23/96	Essential Public Services Law	Protect users of public services such as: water, electricity, gas and telephone, however not necessarily universal.
Law 91/97	The Telecommunications Law	The public network was open to competition but still state property (ONP). Thought the Universal Service obligation must be guarantee by PT.
Decree-Law 458/99	Essential Public Services Law	Transposition of the CE directive 97/33/EC [21] concerning Universal Service and the 98/10/EC [5] concerning interconnection in telecommunications through application of ONP.

Law 29/202	The Law Public telecommunications service concession	First amendment to Law 91/97. Determined the evolution of the concept of Universal Service.
Law 05/04	The Law of Electronic Communications	Allow users to functional internet access.
Law 12/08	Amend to Essential Public Services Law	The word “telephony” was replaced by “electronic communications”.
Decree-Law 123/09	Strategic guidelines for next generation networks (NGN)	Sets out the system’s general principles, namely the principles of competition, open access, non-discrimination, effectiveness and transparency. Regime governing the construction, access to and set up of electronic communications networks and infrastructures in buildings, housing developments and urban settlements (ITED/ITUR regime)
Law 51/11	Amend to the Law of Electronic Communications 05/04	Transposing to the national legal order Directive 2009/136/EC amending Directive 2002/22/EC, on universal service and users’ rights relating to electronic communications networks and services, as well as Directive 2009/140/EC , amending Directives 2002/21/EC, on a common regulatory framework for electronic communications networks and services, Directive 2002/19/EC on access to, and interconnection of, electronic communications networks and associated facilities, and Directive 2002/20/EC on the authorization of electronic communications networks and services

Table 11 -Summary of Portuguese Universal Service legislative milestones

4.5.1 From Bell´s to the 90´s Liberalization

Portugal had its first private telecommunications networks in 1877 connecting the two major cities, Lisboa and Porto within Edison Gower Bell Telephone Company of Europe Limited. In 1877 the licensing agreement changed to the Anglo Portuguese Telephone Company (APT) and in the beginning of the XIX century the Posts, Telegraph and Telephone (CTT) expanded the fixed telephony network all over the country, while Companhia Portuguesa Rádio Marconi (CPRM) provided the wireless long range communications. A glance on this historical period is given at Figure 60.

Figure 60 – Images allusive to the beginning of the telephone in Portugal. Source: : restosdecoleccao.blogspot.pt, [151].

As long CTT provided the expansion and interconnection of all the cities in the country and abroad, a new company was born in 1968, Telefones de Lisboa e Porto (TLP) concerned the two major cities, Lisboa and Porto. By this time Portugal had a single operator monopoly; indeed there were several companies providing the voice telephony service but with clearly defined target regions. An experimental communication connection with optical fiber was made between Lisbon and Aveiro by the late 60's.

In the following decades the telephone twisted copper pair network grew and reinforced its place in the national economy. From a technological point of view the telephone central offices became automatic and by the 80´s digital.

Meanwhile in 1957 there was the first television broadcast with the public channel RTP1 in the VHF band, followed by 3 more channels in the UHF band, RTP2 in 1968, RTP Madeira in 1972 and RTP Azores by 1975. The service of television was considered essential and repeaters and transmitters were deployed almost everywhere to ensure full access along the national territory. The first color broadcast started in 1979, but only in 1980 and with the European Song contest, the transmissions became regularly in color.

With the pacific political revolution of 1974 most of the economic sectors pass through several nationalizations and telecommunications was not an exception - CTT became a public company as many others. Soon in 1981 the telecommunications regulator, Instituto das Comunicações de Portugal (ICP) was established by the Decree-Law 188/81 [152] and has been endowed with approved statutes since 1989 (which would change the name to ANACOM in 2001), Figure 61.

Figure 61 - Portugal´s regulator logos in 1981 and 2001.

In 1989, ICP provided the license agreement to the three communications operators: TLP in Lisboa and Porto, Telecom Portugal responsible for the fixed communication all over the country (except Lisboa and Porto) and Marconi for international communication traffic.

In order to create a strong telecommunications operator, with the size and structure needed to provide services with variety and quality, Portugal Telecom, PT, the incumbent was born in 1994 [153].

In 1995 and by the Decree-Law 40/95 [154] the basis for the public telecommunications service was approved. The exploitation of the state telecommunications network was granted by Law to PT, until 2025 as well as several obligations. These obligations included the provision of public telecommunications services and the concession in terms of Universal Service in the whole country without showing preference or discrimination, in relation to any natural or legal person who requests the telecommunication service.

Influenced by the liberalization directives from Europe, PT starts the privatization in 1996 becoming Portugal Telecom, SGPS, S.A. The full process would end by the end of 2005, with the exception of one share retained by the state ("golden" share).

The Law n.º 23/96 [155] created legal mechanisms to protect users of public services such as: water, electricity, gas and telephone. The Law did not include the word "universal" and was not a universal telecommunication direct measure but ensured the state´s concern about the effective need to provide citizens with a minimum set of services to improve daily life and the overall economic development of the country.

The Law nº 91 of the 1st of August 1997 was called the Law of Telecommunications [39] and replaced the old Law nº88/89 to surpass the profound technological and institutional changes that have driven the development of global telecommunications by opening the public network provision (ONP) to other operators. The most relevant article concerning Universal Service issues was at article eight that mentions that it is the state responsibility to ensure the existence of a universal voice telecommunications service based on a twisted copper pair network.

During the privatization process of the incumbent, new approaches to full market came from Europe and in 1999 the Portuguese Law 458/99 [44] applied the use of the open network provision to voice telephony as the European Commission recommended in directive 98/10/CE, [156] . New players appeared in the fixed market enabling best customer services and prices to go down. The next three years will be growing years in the fixed telephone sector but rapidly the rise of the mobile communications affected this trend. The growth shall be restarted ten years later with the triple and tetra play services in cable offers, Figure 62.

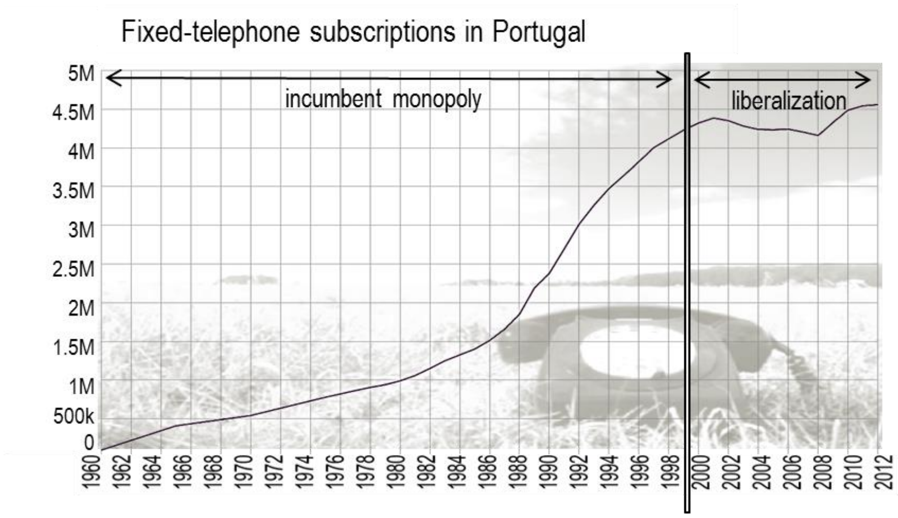


Figure 62 – Fixed-telephone subscriptions in Portugal between 1960 and 2012, Source: ITU.

Still in 1999 the public network was opened to competition, even though the public infra-structure was still state property. The use by other operators of the twisted copper pair from the public network allowed the growth of the number of players within the sector, as well as the growth in quality and quantity of services offered based in the xDSL technologies (the basis of the today's massive internet usage).

4.5.2 From the 90´s Liberalization towards the New Generation Networks

By 2001 the former regulator ICP changed its name to *Autoridade Nacional de Comunicações* (ICP-ANACOM) and became an independent regulatory authority relieving the status of public institution with the Decree-Law 309/2001 [157]. In 2002, the Law 29/2002 , determined the decommissioning of the network from the public domain and as a consequence of the "market liberalization and from the 3rd quarter 2002 the market share began to move from the incumbent towards the other operators, as mentioned previous, [158].

In 2004 the Electronic Communications Law 5/2004 [159] transposed several EC directives [160-163] determined the existence of condition for users to make and receive local, national and international communications, facsimile and data communications at rates sufficient to enable the functional internet access. Several regional contests to deliver internet everywhere were open under the program Portugal Digital.

In order to ensure a healthy completion among all operators and to answer the strong pressure by the non-incumbents operators, the Regulator decided to open the access to all conducts (ORAC). With this measure PT was somehow forced to open their conducts, towers, masts or other's to infrastructure and service operators that required so, [164].

The liberalization context and the new fixed operators led to fixed telephone market fragmentation. Moreover at the same time the mobile technology entered as a non-expected competitor causing serious damages in the so far faithful fixed network. Fixed operators started using the internet as an application to retain subscribers with double play offers or even triple play but apparently it was not enough, as subscribers started to abandon fixed telephone towards mobility, Figure 62.

By 2005 Portugal (and most of the Western countries) became to be under a strong economic pressure and the TIC´s appear to be one of the drivers of the economy. A new plan called "*Portugal Tecnológico*" was introduced to approach citizens to the technology and the internet for the young children and the elderly. The seed of new generation networks was launched.

The Decree-Law 68/2005 [165] created the first legal framework for infrastructures sharing among operators. This occurred by the time optical fiber started to become a reality as a technological solution for the access networks, between the central offices and the subscribers. Portugal has already given the first steps in the fiber roll out network expansion and the regulatory framework with Law 123/09 [166] was quite innovative in the European context. This latest framework defined strategic guidelines such as an effective and non-discriminatory access to ducts and other infrastructures, and the adoption of solutions aimed at eliminating or reducing vertical barriers to the roll out of fiber optics, so as to prevent the first operator from monopolizing the access to buildings.

By December 2009 and only one year after roll out, Portugal presented 1.06% of homes passed with optical fiber, corresponding to 1.2 million of houses. The number of connected homes (FTTH/B) with internet is around 54 000 [13], with a semester evolution of more than 78%. The number of connected homes with TV is around 58 000 [14]. Against most of the expectations in Portugal the driver for the fibber subscription is not broadband internet but the HD and 3D television offer.

In 2010 the contest for deployment of optical fiber among rural zones was opened due to National Strategic Reference Framework (NSRF) and the Regulator ANACOM applied another innovative solution. After the identification of the 140 zones without any type of broadband coverage, they were catalogued by economic forecast revenue and the roll out licenses were divided among operators, each one getting a "good" forecast revenue and a "bad" forecast revenue.

Meanwhile in Portugal and in Europe several funds have been allocated by contest to regions in order to implement the broadband network in geographic areas that are usually economically disadvantaged. It is a requirement of these contests a minimum coverage of 50% of the population, it is a relevant effort to reduce asymmetric development but it does not guarantee the universal access.

4.6 Portuguese Residential Broadband Deployment

At the present time the Portuguese telecommunication market is fully liberalized and contains 33 service providers which operate in the following classes: 17 in fixed telephony, 7 mobile operators, 4 of them providing mobile broadband, 34 operators in fixed broadband and 20 internet access providers. There are several companies providing the service using more than one access technology, Figure 63.

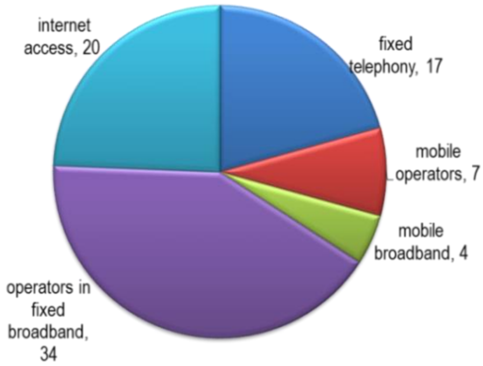


Figure 63 – Portuguese telecommunications sector. Source: ANACOM 2013.

4.6.1 Broadcasting

In Portugal it is difficult to dissociate the pre-history of the history of Radio Telegraphs, and Telephones of the Post Office, as well as the history of television cannot be separated from the history of radio.

Radio

At the late 1850's all these entities were overseen by the Ministry of Public Works and Communications. The telegraph lines were already in Portugal since 1855, and the phone was a reality in the country in 1879, arriving to be made that year tests with a device invented by the Portuguese Cristiano Bramão - the famous desk phone. There were two employees of the Post and Telegraph that in May 16, 1902, did that one can consider the first issue of civil radio broadcast transmission in Portugal, between the cruiser "D. Carlos "and the Semaphore Station Cascais. The experience has been reported by the time newspapers.

Only in 1935 the official opening of the National Radio Broadcasting took place (Emissora Nacional, EN) and since 1941 retransmits to the United States and Brasil. The emissions were most in medium wave (300 KHz – 3000 KHz) and in modulated amplitude (AM). After the war in 1950 the European Broadcasting Union is founded and in 1955 the first emissions in modulated frequency (FM) are emitted. During the 1960's the deployment of the FM network is densified.

In 1977 the frequency spectrum of the FM band was stretch to 108MMHz leading to the appearance of thousands of pirate radios, that would only be legalized in Portugal in 1988.

Ten years later (1998) the first licenses for digital radio appear in the United States with Digital Broadcast Audio(DVB-A) In 2002 the process of introduction of Digital Radio in Portugal was initiated through the assignment of a license to RDP - Radiodifusão Portuguesa for the establishment of a national infrastructure of digitalization, codification, multiplexing, transport and emission of the broadcasting service, using the T-DAB norm (terrestrial DAB). In 2011 ANACOM, the national regulator revokes of the right of use of frequencies associated to TDAB service due to lack of interest of the sector players, .[115]

Nowadays there are more than three hundred (frequency modulated) legalized radio stations. In Portugal the transmitters of AM / FM radio (as well as analog TV) are distributed throughout the territory and most of them collocated, i.e. both systems are transmitted from the same telecommunication towers. The red dots are transmitters and the green dots re-transmitters, Figure 64 on the left. The Grand Porto region is the country with a bigger percentage of radio listeners, 60.7%, and the north interior is the region with lower percentage 49.5%, data from June 2014[9]. In average the values around the country are quite significant, Figure 64 on the right.

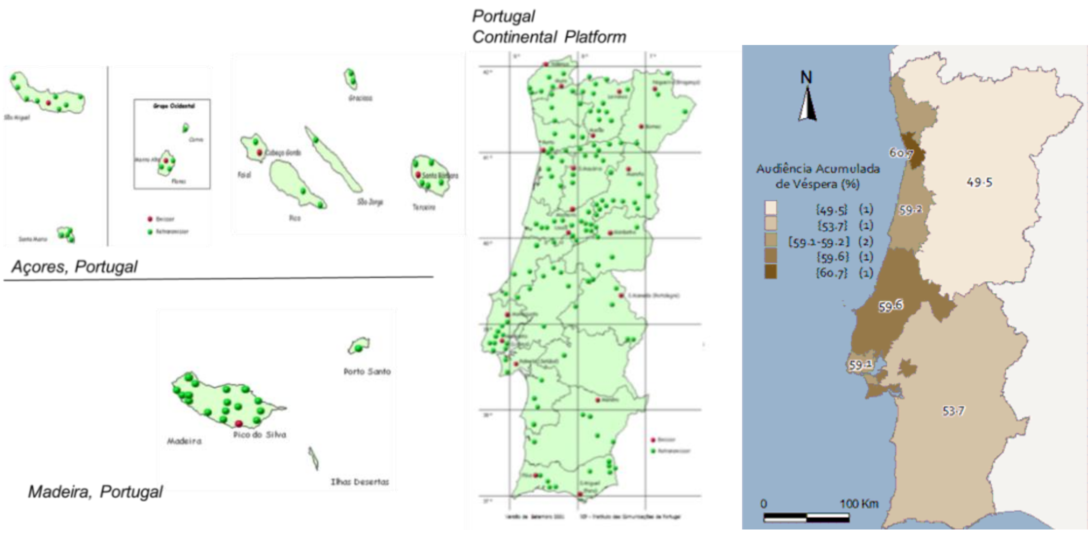


Figure 64 – Portuguese Broadcast network, continental platform and islands Madeira and Azores (on the left), [167] and FM radio audience 8on the rght). Source: Barame radio, Marktest.

Television

By 1875 Professor Adriano de Paiva from Oporto made the firsts experiments with the transmission of images in the so-called electric telescope[10] (source: on line RTP´s museum). Many experimentalists tried out this new medium but only in 1927 the Bell Company, New York, held a televised broadcast between two points, situated 45 kilometers from each other, making the first public use of the successful iconoscope, leaving behind the constraints of predecessor and inventions opening new paths. By the late 20's in the XX century, there were already 20 Broadcast stations licensed to establish "visual transmission", mainly faces and silhouettes. This invention, of doubtful usefulness in its origin, entered the daily life of people marking a new way of life and profoundly changing habits and customs.

The introduction of the national television in Portugal dates from 1957 with the first television channel, *Radio Televisão Portuguesa*, RTP1. They were later released three more channels: RTP 2, 1968, RTP Madeira, RTP Azores in 1972 and in 1975. With the resolutions of the Council of Ministers nº183/79, it was authorized the introduction of color television in Portugal, and with the nº 245/79 of July 25 was adopted PAL (Phase Alternation Line) taking into account the compatibility with systems in potential export countries (except France who opted for SECAM). The PAL system normalizes the line number on the screen 625 scanning lines of 25 images / frames per second being each constituted by two fields (50 Hz).

The first color broadcasts began on an experimental basis in 1979, however only in 1980 that began the regular broadcasts in color, and the RTP European Song Festival 1980 was the first color broadcast program in Portugal.

In 1990 with the advent of liberalization of telecommunications and the development of a European common market, it began to emerge the competition in the markets for telecommunications services,

[9] Available on line: http://www.marktest.com/wap/a/n/id~1d8d.aspx, access July 2014.

[10] Available on line: http://museu.rtp.pt/#/en/intro , access January 2009.

making way for new private channels. The appearance of SIC and TVI is formalized in 1993 and 1992 respectively, duplicating the number of TV channels, from two to four.

The market for analogue terrestrial television began to be deeply affected by the introduction of pay TV services, mainly due to the cable TV after 2000, Figure 65, [168].

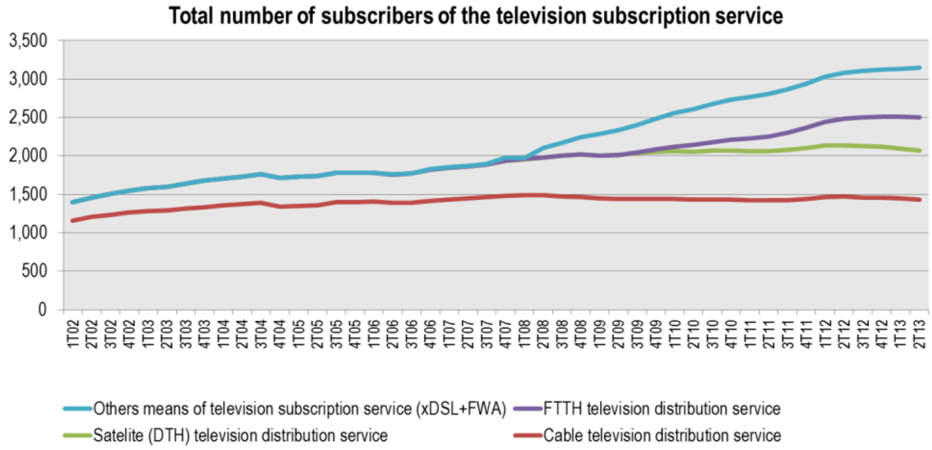


Figure 65 – Portuguese number of subscribers of the television service. Source: ANACOM [168].

The current Portuguese television broadcast system in based on free space use of radio frequency signals in the VHF (Very High Frequency) and UHF (Ultra High Frequency) bands. The signals from the transmitter are sent to the user via local transmitters that receive the signal, amplify it and send back to other transmitters. The diffusion of television was initially a problem regarding their coverage, which was solved by using a complementary system of transmission of television via satellite. In February 2008, 99.5% of its population had at least one television set and 74.1% had more than one, [169].

By resolution of the European Community, most Member States expect to complete the transition from analogue terrestrial television broadcasting in 2012, and some have done it on a regional or national level before 2008, [170]. The advantages of the digital service include the efficient usage of the frequency spectrum by replacing the bandwidth used by one single analog channel with four digital ones, expecting to improve the offer to the subscribers. Better image and sound, possibility to use subtitles or several audio tracks for the same channels (in different languages for example), interactive services and return channel, as some of the digital improvements.

The plan for the analog TV switch-off associated with the introduction of digital television in Portugal began officially in January 2008 by the Council of Ministers resolution 12/2008, [6], where it is stated that the introduction of digital terrestrial television (DTT) in Portugal constitutes one of the objectives set out in the government program, Figure 66.

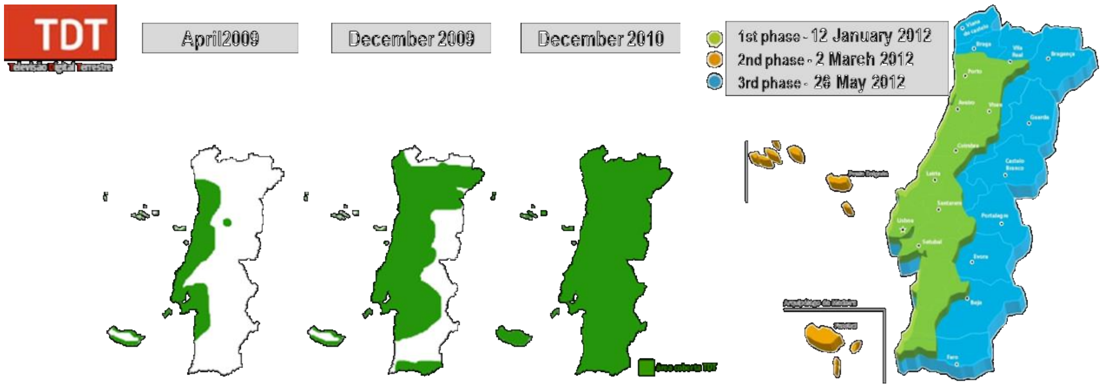


Figure 66 - Analog to digital transition map in Portugal in 2012, www.anacom,pt.

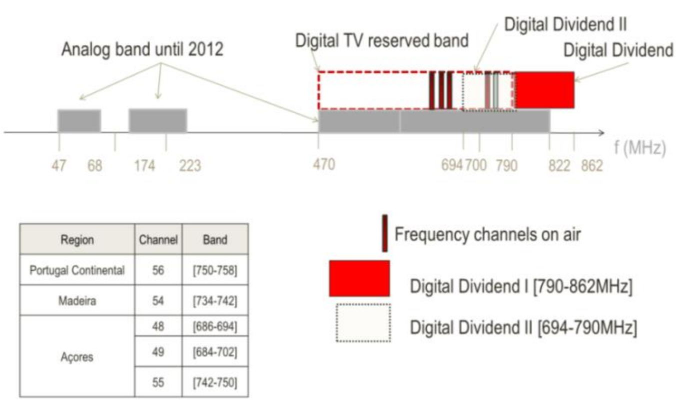
In October 2008, the regulator ANACOM has approved the proposals of the review committee of tenders DTT, which attach to the PT Comunicações the frequency usage rights associated with Multiplexers (MUX) A and B to F. The MUX A was reserved for free signal emissions and the others to TV pay channels, [171].

All the digital licenses were granted by public contest to PT Comunicações, dated the final decision on the detailed plan for the cessation of analogue terrestrial emissions for 2012. In December 2010, ANACOM approved, in accordance with the provisions of the plan for the switch-off, the final decision on the cessation of analogue terrestrial television in the pilot phase.

Initially ANACOM attributed the Multiplexer (Mux A) channels in the sub band[790-862] MHz However as a result of decision 2010/267 of the European Union (EU), [172]it was necessary to the corresponding amendment to the National Frequency Allocation Plan in order to provide the said sub-band for electronic communications services. To proceed to the commonality with other European countries, this adjustment has forced the use of frequency spectrum reserved for MUXs B to F and led to the revocation of its tender in 2010, [173] [174].

The sub-band [790-862 MHz] available for other uses adjacent to the GSM system is called "Digital Dividend". In 2012 Resolution 232 of ITU´s Congress WRC-12 allowed the use of the 694-790 MHz band for mobile communications The 700MHz band that is intended to be shared with broadcasting by 2015 is called Digital Dividend II, [175], Figure 67.

The frequency plan is based on a single frequency network (SFN) meaning that all the country (continental platform) has only one frequency (channel 56).



Region	Channel	Band
Portugal Continental	56	[750-758]
Madeira	54	[734-742]
Açores	48	[686-694]
	49	[684-702]
	55	[742-750]

Figure 67 – Frequency allocation: analog, digital, Digital Dividend I and II.

In May 2011 the 3 first pilot areas were switch off with success. One year later and according to the plan, all the three switch-off phases was completed, the analog TV was definitely off and the digital single frequency network implemented.

The population covered by additional means of coverage should not exceed 14% of the population, subject to the endorsement by the regulatory obligation to ensure end-users have conditions of access comparable to the areas covered by the analog system. This means that 87% of the population should be targeted to have terrestrial coverage, DVB-T and the remaining 13% can have any other complementary technology that PT might chose. Satellite distribution, DVB-S; complement the areas without terrestrial coverage.

Both terrestrial and satellite digital broadcast brought additional investments for the subscribers to a free to air service, each one in different proportions. To face this unexpected expenses a decision on the reimbursement procedure of facilities and equipment in areas covered by means of topping up with satellite (DVB-S) were defined to be promoted by the DTV provider.

During 2012 several problems concerning the coverage area and serious quality problems were reported to ANACOM and a second frequency was used punctually in strategic geographical places. In consequence of these problems a public consultation on the future of the DTT was open [176] and a redefinition based on a multi-frequency network planning in 2017. By that time the evaluation of the second digital dividend will be closed to redefine the usage of the present frequency 56 at the 700MHz band.

At the present time, the digital free-to air service is based on five channels (the four analog previous ones, plus a new one) in standard definition and an empty high definition signal. There is no digital audio implementation; there is no relevant increase on the number of channels, there are no multiple audio tracks, subtitles, interactive services or return channel of any kind. According to ANACOM data provided by Portugal telecom [11] 100% of the population has access to digital television broadcast, Figure 68.

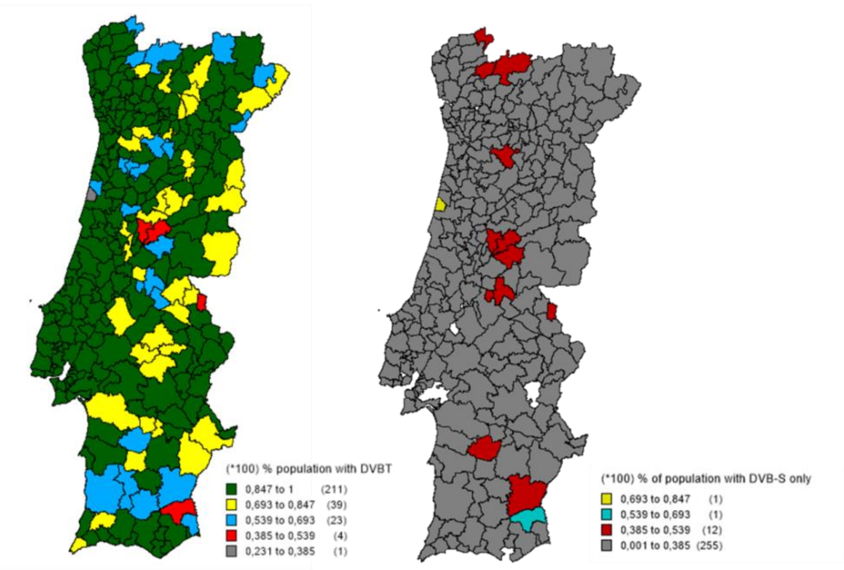


Figure 68 – Percentage of population with DVB-T coverage.

[11] On line @ http://www.anacom.pt/render.jsp?categoryId=344891. Access January 2013.

The forward and backward of the analog switch off |digital tender, the unbalanced investments of the subscribers depending on the geographic region , the complains due to lack of coverage, bad quality signal and few digital improvements, lead to several interpretations as Denicoli stated: "*However, in Portugal, unlike other EU countries, public authorities legislated responding primarily to corporate interests, without showing a systematic concern with the population or digital inclusion*.", [177].

4.6.2 Mobile Communications

Wireless networks use the electromagnetic spectrum as the transmission medium. The radio-electric spectrum is typically owned by the state. That also happens in Portugal [39] where it is regulated through the National Regulator Authority (NRA), ANACOM, [152] and [159]. Each year the National Frequency Allocation Plan (NFAP) identified all the frequency bands and allocate them to public, privates companies or general public as radio amateurs [178].

To ensure that the competing applications for radio spectrum do not interfere with each other's operations it is essential that the allocation of frequencies is coordinated and properly regulated both nationally and internationally. When a single European market is needed, this coordination must happen on a European scale. Rules for spectrum use must be harmonized across borders. The present frequency assignment is fixed and follows the framework of Portugal spectrum allocation [179], it is summarized in the following figure. The total volume of services which depend on radio spectrum availability but it is estimated to be worth at least €200 billion annually in Europe.

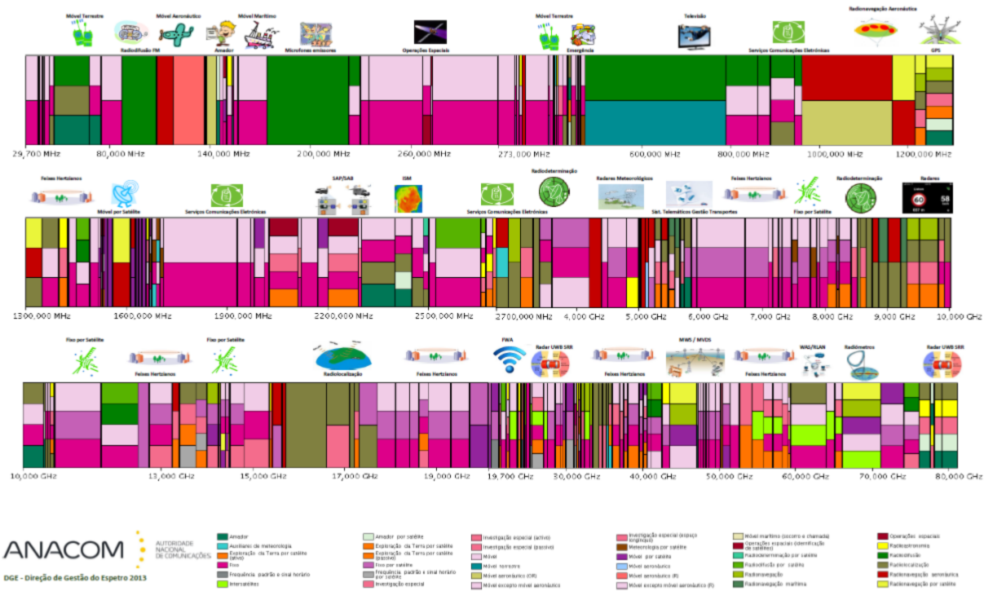


Figure 69 – Spectrum allocation in Portugal. Source: courtesy ANACOM

According to the regulator´s ANACOM the fixed telephony subscribers by the end of September 2009 are 3,286,000 (33% pop) and the mobile subscribers are around 15,500,000 (140% pop). With this numbers Portugal in under the top 5 UE27 countries with biggest mobile penetration per 100 inhabitants, Figure 7.

<u>*GSM/GPRS*</u>

In Portugal as in most European countries, the GSM operate in two different frequency bands, 900MHz and in 1800Mz (Digital Cellular Service, DCS or GSM1800). DCS was developed under the auspices of the European Telecommunication Standard Institute (ETSI) as the standard for a European network PCN (Personal Communications Network).

The GSM 1800 is based entirely on the GSM 900 technology, but using smaller power transmission. In practice, operators have opted to distribute dual band mobile terminals, i.e., supporting both GSM 900 and GSM 1800, with the advantage of using the synergies of the two networks.

Parameter	***GSM900***	***GSM1800/DCS***
Frequency band DL (network->UE)	890-915MHz	1805-1880MHz
Frequency band UL (UE-> network)	935-960MHz	1710-1785MHz
Multiple Access	TDMA	TDMA
Multiplexing	FDD	FDD
Carrier separation	200KHz	200KHz
Channels per RF carrier	8	8
Number of channels	125x8	375x8
Modulation	GMSK	GMSK
Control	Digital	Digital

Table 12 – Comparison between GSM e DCS technologies.

The GSM technology has been widely used in Europe and with great success since its launch. The current penetration rate in Portugal is around 114% [180].

In Portugal three operators are allowed to operate in this band: Vodafone, Optimus and TMN, each one with 39 channels in the 900MHz band and 30 channels in the 1800MHz band. The ANACOM licenses involve a minimum of a percentage of the population, which increases over the years and requires a minimum number of base stations [181] .

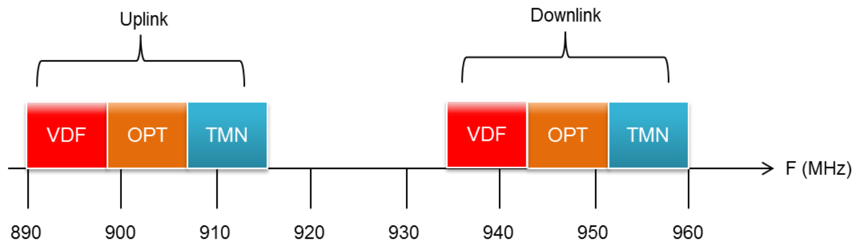


Figure 70 –Spectrum allocation in Portugal in the GSM900 band. Adapted by the author from ANACOM.

UMTS (3G)

In Portugal, UMTS licenses were granted to four operators, with three of them already with GSM networks and a new player. They were named at the time: OPTIMUS (later SonaeCom), TMN, TELECEL (later Vodafone) and ONIWAY. The license ensured coverage rates above 128 Kbps and deployed at the following scheduled rate[12]:

- 20% coverage of the national population at the end of the 1st year of the license

[12] http://www.anacom.pt/render.jsp?contentId=13109. Access September 2013, available in Portuguese.

- 40% coverage of the national population at the end of its 3rd year of the license
- 60% coverage of the national population at the end of the 5th year of the term of the license.

The commercial opening of UMTS in Portugal has been announced for January 1st, 2002, but opened effectively on January 1st, 2004 due to limited availability of terminal equipment and equipment infrastructure network. Each operator has been allocated three frequencies in FDD mode and a frequency in TDD mode. The spectrum for IMT-2000 contains 11 blocks of unpaired 5MHz in the band of 1880-1920 MHz and 2010-2025 MHz. Despite that, in Portugal, a part of the spectrum is part of the DECT network and other mobile satellite networks, MSS (Mobile Satellite System). These frequencies are not allowed to be used with FDD (Frequency Division Duplexing) technology so the technology UTRA TDD (Time Division Duplexing) is identical to the UTRA FDD except in how you access the radio channel. This technology presents itself as a fallback solution in areas where spectrum is not able to implement UTRA FDD.

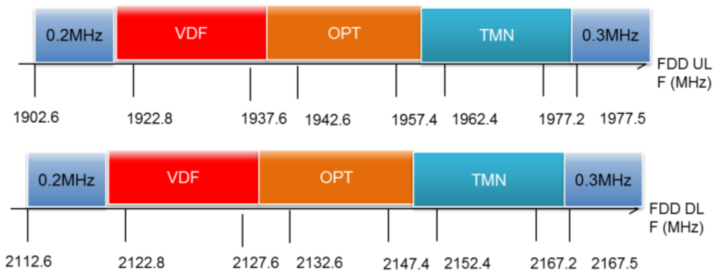


Figure 71 –UMTS FDD frequency allocation in Portugal, in www.anacom.pt.

LTE

In 2011 Portugal Telecom, SonaeCom and Vodafone Portugal have each won spectrum in Portugal's LTE spectrum auction, the current GSM and 3G operator´s. The LTE license works in 3 frequency bands, the 800MHz (consequence of the first digital dividend), the 1800MHz (where the DCS used to operate) and the 2600MHz, Figure 72, [182].

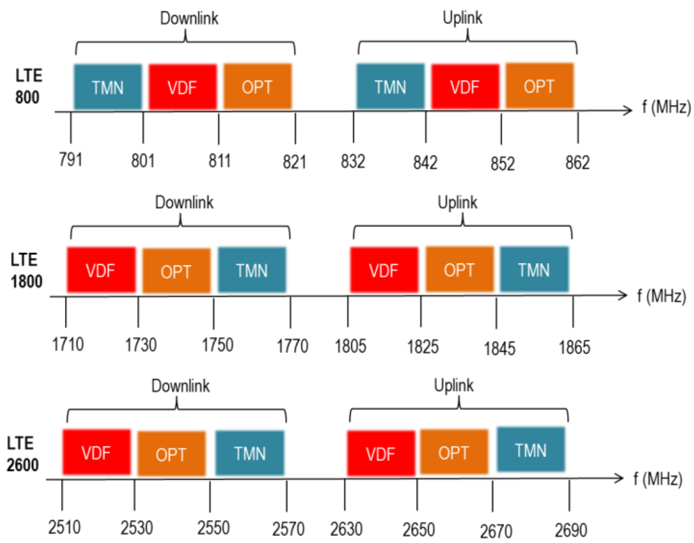
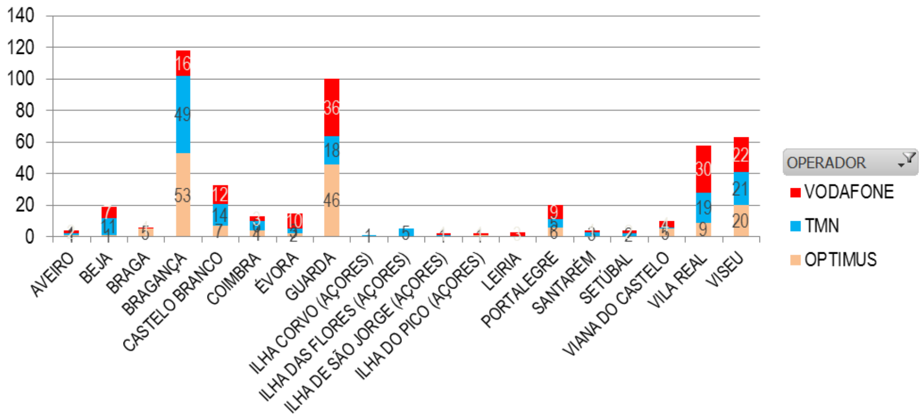
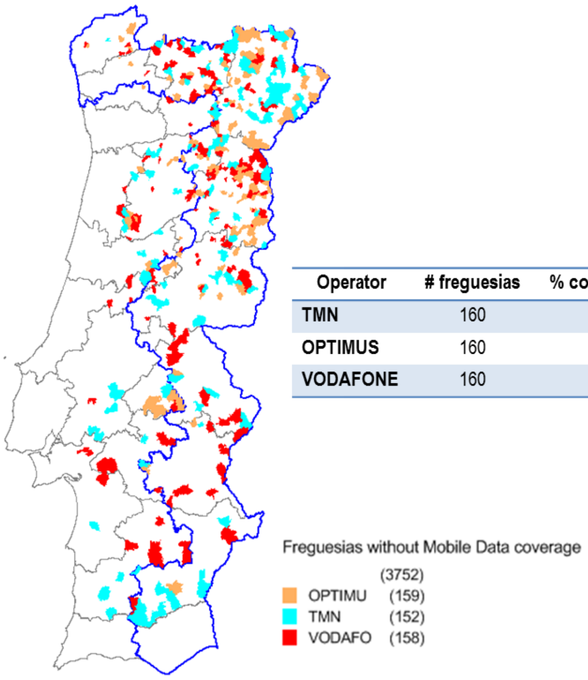


Figure 72 – LTE frequency bands. Source: ANACOM.

All the three existing operators assume the 2G voice coverage bigger than 99% of the area of the country. On the other hand, considering the 3G mobile data coverage some "freguesias", around 4 or 5% of the total “freguesias”, are assumed not to have coverage, Figure 73. It was not possible to find data at municipality level about 4G coverage and data rate.





Operator	# freguesias	% country area	% population
TMN	160	5.5%	5.5%
OPTIMUS	160	3.8%	3.8%
VODAFONE	160	5.1%	5.1%

Figure 73 – List of “freguesias” without 3G data coverage per mobile operator. Source: ANACOM [13]

4.6.3 Wireline Communications

The Portuguese wireline history was born in the late 1880’s with the telegraph and the telephone and is intrinsic to the telecommunication history of Portugal as described previously. One hundred years later, the liberalization, the open network provision for voice telephony and the technologic improvements with the digitalization, open the market to new service providers and new services.

The swap between the internet accesses by dial up has being done as new broadband technologies enter the market, Figure 74. Since 2002 the twisted pair dial up modems are replaced by ADSL cable transmissions, cable modems or more recently, after 2008, fiber to the home connections, Figure 75.

[13] Available on line: http://www.anacom.pt/streaming/anexo_decisao22ago2013Obrigacoes_cobert_faixa800MHz.pdf?contentId=1171432&field=ATTACHED_FILE, access July 2014

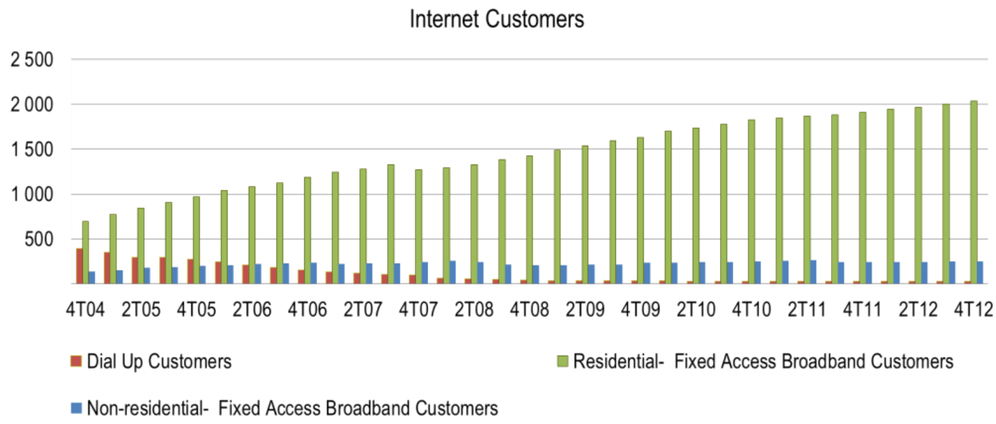


Figure 74 – Internet Portuguese access types since 2004 in quarters. Source: ANACOM.

As time goes by and technology evolved the broadband data communications steadily increase the number of subscribers in the various types of access solutions, Figure 75.

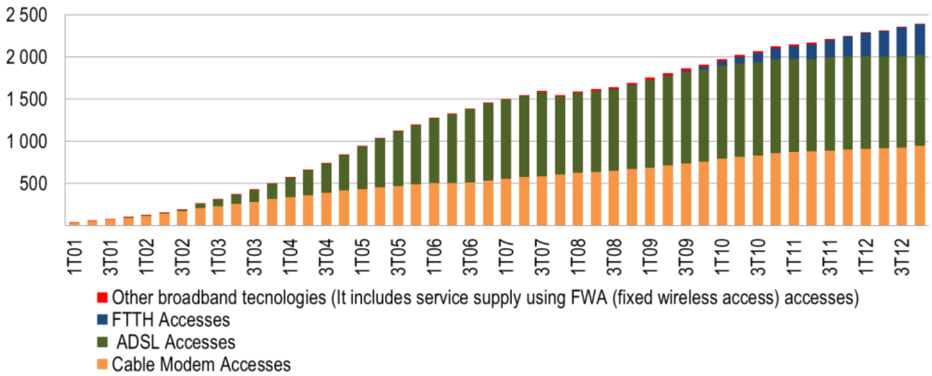


Figure 75 – Portuguese broadband subscriber access profile from 2001 to 2012. Source: ANACOM.

At the present time all providers of fixed access internet active offer access service internet in broadband. ADSL is used by 18 companies, while modem cable is used by 7 entities and optical fibers by 10 entities. There are 17 companies providing the service through other means (e.g. leased lines, FWA). Moreover, 4 of the providers of mobile telephone service, also provided and mobile broadband mobile access internet using the UMTS/HSPA, [111].

4.7 Regulatory and Public Investment

4.7.1 Universal Service in Portugal

As was previously described, in September 2009, the Portuguese government determined the purpose to discuss with PT the provider contract. In fact, this task was given to PT by 2001, but according to the Law 91/97 [39] there should be equal opportunities to all the operators to apply for Universal Service provider. In July two operators assign the task of the universals service splitting the country zones: Optimus, a mobile operator and ZON a cable TV operator. By the end of 2013 these two companies will merge.

The Universal Service impact laws in Portugal are:

- Decree-Law 40/95, provide public telecommunications service concession and the basis for the public telecommunications service. Also mention the exploitation given to PT as well as Universal Service obligations and financing, until 2025, [154]
- Law 23/96, the essential public services law. Protect users of public services such as: water, electricity, gas and telephone, however not necessarily universal, [183].
- Law 91/97, The Telecommunications Law. The public network was open to competition but still state property (ONP). Thought the Universal Service obligation must be guarantee by PT, [39]
- Decree-Law 458/99 Essential Public Services Law. Transposition of the CE directive 97/33/EC, [38] concerning Universal Service and the 98/10/EC, [156] concerning interconnection in telecommunications through application of ONP, [44].
- Law 29/02, The Law Public telecommunications service concession. First amendment to Law 91/97. Determined the evolution of the concept of Universal Service, [158].
- Law 05/04 The Law of Electronic Communications. Allow functional internet access, [159].
- Law 12/08 Amend to Essential Public Services Law The word “telephony” was replaced by “electronic communications”, [6].
- Law 35/12 Proceeds to the creation of the compensation fund for the Universal Service of electronic communications provided in the Communications Act Electronic - intended to finance the net costs arising from the provision of Universal Service, [184].

The Portuguese (and European) requirements for the Universal Service concept include the following items that are going to be discussed below:

- Scope of Universal Service (USO);
- Designation of providers (USP);
- Financing mechanism.

In this 21st century scenario, the Universal Service obligations in Portugal are according to Decree-Law 458/99 [44]; mature fixed twisted cooper for robust voice and data rates sufficient to permit functional Internet access, public payphones, paper directories, directory enquiry service and emergency number access. Universal Service´s special fares are also applied for disabled and elder citizens. However, these special fares might raise as maintenance costs rises.

Until mid-2014 the Portuguese Universal Service provider (USP) is Portugal Telecom [154], the former incumbent. Since 2008, several Portuguese operators presented their motivation to be candidates for USP as it was regulated [44]. Nominee mechanisms should be efficient, objective, nondiscriminatory and transparent, however the provider designation was conceded to Portugal Telecom until 2025 and the regulator is still trying to get to a consensus among the players to circumvent the situation. Meanwhile infringement procedures were opened for incorrect implementation of the EU´s directives [45] and in 2013 the situation was regularized.

Most EU member states allow Universal Service financing compensation only from sector-specific funding. Some members, as Portugal, allow both public and sector specific funding and two EU members only allow public funding. The compensation fund is intended to finance the net cost of universal service. Universal Service Net Cost (USNC) is the difference between operating with the Universal Service obligation and without one. Any benefits including indirect and intangible benefits have to be assessed to calculate it and should be presented annually by the USP to be audited or verified by the NRA and made public on annual report.

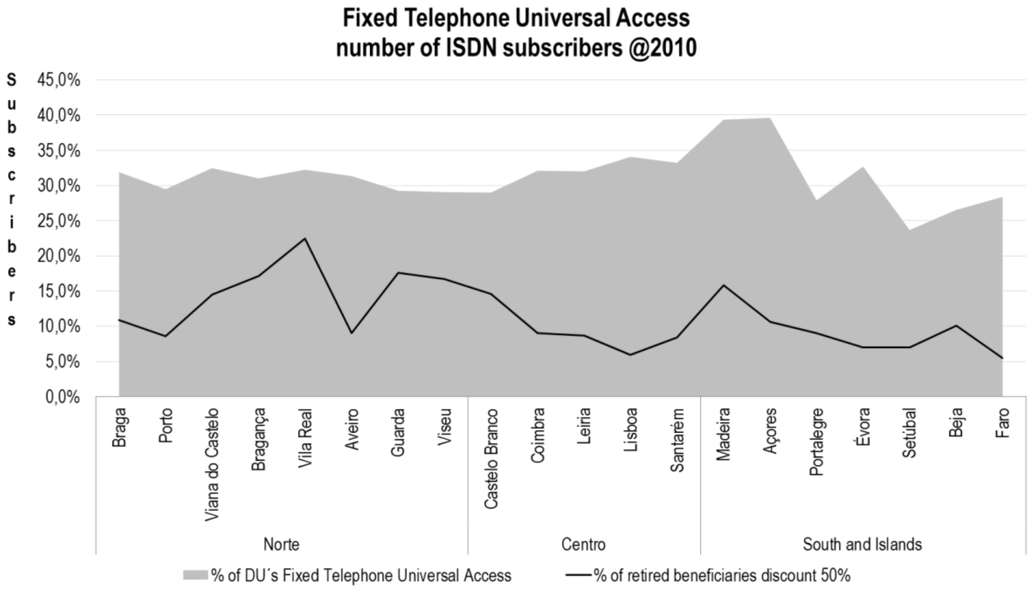
Since 2001, by the time PT became a private company and was defined as the national Universal Service provider (USP), it has claimed that the Universal Service obligation is a financial burden and that PT should have some financial support, as determined by the nº1, art. 5º from CE Directive 97/33/CE[185].[44]. The regulator ANACOM did not accept PT's claim, as there were no conditions to accept the net costs of the Universal Service provision estimates for 2003 nor the estimate reviews for 2001 and 2002 presented by PT [186]. In 2013 the situation was regularized and a Universal Service tender was open and ZON-OPTIMUS will be the next Universal Service providers.

The compensation fund for Universal Service electronic communications is ruled by Law35/12 and lies in its universal distribution among companies that offer in the national territory, communications networks and public or publicly available electronic communications services.

The total amount of Universal Service fixed telephone subscriber´s has slightly declining along the past years, but it is still a relevant 30% of the dwelling units that use this service, Figure 76. From the universe of the Universal Service subscriber´s around 10% are retired beneficiaries of fifty percent of discount.

PORTUGAL UNIVERSAL SERVICE PROFILE (2010)

(Grey shadow)Number of fixed telephone universal access subscribers in 2010 per District and (black line) percebtage of subscribers with 50% discount:



(on the left axis, red and green rectangles) Number of fixed telephone universal access subscribers in 2010, per type: regular universal service or retired thet beneficiaries from 50% discout, per district and (on the right axis, blue line) number of dwelling units in 2010 per District:

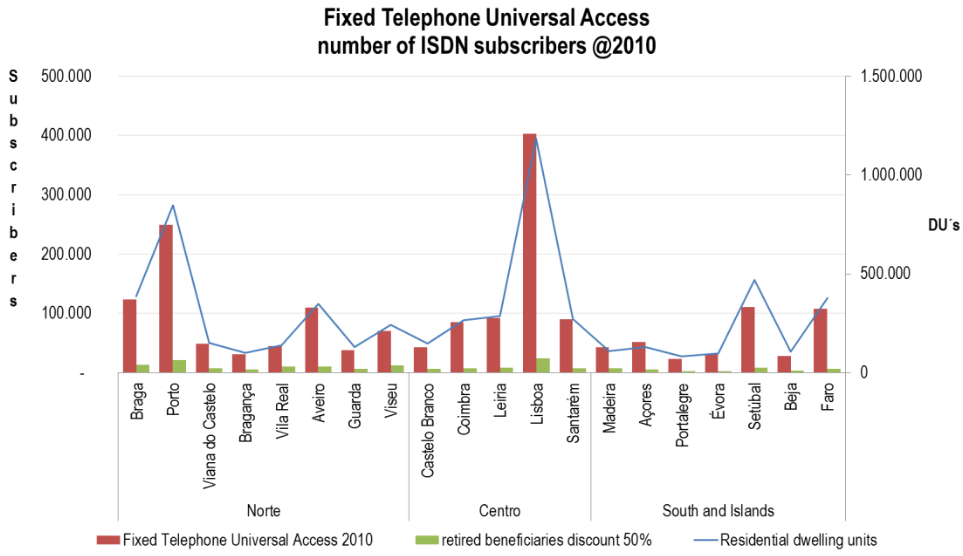


Figure 76 – Universal Services subscribers in Portugal in 2010 (top graph total number of Universal service subscribers per region, top graphcomparison subscriber number with dwelling units per region). Source: ANACOM[14].

From the same ANACOM data, it is also possible to understand and extract the values concerning the net cost of the Universal Service per type of area: profitable and non-profitable. These data include the residential access as well the public phones and Universal Service obligation, Figure 77.

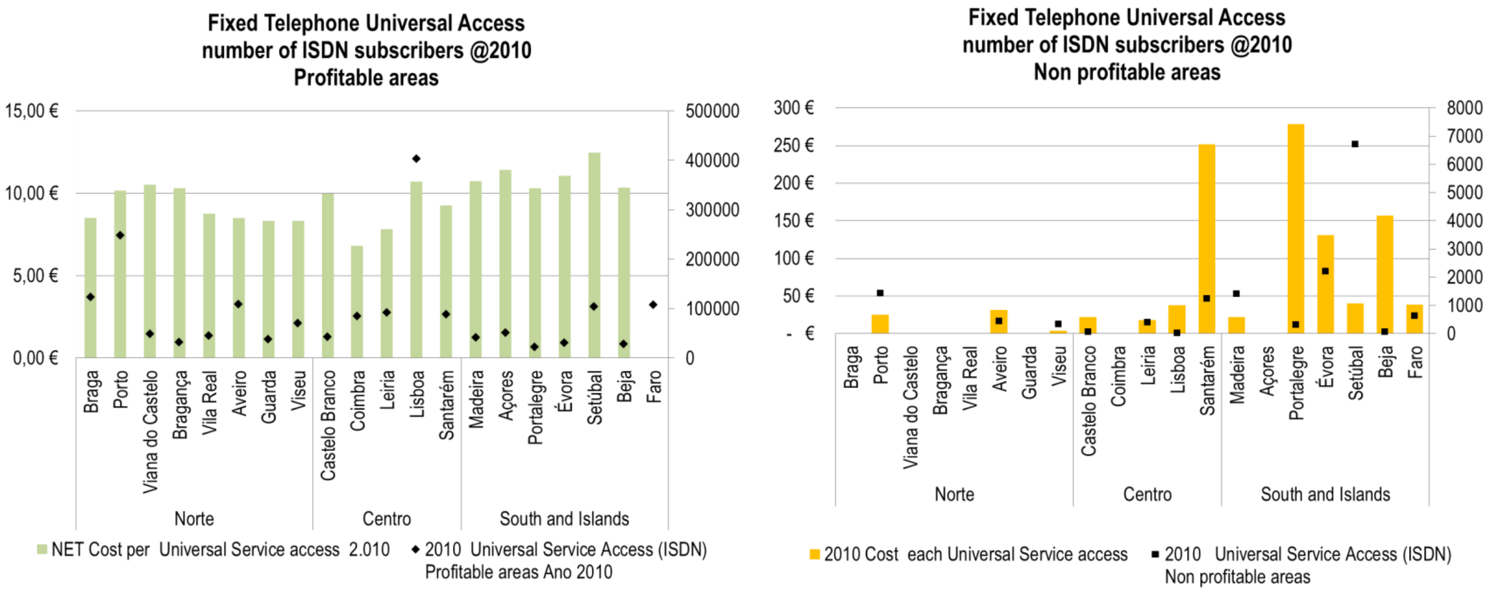


Figure 77 – Universal Service net costs in profitable and non profitable areas Source: ANACOM.

While geographic coverage obligation has vastly improved over the past decade, the scope of Universal Service has expanded to include other categories of underserved populations. Among those, persons with disabilities and senior citizens, who represent 15% of the world population, are an increasing concern for

[14] Available on line and in Portuguese @ http://www.anacom.pt/streaming/informacao_concurso1_STF_12102012.pdf?contentId=1140071&field=ATTACHED_FILE. Access June 2014.

legislators and regulators. Basic accessibility features for public telephone booths, fixed line handsets, customer services in alternate formats such as Braille, or assistive services such as relay services for hard of hearing or deaf persons are in fact not implemented in a majority countries. In Portugal from the obligations of the universal service provider, the operator also offers special emergency lines and adapted equipment for people with physical limitations, Table 13.

Special lines or equipment	***Number of access***	
	2009	***2010***
Braille card for emergency access for blind people	721	715
Braille invoice	139	126
Fixed Line Destination (used by elderly or physically disabled)	179	147
Special phone for people with poor hearing	19	15
Telltales call signaling for low hearing	3	1
portable device for people with poor hearing	105	74

Table 13 – Total access for special lines or equipment. Source: ANACOM.

The evaluation of Universal service net costs (NCUS) incurred through the provision of universal service in non-profitable areas and with special services for disabilities presents every year a growing cost (burden) for the Universal Service provider. Figure 78 represents the agreed NCUS value per year between Portugal Telecom and ANACOM, from 20 to 25 Million Euros per year.

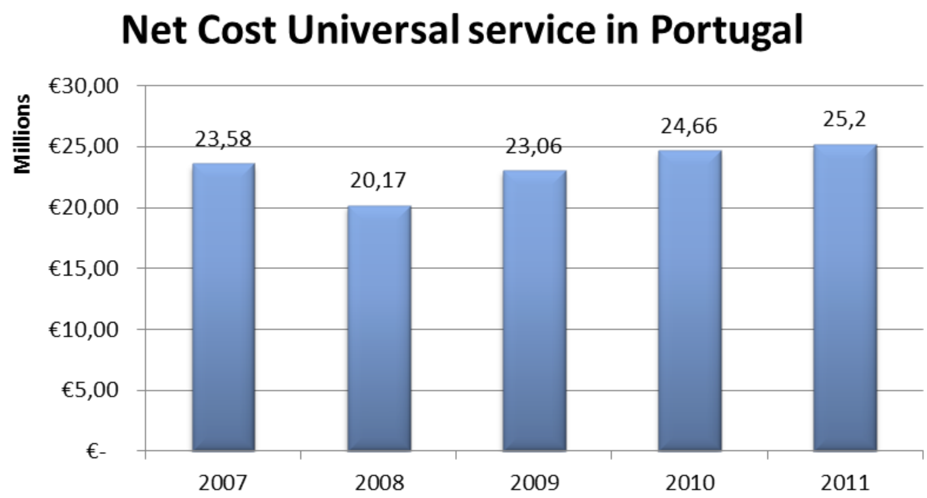


Figure 78 - NCUS value per year in Portugal. Source: ANACOM[15].

4.7.2 National Strategic Reference Framework

In 2008 the Technological Plan also is also the pillar for growth and competitiveness of the National Action Program for Growth and Employment, which translates the application in Portugal of the Lisbon Strategy's priorities, [187]. This plan defined the following actions:

[15] Available on line @ http://www.anacom.pt/render.jsp?categoryId=365715 and http://www.anacom.pt/render.jsp?categoryId=349787 . Access on July 2014.

- To promote the mass adoption of high speed Internet accesses and the development of advanced applications, in order to have 1 million users connected to next generation networks until 2010;
- To connect all primary and secondary education schools to next generation networks until 2010;
- To connect the whole network of hospitals and health centers to next generation networks until 2009;
- To connect all public justice services to next generation networks until 2010;
- To connect the public higher education and polytechnic institutions to next generation networks until 2009;
- To connect the public museum and library networks to next generation networks until 2009.

It was not possible for the author to analyze the rate of execution of those measures.

By 2010, funds from the National Strategic Reference Framework (NSRF) [75] were allocated by contest in order to implement broadband networks in geographic economically disadvantaged areas usually economically disadvantaged. These contests required a minimum coverage of 50% of the population. In 2010 public trends for rural broadband coverage were launched. As the International crisis affects the Portuguese investments, the optical broadband network is still raising with the continuous roll out, Figure 79.

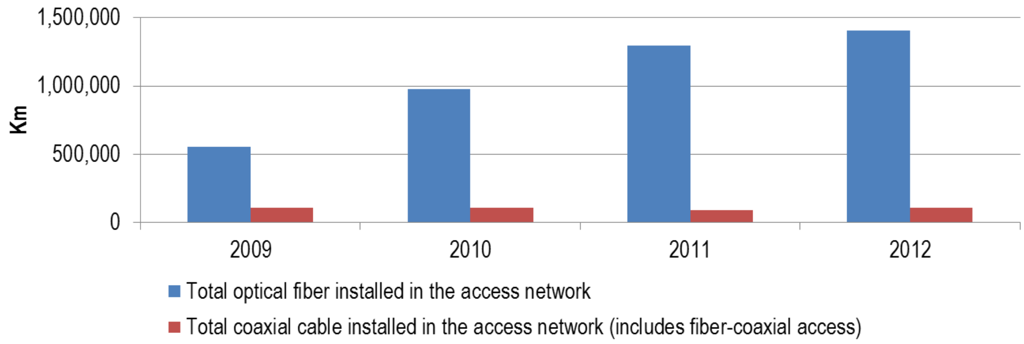


Figure 79 – Optical fiber in Portugal. Source- ANACOM.

After these plans, the investments in infrastructure slow down as the 2012/14 crisis impact Europe and most in particular Portugal.

4.8 Analysis Method

It is relevant at this moment to recall the goal of this work to clarify the adopted strategy in the next sections. The streams of thought that are implicit in this work, are based on several authors and countries actions that extend the existing concept of universal service to another one, that complement a failure detected in the free market mechanism. This failure concerns the existence of shadow zones, as geographic areas that doesn't interest any telecommunication operator leading to digital gap among citizens.

In this context the state has to interpose and guarantee a solution for those populations. The current mechanism is a legal instrument with fixed and rigid definitions, most of them unable to answer the current subscriber´s demand. The streams of thought allow the disruption of the traditional rigid definition to concepts as for example the network neutrality, extending the current twisted copper pair to other technological solutions.

This concept adaptation will allow the access to a modern type of life, based on modern telecommunications solutions. This way of life is aspired by the governments for all citizens to achieve an equitable development model for their countries. Those solutions are based on existing approaches implemented on the Portuguese society or derived naturally from the evolution of the market.

The current answer to the initial problem: "***to provide technical solutions to support political and regulation decisions for short/medium term Portugal Broadband Universal Service implementation, based on a geographical financial analysis***", hasn´t been given so far in the literature. The European Commission conducts a review of the scope of the EU Universal Service rules every three years in order to reflect (among other issues) on the implications and needs of the extension of broadband services as Universal Service as a global approach for all the union members. It is generally consensual, that after the last twenty years of experience of this type of regulation model, the free liberalized market by itself doesn't answer the lack of penetration for less financial attractive regions. Proof of that, are the several attempts to reduce the digital gap all around several liberalized countries by national broadband programs.

This thesis work adopts an objective justification as its philosophical stance. It is focused in an objective reality. The research strategy is a case study, based on the application of a developed architecture using financial models applied to Portugal. The data collection is based on statistical data both from the Portuguese statistics body concerning the country characterization and from the telecommunications Regulator, concerning the Portuguese consumer profile.

The data analysis technique is a logical analysis based on cause-effect relationship; this is implemented using an algorithm developed by the author that allows the financial calculation of several technological solutions, based on customized inputs. By forecasting the trends of the access telecommunication networks, the technical and economic advantages and disadvantages of its implementation in the specific context of a legal frame as the universal service and in a particular environment as Portugal has been evaluated.

The granularity of analysis is the Portuguese municipality, characterized by the population density, housing and consumer profile. Although it is a major important variable, the relief is not included. The main limitation of this research is the granularity of some data and also some lack of comparison for certain technologies to validate the results.

The scientific and public interest implicit in this research is to provide a neutral engineer evaluation of the economics of the telecommunication networks under the frame of the universal service.

The positive emotions are the awareness of the technology implication in the society way of life and at the end of the day the economic development of country people welfare, versus the economical capability of a country to provide a certain level of technological solutions. Political decisions can impact the Universal Service outcome, and this will not be considered in this thesis.

The philosophical stance and research strategy adopted in this work is based on the assumption that the Universal Service concept should be preserved in a modern society (Thesis), but adopted to the emerging needs of the citizens (Hypothesis), based on modern architecture and telecommunication technologies, that have inherent diverse costs and features.

It is expected that the author´s education and professional background provided the technical skills to understand both the technologic solutions as the business synergies. The participation on discussion panels, opened raised awareness for the citizens' needs and how political decisions are involved in a country economic' s consolidation.

The developed model is a general tool that allows the dimensioning of any telecommunication solution, based on the target area and subscription. It is optimized for the wireless mobile communication 4G, fiber to the home passive optical network and digital television broadcast. These technological solutions were chosen based on the previous described state of the art in Chapter 3 from the technological evolution point of view and also from the Portuguese point of view, as solutions widely implemented in the country.

Despite the possibility of the tool to calculate the total investment per technological solution for all the subscribers of a certain operator, the approach was slightly different. More than the rigorous value of the network deployment per scenario, the tool results were used to find the delta investment between two deployment solutions to provide broadband network among a certain percentage of the population that lives in the shadowed zones.

To support the decision of extending the new generation networks to the universal services obligations is mandatory to analyze the financial impact of that decision. The values derived by this analysis should then be evaluated in terms of the political choices based on operator´s and country economic strategy and regulation impact.

4.9 Simulating Universal Service geographic area

Revisiting the objective, which is the comparison of the financial impact per technological solution, a financial comparison model is going to be built based on a self-developed tool for several technological solutions. The comparison is based on a scenario where an existing operator invests in the most obvious geographic areas with another scenario extended to potential less profitable areas.

- Two geographic areas are going to be defined, a region with the "typical" network roll out without Universal Service obligations (USO) and a region with the network roll out due to the Broadband Universal Service obligations, schematic in Figure 75.

The standard roll-out deployment objectives depend only on the regulators license obligations (usually a percentage of population) without any constraints or duties on geographic zone. Typically the network deployment is based on regions with high levels of population concentration and high economic power. It is mainly focused on urban and suburban areas of higher GEOTYPES.

The forecast deployment with universal service obligations has much more randomness and uncertainty. It will certainly include all the areas of a standard deployment with addition of two types of subscriber requests: subscribers with financial constrains and subscribers from less populated, dispersed and scatter zones, mainly rural areas.

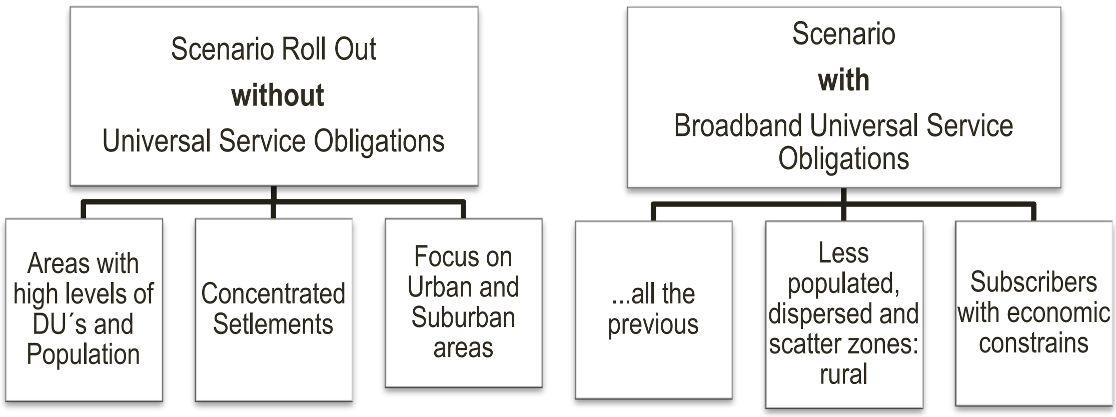
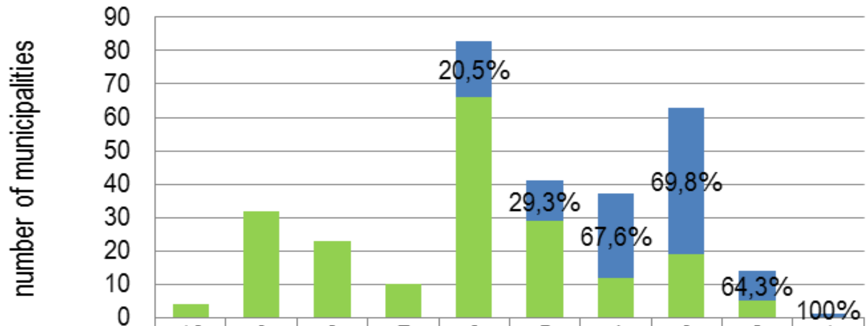


Figure 80 – Strategy scenarios for universal service simulation.

Even though all the municipalities are already catalogued and characterized based on the same criteria's, the fact is that in practice municipalities with the same GEOTYPE are not treated equally in terms of network deployment. For this reason an imaginary line along Portugal mainland is adopted as described in next figure. This line was drawn including the lower GEOTYPES in the same "blue line" zone. It was found later that this border is similar with the border adopted at the final deployment stage of the analog to digital television transition (Figure 66).

The number of municipalities on the blue zone includes almost all the GEOTYPES 1, 2 3 and 4 and part of the 5 and 6, Figure 81. An exception of this border is the type of municipalities inside the blue area with cities "*Capitais de Distrito*", as Braga, Faro and Castelo Branco, catalogued with GEOTYPE 9 and 8.



	10	9	8	7	6	5	4	3	2	1
TARGET US					17	12	25	44	9	1
PORTUGAL	4	32	23	10	66	29	12	19	5	

Figure 81 – Municipalities distribution based on the "blue line" border.

The municipalities inside the dark blue line (*the blue zone*) represent the areas where it is assumed to be the ones with more probability of lack of new generation network roll out and therefore with more probability to have broadband universal services subscribers, Figure 82.

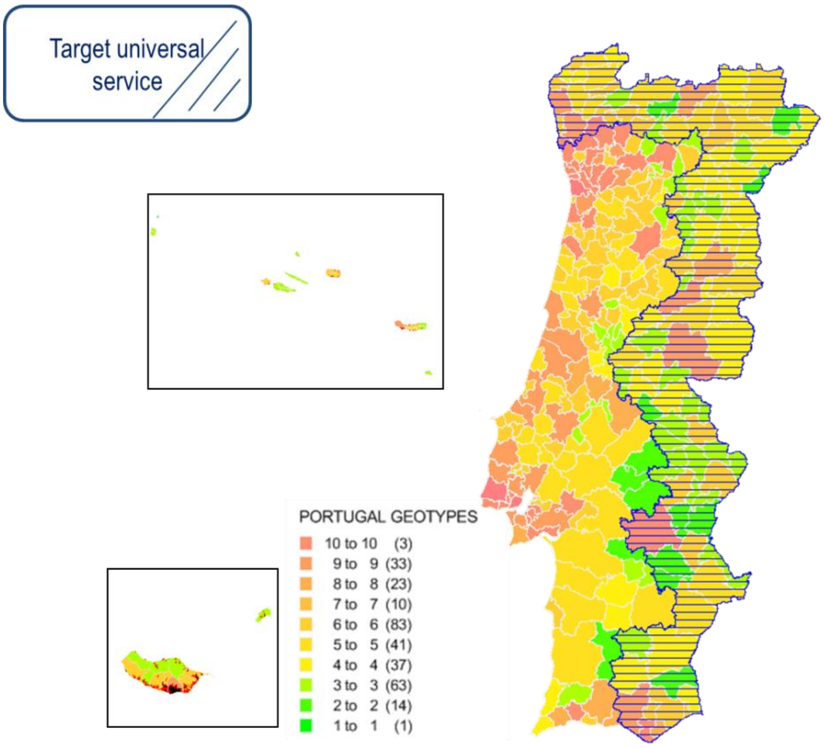


Figure 82 – Strategy model for universal service simulation.

The “blue zone” target Universal Service, is the geographic area of Portugal that is assumed to be less attractive from a business point a view: less population and purchasing power. This area definition is based on the distance from the biggest urban centers (in the shore) to the countries´ interior with less and scattered population. These municipalities represent only 9,5% of the total Portuguese population, 13% of the homes but a representative 41% of the total mainland area, Table 14.

	Count of Municipality	Sum of Pop	Sum of DU	Sum of Area (Km^2)
PORTUGAL without USO	200	90,54%	86,72%	59,37%
PORTUGAL with USO	108	9,46%	13,28%	40,63%
Grand Total	308	100,00%	100,00%	100,00%

Table 14 – Target Universal Service potential area data.

4.10 Evaluation Criteria

As any other telecommunication service the adoption of the Universal Service follows a random pattern both in adoption rate and location. The calculation of the impact of the extension of broadband by random requests depends on the initial conditions and growth behavior. To describe this behavior the adopted model was a sigmoid logistic curve as in Figure 83, which corresponds to the adoption of different real telecommunication services. The adopted values for the “standard roll out” are based on:

- the operator´s license obligations imposed by the National regulator,
- the trend of service adoption based on the subscription cable TV, internet , wireline broadband and wireless and
- the leader operator market share.

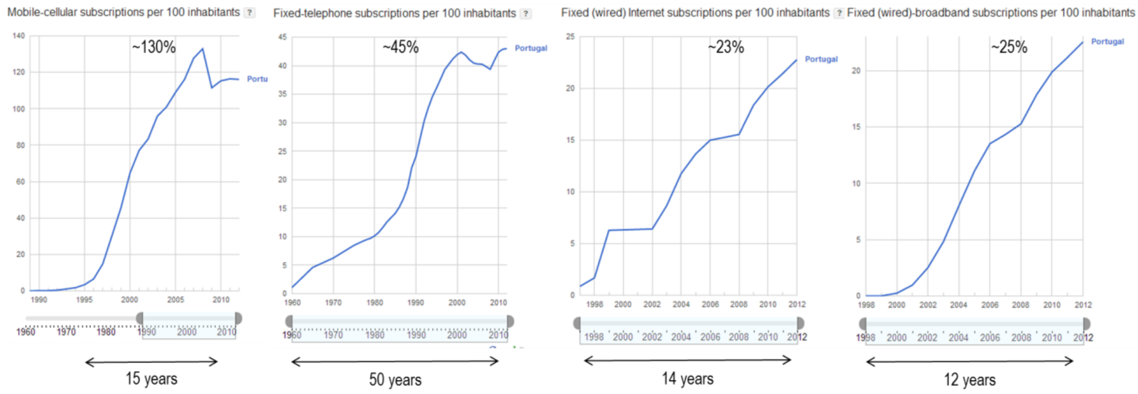


Figure 83 – Portuguese rate subscriptions per 100 inhabitants for several ICT statistics. Source ICT-ITU [16].

The reasons subjacent to these choices are explained next.

Operator´s license obligations – This indicator is used to up limit the geographic deployment regions on a typical roll out, based on the license obligation limits. The UMTS license was used as an example, which main obligations after 5 years of license should reach coverage of 60% of the population. This license request was chosen because this technology is a combination of voice and data services and therefore closest to the type of service desirable to broadband universal service.

Service adoption based on the subscription cable TV – To forecast the penetration level of a voice plus data operator, the rate profile of the National Cable TV subscription per GEOTYPE was chosen. The reason that lead to this choice is due to the fact that is a Nomenclature of Territorial Units for Statistics, NUTS III statics (on the contrary the National internet penetration rate is a NUTS II and therefore without the desirable granularity) also it is a mature subscription service (since 2002), Figure 84.

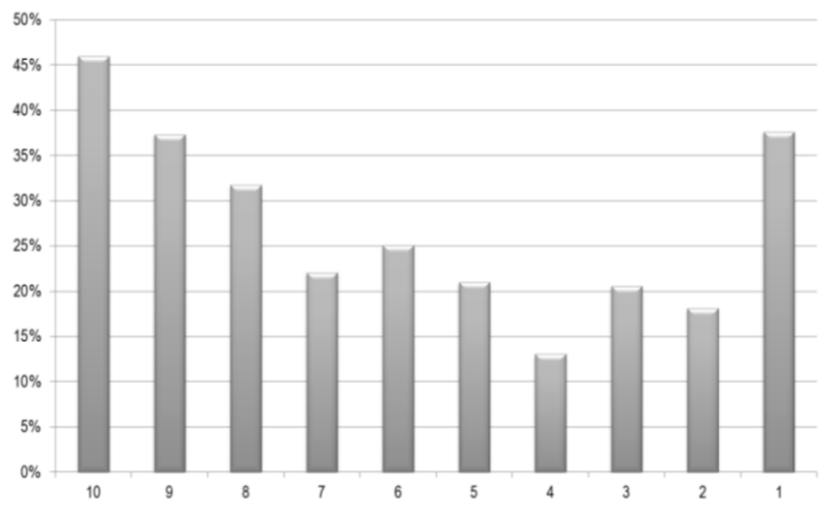


Figure 84 - Total subscribers of television subscription service per GEOTYPE, 4th trimester 2012. Source: ANACOM [188].

[16] Available on line: http://www.google.com/publicdata/explore?ds=emi9ik86jcuic_&ctype=l&strail=false&bcs=d&nselm=h&met_y=i993&scale_y=lin&ind_y=false&rdim=country&idim=country:PT&ifdim=country&tstart=863910000000&tend=1337295600000&hl=en_US&dl=en&ind=false&icfg

Market share: The cable TV market share is analyzed to adopt a reasonable market share for the theoretical operator described in this work, Figure 85. It is observed that even though the market is liberalized, there is a notorious dominance from two operators with 49% and 40% share. Thus a target market share of 45% is assumed.

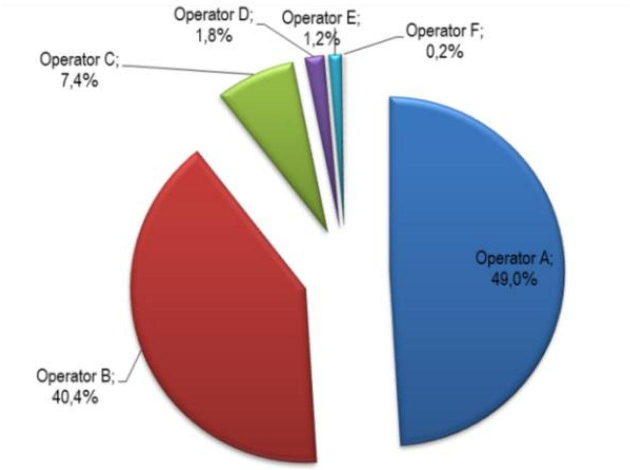


Figure 85 – Cable TV market share. Source: ANACOM, [188].

The next table illustrates the variables adopted for each one of the scenarios as the main input characterization for subscriber forecast in the developed tool TENTUS Table 15 and Figure 86.

License obligation after 5 years	***Market Share***
60% population	45%

Forescast penetration rate per GEOTYPE									
Geotype 10	*Geotype 9*	*Geotype 8*	*Geotype 7*	*Geotype 6*	*Geotype 5*	*Geotype 4*	*Geotype 3*	*Geotype 2*	*Geotype 1*
46%	37%	32%	22%	25%	21%	13%	21%	18%	38%

Table 15 – Simulation Subscribers´ Criteria.

The same variables in graphs:

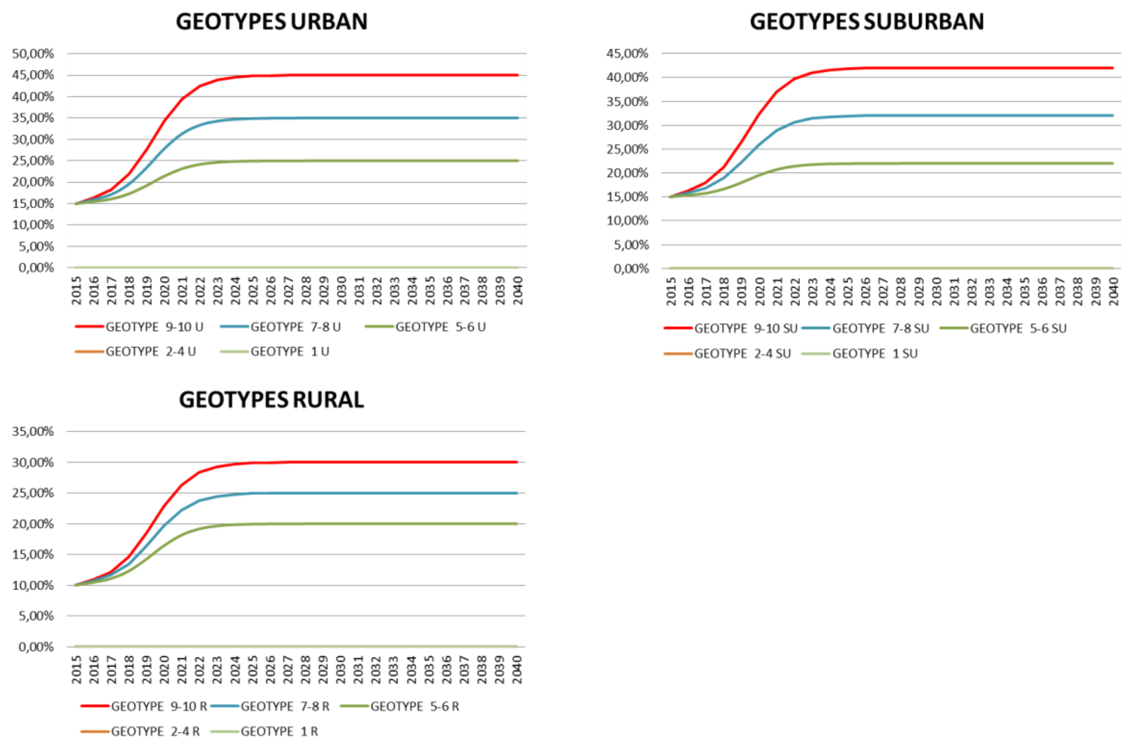


Figure 86- Forecast scenarios: penetration rate, subscribers per year and total subscribers per year (cumulative).

An increase due to universal service subscribers of 10% in the highest GEOTYPES (9, 8 and 7), due to economic needs, was chosen. At these GEOTYPES it is expected to have an increase of the network efficiency, as this subscriber increase occurs in a zone where the network is already implemented. However those subscribers will have a reduced pricing that might impact the Revenues.

For the other GEOTYPES, where an alternative network is not expected, the target penetration rate increase is assumed between 20% and 30%. It is expected that the inclusion of those subscribers will imply high network investments. Those subscribers will have a mixture of reduce and normal pricing customer profile.

4.11 Methodology

After the identification of the geographic regions added to a typical deployment without any Universal Service constrains and the identification of the market uptake behavior, a software tool was developed to calculated the number of network elements of a specific technological architecture and its cost. The tool is going to be described in detail in the next chapter (Chapter 5).

It should be stressed that this tool is not only a bill of materials, but it is a dimension planning tool that considers electrical engineering planning strategies for the calculation of the data network coverage zones. Moreover the planning simulator is adapted to the particularities of each one of the technological solutions.

Following the initial study of technologic solutions (Chapter 3) the selected architectures concerning broadband data communications, are the LTE and FTTH- GPON. These technologies were selected since they are the most prominent broadband solutions already implemented in the country The Digital Video Broadcast is also quantified as an alternative solution due to its universalized usage in the television broadcast service.

In Chapter 6 the tool will be applied to several scenarios that will allow comparing and discussing the technical solutions to support political and regulation decisions for short/medium term Portugal Broadband Universal Service implementation, based on a geographical financial analysis.

All solutions are analyzed assuming the exact same conditions of roll out in time and geographical penetration. This comparison will be done in two phases. First within each technology a comparison is going to be made between the typical roll out and the extended roll out due to the Universal Service burden. The second phase compares these results among technologies.

4.12 Summary

The objective of this chapter was to provide a full knowledge to the reader of Portugal. The administrative organization is described and a brief look on the main socio-demographic statistics is presented. The second section of this chapter describes the history of the telecommunication sector in Portugal to contextualize the reader to the challenges of the implementation of the new generation networks, since they do not appear in a sterile environment. The efforts of Portugal to overcome the digital gap are also mentioned

This final section of this chapter intends to direct to the strategy developed in the following chapters, focus on the method followed to simulate a universal service operator obligation. The Universal Service burden simulation is done by dimensioning a typical telecommunications network that will add into a second analysis, the duties of the Universal Service. For that three technological solutions are chosen and for each one a techno-financial analysis is done based on designed architectures. To achieve high levels of simulation freedom and to have total control of the variables, a simulation tool was developed.

Chapter 5. **TECHNO-ECONOMIC ACCESS NETWORKS' DIMENSIONING TOOL**

The dimensioning of a telecommunication network depends on several factors such as the system inherent characteristics but also depends on the field constrains that sometimes overlap the system designing optimization such as: the components limitations; the adopted architecture; the elements capacity and the specifications of each one of the components. Also other external constrains constrain the design engineer as: the inaccurate forecast of the subscriber homes; the cost of municipal licenses for duct digging; the equipment placement and most of the time the condos authorization for equipment installation or available space for new equipment at the buildings or towers. However beside these practical adversities this section will describe a theoretical model developed to calculate both the quantities for components and network elements as well as the civil works that are implicit to do in each type of architecture implementation, considering that the target candidates accept the network deployment.

The algorithm that was developed offers a completely control on all the variables and for most of them adds an efficiency coefficient to better control it. The total amount of equipment and work at each moment of the project implementation (each year of analyze) depends on the forecast amount of clients as it will be described in the next Sections. The raw data, concerning Portuguese statistics, can be updated at any time at the model input. The tool focuses on the gigabit passive optical network and on the wireless network architectures, but can also be adapted with other networks with slightly updates and modifications.

The focus relies on the cost of the access network, from the core network that manages the inter-dependencies inside a network and interconnects the network with other networks; and the client network that concerns the equipment inside the subscriber home. There are two types of methods to determine the costs of a network. The difference between these two methods lies in the way the cost of network components is determined:

- Bottom-up ("scorched node" or "earth node"): with this method all the calculations are based on a fictitious network with estimate traffic needs based on statistical data;
- Top-down: with this method all the data came from an existing network.

Bottom-up models are used to establish efficient costs in telecoms price regulation and are recommended by the European Commission as the preferred costing methodology for EU member states. Costs are incurred in an operator's business in response to the existence of, or change in, service demand, captured by the various cost drivers. Long-run costs include all the costs that will ever be incurred in supporting the relevant service demand, including the ongoing replacement of assets used.

In this study the applied method is going to be theoretical approach of the bottom-up type from a real study area (Portugal) with several scenarios for a broadband universal network. As previously described, the country´s municipalities were agglutinated and subdivided in Geotypes from 1 to 10, depending on several variables, in Section 4.4. The networks architectures´ s proposed were modeled to be implemented per municipality type (sub-Geotypes), as type is defined as Urban, Suburban or Rural. Each sub-Geotype is therefore divided in smaller areas, called subsections.

To respond to the author's needs, a new Excel based tool was developed by the author, with the desirable flexibility and full control on the algorithm critical variables. It is called **Techno-Economic Access Networks' dimensioning Tool for Universal Service, TENTUS**.

This section describes the methods analytics base case that is subjacent to the algorithm decisions as well the initial conditions for all the studied technologies: GPON, LTE and TDT. Moreover the TENTUS´ financial management engineering approach is also outlined.

5.1 The tool: Techno-Economic Access Networks' dimensioning Tool for Universal Service (TENTUS)

To understand the tool from the user point of view, a schematic table is presented, explaining the developed worksheets, Figure 87. The tool is based on several Excel worksheets, each one concerning a certain algorithm model. Each scenario implies an Excel file with the corresponding worksheets.

RAW DATA		
PORTUGAL		all raw data from CENSOS, ANACOM
MODEL		Explanation of the architeture model and data agregation
Tables		Pivot tables based on raw data
GEOTYPES		Explanation of the Geotypes characterization model
Neigh		neighborhood characterization
0. PARAMETERS		Excel explanation
1. INPUT		Input data - costumized by the user
	1.1 INPUT Charts	Charts based on input data
2. OUTPUT		Financial Feasibility Model
	2.1 OUTPUT Charts	Charts based on output data
	2.2 Bill of Material	Number of network itens by year
	2.3 CAPEX	Cost per network itens and expenses by year
	2.3.1 Finantial geotype	Cost per network itens and expenses by year per U/SU/R
	2.4 OPEX	Operator´s Operational expenses per year
	2.5 REVENUES	Operator´s Revenues per year based on billing plans
3. Investment decisions		
	3.1Operator´s Investment Plan	Assumption of the Build Plan per yera, per Geotype
	3.2 Penetration forecast	Percentage forecast for subscribers, considering the equation: $Traffic\ evolution_{per\ year} = \%\ Initial\ Subscribers + \frac{(\%\ Final\ subscribers - \%\ Initial\ subscribers)}{1 + \alpha \cdot e^{\beta\, year}}$
	3.3 Subscriber forecast	Calculation of the real number of houses to deploy based on 3.2 penetration´s evolution
4. GPON Equipment forecast		
	4.1 ONT	Calculation of the number of ONTS based on forecast PLUS the time life replacement´s needs
	4.2 ODP	Calculation of the number of ODPs based on forecast PLUS the time life replacement´s needs
	4.3 Splitters	Calculation of the number of splitters type N and type 2 PLUS the time life replacement´s needs
	4.4 Cabinets	Calculation of the cabinet´s needs for all the municipalities, acording subGeotype PLUS the time life replacement´s needs
	4.5 FP´s	Calculation of Flexibility Points
	4.6 CO	Calculation of CO elements: OLT cards and racks PLUS the time life replacement´s needs
5. Fiber Lenght Dimensioning		
	4.7 Fiber DCO	Calculation of the fiber feeder segment
	4.8 Fiber DistCable	Calculation of the fiber distribution segment
	4.9 Fiber drop	Calculation of the fiber drop segment
	4.A PON Link Budget	Link Budget Calculation
5. LTE		
	5,1 LTE sites	LTE number of sites calculation
	5.2 LTE Type of service	All the calculations related to trafic forecast and sites calculation for LTE
6. TDT		
	TDT	All the TDT calculations
7. PRICE LIST		
	Price List	All the costs per item and respective learning curve index per year

Figure 87 – TENTUS_ScenarioXXX.xlsx worksheets summary snapshot.

A second stage of the tool was built later to increase the granularity of the result data per sub_Geotype. This way each sub-Geotype is characterized from the techno economic point of view. This new file is automatic updated from the other.

- The Excel files per scenario for all the country are named: *TENTUS_ScenarioXXX.xlsx*
- The Excel files per scenario per sub-Geotype are named: *TENTUS_vGEOTYPExx.xlsx*

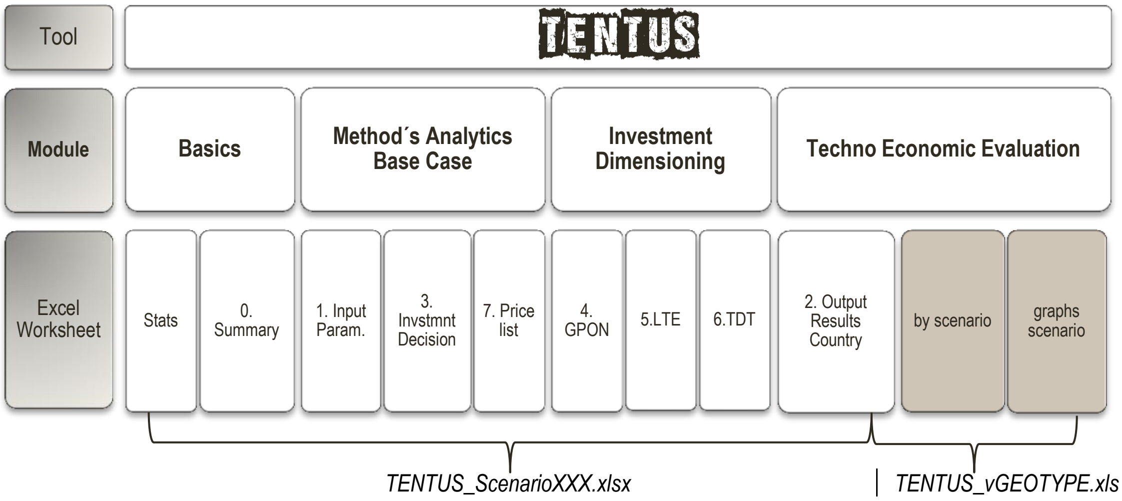


Figure 88 – TENTUS modules organization.

This section explains how the Excel worksheets are built according to the Figure 87.modules: Basics, Method´s Analytics Base Case, Investment Dimensioning and Techno Economic Evaluation.

5.1.1 Basics

There are some initial worksheets PORTUGAL, Matrix and Tables that are part of a basic module concerning raw data and data manipulation per municipality. (*TENTUS_ScenarioXXX.xlsx)*

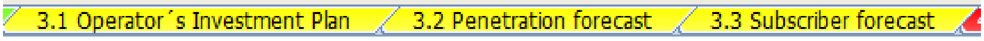
- PORTUGAL: These data source are statistical and geographic entities as ANACOM and INE, [20], [189]. It also contains the calculation of several network elements per municipality if all the population subscribes this theoretical operator. Those elements include: cabinets, splitters, optical distribution points or cable distances.
- MATRIX: This matrix is used for the geographic modelling and traffic dimensioning. It characterized each sub_Geotype concerning the area in Km^2.
- Tables: From the table PORTUGAL, several pivot tables are built concerning data aggregation such as: area, population and network elements per GEOTYPE aggregation.
- 0. PARAMETERS: This worksheet presents the excel worksheets description.

5.1.2 Method´s Analytics Base Case

The orange worksheets concern the input parameters. It means that it is at this stage that the input variables are defined. (*TENTUS_ScenarioXXX.xlsx)*

- 1. INPUT: This worksheet allows the user to define several variables such as: subscriber forecast per sub-Geotype; life time parameters, billing plans, target population; infra-structure sharing rate; equipment capacity; efficiency and reuse factor or the starting of investment per sub-Geotype;
- 1.1 INPUT Charts: Charts are created based on some input variables.

The yellow section reflects the investment decisions that were defined at INPUT worksheet. (*TENTUS_ScenarioXXX.xlsx)*



- 3.1 Operator´s Investment Plan: at this point is reflected the input from the user (as the operator) for the time to invest in each type of Sub-Geotype (@ year 0, @ year 1….).
- 3.2 Penetration forecast: reflects the choice of the user concerning the percentage of market reached each year per sub-Geotype.
- 3.3 Subscriber forecast: converts the defined percentage into absolute number of subscribers per year of project, per sub-Geotype.

The price list presented at the right top of the excel file is both an input file and calculation file. (*TENTUS_ScenarioXXX.xlsx)*

- 7. PRICE LIST. At this worksheet the prices per equipment or network component are defined for the project starting year. Then its values are projected along the period of analysis considering a depreciating of its cost based on a learning curve depending on the maturity of the technology.

5.1.3 Investment Dimensioning

The red and blue worksheets are required for calculate the quantity of equipment and optical fiber for FTTH-GPON solution. At the end of each element time life it is considered the replacement all at once. (*TENTUS_ScenarioXXX.xlsx)*

- 4.1 ONT: Calculation of the number of optical network terminals per year. It was defined one ONT per subscriber.
- 4.2 ODP: Calculation of the number of optical distribution point. The ONT are aggregated in groups of 22 leaving two empty fibers for maintenance purposes. The housing scattering is simulated by imposing a low efficiency factor (@ INPUT).
- 4.3 SPLITTERS: Calculation of the number of 1:32 splitters.
- 4.4 Cabinets: Calculation of the number of splitters per cabinet and number of cabinets.
- 4.5 FP´s: Calculation of the flexibility points.
- 4.6 CO: Calculation optical line terminals, OLT (each one with 4 PONs) and corresponding number of racks (each one with 4 OLTs).

The light blue group calculates the length of the ducts needed to be built at the three networks segments, Figure 93. The geographic correspondent value of optical fiber is derived from this calculation, without the efficient factor.

- 4.7 Fiber DCO: Calculation of the duct length between the central office and the center of the sub-GEOTYPE.
- 4.8 Fiber distcable: Calculation of the duct length between the center of the sub-GEOTYPE and the street level.

- 4.9 Fiber drop: Calculation of the duct length between the street and the DU.
- 4.A PON Link Budget: Calculation of the link budget.

The purple worksheets are required to calculate the number of sites of the wireless LTE solution

- 5.1 LTE sites: LTE sites are calculated based on traffic demand versus the coverage area.
- 5.2 LTE Type of service: Calculation of the traffic profile depending on the GEOTYPE usage profile.

The dark green worksheet analyses the broadcast solution. (*TENTUS_ScenarioXXX.xlsx);*

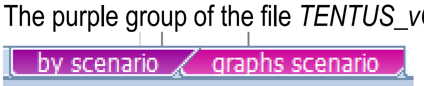
- TDT: Calculation of the network elements and the respective investment in reception equipment. The first calculation allocated to the operator, the second one to the final user.

5.1.4 Techno Economic Evaluation

The black group of worksheets, and the light green, reflects the financial analysis done base on the quantity of material found on the previous ones. (*TENTUS_ScenarioXXX.xlsx)*

- 2. OUTPUT: Data collection per year of the above worksheets. Financial calculation per year for all the country.
- 2.1 OUTPUT charts: Data charts from OUTPUT data.
- 2.2 Bill of Material: Complete bill of material
    - FINANCIAL –GEOTYPES 1-10: The same type of calculation as OUTPUT but per sub-GEOTYPE
- 2.3 CAPEX: Material cost per item per year (global country).
    - 2.3.1 FINANCIAL GEOTYPE: Material cost per item per year per Urban Suburban or Rural area.
- 2.4 OPEX: Calculation of operational expenses: a percentage of the equipment investment, plus other expenses as rental of ducts, pylons or rooftops.
- 2.5 REVENUES: Calculation of the total revenue per year. It is not assumed loss of subscribers (churn).

The purple group of the file *TENTUS_vGEOTYPE.xlsx* is updated by the previous file per sub-GEOTYPE.



- by scenario: The same type of calculation as OUTPUT per sub-GEOTYPE, per year;
- graphs scenario: Corresponding graphs of the previous worksheet of accumulated investment and maintenance cost per year, per sub-GEOTYPE and per technology.

5.2 TENTUS Method´s Analytics Base Case

In the deployment of a telecommunications network the time lag between identification of the need to provide subscribers' equipment, lines and exchange plant, and the ability to meet those needs may be quite considerable. This means that as the network raises it is necessary to accurately forecast the traffic needs so that plant arrives and is installed before existing capacity is exhausted. In an ideal deployment, with no restrictions, forecasting and planning would ensure that demand for services are accurately anticipated and satisfied as they rise, however, in practice this will not be the case, as planning is often constrained by availability of funds and policies of the administration or government.

In order to produce accurate forecasts relevant data should be available as the historical records of service adoption and traffic behavior. When this is not possible, as in the present study, some empirical assumptions have to be done to proceed. These forecasts should indicate the degree of uncertainty which is inherent in their estimation, and as far as possible include some indication of its magnitude so that planning and provisioning strategies may account of this uncertainty.

Associated to the quantity of subscribers is their location and adherent rate to the implemented network. This uncertainly leads to the implementation on the field of more components than the real needs. Consequently it develops to a certain degree of inefficiency that should be supervised.

Dealing with uncertain forecast is one of the most difficult barriers to cross over, mainly in Wireline technologies forecast due to its point to point characteristics. Basically there are three big questions to answer:

- How many are the forecast subscribers?
- What are the subscribed services?
- Where the network components should be located?

The Universal Service deployment aims to achieve the highest number of subscribers, however aware of the existence of competition, sometimes quite well implemented in the field. The effects on the competition are not an issue of this work but part of game theory studying area.

As in the end of the day this is a business, there are also other factor's to considerate as the subscriber´s adoption rate and service type adoption so operator´s return can be calculated based on the billing plans adopted.

The main elements of the main algorithm are systematized in the next figure, Figure 89, and detail in the next sections. Most part of the algorithm is shared among all the candidate technologies for Universal Service. The main differences will appear at the network dimensioning and the variables used.

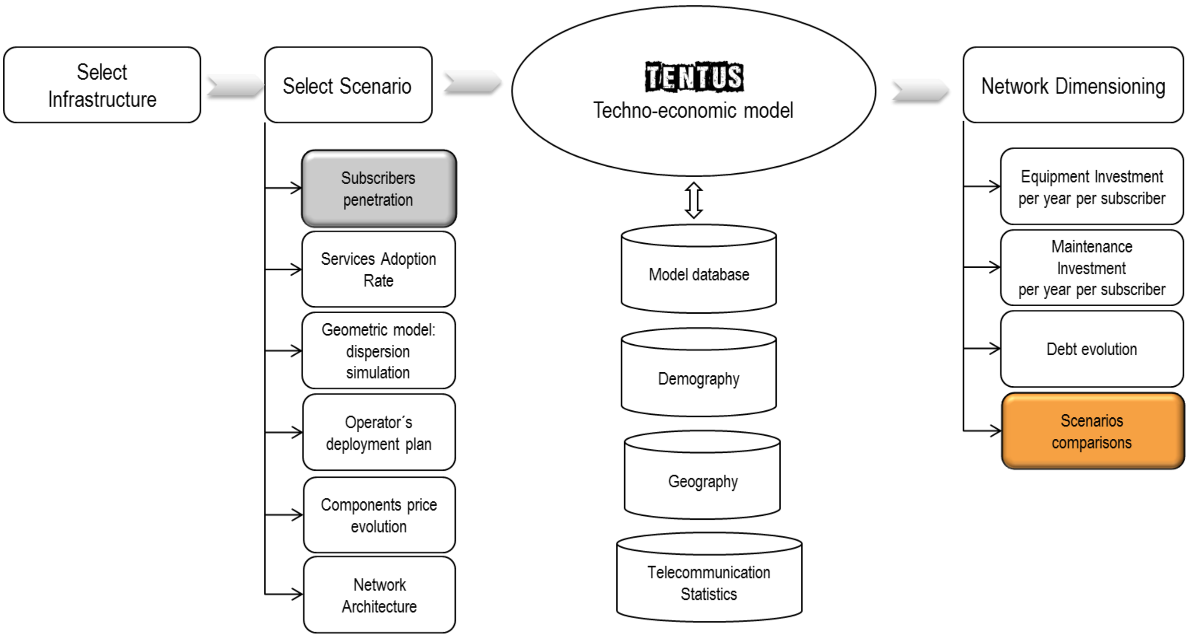


Figure 89 – TENTUS algorithm basis.

5.2.1 Infrastructure issues and availability

Depending on technology of telecommunications network, the physical layer can vary accordingly the best suitable propagation mean. The physical mean of signal propagation define the physical support. Some basic installation techniques of a telecommunication network are pictured in Figure 90, for general information.

The type of site will be a key factor in deciding the most appropriate network design and architecture. Types include, Overbuild – adding to the existing infrastructure; Greenfield – new build where the network will be introduced at the same time as the buildings and Brownfield – where there are existing buildings and infrastructure but the infrastructure is to a lower standard.

At this study the techniques used for wireless are both pylons and masts at the top of the buildings. As it is considered that the Universal Service provider already owns a wireless infrastructure with old generation technologies the approach is a mixture of an overbuilt type when co-locating the new technology to an existing site and brownfield.

For the wireline optical architecture this study considerers a general approach with ducts and trenches, outline in red at Figure 90. The author is aware of the potential significant investments depending on that choice. The wireless architecture is based on a combination of mast over existing buildings such as condos or water towers and infra metal structures constructed for this purpose as masts or pylons, outline blue at Figure 90.

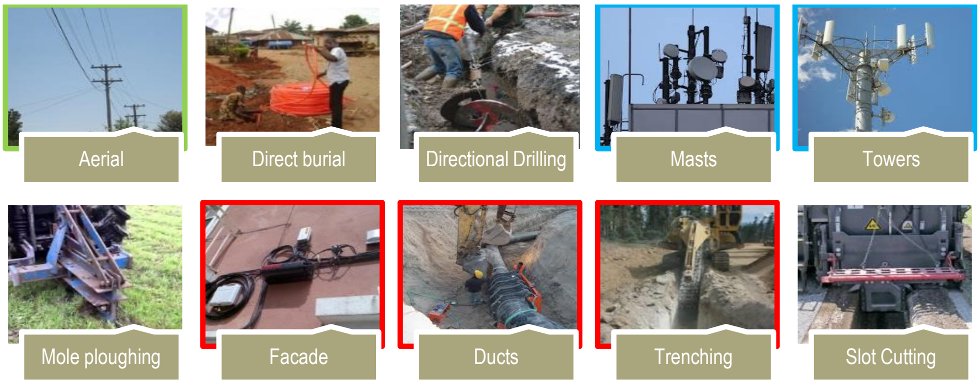


Figure 90 – Some telecommunications network´s installation techniques.

At the authors´ paper "*The impact of geography and demography on the economics of fiber optic access networks*", [33]. and at book chapter "*Custos e Benefícios, à Escala Local, de uma Ocupação Dispersa*", [34], a reflection on the investment between the fiber implementation by trenches and by an aerial mean is done and evaluate, outline green at Figure 90. By the time this work started it was not a common practice the use of aerial fiber, few years later is a common practice at rural but also urban zone, most of the time without any respect for the private propriety and street cross rules.

Figure 91 – Examples of aerial fiber in Portugal.

5.2.2 Operator´s Investment Plan

Associate to each telecommunication network there is always an investment plan. The investment plans depended on several variables as the geo-marketing inputs, the social economic conditions per geographic location, the network effect among clients (if there is already a network on the field) and the operators´ financial availability.

The telecommunications operator as Universal Service provider, which has the Universal Service obligation, has a strong social dimension and special requirements beyond due to other providers of fixed services, notably with regard to performance targets related to the quality of the service, the facilities made available, the price system, information services and the delay in delivering the connection.

The type of client of Universal Service should not be dependent to any investment plan but always be able to request the service adopted by the Universal Service obligations. However as we are talking about a new network, with several lacks of deployment all over the country and implicit very time consuming civil works; is natural to reflect that process in an investment plan diluted over time. The time to connection is a relevant matter when the new generation networks are introduced as potential Universal Service technologies. If nowadays the POTS networks are stable and with high capillary, that doesn't happen for most of the candidates technologies to the near future Universal Service. The target delivering time from 5 to 30 days, might be short in such a new environment, and that is one of the issues to reflect about, at Chapter 7.

At this point is relevant to mention that TENTUS algorithm takes into account, if needed, the time to market per sub-Geotype, leading to another freedom degree when planning such a network. In the limit the related variables can all be put at zero leading to a total dependency of the subscriber´s demanding.

5.2.3 Market uptake: subscriber´s penetration rate evolution

At this point is relevant to remind that the market target of the Universal service it is not targeted to the majority of the population in the country. The majority of the population is going to adopt other communication solutions that are not the ones offered by Universal Service. There is also a residual remaining percentage of population that will not adopt any communication rate plan. The user profile of Universal Service subscriber is based on citizens with economical constrains, physical disabilities or citizens living in unserved areas:

- At regions where there is a complete offer on telecommunication services, the subscriber profile is mainly dependent on the economic condition of the families as well the age of physical disabilities. This subscriber profile reaches the universal access at lower tariffs.
- At regions where there isn´t any offer on telecommunication services the subscriber profile is a mixture of the same subscribers due to economic restrains but also from those that find at the Universal Service the only possible solution to achieve broadband services.

For this last group of subscribers it is assumed the same type of adoption profile as for the standard roll out in a competitive market.

As previous explained at Section 4.10 Evaluation Criteria, to understand the subscriber´s adoption dynamics, mathematical models were used, [190]. To answer about the subscribers target and uptake rate it was applied a numerical method based on logistic function - sigmoid logistic curve described in Equation 1 that is dependent of the initial and final number of forecast subscribers and of two independent variables: α and β that control the delay to uptake the demand and the adoption rate respectively.

$$Traffic\ evolution_{per\ year} = \%\ Initial\ Subscribers + \frac{(\%\ Final\ subscribers - \%\ Initial\ subscribers)}{1 + \alpha \cdot e^{\beta \cdot year}}$$

Equation 1 – Traffic forecast evolution per year.

The values that of α and β, Equation 1, can be configured per Geotype and can also be dependable of the scenario conditions: optimist or pessimist. Depending on the region´s Geotype the impact caused by those variables determines the time to subscribers' uptake and the faster it reaches to a stationary situation. It is expected that urban and denser regions will be potential faster service up takers.

Optimist and pessimist scenarios are defined by the percentage of sharing infra-structures, where an optimist point of view is the one with more potential sharing's and therefore potential less investment. This terminology is also used for the perspective of traffic forecast where an optimist view considers a bigger percentage of subscribers as a final target. The α and β parameters are then adapted to each type of typology and the final aspect of the penetration curve is in Figure 86. The penetration in a rural environment is expected to be more smoothly and slow than in urban environments due to the residential customers and also due to the low rate of enterprises.

The following table presents the penetration rate evolution as well the subscriber evolution per year and the cumulative subscriber evolution per year and typology based on the target values defined at Section 4.10 for the scenarios without Universal Service obligations, Table 16.

	Scenario Roll Out without Universal Service obligations			***Scenario Roll Out with Universal Service obligations***			***Delta due to USO obligations***
GEOTYPE 9-10	*U*	*SU*	*R*	*U*	*SU*	*R*	***GEOTYPE 9-10***
% Subscribers/DU initial	*15%*	*15%*	*10%*	*15%*	*15%*	*10%*	***+10%***
% Subscribers/ DU final	*45%*	*42%*	*30%*	*55%*	*52%*	*40%*	
GEOTYPE 7-8	*U*	*SU*	*R*	*U*	*SU*	*R*	***GEOTYPE 7-8***
% Subscribers/ DU initial	*15%*	*15%*	*10%*	*15%*	*15%*	*10%*	***+10%***
% Subscribers/ DU final	*35%*	*32%*	*25%*	*45%*	*42%*	*35%*	
GEOTYPE 5-6	*U*	*SU*	*R*	*U*	*SU*	*R*	***GEOTYPE 5-6***
% Subscribers/ DU initial	*15%*	*15%*	*10%*	*15%*	*15%*	*10%*	***+10%***
% Subscribers/ DU final	*25%*	*22%*	*20%*	*35%*	*32%*	*30%*	
GEOTYPE 2-4	*U*	*SU*	*R*	*U*	*SU*	*R*	***GEOTYPE 2-4***
% Subscribers/ DU initial	*0%*	*0%*	*0%*	*15%*	*15%*	*10%*	***+25%***
% Subscribers/ DU final	*0%*	*0%*	*0%*	*25%*	*22%*	*20%*	
GEOTYPE 1	*U*	*SU*	*R*	*U*	*SU*	*R*	***GEOTYPE 1***
% Subscribers/ DU initial	*0%*	*0%*	*0%*	*15%*	*15%*	*10%*	***+35%***
% Subscribers/ DU final	*0%*	*0%*	*0%*	*35%*	*35%*	*30%*	

Table 16 - Penetration rate evolution per GEOTYPE.

5.2.4 Services Demand

The importance of predicting the type of service subscribed per user is important in two layers of study: the forecast of the consumed broadband and the prevision of the incoming return.

The model represent an average PON subscriber with a demand up to 30Mbps downstream capacity and an Average Revenue per User (ARPU) of 38.6€ per month. This is based on the customer fixed service choice of double play (voice and 30 Mbps High Speed Internet (HSI)). The wireless model assumes a LTE 200MB billing of 27€ per month.

The billing adopted for the universal service is purely theoretical as there is no comparison with a real scenario. The universal service data subscriber is assumed to be 25€. This value assumes the same service as the conventional subscriber and a wireless fixed 1Mbps DL and 500kbps UL guarantee.

5.2.5 Infra-structure variables

Simulations are depending on several TENTUS flexible parameters that simulate the dispersion and the infra-structure sharing, Table 17, Table 18 and Table 19:

Settlement dispersion and efficiency:

A lower inefficiency rate represents a higher unused equipment capacity. By this way the settlements dispersion and scattering are simulated, Table 17.

	Efficiency and Reuse factors			
	ODP efficiency	*Splitter efficiency*	*Cabinet efficiency*	*FP´s reuse*
U	70%	70%	70%	70%
SU	30%	30%	30%	70%
R	10%	10%	10%	60%

Table 17 - Settlement dispersion and efficiency

Duct sharing and type:

The deployment of a new telecommunication network doesn´t happens in a sterile environment. There are already ducts and manholes due to plain old telephone system and other utilizes as gas, and electricity, that can be shared, Table 18.

	Duct Reuse			***Type of duct***		
	fDCO	*fdistcable*	*fdrop*	*Rock*	*Sand*	*Aerial*
U	70%	70%	70%	14%	14%	3%
SU	30%	30%	30%	32%	32%	7%
R	60%	40%	10%	29%	29%	6%

Table 18 - Duct sharing and type.

<u>Site sharing and type:</u>

In the same way the deployment of a new cellular network appears in a country with existing pylons for old generation technologies that can be shared and co-located. Moreover the relation between pylons and rooftops can be taken into consideration, as they have most impact in infra-structure investment, Table 19.

	Site sharing	***Infra-structure relation*** *(pylons versus rooftops)*
U	70%	20%
SU	50%	30%
R	20%	70%

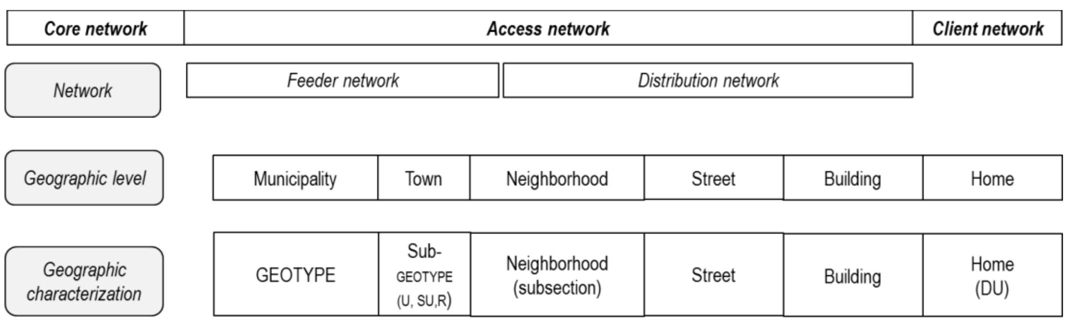
Table 19 - Site sharing and type:

5.2.6 Analytic/Geometric Models for Deployment

This section describes the method used to calculate the geometric model of wireline deployment. This issue is not applied into the cellular wireless deployment where the distribution mean is the air interface.

The study focus is a concrete geographical target the deployment analysis however to manipulate the real data it is necessary to model the fractal reality into a geometric model. Because of this the applied method is going to be a theoretical approach of the bottom-up type. The bottom-up method is based on a forecast per section and then sum all the sections forecast. Also it will be an intuitive forecasting exercise to produce forecasts of subscribers´ development.

As previously described, the study unit of this analysis is the municipality, categorized by Geotype. Each Geotype is then divided in sub-geotypes namely Urban (U), Suburban (SU) and Rural (R) and each one of the sub-geotypes is divided in small units named <u>subsections</u>. Each one of these subsections is detailed characterized with the available CENSUS variables. These subsections are agglomerations of households and can be described as the neighborhood. The following images try to picture this reality for a certain municipality, Municipality X, Figure 92.



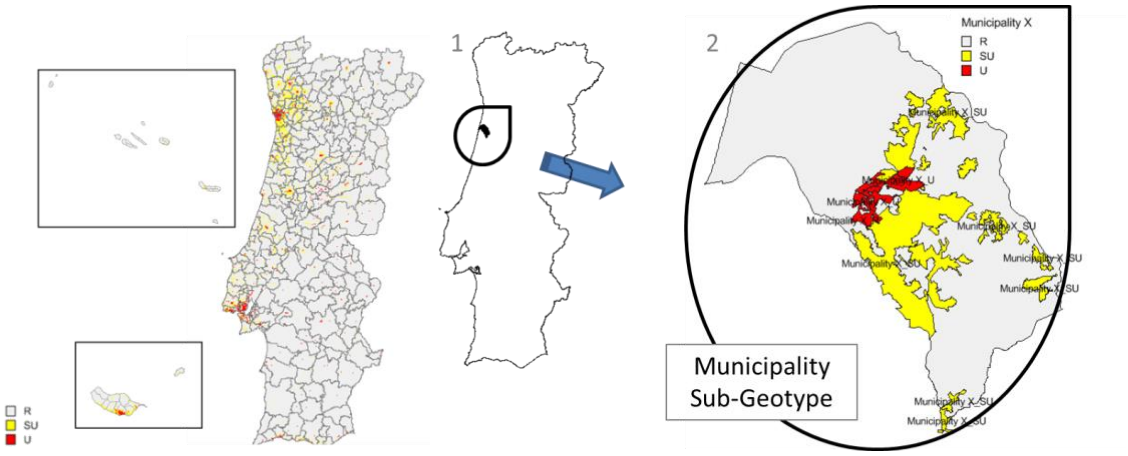


Figure 92 – Global aspect of Portugal´s sub-Geotype (right side) and Municipality X detail (left side).

For each municipality sub-Geotype, the variable calculation is the sum of all the subsection´s contributions for each one of the analyzed variables (VAR). Some of these variables are; the subsection´s: area, the population, the number of dwelling units and the housing type (1floor, 2floors..) with the respectively number of floors per housing.

$$VAR_{Sub\_Geotype_{municipality X}} = \sum VAR(subsection)_{Sub\_Geotype_{municipality X}}$$

Equation 2- Variable agglomeration per municipality sub-Geotype.

The final value to VAR per sub_Geotype is the agglomeration of all the municipality sub-Geotype contributions and therefore the average values per municipality´s sub-Geotype VAR, Equation 3.

$$VAR\ Sub\_\ Geotype_{x} = Average\left(VAR\ Sub\_Geotype_{\ MunicipalityX}, VAR\ Sub\_Geotype_{\ MunicipalityY}, \dots\right)$$

Equation 3 – Variable calculation per sub-Geotype.

In the end, a list of socio-demographic variables per sub-Geotype can be built:

Variable	Description
POP	Municipality´s Average Population per sub-Geotype
Area	Municipality´s Average Area per sub-Geotype
DU	Municipality´s Average of dwelling units per sub-Geotype
Average 1HH	Municipality´s Average of one household type per sub-Geotype
Average 2-6HH	Municipality´s Average of two to six floors household type per sub-Geotype
Average 7-12HH	Municipality´s Average of two to six floors household type per sub-Geotype
Average >13HH	Municipality´s Average of more than thirteen floors household type per sub-Geotype
W	Municipality´s Average (not available per sub-geotype)
TPH_SUB	Telephone penetration
TV_SUB	Total subscribers of television subscription service (NUTS III)
FTHH_TV-SUB	Total number of subscribers of FTTH television distribution service(NUTSIII)

Table 20 - List of variables available per Municipality used to build sub-Geotype units.

For every designer engineer, modeling the reality is always a challenge. The way the population settlements evaluate depends on many variables and circumstances lost in time and history and independently from region to region. The GIS territorial evaluation has been object of study from the social sciences' empirical models, [191, 192], to the engineer geometric models as described by several authors, [193], [194], [195-198] and [199]. An approach to the empirical geographic model was used at [33] at the local scale level (neighborhood) with results quite comparable to the typical values in the literature.

The geometric model approach of the reality model in this work is done based on four steps:

- The first step considers the length from the central office to the theoretical centroid of each sub_Geotype. One of the relevant variable that defines the geometric approach of the TENTUS model is the D_{CO} variable, as it is defined as the average distance of each sub-Geotype' s (U, SU and R) to the nearest central office optical fiber equipped (main CO, green star), Figure 93.
- The second step reduces each sub-Geotype to a square of side length equal to the squared area of the sub-Geotype, Figure 94.
- The third step applies the bus typology to calculate the length of the fiber inside the sub-Geotype, variable *distcable*, Figure 95.
- The forth step applies the same squared method inside the neighborhood.

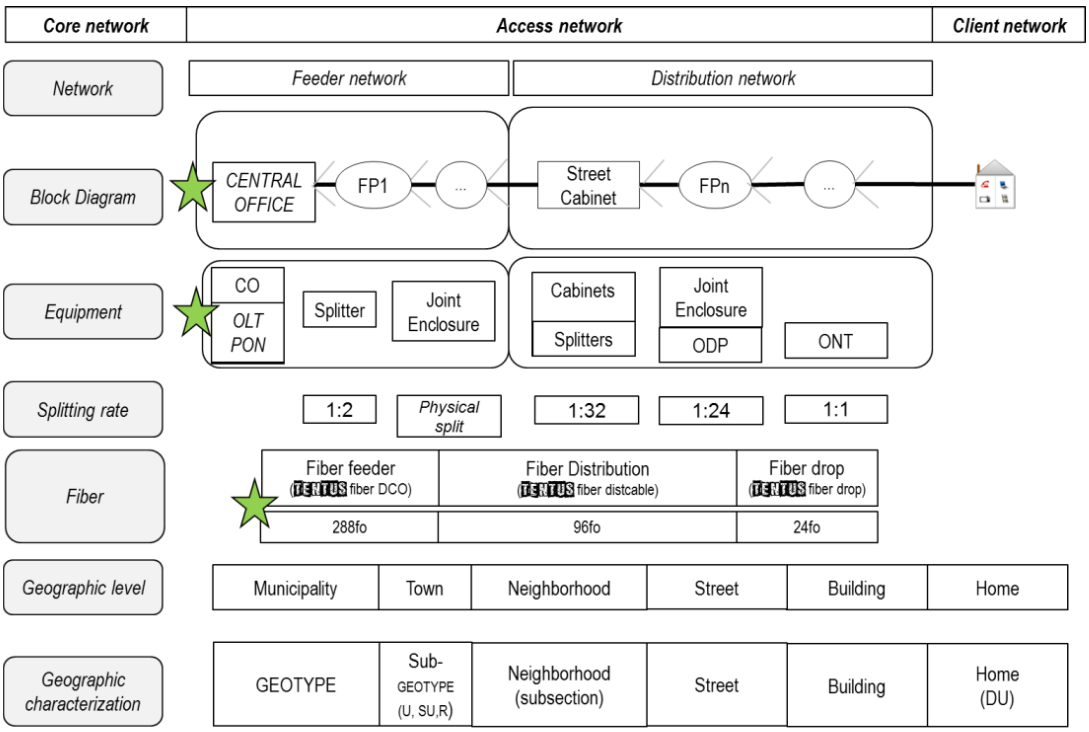


Figure 93 – Bone diagram for TENTUS

For each municipality it is assumed the existence of only one central office (CO) equipped with optical fiber and therefore the concentrated point, mainly for wireline connections. The exception of this assumption is the Lisboa and Porto cities where they were considered three central offices per each. This "square" approach can be depictured as in Figure 94 (for Municipality X as an example). It is assumed that there are some D_{CO} links that can be geographically overlapped, as an upper bound of duct and cable length.

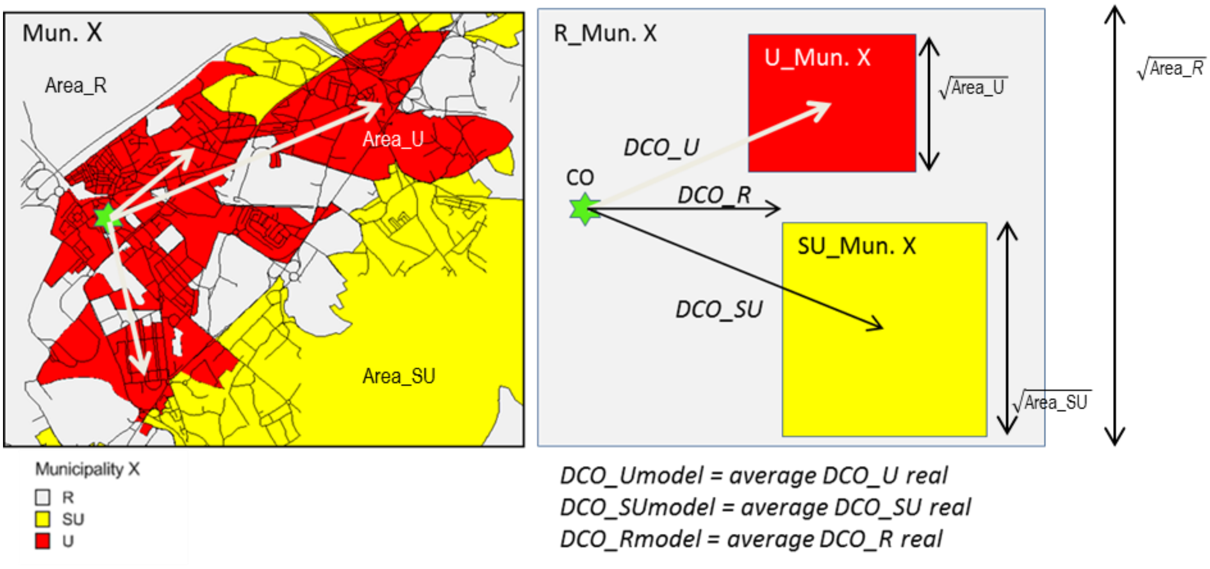


Figure 94 – Detail of distance from sub-Geotype centroid to the nearest central office optical fiber equipped 8reality on the left, model on the right).

Each municipality has one or more sub-geotypes of the same type (U, SU or R). The value of D_{CO} is calculated based on the average distance between the central office and the center of each sub-Geotype from the same type, Equation 4.

$$D_{CO} per\ Sub\_Geotype = Average(D_{CO\ subsection1}, D_{CO\ subsection2}, \ldots, D_{CO\ subsectionN})$$

Equation 4– Distance of each subsection´s centroid to the nearest central office optical fiber equipped.

This metric was applied to all the country, per municipality and a factor of $\sqrt{2}$ is applied as the probability of building ducts in straight lines is very low. There are cases where the distance is bigger than the 20Km technologic PON limitation, in this case a new central office equipped with fibber must be installed and for this reason Lisboa and Porto have more than one central office. Other analog situations concern the islands municipalities that don't have any central office considered due to lack of data.

At this point the model only considered part of the distance between the central office and the center of the sub-Geotypes. The next step is to identify an approach at the neighborhood level. There are several available models based on different geometries as the star, bus or ring geometric models. As a starting point it was defined to use the bus model used for the TONIC [199] optional geometric mode with slight modifications. In the original model the target area is converted into a rectangle and in this model each to simplify each sub-Geotype will be converted into a square, with side equal to the square of the sub-Geotype area, Equation 5.

$$A_{sub_{geotype}MunX} = \sum_{i=1}^{N} A_i, \quad with\ N = number\ of\ subsections \Rightarrow a = \sqrt{A_{sub_{geotype}MunX}}$$

Equation 5 – Area calculation of the geometric model of the sub-Geotype.

At Figure 96 there is an example of the theoretical Tonic model and this work model. The image on the left represents the TONIC´s bus topology applied to a certain area $A = a \cdot b$ .This area is then modeled as a cluster of $n = a \cdot b$ units and consequently duct and distribution cable (distcable) lengths are calculated by the expression:

Distribution duct=distcable= $l_d = l_c = n - 1.$

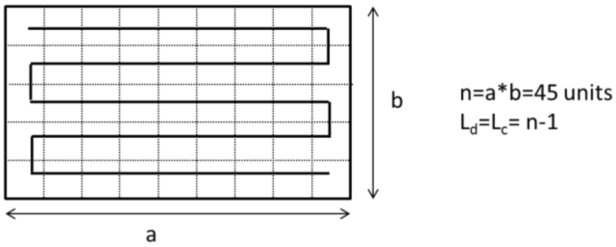


Figure 95 - TONIC bus typology (ex: n=45).

Due to the fact that inside each sub-Geotype characterization there are completely different area values, it is not possible to normalize this type of relationship per Geotype. This exercise has to be done a case by case exercise. The next figure presents the conversion of a real portion of the Urban sub-Geotype (red portion) of municipality X to calculate the fiber and duct distcable length based on the sub-Geotype and fiber/duct Drop length neighborhood characterization, Figure 96.

From the subsection information (raw data) it is possible to get an approximation of the size of the neighborhood width and therefore build a matrix of relation between the length of the sub-Geotype square model and the length of the neighborhood, Equation 5. At each neighbor it is taken into account the average number of households with 1 floor, 2 to 6 floors, 7 to 12 floors and more than 13 floors. This information will be used by the time the equipment needs is going to be calculates as distribution points, splitters or cabinets at Section 0.

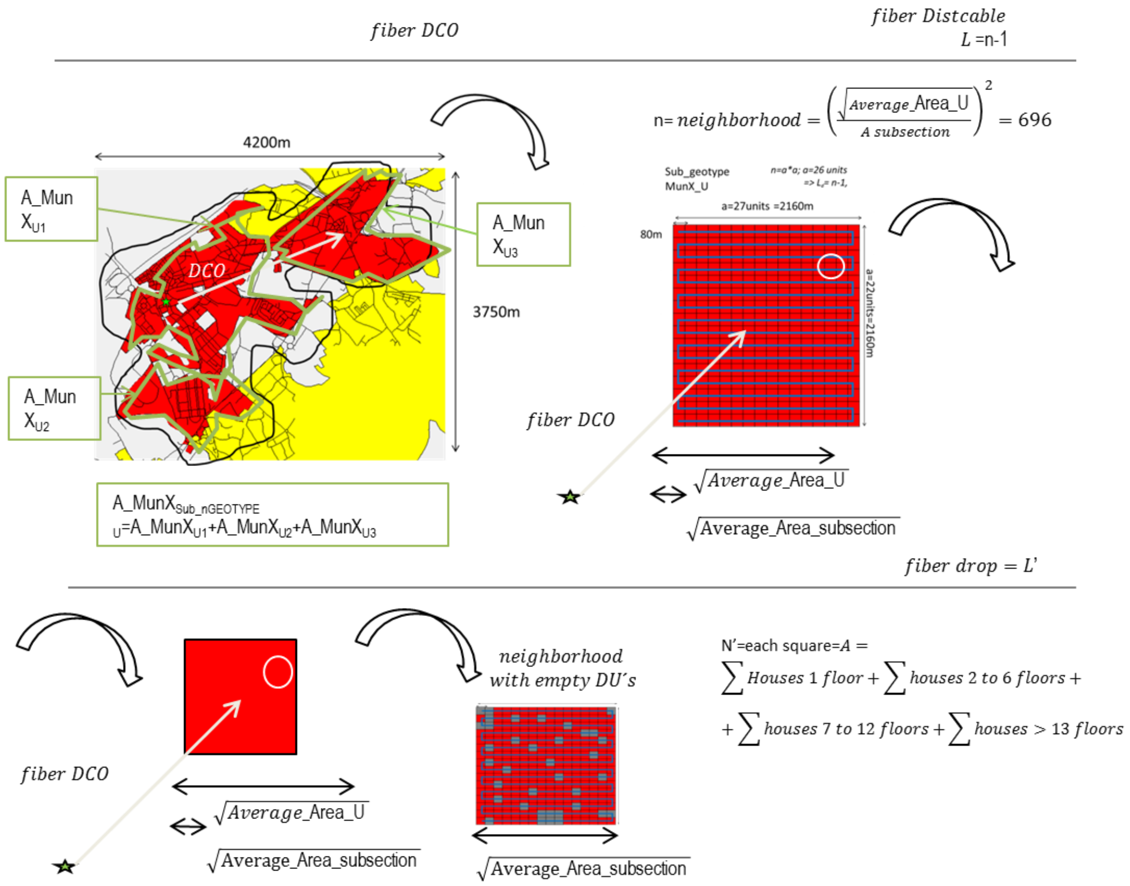


Figure 96 – Comparison of the real map and TENTUS geometric model for Urban sub_Geotype of municipality X.

In this model it was also taken into account the percentage of non-built area. In this case it is assumed the need to account the ducts length to reach further households but it doesn´t have any households to serve. Those squares they are represented by the grey squares at Figure 96. Note that their location was positioned randomly.

With this geometric model all the country´s municipalities are reduce to squares and therefore more easily manipulate for deployment purposes described in the next sections.

5.2.7 Components Price Evolution

An important input for any techno-economic tool, are the component´s prices. These are dependent of the available sources that can be both in the internet and directly from the suppliers. The indicated values are most of the time references as the final values paid by a telecommunication operator depend on the dimension of the whole business and depend on the business model concerted between the players.

At this point is relevant to referrer that no matter the input value, that can be modified in the tool at any time, all prices are predict to have an evolution following the depreciation formula as in Equation 6.

$$Price_{year\ x} = Price_{year0} * \left[nr(0) * \left(1 + e^{\left\{ ln\left[\frac{1-n_{r(0)}}{n_{r(0)}}\right] - \left[\frac{2\ ln(9)}{\Delta T}\right] t \right\}} \right) \right]^{-ln(K)/ln(2)}$$

Equation 6 – Depreciation in the price of components, [200].

This theoretical model, developed at TITAN project, [200], is based on four parameters that result from a combination of a standard demand logistic curve for the growth over time of the accumulated component volume with a learning curve. These four parameters are: the price today, $Price_{year0}$; K, the time it takes for the accumulated volume curve to go from 0% to 90%of the saturation value ΔT and the value of the accumulated volume today $n_{r(0)}$, normalized to the saturation value.

Class	***nr(0)***	***delta(t)***
old, fast	0.5	5
mature, fast	0.1	5
new, fast	0.01	5
emerging, fast	0.001	5
old, medium	0.5	10
mature, medium	0.1	10
new, medium	0.01	10
emerging, medium	0.001	10
old, slow	0.5	40
emerging, slow	0.001	20
new, slow	0.01	20
old, very slow	0.5	20
new, very slow	0.01	40
emerging, very slow	0.001	40

Learning Curve	***K***
CW	1
Manpower	1
Copper wires	1
Electronics	0.8
Optical fiber	0.9
Advance optical components	0.7
Passive optical components	0.8

Table 21 – Tables of components´ classes and learning Curve K parameters.

As an example the next graph presents an hypothetic component with starting price 10000€ and for K=0,7, the variation of price according the component class, Figure 97. From the starting price of 10000€ per component in the beginning of the project, a component classified as "*emerging, fast*", can drop up to 66% in five years. On the other round an "*old, slow*" component price only drops up to 6% of the initial value.

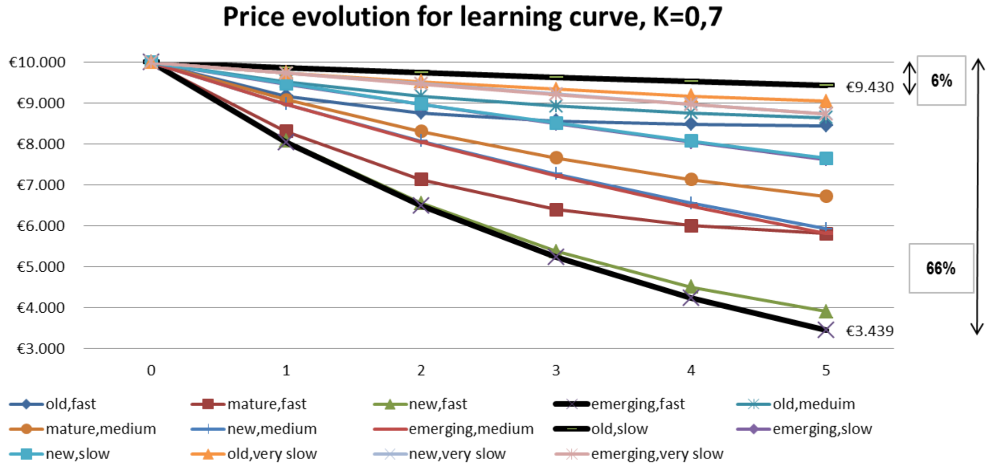


Figure 97 – Component price evolution accordingly the component classes. Theoretical example.

5.2.8 Component´s time life

In assessing the costs of a project of N years, is crucial to account for the cost of the investment related to the introduction of components or equipment required, as defined above. However it is also very important to account for investments due to the periodic replacement needed due to the end of its useful life (V´). Statistically, the age of the equipment of an ordinary telecommunication network is V=V´/2 (half the lifetime), [201]. To achieve a simple algorithm is necessary to define some variables, Table 22:

Variables detail	Variable	Type
Component life time	V´	INPUT
Half the lifetime	V	V=V´/2
Years of project	N	INPUT
Year of study	n	[0,(N-1)], $\boldsymbol{n} \in \boldsymbol{N}_0$
Time of each x investment	ti(x)	INPUT
New component (CN) for x investment turn	$\boldsymbol{CN_x}$	
Replacement (CS) for x investment turn	$\boldsymbol{CS_x}$	
Replacements per investment in the whole period	S	S=Roundup((N-ti(x))/V)-1
Total number of new investments in the period	X	$\boldsymbol{X} \in \boldsymbol{N}$
Represents the index for new investment, Type x	x	$[\mathbf{1}, \boldsymbol{X}]$; $\boldsymbol{x} \in \boldsymbol{N}$
Total components at the end of the project	C	C=f($\boldsymbol{CN_x}, \boldsymbol{X}$)

Table 22 – Component time life replacements variable´s.

Let´s considered a component, component x, with a V´ years' time life. This component will be needed to be bought several times along the project period due to two reasons: due to natural network growing needs and due to time life replacement reasons. Extra failures or mal functions are implicit in the usage of the time life V=V´/2 instead of V´.

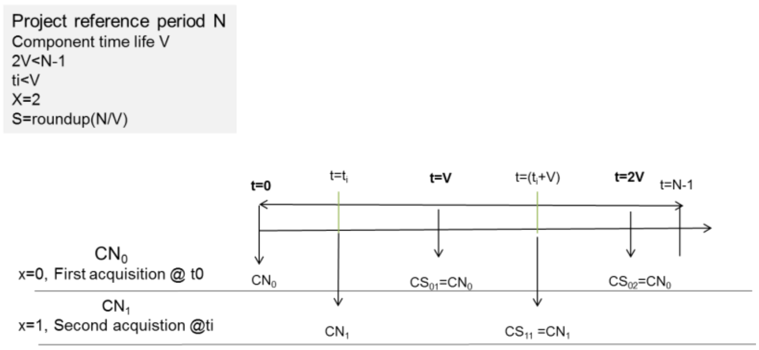
Because the first year of investment is considered n=0 the final year is then N-1.

The total number of needed components among the period of project can be calculated as the total sum of new components (CN_x) plus the number of corresponding replacements (CS_x), each time a new investment is done (x); or the total number of components bought for the first time plus the total number of corresponding replacements, Equation 7. It may be assumed that in the limit the number of replacements X can be the same as the number of years of the project and therefore x varies from o to N-1.

$$C(x,n) = \sum_{x=0}^{N-1} CN_x + \sum_{n=1}^{N-1}\sum_{x=0}^{N-1} CS_{xn}$$

Equation 7- Total cost per component at the end of the period N, after X=N-1 new investments.

The next diagram intends to clarify this dynamic, Figure 98.



$$C = CN_0 + CN_1 + CS_{01} + CS_{02} + CS_{11} = \frac{N}{V}\cdot CN_0 + \left(\frac{N-ti}{V}\right)\cdot CN_1$$

Figure 98 – Total amount of components at the end of the project period.

With this metrics in mind it is possible to move forward to the analysis of that same investment per year, building a matrix N-1 per N-1 simulating the needs per year. A new index variable is used: i_j, with j $\in [0,(N-1)]$ to identify if a certain year is it or isn´t an year of replacement.

$$i_j(x,n) = \begin{cases} 1, & \frac{x-n}{V} - int\left(\frac{x-n}{V}\right) = 0\ (replacement\ year) \\ 0, & \frac{x-n}{V} - int\left(\frac{x-n}{V}\right) \neq 0\ (non\ replacement\ year) \end{cases}$$

Equation 8– Index variable for replacement year check.

The Equation 7 can then be rewritten as Equation 9:

$$C(x,n) = \begin{cases} CS_x = 0, & \frac{x-n}{V} - int\left(\frac{x-n}{V}\right) \neq 0\ or\ n < V \\ \sum_{n=0}^{N-1}\sum_{x=0}^{N} i_x(x,n)\cdot CN_n, & \frac{x-n}{V} - int\left(\frac{x-n}{V}\right) = 0 \end{cases}$$

Equation 9– Total amount of components each year of the project.

This algorithm allows building a calculation matrix which is pictured in Figure 99, with a small example. Both axis, x and y represent the years of project. Each row represents per year the first investment to be done and the corresponding needs concerning the replacements for 5 years' time life. The total amount of components needed per years is then accounted per column.

x →

y ↓ n	0	1	2	3	4	5	6	7	8	9	10
0	103052	0	0	0	0	103052	0	0	0	0	103052
1	0	18992	0	0	0	0	18992	0	0	0	0
2	0	0	8138	0	0	0	0	8138	0	0	0
3	0	0	0	11540	0	0	0	0	11540	0	0
4	0	0	0	0	16263	0	0	0	0	16263	0
5	0	0	0	0	0	22716	0	0	0	0	22716
6	0	0	0	0	0	0	31329	0	0	0	0
7	0	0	0	0	0	0	0	42440	0	0	0
8	0	0	0	0	0	0	0	0	56105	0	0
9	0	0	0	0	0	0	0	0	0	71812	0
10	0	0	0	0	0	0	0	0	0	0	88228

Figure 99 – Detail of calculation matrix for component X with five years life time.

At the end of the day the total value per year (x axis) is the sum of all the contributions per column: new acquisitions and replacements per component.

5.2.9 Network efficiency and Performance

Efficiency is calculated by combining the following factors: installed capacity; utilized capacity; average annual growth rate in number of subscribers; replenishment period.

A telecom network performance depends on many factors. The following measures are often considered important:

- Bandwidth commonly measured in bits/second is the maximum rate that information can be transferred;
- Throughput the actual rate that information is transferred;
- Latency the delay between the sender and the receiver decoding it, this is mainly a function of the signals travel time, and processing time at any nodes the information traverses;
- Jitter variation in the time of arrival at the receiver of the information;
- Error rate the number of corrupted bits expressed as a percentage or fraction of the total sent.

A common misunderstanding is that having greater throughput means a "faster" connection. However, throughput, latency, the type of information transmitted, and the way that information is applied all affect the perceived speed of a connection.

5.2.10 Business Models

Different types of business models can be applied to such a complete sector as the telecommunications, based on several different types of layers as infra-structures, technology and services. It all depends on the ownership of each one of this layers as well as the regulation beneath for unbundle and sharing allowance to determine the integration among different operators.

The FTTH Council resumes those business models 'approaches in four types: vertically integrated, where an operator owns from the physical infra-structured to the service, through two intermediate stages passive and active sharing, (depending on the regulation directives) until the full separation model, where all the different layers can be owned and managed by different actors, Figure 100.

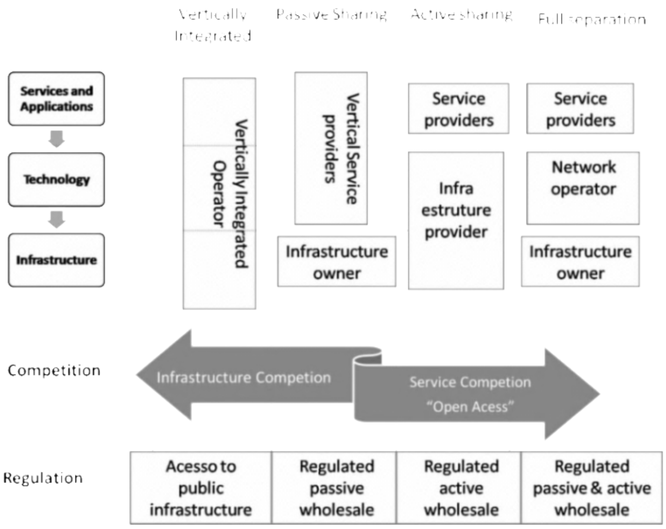


Figure 100 – Types of business models. Open market interaction. Source: FTTH Council, [202]

In detail, each one of the business models can be defined as: Vertically integrated, one major player covering passive, active and service layers, who offers services directly to their customers, conveys traffic on their networking equipment and uses their own passive infrastructure (exclusively or with wholesale to other communications providers); Passive sharing, in this model, the infrastructure owner deploys the passive infrastructure and provides passive access to other players, who concentrate on the active and service layers; Active sharing, the vertical infrastructure provider deploys both active and passive infrastructure, and opens it up to service providers, with each service provider taking care of its base of subscribers and Fully separated, in some countries the fully separated model has emerged, featuring an infrastructure owner, a network operator and a series of service providers, [202].

In Portugal there is a mixture of business models approaches depending on the target region and also from the technology. The natural Portuguese trend is that each operator owns all the aspects of the business, from the infra-structure to the services provision.so the most common business model is the vertically integrated. However as deployment densification intensifies and costs start raised the operator´s started to adopt sharing infra-structures between them (passive sharing) or even providing infra-structure and technology to virtual operators (active sharing). These contexts lead the Portuguese regulator to adopt most of the advanced standards in Europe defining demanding rules for infra-structure sharing both in wireless and fiber deployments.

In a liberalized sector as in Portugal and most countries of Europe, the current present models correspond to different approaches of the business from private capital companies even though from historical reasons most states are incumbent´s stake holders.

With the advent of the new generation technologies, and the ambitious target of Europe2020 for the emergent society of knowledge, huge amount of investments are required, sometime unaffordable for the smaller private companies. Because of that currently, several European Union states members are turning their attention to support broadband networks that can deliver high-speed services and support a range of advanced digital converged services. These NGN networks are usually fiber optic networks or cable networks modern and advanced intended to replace all or part of the broadband networks of copper wire or cable networks today.

The European Commission has assessed the compatibility of State aid for broadband development traditional, distinguishing between areas "white", "gray" and "black". The Commission considers that this distinction is still relevant for assessing whether State aid to NGA networks are compatible under Art. 3, paragraph c) of Article 87. º, but that requires a more precise definition, to have into account the specificities of the NGN, [203]. For the framework for electronic communications within the scope of the rules on state aid, NGN network is defined as including : (i) installing fiber optic cable in street cabinets exist, offering the possibility of bandwidths of at least 40 Mbps to 15 Mbps downstream and upstream (compared with the maximum output current downstream of 8 and 24 Mbps for the technologies ADSL and ADSL2 + , respectively) , (ii) upgrading of cable networks present in order to provide speeds up to 50 Mbps or higher , compared with the max previous 20 Mbps using the new cable modem the standard DOCSIS 3.0 , or (iii) equipping new residential buildings and offices with fiber optic links that provide services at a rate up to 100 Mbps or superior44

The present study takes the governmental point of view, in which is responsible for the guarantee of the social equity based on a legal instrument that is the Universal Service, whose compliance is overseen due by the national regulator. The Universal Service is based in the principles of universality, equality, continuity and affordability and in case the natural dynamics of the market does not fulfill this intent, the state can step as a financier. As previously mention this work intent to contribute to the government to quantify the financial derivatives additions of Universal Service obligations.

Even though, the Universal Service license should be assigned based on a public tender which defines the Universal Service obligations as: the key performance indicators of quality of service, time to installation, time for repair, pricing and financing scheme. The Universal Service business model depends on the choices of the Universal Service provider. It is built above an operator that might or might not have their own infra-structure. Even in geographical places where there isn't installed any type of infra-structure, the Universal Service provider might create consortiums for the purpose.

5.3 TENTUS Investment Dimensioning

Associated to each technologic solution there is always a network architecture where some critical decisions are necessary to define that involve connections strategies and flexibility in terms of access points. This section describes the dimensioning issues and strategies defined for the wireline and wireless technological solutions, GPON-fiber to the home, LTE and broadcast DVB, underlying the sizing tool developed, the TENTUS tool.

5.3.1 Fiber to the X, FTTx Architecture

One of the challenges in the wireline architectures, in order to provide higher throughputs, is the need to shorten the distance of the copper cable between the central office and the final user. FTTx architectures introduce optical fiber in the access network to reduce the copper usage getting closer the subscriber immune to electromagnetic interference, with less signal loss and higher bandwidths. So, to expand subscriber´s bandwidth, operators need to move the broadband access equipment, from the central office, closer to subscribers. In other words, the broadband access equipment has moved from the trunk section, to the feeder section, to the distribution section, and finally, to the access section. Currently, there are four deployment scenarios for the FTTx:, depending how far the fiber reaches in the access network [204], Figure 101.

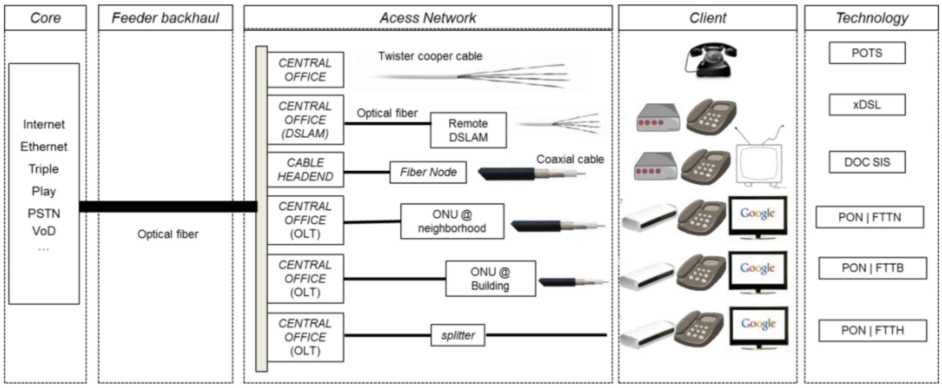


Figure 101– FTTx architectures. Adapt from FTTH Council [202].

PON (Passive Optical Network) is the technology used in this study based on the FTTH architecture, (section 3.3.5). This technological solution is a completely passive network consisting of fiber optic cabling, passive splitters, attenuators and couplers These items are also referred as the ODN - Optical Distribution Network elements, Figure 50, that distribute an optical signal through a branched topology to an ONT (Optical Network Terminal). This architecture is a point-to-multipoint system that allows a maximum of 64 ONT's to be serviced, with a OSP topology of 1x32 Home Run Split , 1x4 to 1x8 Distributed Split , or 1x8 to 1x4 Distributed Splitter build out.

The assumed architecture at this works is fiber to the home (FTTH) and it is assumed to be organized as depicted in the next figure, Figure 102 reusing Figure 93 . This means that the architecture is composed with a central office where the passive optical elements are (PONS), one or more splitting stages and several flexibility points along the path depending on the geography and operator's deployment plans.

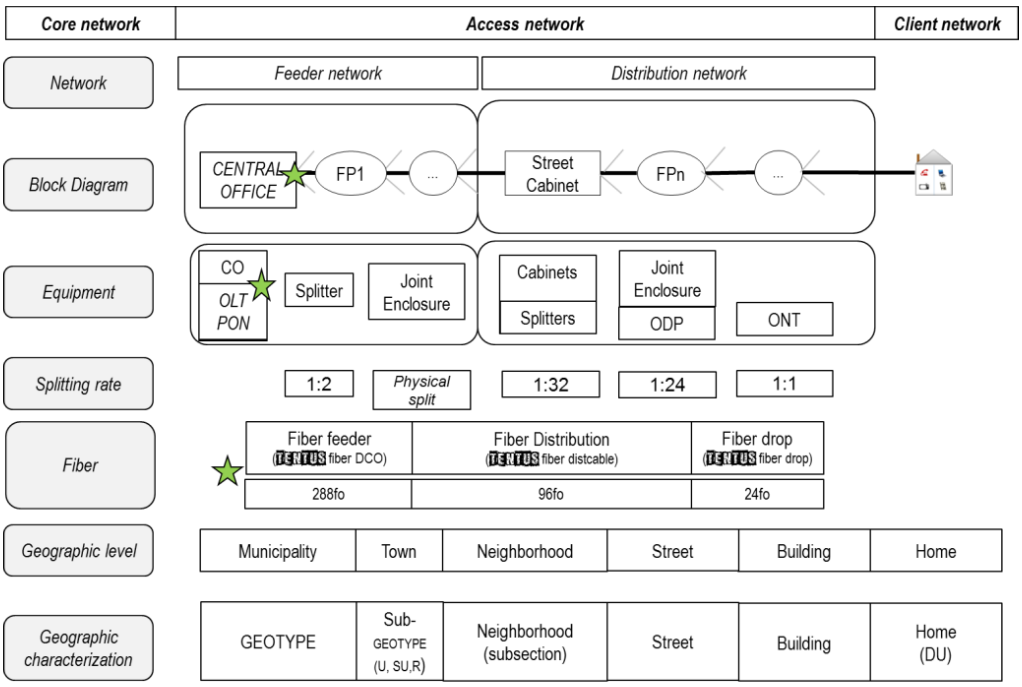


Figure 102 – GPON bone diagram.

As in any other telecommunication network the available bandwidth is shared among the users and it can be determined at the Optical Line Terminal (OLT) at the Central Office (CO) and increased by reducing the splitter stages or the splitting factor per stage.

The locations of the splitters are depending on the operator´s design. At this work they will assumed to be inside the central office a 1:2 splitting stage and then closer to the subscriber, at the neighborhood level, another splitting stage of 1:32. The same PON wavelength is shared among all the subscribers and each subscriber receives one optical fiber at home.

The main network elements are described on the next table and are the basis of the cost algorithm to deploy FTTH architecture for a certain geographic area, or even a whole country. The network deployment is based on two big cost families: the components/equipment cost and the civil work associated.

It is relevant to highlight that there are much more elements inside a real network that are also important for its fully working, however in this work the focus are the great numbers and therefore only the key elements were considered. Moreover some cost elements are estimate due to the impossibility to know the real market values.

Optic Link Budget and Power Margin

The key to network distance is optical power budget as it is defined as the amount of light available to make a fiber optic connection. The link budget represents the final calculation of the optical power available at the output of the transmitters, the receiver power sensitivity and the optical path loss at ODN in fibers, joints and splitters, is thus the calculation and verification of a fiber optic system's operating characteristics.

$$Power\ Budget = Minimum\ transmitter\ power - Minimum\ receiver\ sensitivity$$

$$Link\ Margin = (Fiber\ attenuation * Fiber\ lenght) + Losses\ (connectors\ and\ splices)$$

$$Power\ margin(dB) = Power\ budget - Link\ Margin - Safety\ Margin$$

Equation 10 – Optical link budget.

Remembering Figure 51 the upstream the wavelength is 1310nm and the downstream 1490nm. The next table presents the power budget calculation for a OLT/ONT B class+, [84], Figure 103:

Item	***Downstream @1490nm***	***Upstream@1310nm***
$\boldsymbol{a)\ Minimum\ transmitter\ power}$*(dBm)*	2	2
$\boldsymbol{b)\ Minimum\ receiver\ sensitivity}$*, (dBm)*	-28,5	-28,5
$\boldsymbol{Power\ Budget}$ *(a-b) (dB)*	30,5	30,5

Figure 103 – Optical power Budget.

Then all the components involved along the access network and their losses, are considered. The characteristics of the optical fibers are properly standardized according to the ITU-T G.652D [135] and the connectors ITU-T G.671 [205]. The losses of the fibers are dependent on distance and wavelength; the other components do not have these dependencies only depend on the number of items installed.

Item	***Downstream@1490nm***	***Upstream@1310nm***
c) Fiber(dB) (dependent on distance and wavelength)	4,8	7,0
d) connectors (dB) *ex: 4 *0,5dB*	2,0	2,0

e) splices(dB) *ex: 7*0,1dB*	0,7	0,7
f) Splitters(dB) *ex: 2*7,5@Km (1:4)*	15,0	15,0
g) safety margin (dB)	3,0	3,0
$\boldsymbol{Link\ Margin + Safety\ Margin}$ *(c+d+f+g) (dB)*	-25,5	-27,7
Power margin (dB) =Power budget-Link Margin-Safety Margin	5	2,8

Table 23– Optical Power margin example.

Typically network engineers incorporate a safety margin between 3-5 dB attenuation. The final difference between the maximum loss allowed and the actual total loss is less than zero, and then there is not enough power to settle this optical system. The engineer must consider an increase in transmitter power or receiver or both. If the final result is greater than zero, it means that there is sufficient power to establish the optical system and the result is called the power margin of the system.

FTTX _ GPON equipment

Central Office

The first element of the access network is the central office.

The Central Office, CO, also called the headed, the hub or the node, is the physical place where the optical network termination, ONT and other type of equipment are stored. This is where voice, video and data are received from the Service Node Interface (SNI). At this point the signal is converted and/or multiplexed digitally into various wavelengths. The basic function of an FTTx network in the CO is to connect the OLT equipment to the outside plant, OSP fibers, deploying Wavelength Division Multiplexing, WDM somewhere in the middle to enable voice and data signals to be combined with video signals, Figure 104. Often inside the CO there is a first splitting stage 1:2.

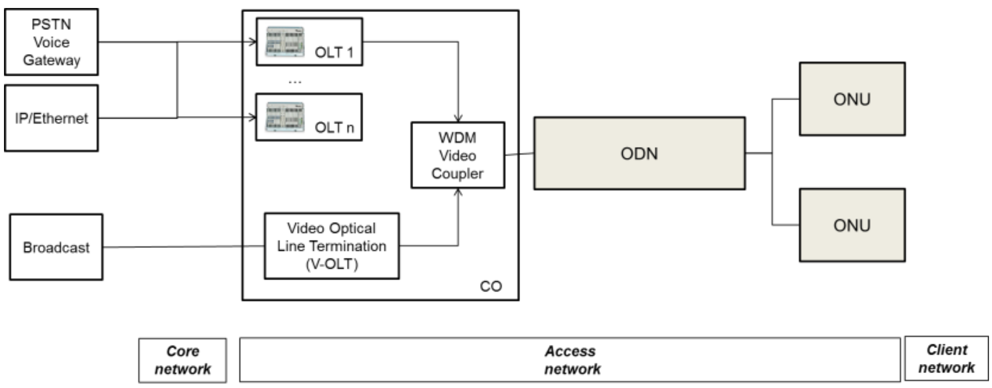


Figure 104 – The OLT at the CO. Source: ITU-T,

When the service provider already possesses a cable network the digital subscriber line access multiplexer (DSLAM) may be replaced or required an upgrade to support the new services. In this case an audit to the CO should be done to find dead cables and removing old lineups of POTS or copper equipment no longer in use. A good CO dimensioning is indispensable to prepare the evolution of the FTTx subscriber penetration. At TENTUS algorithm it is considered one central office fiber equipped per municipality, except Lisboa and Porto where three are considered. For the cost analysis the main equipment considered was the one presented on Table 26.

OLT

The PON equipment comprises a passive element: the optical line terminal (OLT) at the central office. The Optical Line terminal is a combination of transmitters, receivers and control electronics as defined by ITU [134], Figure 105. [17]

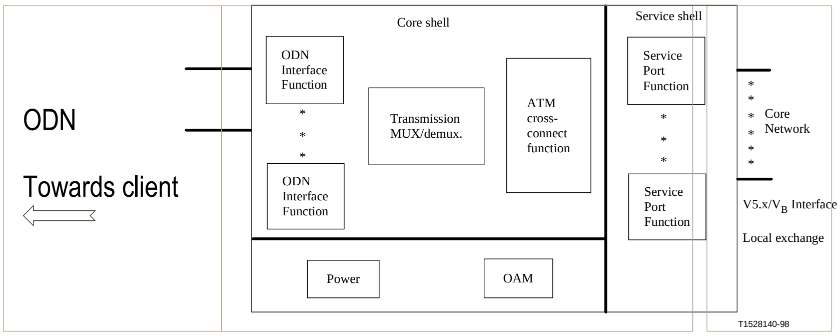


Figure 105 – OLT function blocks according to ITU specifications [134]. Source:ITU.

The OLT is the network control processor that allows delivering triple play services to customers. This card resides in the local CO cross connected to the video and data networks, it consists of a special Distributed Feedback, DFB, calibrated laser that is always on. This control card acts as a traffic signal to the remote ONT's for complete data / video throughput upstream and downstream. The following images depicted the real aspect of an OLT from several suppliers.

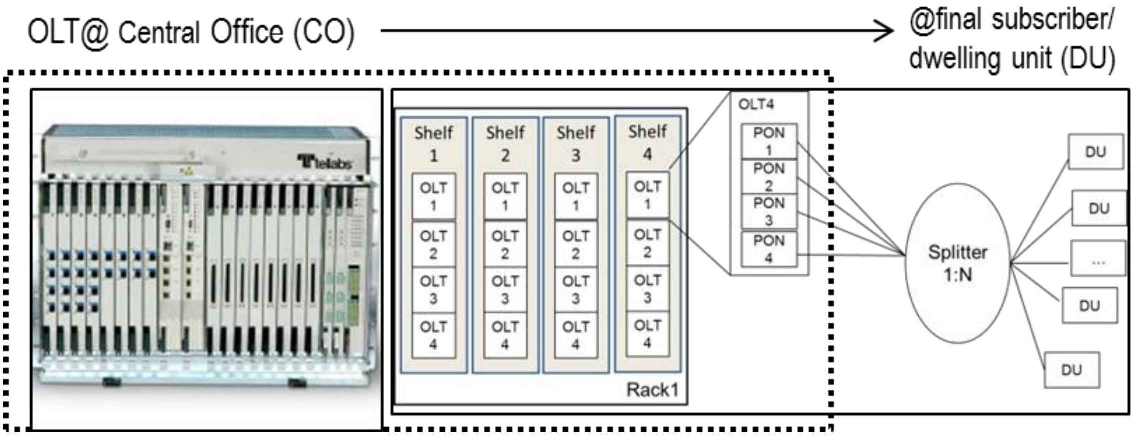


Figure 106 – OLT Example: Tellabs1150 Schematic at the bottom. OLT image Source: http://www.broadbandsoho.com/Verizon_FTTP_Tutorial.htm, [Setember2011]

According to the ITU standards GPON deploys voice, data and video services directly to users over fiber optic facilities at rates to 2.5Gbps of bandwidth downstream and 1.25Gbps upstream for a maximum of 64 users per PON. Typically there are 4 PONs per OLT card, 16 cards per OLT rack and 4 racks, at a total of 4096 users (4PONs*16cards*4racks*32splitng ratio). Most recently the supplier offer OLT cards with 8 PONs each, doubling the OLT capacity to 8196 users.

The OLT should be dimensioned to accommodate current and future quality of service (QoS) requirements with minimum GPON resources allocation even though the network planners cannot accurately determine

[17] The specifications tend to present the system blocks with the core network on the right and the access network on the left, as it can be seen in the Figure 105. However the author considers more intuitive the other way round, and for that reason in the original spec this type of presentation is respected but the following author figures will present the core network on the left and the access on the right.

the number of subscribers and their traffic behavior. Next step includes the analysis of the equipment outside the CO the ODN, Figure 104.

ODN

Optical Distribution Network is part of the outside plant, OSP, architecture components and combines the optical with the non-optical components. The optical components are: the fiber-optic cabling, splices, passive splitters, fiber distribution hubs, FDH, attenuators and couplers. Fiber Distribution Hub, is the cross point for the Fiber CO Trunk and Distribution Fiber to the individual homes. The non-optical components are: the pedestals, the closures, vaults, patch panels, cabinets, and other hardware.

Splitters

The splitters are one of the most relevant elements of a PON network. The placement of the splitting stage depends of the knowledge of the future subscriber distribution and location. There is room for some optimization considering the localization of at the splitting stage. It can be either centralized, if near the subscribers or distributed in one or more slitting stages (typically two). The planner should calculate case to case the balance between fiber savings and splitters adding.

At TENTUS algorithm a first stage of splitters 1:2 is located inside the CO. Typically in a commercial telecommunications network, this first splitting level is done due to futures network expansion. In this case, due to the demanding of a Universal Service network, all the capacity is deployed. Another splitting stage is located at the neighborhood level, in this case a 1:32 splitter. The splitters are inside street cabinets (SC) with maximum capacity of nine per SC. Associated to the calculation of the number of SC per sub-Geotype; an efficiency coefficient is added due to the uncertain of subscribers' location.

Joint Enclosure

Fiber optic joints .provide environment protection for splices, splitters and other passive devices, Figure 107. It can be found in vaults or enclosures to prevent exposure to elements. Its location depends on the transitions from feeder cable to distribution cable and from distribution to drop, Figure 107.

In this study they appear at each flexibility point (FP) located at manholes, most of them already existent due to the already existing networks as PSTN or cable.

Figure 107 – Joint enclosure. Source: CABELTE catalog available on line, www.cabelte.pt, [206]

ODP

The optical distribution point is the equipment placed at the entrance of the households, typically at the facade and is used to transport the fibers to the client's home leaving a cable of greater capacity, Figure 108. It may or include the ability to splitting. In this case the street cabinet can be avoided.

In the TENTUS algorithm the ODP are shared among several DU´s, that might or may not belong to the same neighborhood

Figure 108 - Façade optical distribution point, OPD (the grey box) Source: Photo from the author.

ONT - optical network terminal

The optical network terminal is composed of fiber-optic cables that connect the subscribers' homes ODP´s. These may be individual cables (composed of one or two fibers for each subscriber), or multiple (raiser) carrying the riser cables in the building and from which the fibers will be drawn from each subscriber, Figure 109Figure 108. TENTUS algorithm assumes one ONT per DU.

Figure 109 – Alcatel Optical network terminal. Source: http://www.alcatel-lucent.com/product.

Cables

The recommended type of optical fiber for FTTX PON architecture is the ITU-T G.652.D standard [135] single mode fiber with the average attenuation from 1310nm to 1625nm less than 0,40dB/Km or 0,0004dB/m. Optical fiber cables can have fiber counts ranging from 1 fiber to 1728. Typically an optical cable contains several tubes of 1 to 24 fibers, Figure 110, [207].

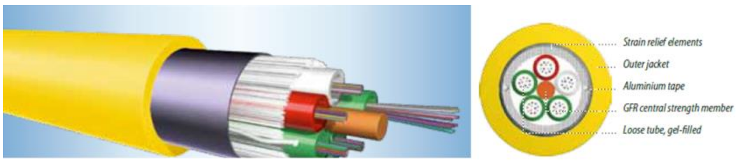
Fibers per tube (fot)	***Tubes (t)***	***Total of fibers per cable***
	1	12
	2	24
	6	72
	12	144
	24	288

Figure 110 – Optical cable. Source: LEONI catalog available on line, http://www.leoni-fiber-optics.com/

From the CO the main cable is known as the “Feeder Cable” or the backbone cable.is typically routed into the service area in a ring configuration with 72 or more fibers. After the first split it is called the “Distribution Cable” that is an intermediate between feeder and drop cable segments. Once it reaches the final split near the subscribers it is called “Drop Cable” and normally consists in one or two fibers, depending on the traffic demand or spare policy, Figure 111.

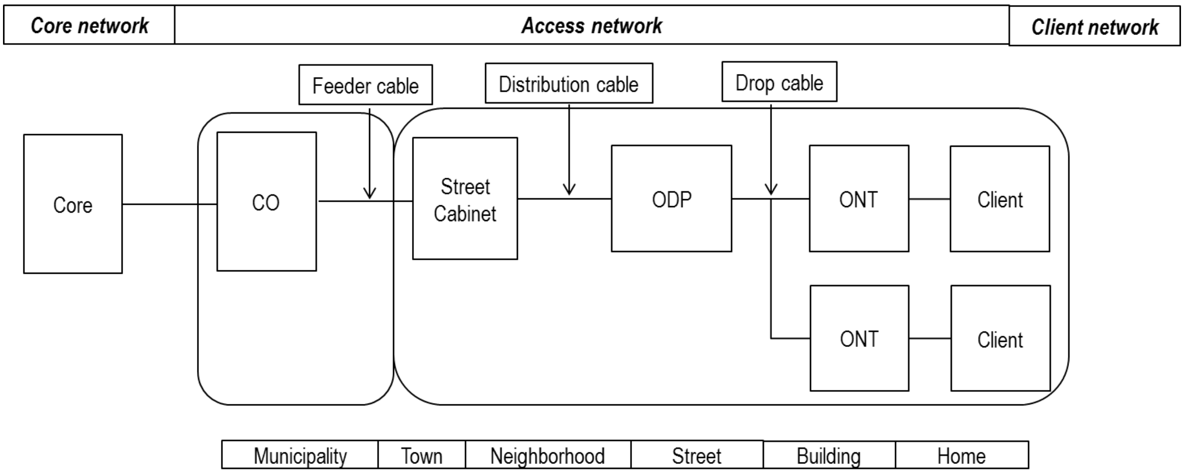


Figure 111- Optical fiber segments in TENTUS´ architecture schematic.

One of the main challenges of a PON network is the cable installation towards the subscriber. This subject will be analyzed in detail in 0 using a bus topology at the neighborhood level.

FTTH- GPON TENTUS algorithm

The TENTUS FTTH algorithm is built in three steps: the input values concerning statistical data and assumptions, the bill of material that include the number of equipment assets evaluations considering the input scenarios and their cost to fulfill the input needs and finally the financial analysis with OPEX and CAPEX or cash flow considerations, Figure 112.

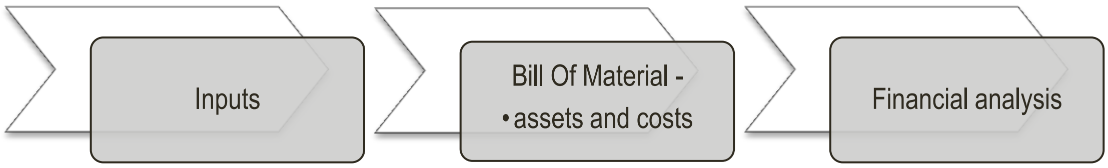


Figure 112 - TENTUS FTTH algorithm.

Step 1: TENTUS FTTH Inputs

The first step of TENTUS FTTH algorithm is the input data. This steps concerns gathering objective data about the reality of the country, such as: project time frame, geographic areas, number of households, equipment capacity; and nonobjective data concerning assumptions with investment plans, subscribers forecast, equipment location and efficiency factors, Figure 113.

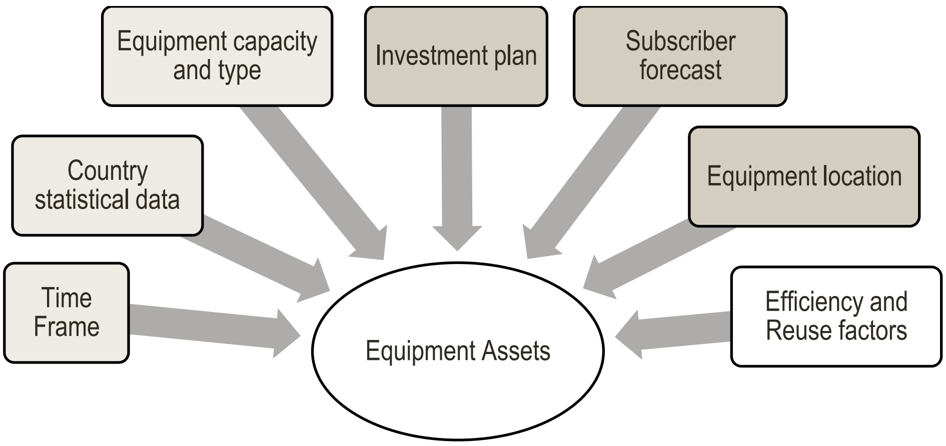


Figure 113 - Input data for TENTUS FTTH algorithm.The next table resumes all the variables related to the equipment assets needs, that are calculated based on several inputs mentioned above, Table 24.

TENTUS INPUT VARIABLES				
Family	***Name***	***Type***	***Granularity***	***Comment***
Time Frame	*Starting year*	INT	Global	Starting year of a 25 year project
	Years			Total years of project analysis
Statistical Data	*Dwelling Units (DU)*	INT	Per neighborhood	Total DU in each neighborhood (“doors”)
	Households or buildings (HH)			Total houses in each neighborhood (a house might have 1 or more DU)
	Area (A)			Area of neighborhoods and municipalities
	Central offices locations (Dco)		Per municipality	Distance to closer CO. Assumption of a central office per municipality with optical network terminations (except Lisboa and Porto that are considered three)
Forecasts	*% Subscribers/Houses initial*	%	Per Sub-Geotype	% Starting subscribers (DU´s)

	% Subscribers/Houses final			% final Subscribers (DU´s) at end of project
	[illegible]	INT		Time to initial booster
	[illegible]			Time to final target
	Investment Plan			Stating year of investment for a certain sub-Geotype
Efficiency and Reuse factors	*ODP* [illegible]	%	Per neighborhood	Coefficient to take into account deployment limitations to fulfill an ODP, and therefore measure its efficiency.
	Splitter [illegible]			Coefficient to take into account deployment limitations to fulfill a splitter, and therefore measure its efficiency.
	Street Cabinet (SC)[illegible]			Coefficient to take into account deployment limitations to fulfill a SC, and therefore measure its efficiency.
Splitters	*Max capacity*	INT	per Geotype	
	Splitting ratio			For 1st splitting ratio and 2nd splitting ratio
Street Cabinets (SC)	*Max capacity*	INT	Per neighborhood	The location of the equipment is implicit at the geometric model
Flexibility points	*manhole* [illegible]	%	Crossroads or each 120m	Percentage of existent manholes

Table 24 – Input parameters for GPON algorithm.

As any other business model, in particular a telecommunication business model, the reality is always a step ahead and the model is a pale reflex of the truth. Even though in this study several coefficients will be introduced to empirical adjust the results simulate dispersion, geographical constrains and uncertainness of the subscriber geographic location. The value assigned to each of these coefficients has no scientific basis and is purely empirical leading to the over dimensioning of the network, Table 25.

	ODP efficiency			Splitter efficiency			Cabinet efficiency		
	U	SU	R	U	SU	R	U	SU	R
GEOTYPE 10	70%	50%	20%	70%	50%	20%	70%	50%	20%

Table 25 – Dispersion simulation coefficients, (example).

These variables intent to simulate physical deployment limitations and the incognita of the location of the subscribers, however the time frame where the requests appear is another deployment uncertain. The timing is simulated in a second interaction with different scenarios of investment per Geotype, analyzed in further sections, 0.

As already mentioned the efficiency coefficients intend to simulate in a simple way, the incognita of the geographic location of the subscribers per year of service subscription, Table 26.

Step 2: Bill of Material

The second step is the intermediate calculation of the quantities of equipment per municipality, considering the geometric model previously described at Section 5.2.5. The main components of FTTH architecture for a PON network (Figure 102) are listed in Table 26.

The values presented in the table are the ones that were possible to gather from suppliers and installers, directly or at internet sites.

Element	***Equipment***	***Granularity***	***Capacity***	***Comment/Method***
@Home façade	*ONT*	*per DU*	*1 per DU*	Equal to subscriber forecast per year aggregated by GEOTYPES
@ODN->Building facade	*ODP*	*per neighborhood agglomeration of DU´s*	*1:24 (2 fibers reserved for maintenance)*	Agglomeration of DU´s per neighborhood considering the ODP % inefficiency due to uncertain location and the Geotype subscriber forecast
@ODN->Street cabinet (SC)	*Splitters 1:32*	*Per Sub-Geotype*	*1:32*	Agglomeration of 32 ODP´s per municipality considering the splitter% inefficiency due to uncertain location and the Geotype subscriber forecast
	Street cabinets		*9 splitters*	Agglomeration of splitters per municipality considering the SC % inefficiency due to uncertain location and the Geotype subscriber forecast. May be reuse or rent.
@ODN->Flexibility Point (FP)	*Joint Enclosure*	*Per municipality*		Every crossroad or each linear120m.
	Manholes			It will be a big percentage of reuse of existent manholes therefore there lower investment on civil works.
@Cables	f_{DCO}		*Cables of 288fo*	Average distance from the central CO to the sub-Geotype. May be reuse or rent.
	$F_{distcable}$		*Cables 96fo*	Average distance from center of geo-Type until the ODP´s. equals n-1 units (bus topology). May be reuse or rent.
	f_{rop}		*Cables 24fo*	Average distance from the center of neighborhood until each HH (bus topology). May be reuse or rent.
	ducts			Depend on the length of each fiber segment. May be reuse or rent reducing the civil works cost.
@Central Office (CO)	*Splitters 1:2*		*1:2*	Typically the splitter inside the CO is to reserve future capacity. In this model all the capacity is deployed, and the output of each 1:2 splitter serves two splitters 1:32.
	GPON		*2.5Gbps*	
	Optical Line termination (OLT)		*4 PONs*	
	OLT shelf		*4 OLT =16PONs*	
	OLT rack		*4 shelves*	

Table 26 – Key GPON components and equipment.

The bill of material (BOM list) also includes the costs per item per year according to the components price evolution described at Section 5.2.7 which depend on the type and maturity of the equipment in the market.

At this point the geographic model (5.2.5 and 0) is applied to the calculation cost of a FTTH network (3.3.5). In order to calculate the overall amount of equipment needs per year, the procedure granularity was based on the country´s municipalities. (Each municipality is geographically divided in CENSUS subsections, with statistic data available per each one)

The initial prices per item are gathered among several sources as internet supplier's official pages, direct requests to operators or equipment suppliers or other non-official sources. The indicated values are just estimations for a starting point of a theoretical exercise since in a real network the associate cost of equipment depend on several variables as the dimension of the orders and others commitments between organizations.

Table 27 describes in detail the algorithm for the calculation of the bill of material list.

INPUT DATA

- Project time frame
- Country statistical data
- Each municipality was categorized as a GEOTYPE.
- Each municipality was then characterized as U, SU, R. (sub-Geotype)
- Each municipality contains one Central Office, Lisboa and Porto contains three each one.
- Infrastructure avaiilability - sharing variables
- Investment plan
- Market uptake
- Subscriber forecast
- Equipment capacity and type
- Equipment life time
- Efficiency and Reuse factors

GEOMETRIC MODEL

- Each sub-Geotype was model in neighborhoods, as a squared of length= sqrt (area of the sub-Geotype) and with n squares, with n=the sqrt (area of the sub-Geotype)/ average length of each subsection. (TITAN Bus topology)
- Each square is then divided again following the same procedure, and therefore divided in squares, representing the households (either single houses or buildings (2 or more floors). For calculating the side length of each new square , the number of neigh_squares= number of HH, and the size of each lneigh= average length of each subsection/ sqrt(nb HH)
- The TENTUS squared_bus model allows calculating the cable and ducting length. TENTUS model assumes the duct length equal to the fiber length multiplied by a reuse coefficient (%duct_reuse)
- The fiber total length=Fiberfeeder_lenght+FiberDistribution_lenght+FiberDrop_lenght
- Fiberfeeder_lenght=distance between CO and the center of the geotype
- FiberDistribution_lenght=(n-1)* average length of each subsection, according to section
- FiberDrop_lenght=(n´-1)* lneigh

ARCHITECTURE MODEL

- For each DU there is an ONT.
- Per sub-geotype the DU´s are aggregated in groups of 22 per neighborhood and then multiplies by the n factor to give the number of ODP. #ODP=sum(DU per neigh)/(ODP cap *%ODP_eff)*n. The ODP_eff simulates the geographical dificulty to aggregate 22 DU´s in a row.
- The number if splitters1:32=(#ODPs*ODP cap*%ODP_eff)/(splitter_cap*%splitter_eff)
- The splitters are inside street cabinet with a max_capc_SC=9. So the #SC=#splitters1:32/(9*%SC_eff)
- At the CO the number of splitter 1:2 is then (#splitter32)/2
- The number of PON´s is equal to the number of splitters1:2
- number of an OLT card is the number of PONS/4 and the number of shelves is equal OLTcard/4
- Along the fiber path several flexibility points will appear due to cross roads or other physical constrains.

Table 27 – Detail algorithm for TENTUS FTTH-GPON Bill of Material.

The calculated variables are the quantities of material needed. This calculation will feed the next stage of the algorithm that is the corresponding annual equipment cost. The bill of material will feed the CAPEX project list in a global approach and per environment: U, SU, and R.

Step 3: GPON financial analysis

The financial analysis is done based as described in detail at Section 0.

The behavior of the bill plan evolution is total dependable to the subscriber forecast when the equipment concerns the usage per a single DU; however it differs when the equipment is shared among several users. In this situation sometimes an equipment of high capacity has to be bought just to serve a small amount of subscribers. Those situations lead to network inefficiency and irregularity in the smoothness curve behavior.

Moreover at the end of 10 or 15 years, depending on the time life of the equipments, a huge amount of investment is required due to equipment replacement. Once again as this is a theoretical exercise and the time life value is an average of time life´s, all the equipments acquired in the same year are replaced at once 15 years later.

The equipment once deployed on the field is assumed to remain there even thought it might occur churn or subscribers who leave the supplier.

5.3.2 TENTUS´ LTE dimensioning

This section is going to look into the issues that are inherent in the planning and design of a wireless telecommunication networks described above (Section 3.1). Cellular systems present a cellular architecture that has solved two limitations of wireless communications: mobility (the capacity to handover between cells and therefore the need to smooth coverage overlap) and increased spectral efficiency (wireless systems share the transmitted power among the users and therefore despite the evolution in wireless family, capacity are a sensitivity point at this type of systems. When start planning a wireless network these are two aspects have to be taken into account.

The cell planning has yet to identify the user so that it is recognized by the network authorizer and to use it as well as knowing where you are so one can receive a voice call. More still need to ensure the security and confidentiality of communications. All this, while respecting the quality of service (QoS).

With the concept of the concept arises naturally cell frequency reuse which contributes to the efficiency of spectrum use and efficiently manages the inter-cell interference, this and other basic concepts of cellular planning are described in the next section.

Basics of Cellular Architecture and Frequency Reuse

When using the electromagnetic spectrum as a communication channel has to take into account a number of physical phenomena resulting from the propagation of electromagnetic waves. These are: the loss in free space, the shadow effect caused by obstacles, the multipath fading; phenomenon of diffraction, absorption and scattering. The radio channel can be considered as a linear filter, which introduces "distortion" in the transmitted signal which can be described in the time domain by the impulse response or frequency domain using the transfer function. The radio channels are random and time-varying depending on propagation phenomena as reflection, diffraction, multipath diffraction and scattering as well as well as penetration absorption losses or guided waves , [208].

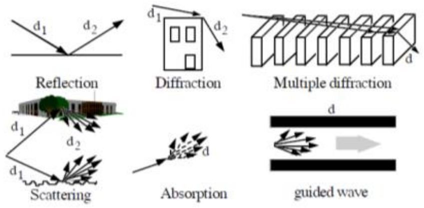


Figure 114 - Propagation phenomena, Source: [208].

In the 40s of the twentieth century the first systems that used radio propagation, have been installed in the USA. Systems with an antenna were located in the center of a metropolitan area with a high height and high power single transmitter. As a result of the service area was very extensive limitations which led to the density of users. These systems not using frequency reuse. The cellular concept was introduced to solve the problem of limited capacity and congestion of mobile radio systems from the utilization of radio resources and optimizing reuse existing spectrum. The transmission stations are spaced by inter-site distance which determines the coverage area of the same station, each area covered by a different station is a cell, Figure 115.

The basis of this concept is frequency reuse, in order to increase the capacity of a mobile radio system without increasing the available bandwidth. The cellular systems take advantage of the fact that the output signals propagated in space decreases with increasing distance from [209] to reuse the same frequency channels in different geographical locations for which the value of carrier to interference ratio, C/I is above a predetermined value.

The mobility was achieved thanks to the cellular systems that are based on the concept of the cell and the new concept of handover (HO). The service area of a cellular mobile communication system is divided into smaller areas called cells, each being served by a base station. When the user moves from a certain location served by a station to another location served by another is performing a handover.

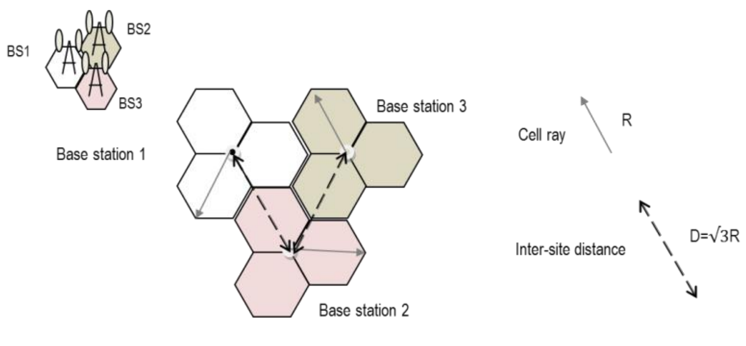


Figure 115 – Cell radius and inter-site distance.

It is during this passage between base stations that might take place the greatest number of dropped calls and thus is a source of degradation of the quality of service. The causes can be several, "coverage hole", late passage to the other station, poor quality of the destination station. The correct calculation of the inter-site distance and proper planning of frequency reuse factors are decisive for the quality of service of a cellular system.

The GSM uses TDMA and FDMA techniques for network access by multiple users. The reuse frequency (FDMA) enables to serve the maximum number of users per cell with minimal spectral allocation. When using the technique FDMA becomes worthwhile tailor a plan of distribution of frequencies by base stations so that they avoid to interference between neighboring stations.

The size of the coverage of each cell depends on the criteria described in the following paragraphs of this section, 0. In this proof of concept, it is assumed that all stations within the same cluster have the same radius of coverage. Consider the following figure with a set (cluster) of GSM cells, [210]:

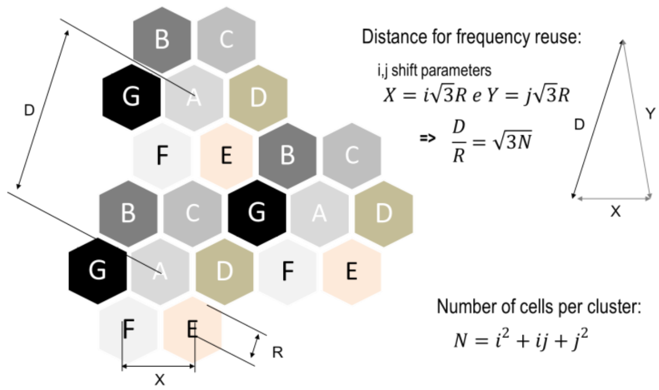


Figure 116 – Frequency reuse and number of cells per cluster.

<u>*Wireless Link Budget and Path Balance*</u>

The planning and design of radio access in a wireless network is a process that involves a wide range of possible configurations and amount of equipment is estimated based on the requirements of the operator. These requirements are related to coverage (*link budget*), capacity and quality of service. When start planning a network it is necessary to plan the coverage of each base station, taking into account the link budget involved, obstacles (buildings, trees, waterways) and frequency planning [211].

As in the previous link budget study for PON systems, at Section 0, the aim of the .link budget calculation is to achieve the maximum path loss allowed, considering all the sources of power gains and losses. Also from this calculation it is determine the minimum threshold for the network design to put in the simulation tool. The basic expression for this calculation is, Equation 11:

$$Link\ Budget(dB) = EIRP\ (dBm) - Rxsensitivity + Gains(dB) - Losses(dB)$$

Equation 11 - Wireless Link Budget expression.

In order to ensure that both up and downlink achieve both the user and the base station this link budget has to be done in both ways, [211]. This assessment of losses from propagation channel UL and DL, determines the maximum allowable losses to establish a connection with a minimum required quality. In the table below shows how to calculate the maximum loss of each connection. The end result will be to consider the lesser of the two values.

The next table presents an example by Toskala, comparing the maximum path loss calculation three 3GPP generations, GSM, UMTS and LTE, [212]. The LTE link budget in downlink has several similarities with HSPA and the maximum path loss is similar. The uplink part has some differences: smaller interference margin in LTE, no macro diversity gain in LTE and no fast fading margin in LTE, Table 28.

Uplink Budget			**Radio Access Network (RAN) technology**	**Downlink Budget**		
GSM	*HSPA*	*LTE*		*GSM*	*HSPA*	*LTE*
12.2	*64*	*64*	*Data rate (kbps)*	*12.2*	*1024*	*1024*
200 KHz	*5 MHz*	*20 MHz*	*CH BW*	*200 KHz*	*5 MHz*	*20 MHz*

UE			*Transmitter*		*BTS/Node B, eNode B*		
33	*23*	*23*	*a*	*Max. TX power (dBm)*	*44.5*	*46*	*46*
0	*0*	*0*	*b*	*TX antenna gain (dBi)*	*18*	*18*	*18*
3	*0*	*0*	*c*	*Body loss (dB)*	*2*	*2*	*2*
30	*23*	*23*	*d*	*EIRP (dBm) (a+b-c)*	*60.5*	*62*	*62*
BTS/Node B/eNode B			*Receiver*		*UE*		
-	*2*	*2*	*e*	*Node B noise figure (dB)*	*-*	*7*	*7*
-	*-108.2*	*-118.4*	*f*	*Thermal noise (dBm) –(depends on the bit rate)*	*-119.7*	*-108.2*	*-104.5*
-	*-106.2*	*-116.4*	*g*	*Receiver noise floor (dBm) (f+e)*	*-*	*-101.2*	*-97.5*
-	*-17.3*	*-7*	*h*	*SINR (dB)*	*-*	*-5.2*	*-9*
-114	*-123.4*	*-123.4*	*i*	*Receiver sensitivity (dBm)*	*-104*	*-106.4*	*-106.4*
0	*50%*		*j*	*Load factor (%)*	*0*	*70%*	
0	*3*	*1*	*J*	*Interference Margin (dB) (10 log10[1/(1-j)])*	*0*	*4*	*4*
0	*0*	*0*	*k*	*Control Channel Overhead %* *10–25% =0.4–1.0 dB*	*0*	*20*	*20*
18	*18*	*18*	*l*	*RX antenna gain (dBi)*	*0*	*0*	*0*
0	*1.8*	*0*	*m*	*Fast fade margin (dB)*	*3*	*0*	*0*
			n	*Penetration loss (dB)*	*0*	*0*	*0*
			o	*Body loss (dB)*	*0*	*0*	*0*
0	*2*	*0*	*p*	*Soft handover gain (dB)*			
162	*161.6*	*163.4*	***Maximum path loss (dB)***		*161.5*	*163.4*	*163.5*

Table 28– Cellular maximum allowable path loss.

For the system to function the two-way balance is vital to ensure that both DL and UL connections are able to establish at a minimum quality of service, Equation 12:

$$Path\ Balance = \ Max.Allowed\ Pathloss\ DL - \ Max.Allowed\ Pathloss\ UL$$

Equation 12 – Cellular path balance.

When the path balance value is other than zero it will be carried out further investigation of the causes of this imbalance, some of the components are involved symmetrically (UL and DL), and that intervene only in one direction, others work (in terms of losses/gains) in un asymmetrically way as shown in the following table, Table 29. This imbalance occurs when the signal found some obstacles and suffers some propagation phenomena's. When the path loss is imbalance there are methods to overcome it as change the transmission power (value configurable in 2dB steps); using of the diversity antennas or introduce of low-noise amplifiers in the uplink (TMA's).

Gains and losses	
Symmetric	***Asymmetric***
Cables	Transmitter Power
Connectors	Receiver sensitivity
Couplers	Combiners
Antennas	Duplexers and TMA´s

Table 29 – Symmetric and asymmetric components at wireless air interface.

Concerning the LTE network some details are relevant to be mentioned while determining the inputs for the calculation of the maximum allowed losses mainly at the receiver parameters. These parameters are the Modulation Coding Scheme (MCS), the index Transport Block Size (ITBS), Physical resource Blocks (PRB), the Cell Edge Throughput and the Signal to Interference and Noise Ratio (SINR), [213].

The first step to planning a LTE network is to define the coding scheme allowed. The LTE offers three modulation schemes: QPSK, 16QAM and 64QAM. The target throughput for the entire network has to be guarantee until the limit of the cell coverage (Cell Edge Throughput) and therefore the cell service and modulation are defined at that point. Note that the higher the Cell Edge Throughput, more resource blocks are required, which means that less free RB are available for Power Gain (PG), and reducing the receiver sensitivity and consequently the coverage distance “shrinks”.

For each modulation scheme a group of MCS are assigned (see tables @ [213]). The higher the MCS the less resource blocks (RB) are needed for the same throughput, but less RBs requires higher SINR and that leads to smaller cells and consequently more sites for the same target area. The choice of the Cell Edge Throughput and MCS should take these consequences into account.

The combination of the modulation scheme index and the throughput leads to the number of the transport block sizes and to the preliminary SINR (PR SINR). Finally the required SINR is accomplished by combining the preliminary SINR with receiver’s gains and margins, h)@Table 28.

Cell Radius Calculation

From the calculation of the maximum path loss it is possible to find the cell radius by using a suitable propagation model. Propagation models can predict network coverage estimated, knowing the equipment involved in the system. Typically models are empirical coefficients whose curves approach the theoretical prediction curves realistic coverage of mobile systems.

The propagation models calculate the maximum allowed loss (MAL) through the combination of the coefficients listed below, Figure 117. Propagation models can also estimate the maximum coverage distance (R) when the value of MAL is a known parameter, as in the studied case.

- Working frequency, f (MHz);
- Maximum coverage distance, R (Km);
- Base station antenna high, hbe (m);
- Mobile antenna high from ground, hm (m);
- Street width, w(m);
- High difference between the mobile and the rooftops, ΔhMS;
- High difference between the base station and the rooftops, Δhbe;
- Distance between buildings, b (m).

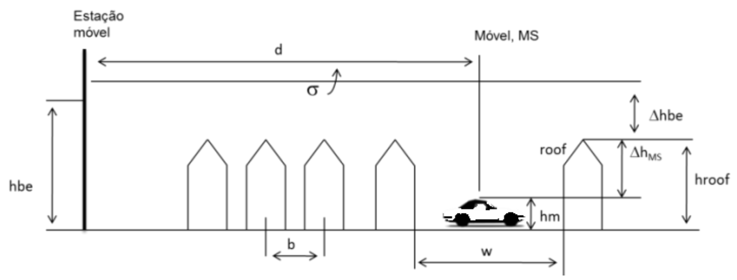


Figure 117 – Typical propagation variable at urban areas, Source: COST models, [214].

The link budget calculated in the previous section has allowed to find the maximum allowable loss (Max path loss), and so at this point it is possible to use the propagation models to estimate the maximum range of the cell's coverage, R (Km).Typically the propagation models used to forecast the cell coverage are the empirical models of HATA [215], COST-231 HATA [214, 215] and COST231-Walfisch Ikegami [216, 217], Table 30. The main differences among them are the limitation of the working frequency or the environment topology, as it will described in detail next.

Model	***HATA Propagation Model***	***COST-231 HATA Propagation Model***	***COST231-Walfisch Ikegami Propagation Model***
Frequency (MHz)	150 a 1000	1500 to 2000	800 to 2000
Antenna distance from ground: h_{be}	30 to 200m (typ.30- 40m);	30 to 200m (typ.30- 40m);	30 to 200m (typ.30- 40m)
Mobile distance from ground: h_m	1 to 10m (typ. 1,5m)	1 to 10m (typ. 1,5m);	1 to 10m (typ. 1,5m);
R(Km)	1 to 20Km	1 to 20Km	1 to 20Km
Other variables			Angle of incidence, ϕ. Typ.ϕ=90° b(m): 20 to 50m w(m)=b/2

Table 30– Cellular propagation models.

HATA Propagation Model

The first propagation model was first published in 1980 by Prof. Hata [215] that based on the previous measurement made by Okumura in urban zones of Tokyo [218], produced a set of equations that reproduce empirical the same behavior. HATA model has two limitations: the limitation on distance and limited in frequency: 150 to 1000MHz, Table 30 and Equation 13. A correction factor was introduced to allow the usage of the same equation to non-urban zones.

$$\textit{Maximum allowable losses}, L = K_1 + K_2 \log_{10} R - a(h_m) - f_c \textit{ or from the coverage ray point of view}$$

$$\textit{Coverage ray per cell}, R(Km) = 10^{\left(\frac{L+f_c+a(h_m)-K_1}{K_2}\right)}, \textit{ with:}$$

$$K_1 = 69{,}55 + 26{,}16 * \log_{10} f\,(MHZ) - 13{,}82 * \log_{10} h_{be}\,;\; K_2 = 44{,}9 - 6{,}55 * \log_{10} h_{be} \quad ; \quad a(h_m) = (1{,}1 * \log_{10} f\,(MHZ) - 0{,}7) * h_m - (1{,}56 * \log_{10} f(MHZ) - 0{,}8) \;\; \textit{With the correction factor for rural or open space}, f_c = 4{,}78 * (\log_{10} f(MHZ))^2 - 18{,}33 * \log_{10} f(MHZ) + 40{,}94$$

Equation 13– COST231-HATA model, [215].

COST-231 HATA Propagation Model

The COST231-HATA model [214] is an extension of the European project COST 231 [214] the first HATA model [215] for frequency-81500 2000MHz based on new measurements and adjustments OKUMURA [218]. Expression of the maximum allowable losses (L) or the maximum distance (R) is expressed in the following equation, and can be used under the following conditions. The maximum loss allowed (MAL) according to this model is calculated using the formulas of Equation 14.

$$\textit{Maximum Loss Allowed}, L = K_1 + K_2 \log_{10} R\,(Km) - a(h_m) \quad \textit{or} \quad R(Km) = 10^{\left(\frac{L+a(h_m)-K_1}{K_2}\right)}, \quad \textit{with:}$$

$$K_1 = 46{,}3 + 33{,}9 * \log_{10} f(MHZ) - 13{,}82 * \log_{10} h_{be}\,;\; K_2 = 44{,}9 - 6{,}55 * \log_{10} h_{be}$$

Equation 14 – COST231-HATA model.

The parameter $a(h_m)$ is a correction factor taking into account the type and location of signal propagation.

Topology	$a(h_m)$
Dense Urban	$(1,1\, log_{10} f(MHZ) - 0,7)h_m - 1,56 * log_{10} f(MHZ) + 0,8 - 3$
Urban e Suburban	$(1,1\, log_{10} f\,(MHZ) - 0,7)h_m - 1,56 * log_{10} f\,(MHZ) + 0,8$
Axial e Rural	0

Equation 15- COST231-HATA correction factor.

COST231-Walfisch Ikegami Propagation Model

In addition to the previous model the group COST231 [214] also proposed a model based on the combination of work Walfish [216] and Ikegami [217] more suited to urban environments and densely urban. The expression of the maximum loss allowed (L) or the maximum distance (R) is expressed in the following equation and can be used in the following circumstances:

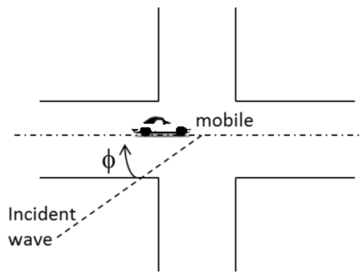


Figure 118 – Definition of incident angle ϕ.

This model distinguishes two distinct situations: line of sight, LOS and non-line of sight, NLOS. In the case LOS, or is line of sight between the base station and the mobile permitted and the maximum losses are given by the following expression for rays becomes equal to 20m equivalent to the expression of losses in free space [209].

$$L(dB) = 42,6 + 26 * log(R)(Km) + 20 * log(f)(MHz),\ with\ R \geq 20m\ COST\text{-}WI,$$

$$And\ with\ free\ space\ losses,\ L(dB) = 32,45 + 20 * log(R)(Km) + 20 * log(f)(MHz))$$

Equation 16 - Maximum losses allowed for LOS, model COST231 WI and losses in free space.

In the case non-line of sight, NLOS, due to dense buildings or other sources of blockage, the maximum losses allowed in this model are calculated by the Equation 17:

$$MAL = \begin{cases} L_0 + L_{rts} + L_{msd} & ,L_{rts} + L_{msd} > 0 \\ L_0 & ,L_{rts} + L_{msd} \leq 0 \end{cases} with$$

$$\begin{cases} Free\ Space\ Loss, L_0 = 32,4 + 20\, log_{10}(R)\,(km) + 20\, log_{10}(f)\,(MHz)\,; \\ L_{rts} = -16,9 - 10\, log_{10} w + 10\, log_{10} f + 20\, log_{10} \Delta_{MS} + L_{ORI} \\ L_{msd} = L_{bsh} + k_a + k_d\, log_{10} R + k_f\, log_{10} f - 9\, log_{10} b \end{cases} \quad with:$$

$$L_{ORI} = \begin{cases} -10 + 0,354\varphi & ,0º < \varphi < 35º \\ 2,5 + 0,075(\varphi - 35) & ,35º \leq \varphi < 55º \\ 4 - 0,114(\varphi - 55) & ,55º \leq \varphi < 90º \end{cases};\ L_{bsh} = \begin{cases} -18\, log_{10}(1 + \Delta_{hbe}) & ,h_{be} > h_{roof} \\ 0 & ,h_{be} \leq h_{roof} \end{cases};$$

$$k_a = \begin{cases} 54 & , h_{be} > h_{roof} \\ 54 - 0{,}8\Delta_{hbe}\ , d \geq 0{,}5km\ e\ h_{be} \leq h_{roof} \\ 54 - 0{,}8, d\Delta_{hbe}\frac{d}{0{,}5} < 0{,}5km\ e\ h_{be} \leq h_{roof} \end{cases} ; k_d = \begin{cases} 18 & , h_{be} > h_{roof} \\ 18 - 15\frac{\Delta_{hbe}}{h_{roof}} & , h_{be} \leq h_{roof} \end{cases} \ and$$

$$k_f = -4 + \begin{cases} 0{,}7\left(\frac{f}{925} - 1\right), average\ cities\ and\ suburban\ of\ medium\ density \\ 1{,}5\left(\frac{f}{925} - 1\right) \quad high\ density\ urban\ centers \end{cases}$$

Equation 17 - COST231-Walfisch Ikegami model.

After calculating the link budget, estimated the maximum loss allowed and applied the propagation model that best fits the reality to study, an estimation of the maximum expected coverage is obtained as such the cell radius, R, Figure 115. This value is calculated per station and in case of a tri-sectorial site the total area value should be done by the expression, Equation 18.

$$A_{trisectorial\_site} = 1.95 \cdot R^2$$

Equation 18 – Area calculation of tri-sectorial LTE site.

<u>Radio Capacity</u>

As previous described, the coverage area of a cellular site depends on the power balance between the down and the uplink. This value represents the area of coverage where a cell site (or station) with several parameters defined, as transmitter power, receiver sensitivity, antenna gain and feeder losses, can guarantee a certain throughput. This means that each cell of the site can provide that up to that value of throughput. However the single user throughput is always going to depend on the number of users at the time of the data session.

The evaluation of the capacity of a certain cell obeys to the analysis of the user behavior and the network offer.

The prediction of the user behavior of a live network, concerning the usage of the spectrum resources is so hard to predict as the subscriber forecast, 5.2.3 of geographic location of new subscribers, 5.2.5. The behavior of the subscriber depends on the application and data request at each moment, Figure 119. The sum of requested amount of data could not exceed the station planned throughput. For this reason the mobile operators cannot guarantee the exact throughput (e.g.: XMbps) per user but specify their product as “up t XMbps”.

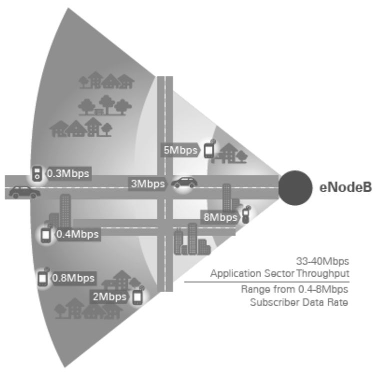


Figure 119 – Example of instantaneous sector throughput and usage. Source: Motorola white paper, [219].

Traffic is also not equally distributed over a 24 hour period and for that reason it is analyzed the busy hour per user (BH). It is reasonable to believe that each subscriber has it BH at different hours of the day from another user, however that was another difficult prediction to do, and therefore the cell capacity planning is very conservative assuming all the BHs simultaneous.

The method followed is based on the estimation of subscribers in a certain location, with a certain consuming pattern and compared to the maximum network throughput at the same place. Each subscriber is assumed to have a settled pattern of behavior at the busy hour (BH), based on data from other packet switch networks already existent, Figure 120, [220].

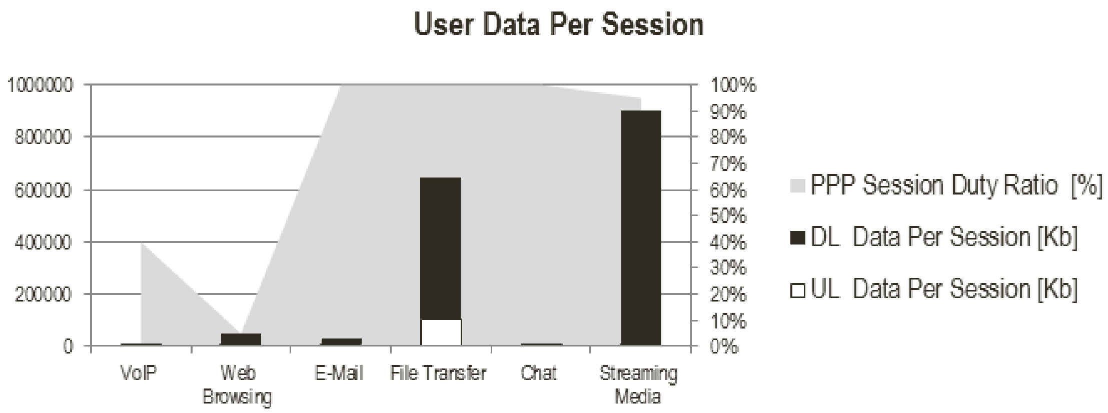


Figure 120 – User data per session. Source: HUAWEI, [220]

This behavior is then associated to the traffic pattern ratio per topology which estimate the session time per type of service. These parameters define the needs per user defined as the Single User Throughput.

The network throughput offer depends on the cell edge throughput modulation pre-defined but also from the awareness that between the center of the cell and its edge several modulations can be used as the interference rate, SINR, allows, Figure 121. The cell behavior along the distance varies with the distance to center and depend on the topology. With this in mind it is possible to estimate the cell average throughput offer per topology.

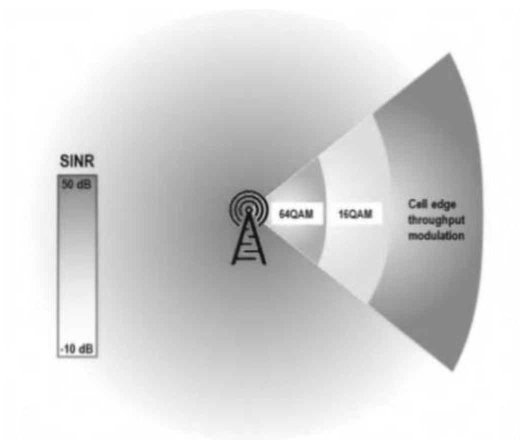


Figure 121 – Modulation variation along the coverage area and according SINR.

The number of sites can be accomplished by comparing the Single User Throughput with the number of potential users and with the station throughput offer. This calculation is based on the busy hour subscriber's rate and the subscriber forecast take up rate, 5.2.3.

Wireless TENTUS algorithm

The TENTUS wireless algorithm is built in four steps: the input values concerning statistical data and assumptions, the site calculation by the radio frequency link budget, the site calculation based on traffic and capacity analysis and considering the maximum the financial analysis considering several assumptions about sharing and investments.

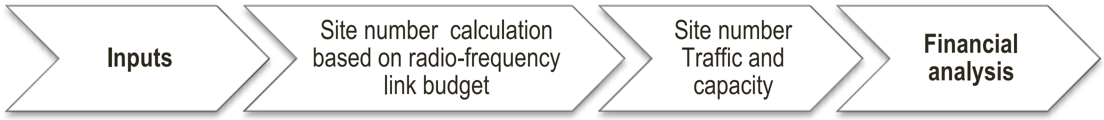


Figure 122- TENTUS LTE algorithm.

Step 1: TENTUS wireless Inputs

The inputs needed to this module are from two types of origins. There are the statistic data available from the National center of statistics with the actual area and inhabitants per sub-Geotype and the initial assumptions concerning the subscriber forecast at busy hour, the network propagation pattern and the packet switch user profile, Figure 123.

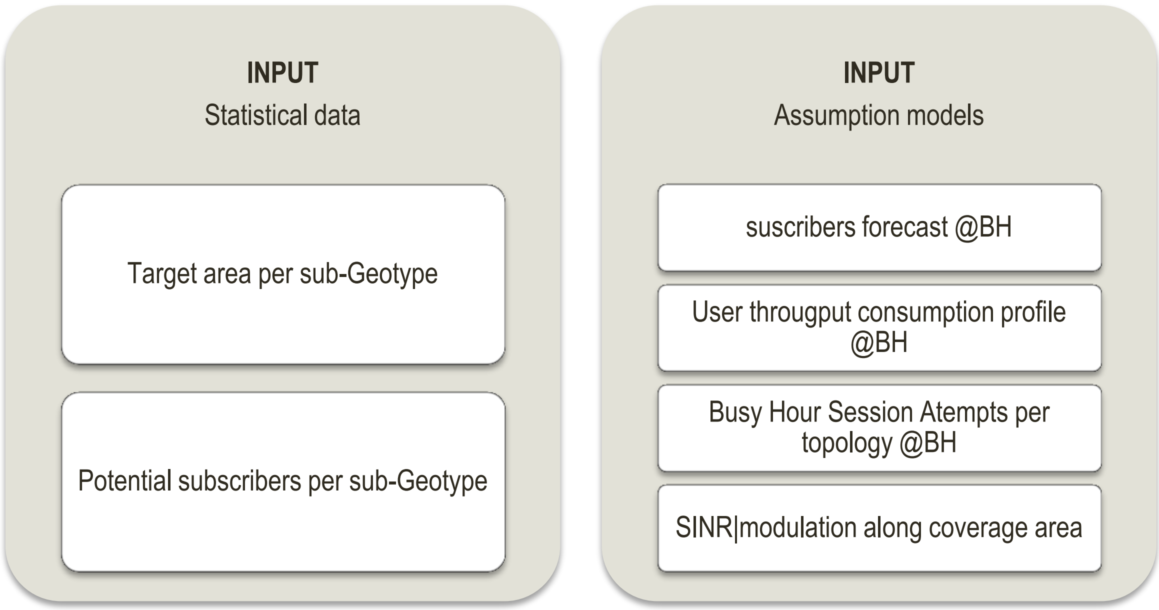


Figure 123 - Input data for TENTUS wireless algorithm

These two combined are the initial assumptions for the next step.

Step 2: Site number calculation

As in the previous section 5.2.10, the site forecast based on the uplink and the downlink balance depends on the link budget analysis, Figure 124 on the left. The site forecast based on capacity demands depends on the network offer and the single user demand, Figure 124 on the right.. This two-step analysis is the base of the LTE module of TENTU´s algorithm, Figure 124.

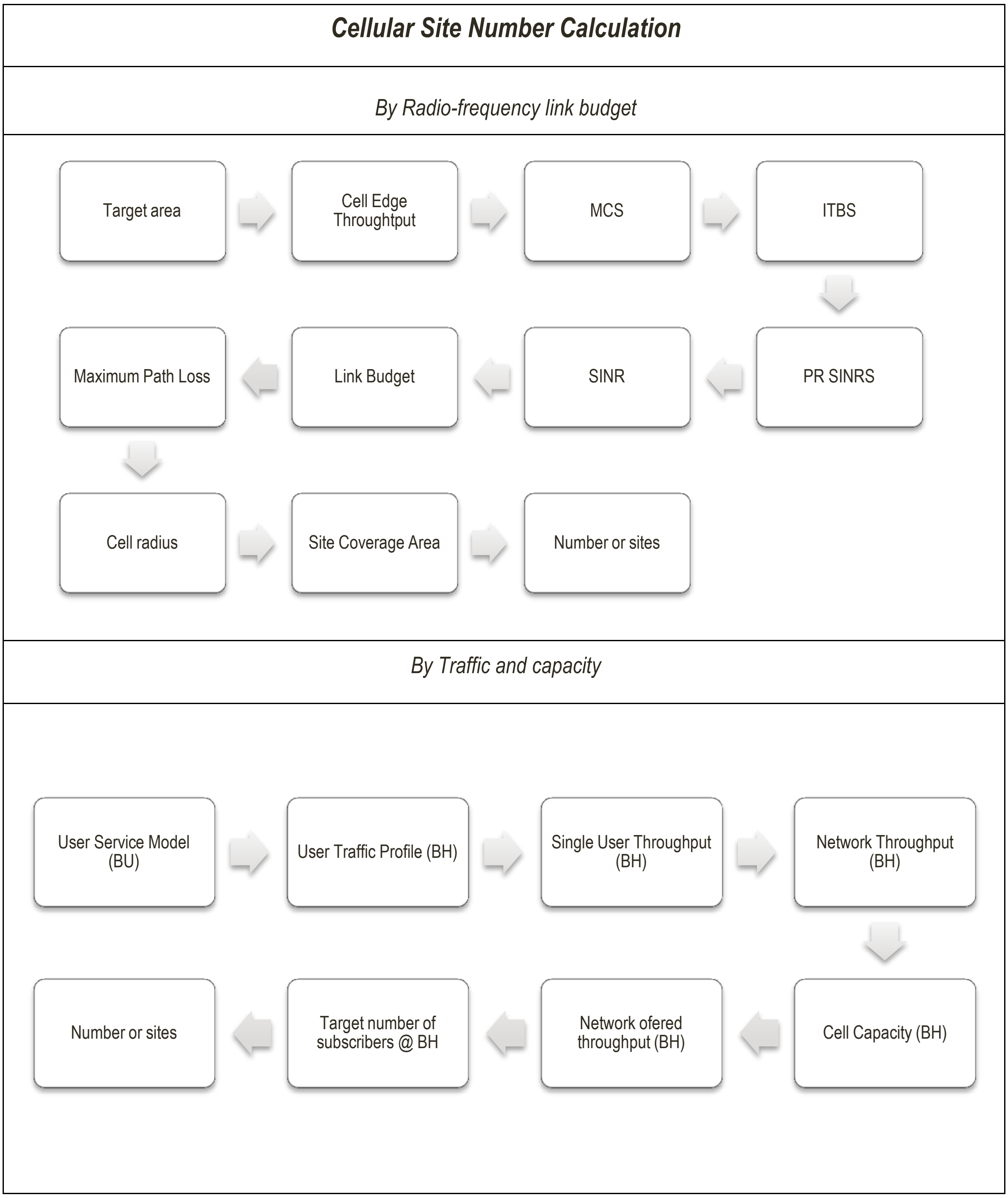
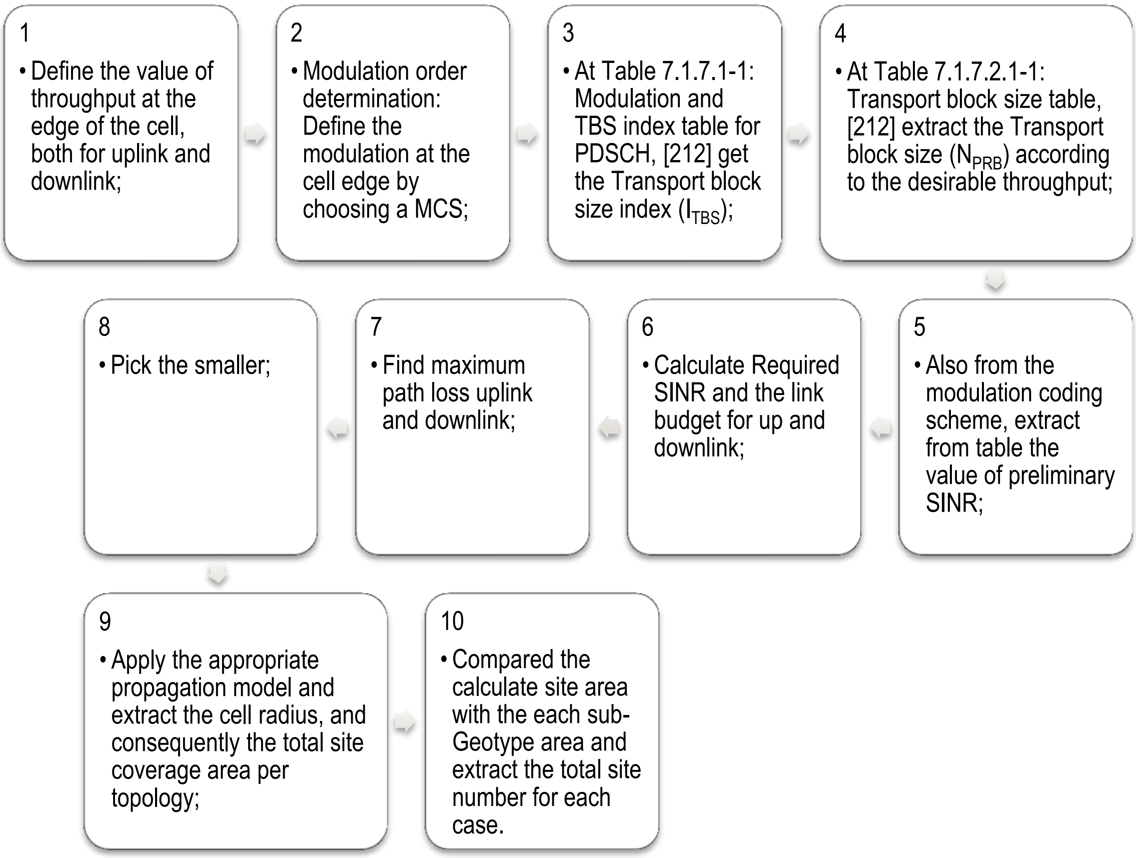


Figure 124 –Site number calculation for cellular technologies, by radio-frequency constrains (on the left) and by capacity (on the right).

Step 2.1: Site number based on radio frequency link budget

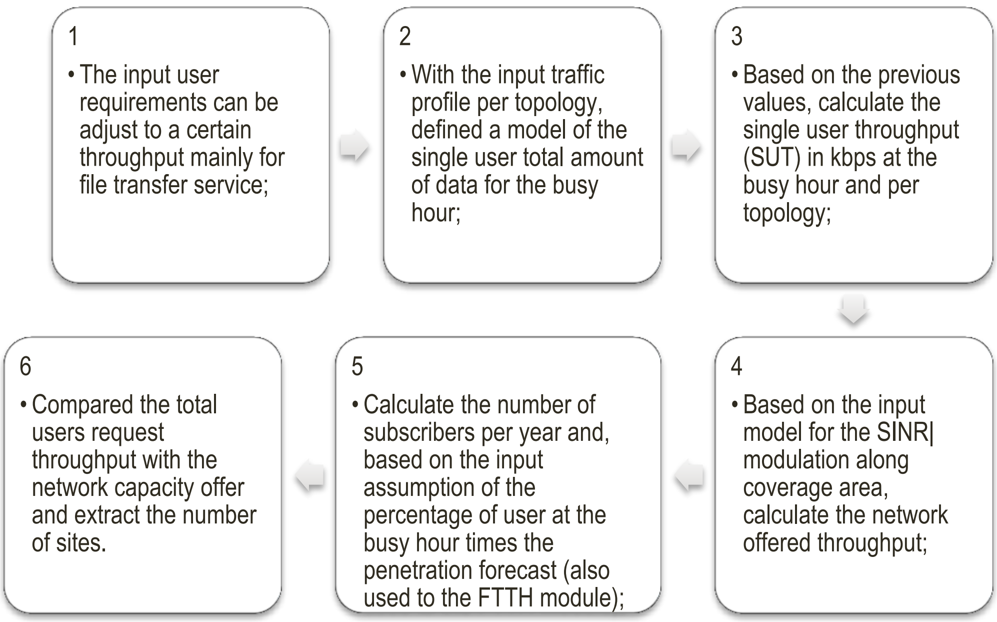
The calculation of a site station coverage area implies the calculation of the actual square kilometers where the transmitted cell can communicate to a mobile phone and receive its response in good radio frequency conditions, with a minimum level of signal to noise ratio (SNR). This method allows the calculation of total number of sites for all the coverage area.

The evolution of the deployment area per year depends on a probabilistic analysis that is out of the scope of this work. The TENTUS algorithm uses the total amount of site calculated with this method to tune the values that came out of the capacity module. This module works as follows:



Step 2.2: Site number based on traffic and capacity

The planning capacity represents the site number calculation for the total number of subscribers in the system with up to a certain guarantee throughput.. Analysis or estimation of the traffic of a given geographical area is crucial to the design of each network node, as well as the distance between network nodes. The planning model of a mobile network should start by analyzing the capacity of network traffic that is determined by the potential and limitations of each of its constituent elements. A process of estimating these initial assumptions is given by Figure 124 on the right, and described below.



Step 3: LTE financial analysis

The financial analysis is done based as described in detail at Section 0.

It is relevant to mentioned that in the case of infra-structure sharing it was not considered the cost due to the monthly lease. This happens because most often the contracts between operator´s are based on a “give and take” process, where the number of pylons or rooftop shared try to be balanced between operator´s and this way any of them have to pay the lease to the other.

5.3.3 TENTUS´ TDT dimensioning (for rural areas)

In parallel to the wide range deployment for the two previous technologies, a more detail study was also made to isolated rural zones where is expectable to reach high investments from those technology roll outs. By the time this PhD work was developed the terrestrial digital television was introduced in Portugal leading to an exploitation of this technology as a window of opportunity concerning rural areas. This study is presented at this section as it is also a module of the TENTUS tool.

The main objective of this study is to provide an alternative solution to deploy a digital TV network in such a way that all the citizens access the broadcast service in parity. The geographical target is a rural zone where the terrestrial base stations roll out is not an option for operators due to the high cost of optical fiber deployment.

For all analysis the technical-economic analysis the following considerations were assumed:

- To provide a terrestrial broadcast network, the operator had to apply for a spectrum license based on a specific terms of reference imposed by the regulator. The spectrum license includes the usage of both DVB-T and DVB-S2 standards. The license cost was approximately 5 Million Euros, for a fifteen years period and is renewable.
- It is an imposition from the regulator to the operator to reimbursement part of the set-up boxes or DTH receiving kit for citizens with special needs, disadvantaged groups of population and institutions of a proven social value. The assumed percentage of households that will benefit from this subsidy is around 30%.
- It is assumed only one multiplexer (MUX) with 5 TV programmatic channels (DTT bouquet) and it is not considered any broadcast radio channel.
- Each television channel, in the DTT bouquet, pays the operator around 2,95 Million Euros per year for the next 15 years[18].
- The target rural zone represents 0, 06% of households in the national overall operator’s network.
- The viewer’s characterization include 99% of the homes with at least one TV set, and more than 74% more than two TV’s[19]. The target viewers are exclusively on residential houses and most of the small enterprises. It is assumed a natural annual erosion of 7% households from free to air to cable TV’s but due to the pressure of the analog switch off an additional 10% is assumed in the first year. For the same reason 2% of households will buy new digital TV’s; 2% of the households will cease to watch TV.

[18] This price is based on the Portuguese approach, in Portuguese newspaper Diário Económico, 4th July 2012. Available in Portuguese on line: http://economico.sapo.pt/noticias/tdt-passa-a-custar-a-rtp-e-sic-29-milhoes-por-ano_145877.html

[19]Available on line: http://www.nationmaster.com/graph/med_hou_wit_tel-media-households-with-television, access January 2013.

Step1: DVB-T deployment

The first calculation will work out as the reference scenario for late investments comparison. It is based on the operator´s DVB-T ´s single frequency network in a small size municipality where it will be used a low power digital transmitter for local broadcast.

It is assumed that the operator also owns a mobile communications network and due to that, the physical infrastructure as the tower and space rental for the base station implementation already exists. Moreover in this study it is considered that the operator will invest in a shared fiber optical network deployment. The closest point with fiber is considered at 50Km and 50% of the ducts, towards the site, are shared with another utility operator. Thus these type of shared investment is reflected in 50% of the total amount if there was the need to deploy all the 50Km of civil construction. Figure 125 depicts the case study DVB-T only.

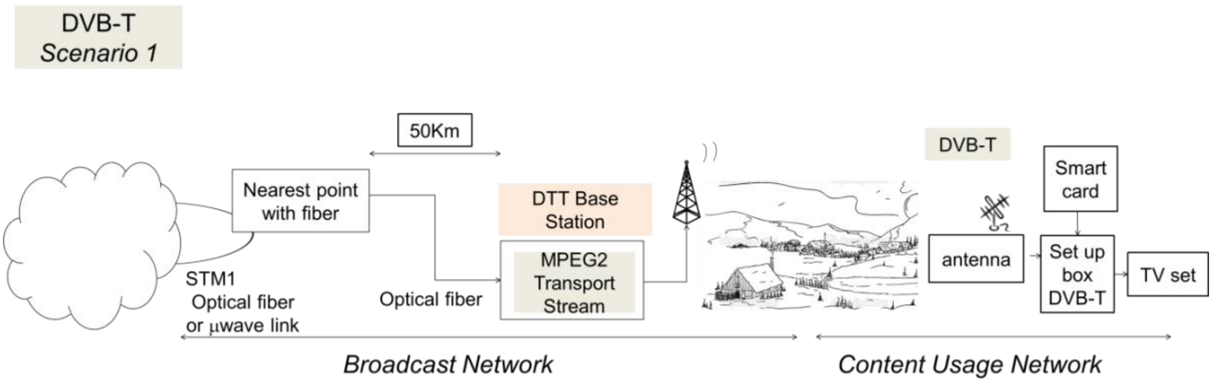


Figure 125 –Terrestrial DVB broadcast network.

It is assumed that all TV viewers pay an audio visual tax to support public television; this tax already existed in the analog broadcast and is kept after the transition. It is presumed that almost all the houses own at least one TV so is assumed 99% of the total of the households having a TV receiver. After the analog switch off, the biggest percentage of the viewers will acquire a DVB-T set-up box and sometimes a second one for a second TV. Around 2% of the households will buy a new digital TV, 7% of them will naturally migrate to cable and it is presumed that in the first year of transition, 10% more will migrate as a consequence of the transition pressure. The regulator can request the operator to reimburse a percentage of the cost of the set-up box in case of person with disabilities, elderly or with low incomings. In this case is the operator that subsidized this fund.

Step 2: DVB-S2 deployment

The second scenario is based on a 100% direct to the home solution to cover the total amount of households in the target area. In this case there it is no need for any type of infrastructure from the operator, apart from the uplink parabolic antenna to deliver the DVB transport stream to the satellite, Figure 126. At the viewer's household there is the requirement to install a DVB-S2 set-up box and a parabolic antenna, with an expressive aesthetical impact in the architectural panorama of the village.

A percentage of the cost of the set-up box can be reimbursement in case of person with disabilities, elderly or with low incomings. As in the previous case, also in this case is the operator that subsidized this fund.

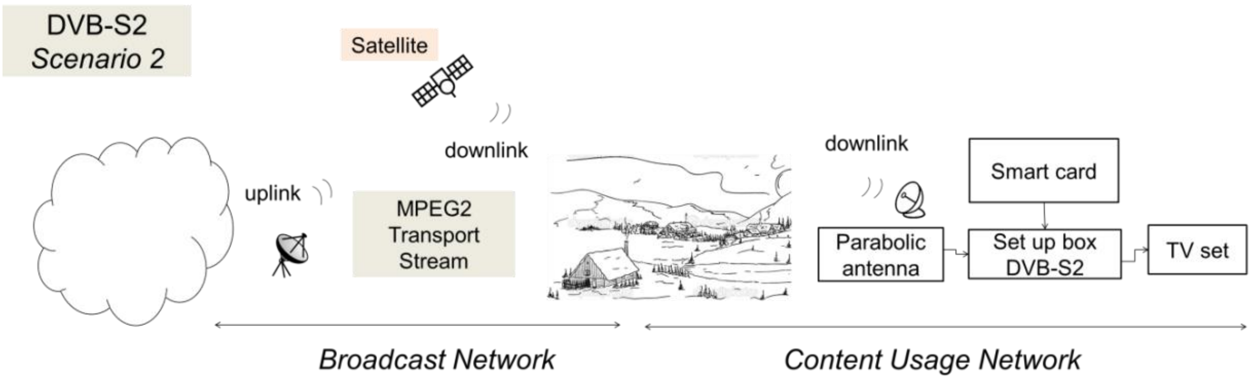


Figure 126 - Scenario 2, satellite DVB-S2 broadcast network.

<u>*Step 3: TDT financial analysis*</u>

The financial analysis is done based as described in detail at Section 0.

5.4 TENTUS Techno Economic Evaluation

TENTUS model developed on a spread sheet software, is based on a techno-economic approach to simulate bottom-up deployment costs using adapted algorithms and methods for calculating annualized investments of different scenarios. At this stage a global financial analysis is done based on an engineering approach.

That means that the main focus of the calculations is the balance between the earnings and payments in a feasible way, even though it is not following traditional financial theory methodology. The perspective is the one from the operator´s access network telecommunication engineer, to ensure his management that each year´s deployment investments and bank loans are cover by all the revenues and profits imposed by the elected business model.

The analyses begin with the evaluation of the required investment to provide the deployment of the access network based on each technology assumptions and market uptake per geographical location. In the case of own capital investment, the operator´s expenses depends both in CAPEX and OPEX annual investment, Figure 127.

In this work, however, it is assumed that there is no self-financing and all the capital needed for the infrastructure and operational management will be requested as a loan to the Bank. This loan is requested annually depending on the deployment infrastructure needs per year. At the end of the day there will be as many loans as the years of project with infrastructure investments.

The concepts of CAPEX and OPEX acquire different meanings. There is no capital expenditures because there is no own capital (equity) and the operational expenditures became the annual payment to the bank. Even though, the traditional concept is kept for business models comparison between scenarios with the nomenclature: Infrastructure Investments and Maintenance Investments.

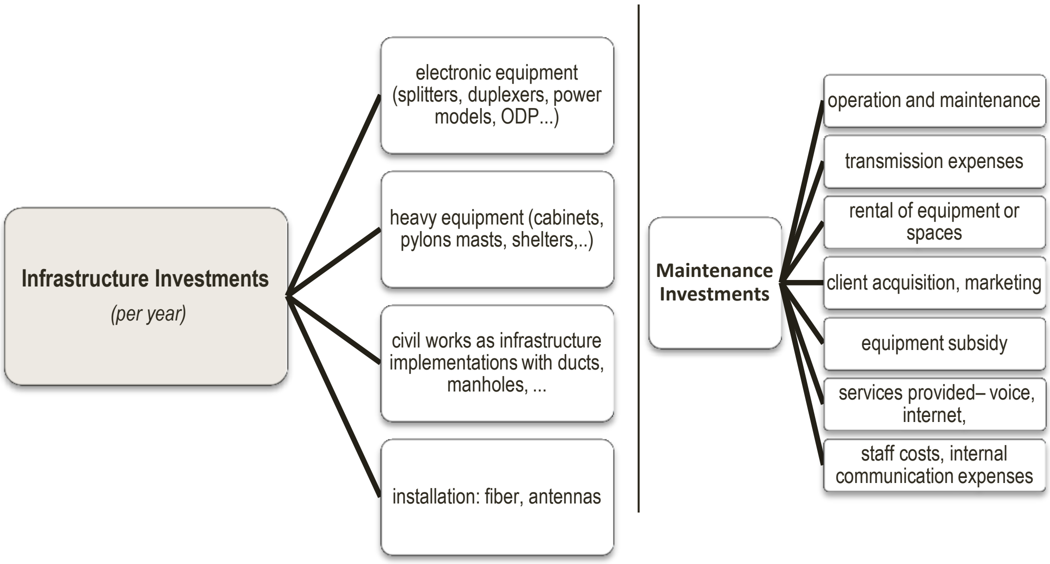


Figure 127 – Operator´s infrastructure and maintenance investment´s chart.

As it is assumed that there are no own capitals, the financial TENTUS´s model calculates the loan repayment and the monthly repayment figures based on the annual interest rate and years of loan, Figure 128. With this assumption the traditional CAPEX calculation is used only to find the Loan Amount request to the bank and a new item – the Principal (or the amortization) is the OPEX.

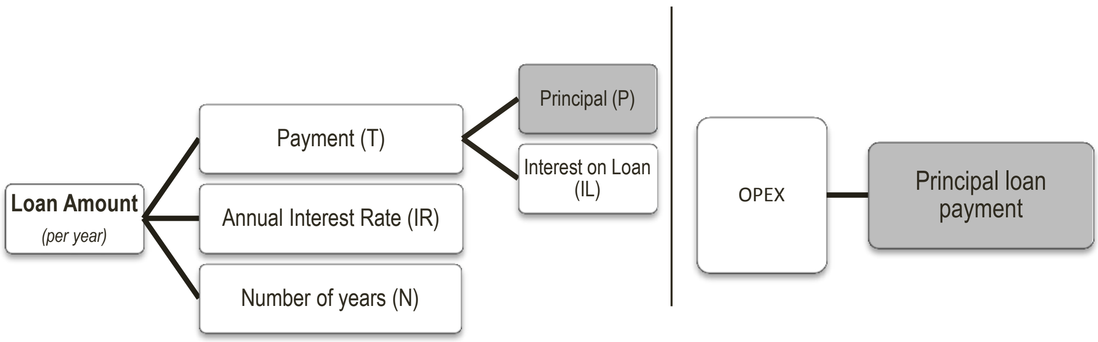


Figure 128 – Capital Loan monthly repayment versus updated OPEX.

Next section describes in detail each one of these concepts and how they interact in TENTUS tool.

5.4.1 Annual Infrastructure and Maintenance Investments

Each annual Infrastructure Investments inputs are mostly the same ones already calculated in the previous stage due to equipment needs, and civil works as infrastructure implementations with ducts, manholes and fiber installation. The capital expenses also include the costs inherent to the design of the network or site acquisition, Equation 19.

$$Infrastructure\ Investments_{\ total} = \sum_{t=0}^{T} Infrastructure\ Investments_{\ year} = \sum_{t=0}^{T}\sum_{i=1}^{N} n_i \cdot \frac{C_i}{(1+j^t)},$$

$$with\ \ t = year\ of\ project; T = total\ years\ of\ analysis, j = rate\ of\ interest\ ,$$
$$i = each\ one\ of\ the\ equipments, infrastructures\ or\ design\ needed\ per\ year,$$
$$N = the\ total\ number\ of\ different\ equipments, infrastuctures\ or\ designs, C,$$
$$and\ n\ the\ number\ of\ \ each\ equipment.$$

Equation 19 – Annual Infrastructure Investments estimation.

Some thoughts must be taken into account at the Infrastructure Investments analysis. As the project is assumed to capitalize by the bank without equity, the annual value assumed for Infrastructure Investments is the annual payment to the bank. Each time a new loan is made, the annual payment is increased with the new installment.

Also the assumption that all the equipments of the same type are replaced all at once periodically leads to an irregular and abrupt behavior of the Maintenance expenses. The Maintenance expenses represent all the expenses as result of daily work related to the network (operation and maintenance, transmission expenses, occupancy rates and rental of equipment or spaces), to the business (client acquisition, marketing, commercial expenses, politics of equipment subsidy, services provided– voice, internet, staff costs and internal communication expenses), Equation 20. The operation and maintenance expenses are presented as a percentage of the annual value of Infrastructure Investments, typically 10%.

From the Maintenance Investments point of view, the PON technology increase the cost investment at the central office, compared to previous cable technologies, due to higher energy consumption and the need to reserve more physical space.

$$Maintenance\ Investments\ _{Total}$$
$$= \sum_{t=0}^{T} Maintenance\ Investments\ _{year}$$
$$= \sum_{t=0}^{T} \frac{(Maintenance\ Investments\ _{network} + Maintenance\ Investments\ _{business})}{(1 + j^{t})},$$
$$with\ \ t = year\ of\ project; T = total\ years\ of\ analysis, j = rate\ of\ interest$$

Equation 20 - Maintenance Investments estimation.

5.4.2 Financing Amount Calculator

TENTUS tool financial model allow the user to choose from three different types of investments: Own Capital, Loan Amount (LA) or a mixture of both.

In this exercise concerning the efforts to achieve broadband Universal Service, it is the author´s option that there is no own capital (equity) and all the financial needs are debt. The used nomenclature is detailed in the Table 31. As part of the initial Load Amount is payed to the bank (amortization, P), each year the LA and respective interest of loans are updated.

Variable	***Acronym***	***Formula***	***Comment***
Loan Amount year 0	*LA0*	*LA0= Investment Investments + Maintenance Investments*	Loan amount requested to the bank at initial point

Annual Loan Amount	*LAi*	$LA_{i+1} = LA_i - P_i;\ i \in N_0$	Loan Amount Update per year based on the amortization
Annual Interest Rate	*IR*	%	Annual interest rate (assumed constant along the loan period)
Number of Years	*N*	$N \in \mathbf{N}$	Total number of yearly payments
Constant Payment	*T*	$T = \frac{LA \cdot IR}{\left(1 - \frac{1}{(1+IR)^N}\right)}$	Loan repayments per year
Interest on Loans	*IL*	*IL=T*IR*	Interest related to annual payment
Principal Loan Ammount	*P*	*P=T*(1-IL)*	Annual Amortzation
Total Payable	*TT*	$TT = \sum_{i=0}^{N-1} T_i$	Total Capital payed at the end of loan

Table 31 – Loan Amount Calculator Variables.

5.4.3 Expected Return on Investment

The investment return depends directly on the subscriber adoption rate and depends entirely on the adopted billing plan. For each sub-GEOTYPE a client profile might be defined. In this study for simplifications purposes it is kept equal for all the regions.

NET+VOICE	
TOTAL 30 fiber/year	545.88€ /per subscriber
LTE 200MB /year	324.00 € /per subscriber

Table 32 – Subscribers´ billing plans options per year.

The Revenues are the company's total amount of money that came mainly from the provision of a certain service or product, but also from the selling of assets or equipment. The revenue calculation taxes or licenses paid to the operator should also be taken into account. No revenues from this type of item were considered in this study.

$$REVENUES_{Total} = \sum_{t=0}^{T} \sum_{j=1}^{J} 12 \cdot Subscriber\ Monthly\ fee$$

$$with\ \ t = year\ of\ project; T = total\ years\ of\ analysis\ and\ J = Total\ number\ of\ subscribers$$

Equation 21 - Revenues estimation.

5.4.4 Financial Feasibility Model

The proposed framework estimation of financial feasibility is based on previous methods already used as Halldor, [221] for residential broadband FTTx in Denmark. In this work the financial approach was adapted for technologies, wireless and wireline, Figure 129.

As previously mentioned it is assumed that there are no own capitals and all the capital for investment and maintenance are capital loan. Therefore the Principal or Amortization is considered by the author as a periodic expense as any other operational expense and the capital expenses are reduced to zero.

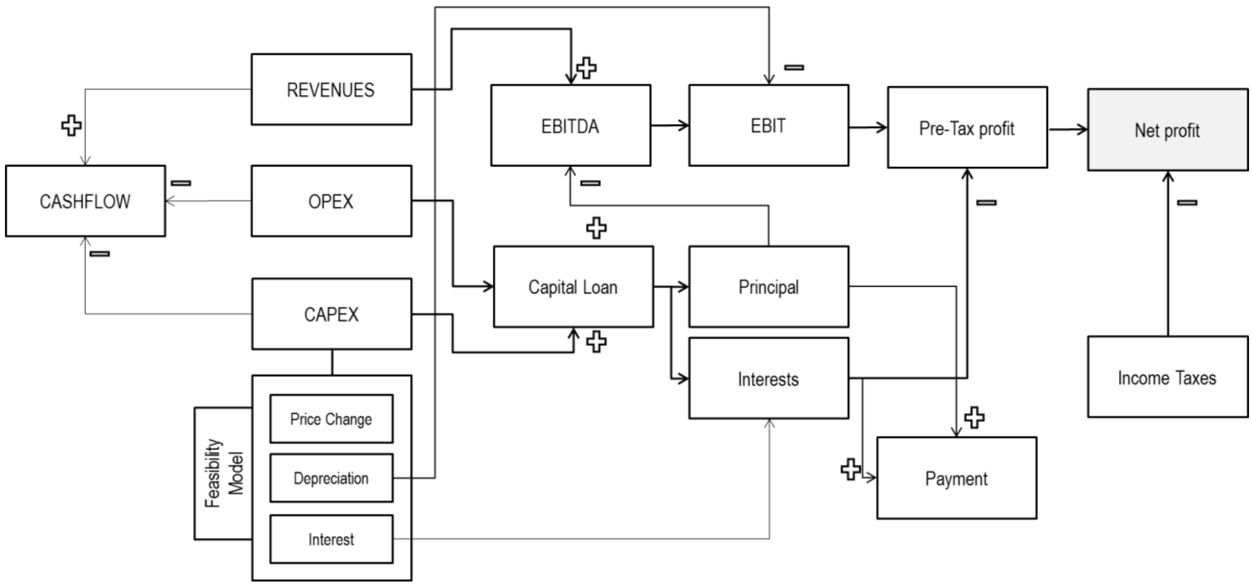


Figure 129 – Financial Feasibility Model.

The EBITDA of a company gives an indication of the current operational profitability of the business, Equation 22. It is an approximate measure of a company's operating cash flow based on data from the company's income statement and it is calculated by looking at earnings before the deduction of interest expenses, taxes, depreciation and amortization. Note that the concept of depreciation/amortization at this point is a tax method designed to spread out the cost of a business asset, and it is not the Amortization or the Principal portion of the loan Payment. This value is use at Equation 23 for the net profit calculation.

The value of cash flow and cash balance (the cumulative value of cash flow) takes into consideration that the capitalization expenses are null as there are no own capitals, Equation 24 and Equation 25.

$$EBITDA = Revenues - Expenses(\text{excluding interest, taxes, depreciation and amortization})$$

Equation 22 – EBITDA calculation.

$$Net\ \ Profit = \sum_{t=1}^{T}(EBITDA - interest\ on\ loans - income\ tax - depreciation\ and\ amortization\ )$$

$with\ \ \text{t} = \text{year of project and T} = \text{total years of analysis}$

Equation 23 – Net Profit calculation.

$$Cash\ Flow = REVENUES - OPEX - (CAPEX = 0)$$

Equation 24 – Cash Flow calculation.

$$Cash\ Balance = \sum_{t=1}^{T}(Cash\ Flow_t - Cash\ Flow_{t-1})$$

$with\ \ \text{t} = \text{year of project; T} = \text{total years of analysis}\ and\ J = Total\ number\ of\ subscribers$

Equation 25 – Cash Balance calculation.

5.5 Summary

This section describes a new developed tool (TENTUS) for subscriber and equipment forecast for GPO, LTE and DVB-T technologies concerning the comparative evaluation cost for the expansion of those technologies as Universal Service. The introduction of the Universal Service obligation is translated in the increase amount of subscribers most of them from non profitable areas (less revenues). The tool description includes the descrition of the initial conditions considering infra-structure sharing; level of civil works; the subscriber penetration algon the 25 year project; the geometric model for wireline architecture deployment to clarify the dimensioning process.

The algorithm calculation method, based on excel worksheets is described step by step. Each tool module and associated variables are presented so a new user can exploit the tool and adapt it for its own needs.

Chapter 6. **SIMULATION RESULTS**

The TENTUS algorithm described at the previous Chapter is quite flexible and has several independent parameters that can be defined with a high level of freedom. The most relevant results from TENTUS algorithm are presented at this Chapter for the described scenarios at Section 4.9. The method is done in two phases, the standard deployment and the Universal Service deployment. For each phase the two next generation networks, FTTH-PON as a fixed networks and LTE as the next wireless generation technology, are analyzed and scenarios will be defined considering several gradations of deployment depending on the penetration rate, infrastructure sharing rate and market penetration rate. The study is done form the operator´s point of view calculating the network equipment investment per year and its corresponding maintenance and debt amortization.

The first analysis phase simulates the operator´s investment in a typical roll out of a telecommunications network for each one of the mentioned technological solutions in a liberalized competitive market. This phase is named as “the standard roll out”.

The second phase of analysis, examines the financial impact of the same network extension to areas where typically it not expected high levels of penetration mainly rural zones, Figure 10 at page 9. This last scenario intends to simulate the extension of broadband services to non-typical investment areas, due to Universal Service obligations imposed to an operator Universal Service provider.

At the end of this chapter a special attention is given to a third solution technological solution based on the digital television broadcast by terrestrial and satellite propagation (DVB-T and DVB-S). This scenario considers the television broadcast service as an extra option for broadband deliverer at rural zones. In this study beside the operator´s point of view it is also analyzed the financial impact to the subscriber´s investment to reach the service depending on the solution type offered by the operator.

Remembering that Universal Service subscribers can derive from several reasons:

- At regions where there is a complete offer on telecommunication services, the subscriber profile is mainly dependent on the economic condition of the families as well the age of physical disabilities. This subscriber profile reaches the universal access at lower tariffs.
- At regions where there isn´t any offer on telecommunication services the subscriber profile is a mixture of the same subscribers due to economic restrains but also from those that find at the
- Universal Service the only possible solution to achieve broadband services.

6.1 FTTH PON Techno Analysis

Several variables are used at TENTUS tool to simulate relevant aspects of the dimensioning planning. One of the most influent group of variables are the ones concerning the duct reuse, due to its financial impact and the impact of the civil works in the roads in the peoples life´s. The TENTUS duct reuse variable for the optical network is used to simulate the percentage of sharing infra-structure in the standard roll-out as well as in the Universal Service simulation. In this last exercise the values of duct reuse are smaller or even inexistent as it is assumed the intervention in regions without any other network, Table 33.

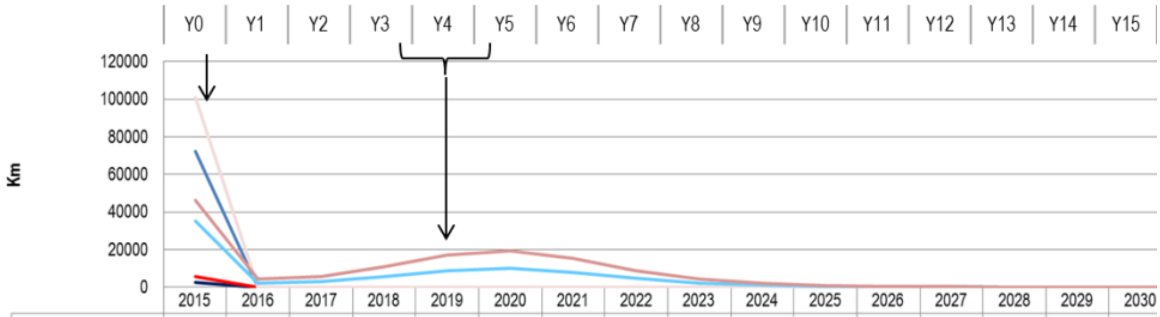
As previously described in Section 5.2.5, the fiber DCO variable, concerns the path from central office to the center of the sub-GEOTYPE; the distCable variable concerns the path from the center of the Geotype towards the center of each neighborhood, by the bus method and the fiber drop concerns the path until the subscriber house.

Fiber	Duct and Fiber feeder (TENTUS fiber DCO)	Duct and Fiber Distribution (TENTUS fiber distcable)	Duct and Fiber drop (TENTUS fiber drop)
	288fo	96fo	24fo
INFRASTRUCTURE SHARING | Duct Reuse			
Geotypes 10 to 5			
U	70%	70%	70%
SU	50%	50%	50%
R	10%	10%	10%
Geotypes 4 to 1			
U	70%	70%	70%
SU	20%	20%	20%
R	0%	0%	0%

Table 33 – Duct reuse variable for FTTH- GPON.

Applying the presented values to the current case study, the duct length needed to be built is reflected in Figure 130. Note that the path of fiber DCO and the path of fiber distCable are all built in the beginning of the project at year zero. This happens due to the fact that the investment plan was choose to start at the same for any kind of sub-Geotype. The length for fiber drop follows the subscriber rate penetration.

It is observed in the next figure that in the beginning of the project Year 0 there is a relevant value of duct to build, this value decreases at Year 1 and 2 however at Years 3, 4 and 5 the length of the duct raises again. This is due to the fact that according the subscribers forecast penetration curve the subscriber number raises exponentially in this period stabilizing the subscribers growing at Year 6, see Figure 86 at page 99.



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Dco Normal	2520	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dco US	5592	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distcable normal	72194	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distcable US	100872	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drop normal	35141	2105	2741	5450	8677	9889	7761	4495	2160	944	395	162	65	26	10	4
Drop US	46352	4121	5366	10672	16989	19363	15196	8802	4229	1848	775	318	130	51	21	8

Figure 130 – Duct length per network segment.

As a qualitative exercise all the investments were summed and divided by the number of subscribers at the end of the period (25 years). This rate intends to observe the distribution of investment per item. As expected, and reinforced by the duct reuse variables used, the value of civil work triplicates its weight in suburban areas and quadruplicates in the rural zones due to less sharing and reuse, Figure 131.

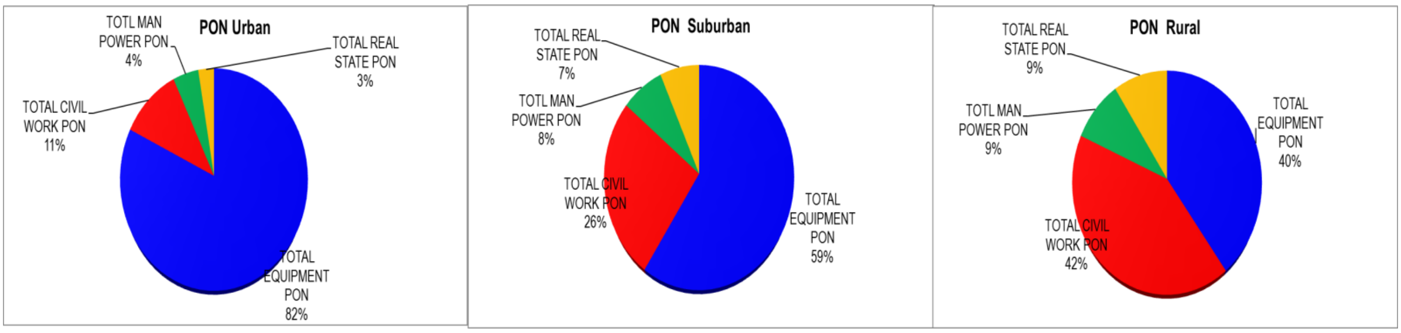


Figure 131 – FTTH PON investment distribution per sub-GEOTYPE.

The next figure, Figure 132 presents the global analysis for the FTTH-PON without and with the Universal Service obligations (USO), concerning the evaluation of the equipment investment, maintenance investment, revenues, cash flow and debt analysis previously described.

The behavious is similar for all the Geotypes whitin a certain environment. It is clear the impact of the investment at the end of each component lifetime.

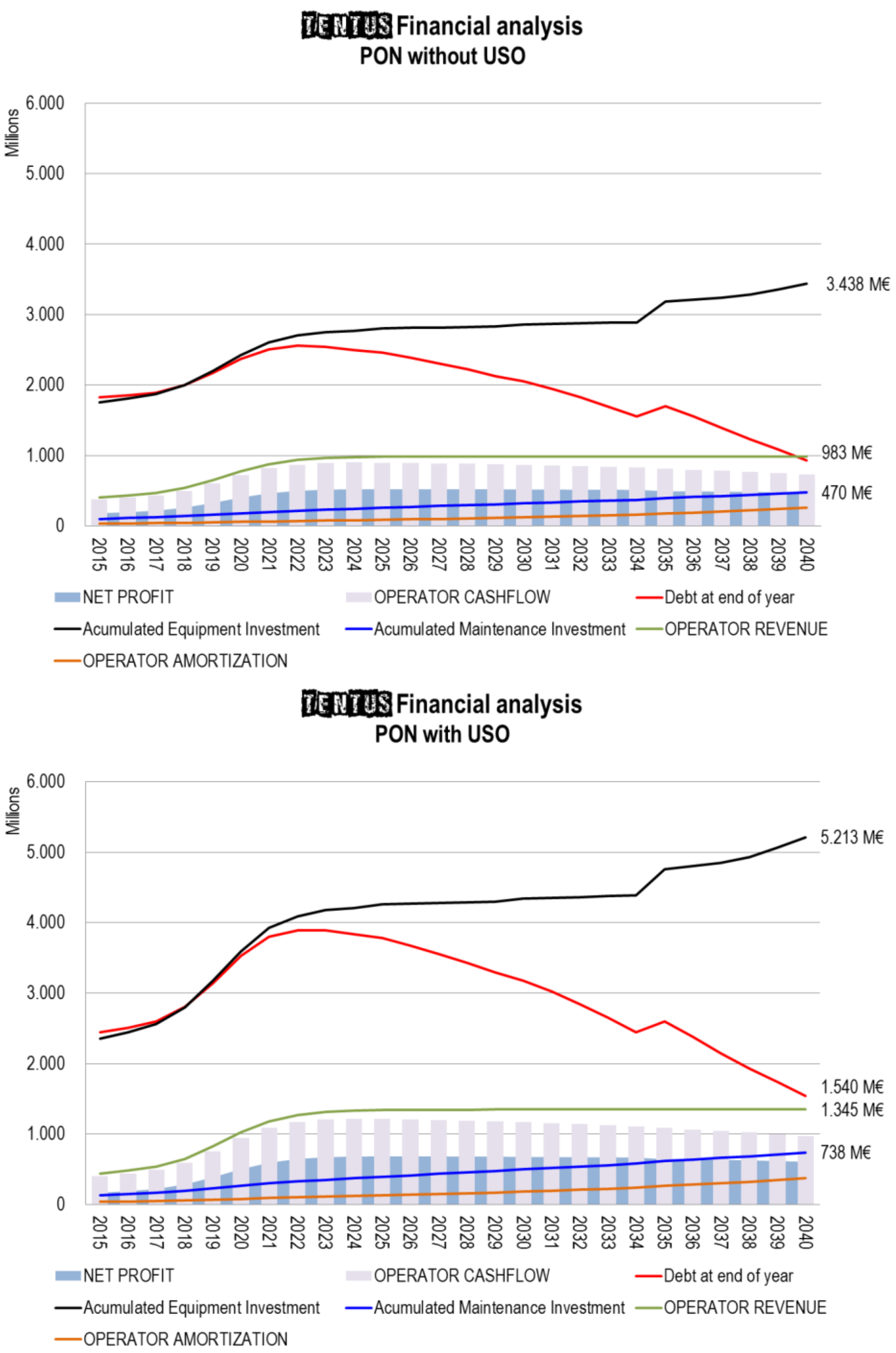


Figure 132 – FTTH PON global financial analysis.

In the graphs of Figure 132 several traces can be seen:

The black line concerns the accumulated equipment investment directly proportional to the subscriber penetration rate. As the number of subscribers grows, new equipment has been acquired as long the existent shared equipment is being fulfilled, as optical network terminals, splitters and cabinets. This line is cumulative and each year has included the previous investments. The final point at the black liner per graph presents the total amount in equipment per scenario, around 3 500M€ and 5 200M€ without and with USO; a 52% equipment investment increase.

The blue line represents the cumulative management investment. This item includes an empirical 5% of the equipment investment plus the lease of the ducts according the reference duct access table (ORAC,

[164]). As years go by this value increases until reaching almost half million Euros in the final of the period of the typical roll out and increasing 57% in a Universal Service scenario.

The green line concerns the operator revenue. This line is proportional to the penetration rate and stabilized without assuming any subscriber loss (churn). Due to the α and β parameters defined, (Section 5.2.3), this value stabilized in 7-8 years, according to a typical network license obligation.

The red line indicates the debt at the end of each year. This item is due to the fact there are no equity (own capital) and all the resources are supplied through a debt (Section 5.4.2). Each year this value is increased by the annual needs of equipment and maintenance investments and deducting the annual amortization. At the end of the period this debt is 57% higher in the Universal Service scenario than the standard scenario.

The light grey bar represents the operator´s cash flow as the result as a result of revenue minus investments. One might expected negative cash flow because of large working capital, capital expenditure, and debt principal repayment needs, however due to high values of revenue, that´s not the case.

The blue area behind the graph signifies the net profit. It is the revenues of the activity less the costs of the activity, taking into account the interest on loans and incoming taxes.

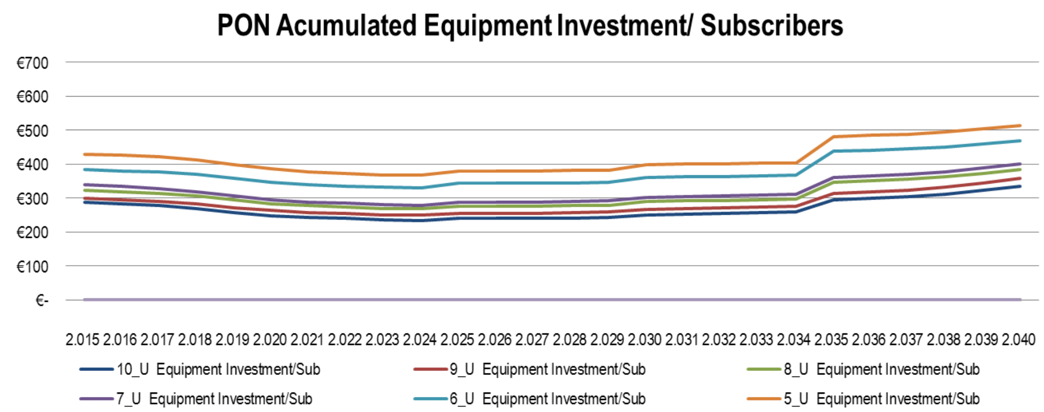
The next sequence of graphs represents the results per Sub-Geotype, per year of the accumulated equipment investment per subscriber, for both scenarios, Table 34. Due to the particular circumstances of Geotype 1, which aggregates only one municipality in an island with low population, its values are not included in the result intervals.

	PON without USO	*PON with USO*
U	[300€-500€]	[300€-600€]
SU	[600€-850€]	[500€-1600€] \ except Geotype 1
R	[2 300€-5 600€]	[2 000€-14 000€] \ except Geotype 1

Table 34 – GPON summary of accumulated equipment investment per subscriber.

The following graphs grouped the several Geotypes per by urban, suburband and rural types.

URBAN GEOTYPES EQUIPMENT INVESTMENT WITH AND WHITHOUT USO
Results for 25 years GPON project



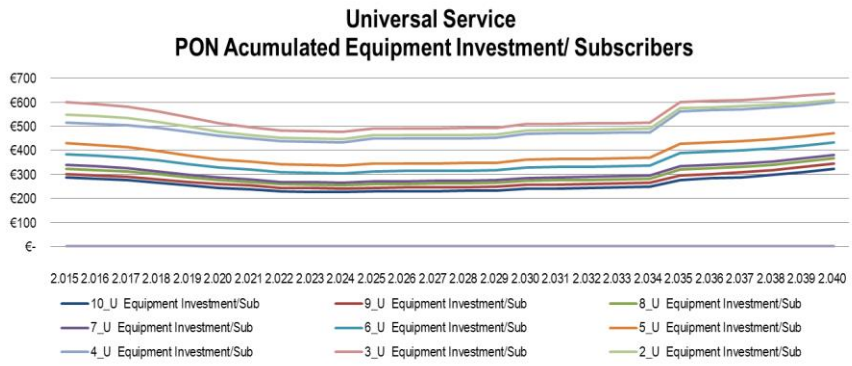
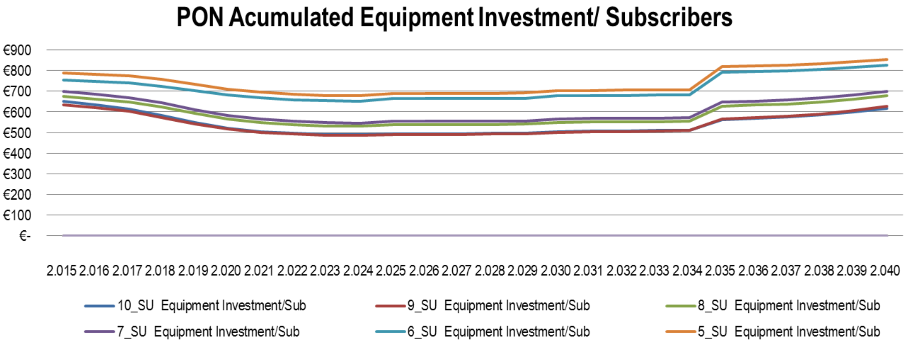


Figure 133 – FTTH PON equipment investment per subscriber per year in Urban zones.

SUBURBAN GEOTYPES EQUIPMENT INVESTMENT WITH AND WHITHOUT USO
Results for 25 years GPON project



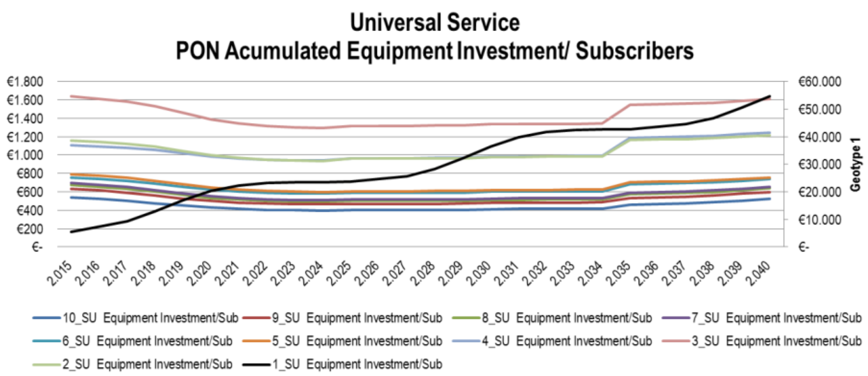
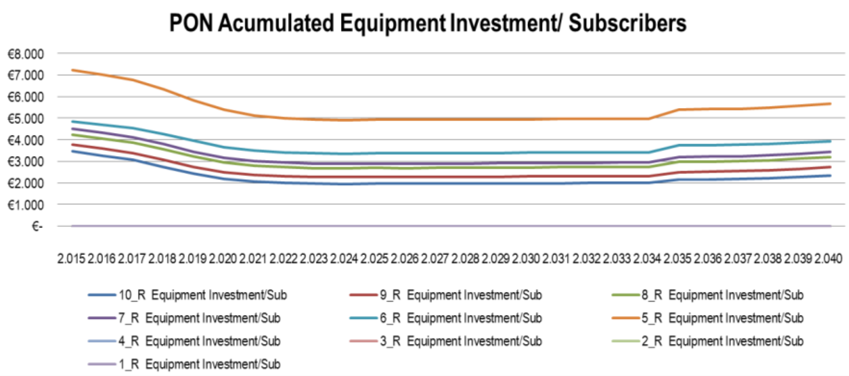


Figure 134 – FTTH PON equipment investment per subscriber per year in Suburban zones.

RURAL GEOTYPES EQUIPMENT INVESTMENT WITH AND WHITHOUT USO
Results for 25 years GPON project



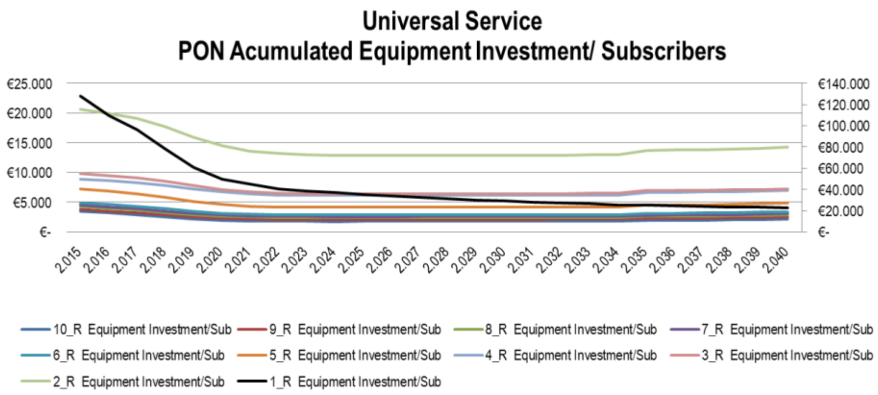


Figure 135 – FTTH PON equipment investment per subscriber per year in rural zones.

The impact of the Universal Obligation per year in the total amount of invest can be seen in the following graph, Figure 136.

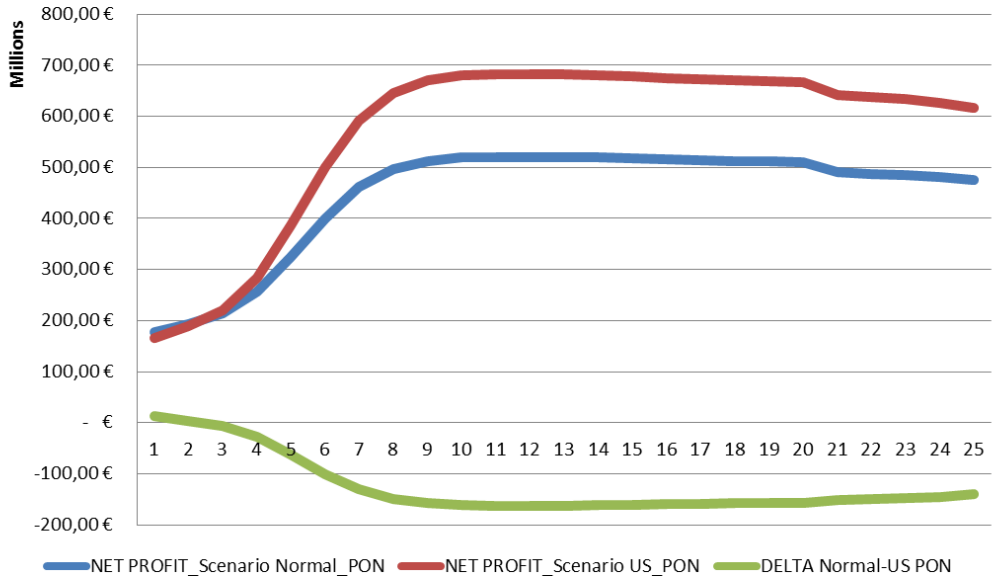


Figure 136 – Net profit comparison with and whithout Universal Service obligations in GPON.

6.2 Cellular LTE Techno Analysis

At this point the infra-structure sharing variables are recall (described at section5.2.5), Figure 137. It is assume a high level of sharing in the urban and suburban zones, sometimes by architecture impact reasons that force the reduction of number of pylons in a town; and less in rural zones where the deployment is less dense and more dependent of each operator´s objectives. The relation between rooftops and pylons is also taken into account. The lease rent is adapted to the topology. The cost of the shared pylon is assumed to be zero euros. The reason of this choice results from a common practice between operators that try to share the same number of infrastructure to balance the accounts, avoiding extra expenses.

	Site sharing	***Infra-structure relation (pylons versus rooftops)***
U	70%	20%
SU	50%	30%
R	20%	70%

Figure 137 – Wireless infra-structure sharing variables.

From the same type of analysis as previous (section 6.1) the sum at the end of the period divided by the total number of subscribers presents the impact of each parcel in this business. It is relevant to mention the impact of the real state (the cost of the monthly fee for the site rent) in the total investment is lower due to the inferior number of base stations, Figure 138.

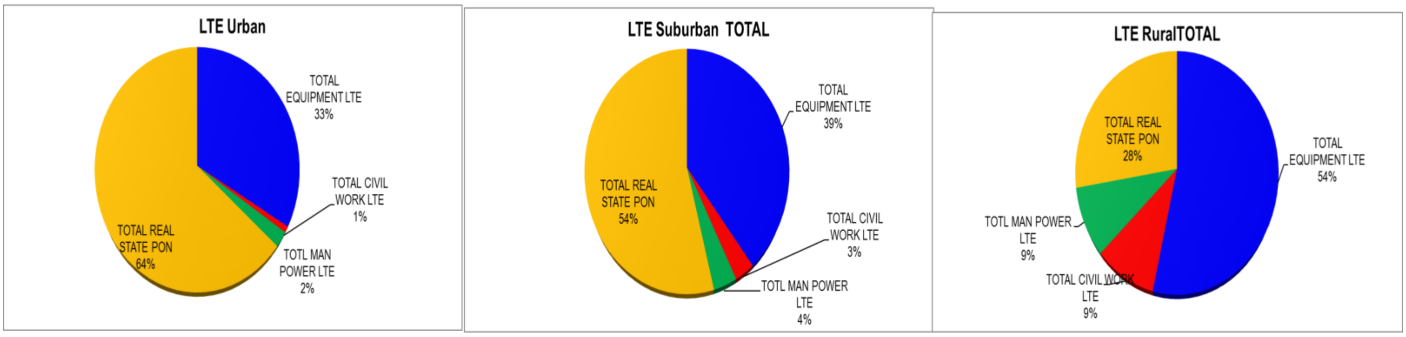


Figure 138 – LTE investment distribution per sub-GEOTYPE.

The number of sites was calculated due to capacity and bandwidth requirements (Section 5.3.2). The next graphs present the total site number per Geotype and per scenario, Figure 139 and per Geotype per year, per scenario, Figure 140. As there is no investment in Geotypes 4, 3, 2 and 1 in the standard roll out there are no forecast sites in this zones.

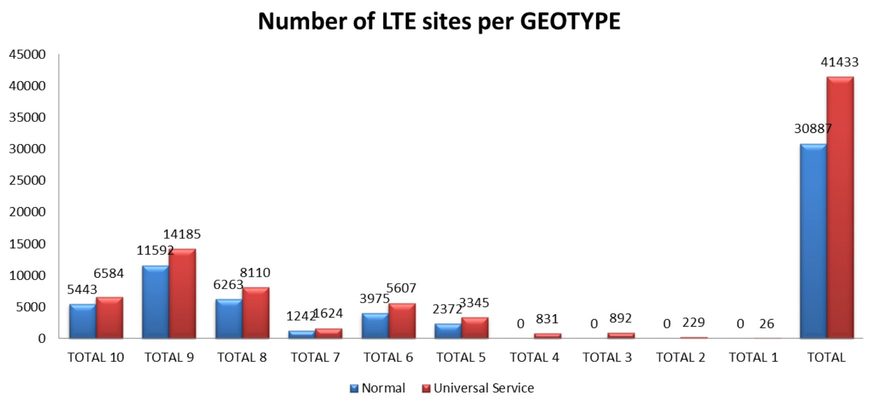
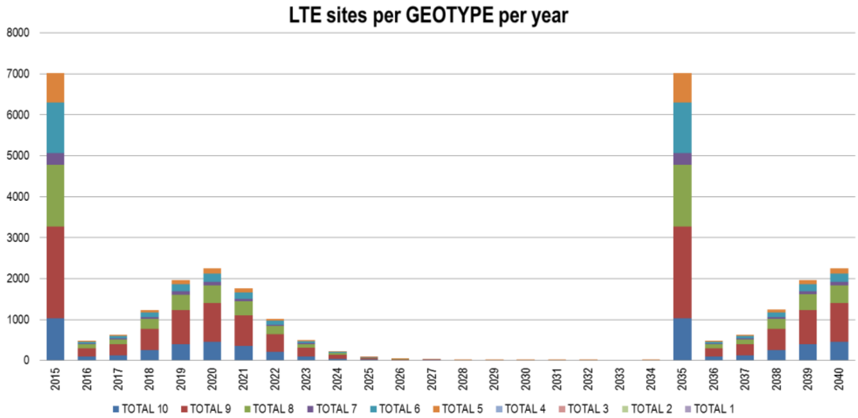


Figure 139 –LTE sites per Geotype.

The amount of sites per Geotype is calculated per year and is dependent from the number of subscribers per year. A new site is added after the network offer capacity is achieved to serve a certain number of subscribers. After twenty years a new investment to full replacement of the initial sites is considered due to the adopted life time for all the components.



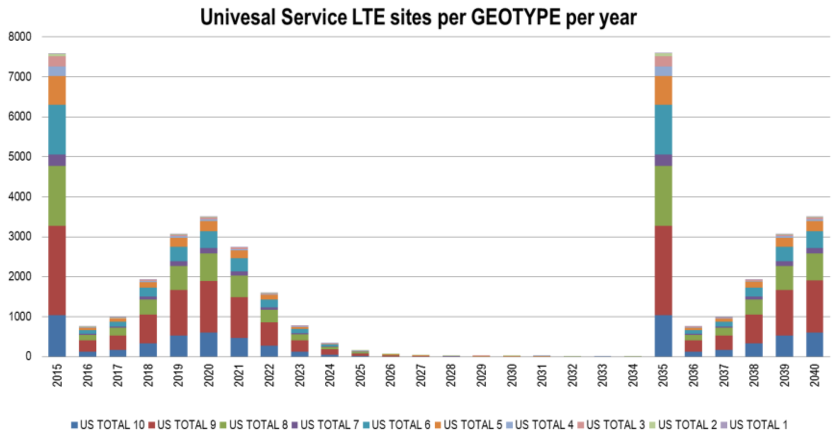


Figure 140 – LTE sites per year per Geotype comparison.

Figure 141 presents the final analysis for the LTE without and with the Universal Service obligations (USO). In those figures several traces can be seen:

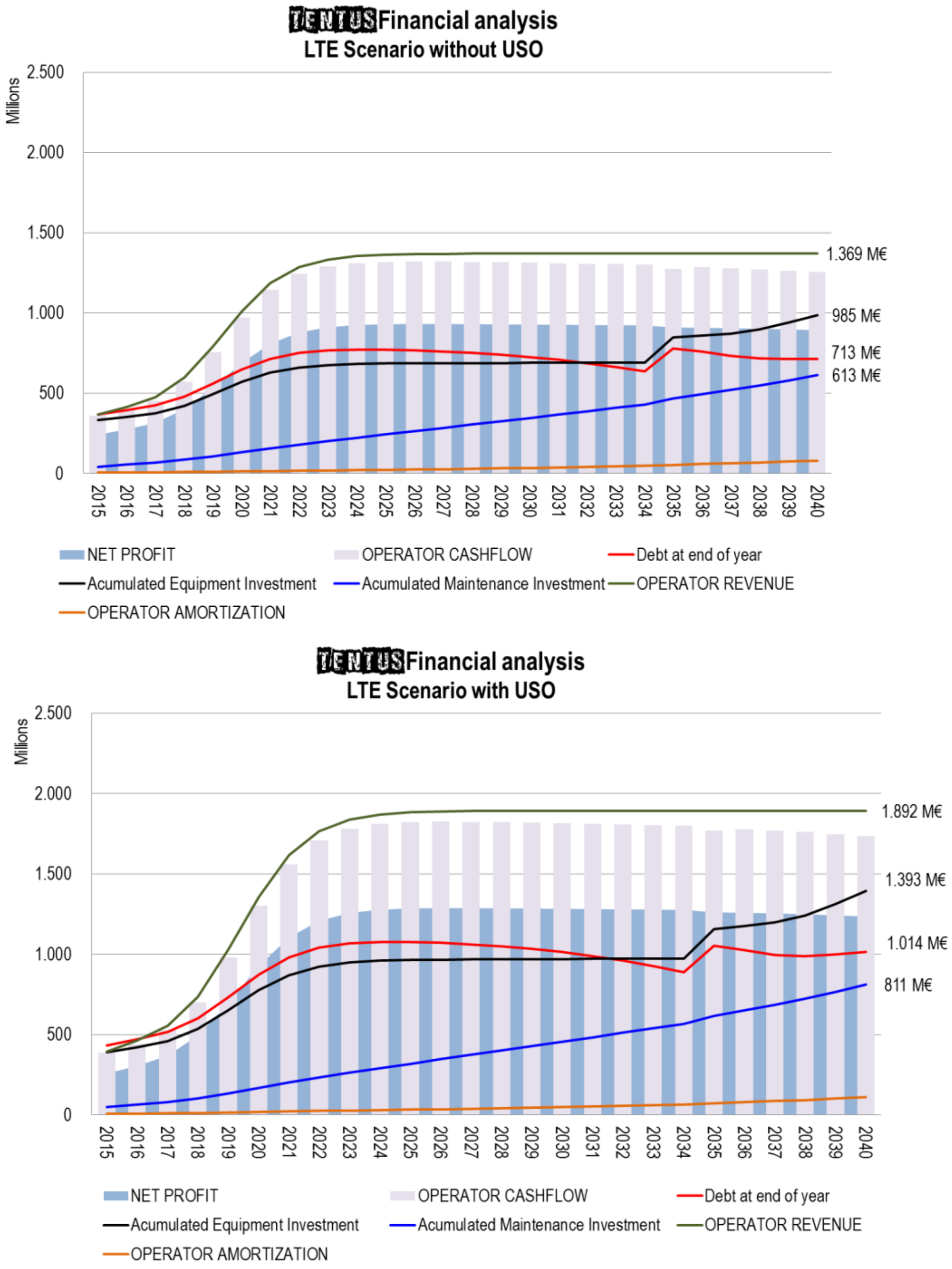


Figure 141 – LTE financial analysis.

The black line concerns the accumulated equipment investment directly proportional to the subscriber penetration rate. As the number of subscribers grows, new equipment has been acquired as long the existent shared equipment is being fulfilled, as optical network terminals, splitters and cabinets. This line is cumulative and each year has included the previous investments. The final point at the black liner per graph presents the total amount in equipment per scenario, around 1 400M€ and 1 900M€ without and with USO; a 36% equipment investment increase.

The blue line represents the cumulative management investment. This item includes an empirical 10% of the equipment investment plus the site rent. Even the shared sites have an annual site lease due to the installation of the equipment in private propriety. As years go by this value increases until reaching more than half million Euros in the final of the period of the typical roll out and increasing 32% in a Universal Service scenario.

The green line concerns the operator revenue. This line is proportional to the penetration rate and stabilized without assuming any subscriber loss (churn). Due to the α and β parameters defined, (Section 5.2.3), this value stabilized in 7-8 years, according to a typical network license obligation.

The red line indicates the debt at the end of each year. This item is due to the fact there are no equity (own capital) and all the resources are supplied through a debt (Section 5.4.2). Each year this value is increased by the annual needs of equipment and maintenance investments and deducting the annual amortization. At the end of the period this debt is 42% higher in the Universal Service scenario than the standard scenario.

The light grey bar represents the operator´s cash flow as the result as a result of revenue minus investments. One might expected negative cash flow because of large working capital, capital expenditure, and debt principal repayment needs, however due to high values of revenue, that´s not the case.

The blue area behind the graph signifies the net profit. It is the revenues of the activity less the costs of the activity, taking into account the interest on loans and incoming taxes.

The next sequence of graphs represents the results per Sub-Geotype, per year of the accumulated equipment investment per subscriber, for both scenarios, Table 35.

	LTE without USO	***LTE with USO***
U	[200€-250€]	[200€-300€]
SU	[270€-350€]	[270€-900€] \ except Geotype 1
R	[900€-1000€]	[900€-1 400€] \ except Geotype 1

Table 35 – LTE summary of accumulated equipment investment per subscriber.

Due to the particular circumstances of Geotype 1, which aggregates only one municipality in an island with low population, its values are not included in the result intervals.

URBAN GEOTYPES EQUIPMENT INVESTMENT WITH AND WHITHOUT USO
Results for 25 years LTE project

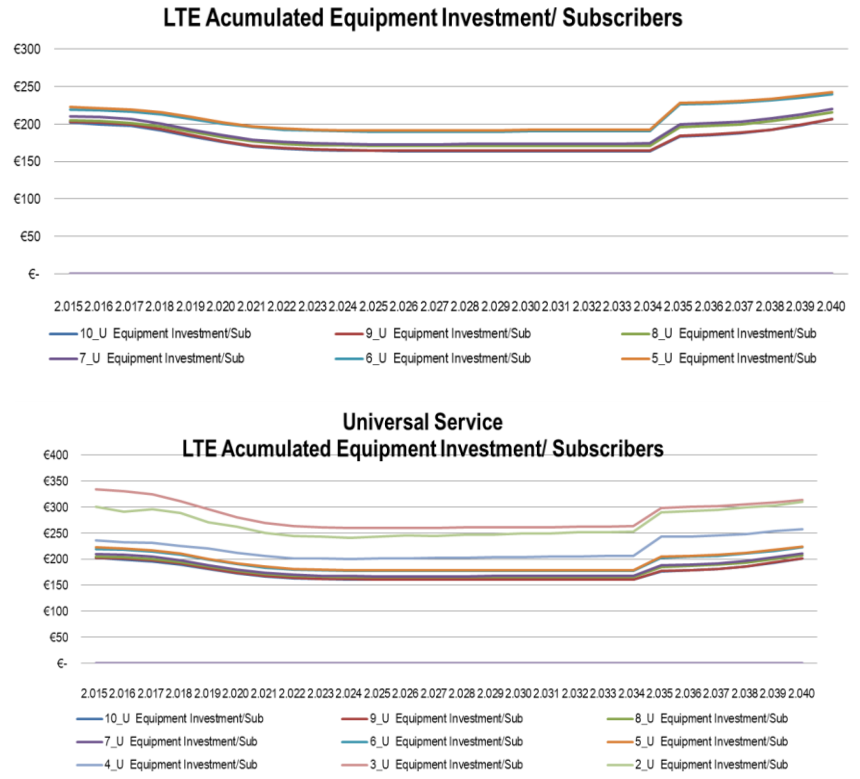


Figure 142 – LTE equipment investment per subscriber per year in Urban zones.

SUBURBAN GEOTYPES EQUIPMENT INVESTMENT WITH AND WHITHOUT USO
Results for 25 years LTE project

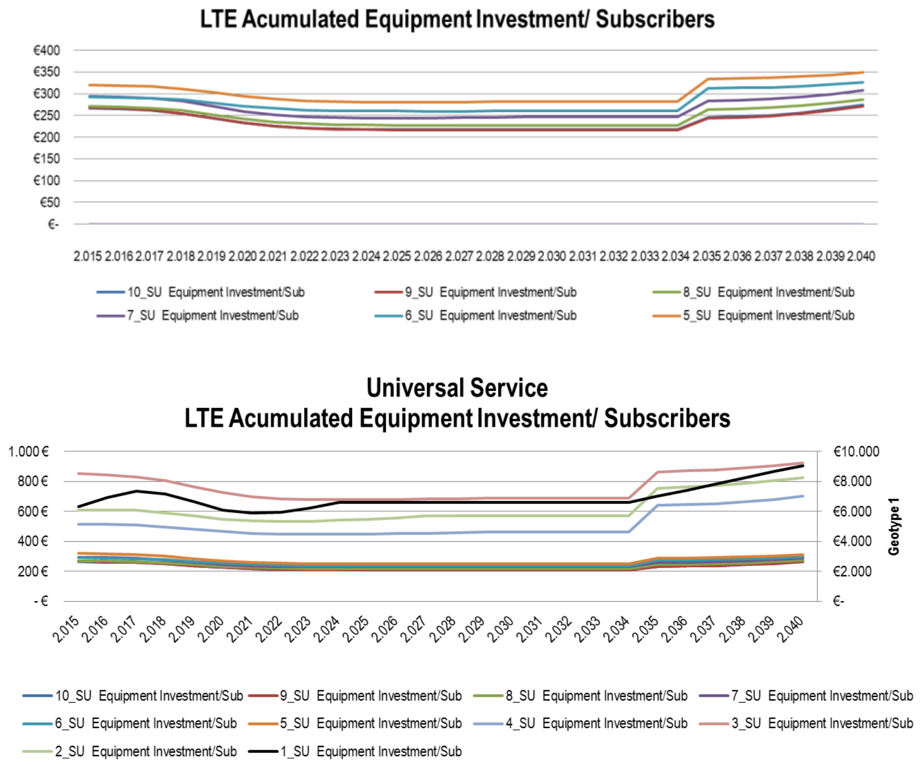
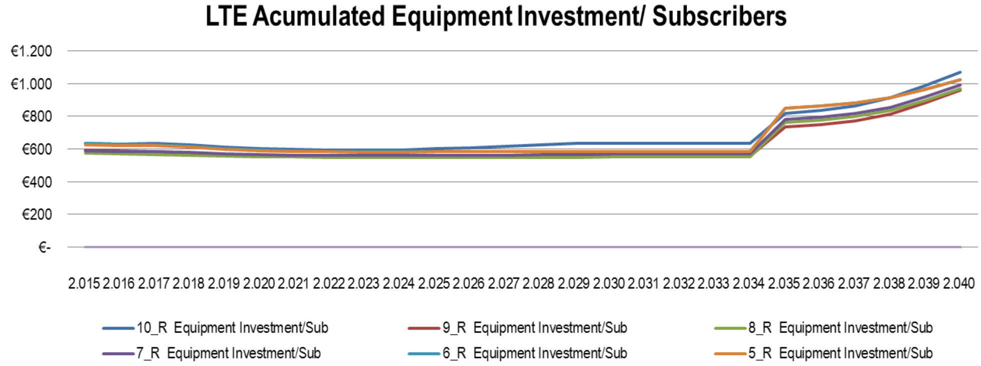


Figure 143 – LTE equipment investment per subscriber per year in Suburban zones.

RURAL GEOTYPES EQUIPMENT INVESTMENT WITH AND WHITHOUT USO
Results for 25 years LTE project



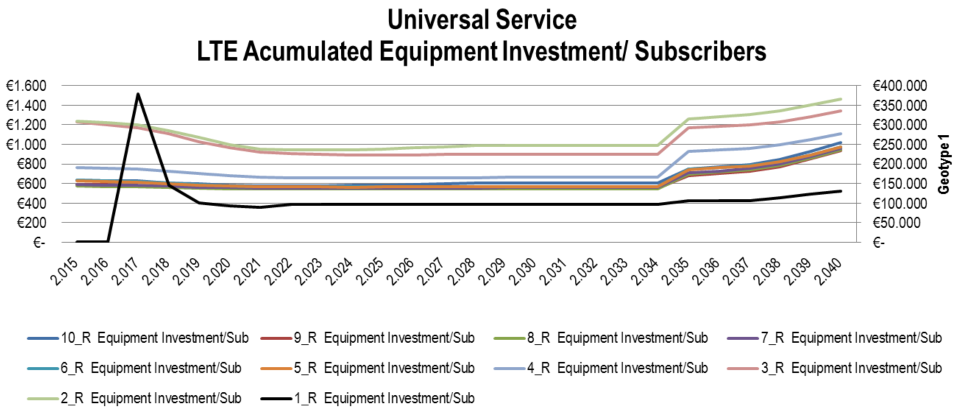


Figure 144 – LTE equipment investment per subscriber per year in Rural zones.

The impact of the Universal Obligation per year in the total amount of invest can be seen in the following graph, Figure 145

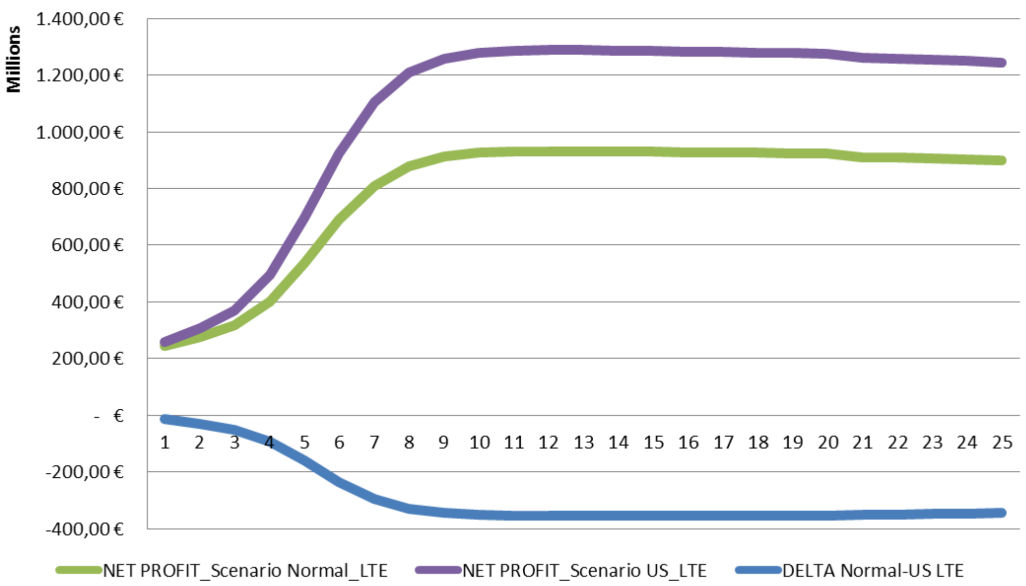


Figure 145 – Net profit comparison with and whithout Universal Service obligations in GPON.

6.3 Digital television for long range data delivery

By the time this work was done, the digital television was introduced in Portugal. Apparently it is a totally completely different subject from the focus of this thesis. However, as the theme raised some curiosity to the author, a new approach to the initial theme appeared with the guiding thread of the universal usage range of this type of service.

The technological solutions implemented in Portugal for digital television broadcast were totally dependable from the geographical location of the viewer's homes, with the adoption of a mix of terrestrial and satellite deployments (in this case, as the service is the free to air, there is no sense in call them subscribers). At the urban zones a terrestrial distribution (DVB-T) was chosen as in the rural zones a satellite solution was adopted (DVB-S2), as described at Section 3.2.

This situation leads to quite relevant different investments in reception equipment, from the viewer's point of view. The satellite distribution is much less expensive than terrestrial distribution, from the operator´s point of view but from the viewer´s point of view it is a much more expensive solution as receivers and reception antennas are more expensive and are associated with more complex installation procedure, Section 5.3.3.

As broadcast television is an universalized service (even though not considered universal, by law) this operator´s approach lead the author analyses of this subject at ANACOM´s Public Consulting, [222] and focus the study in two new directions:

- Adding data transmission to broadcast TV signal;
- How to combine digital broadcast technologies so both operator´s and viewers investment costs are reduced;

The goal in mind is to provide equal access in the receiving equipment investment for digital TV for all the viewer's, regardless the type of settlement where they live in. With this scenario suggestion, the mix of DVB-T and DVB-S2 does not mean different technologies for different settlements, but instead, it means simultaneity and complementarity of the technologies, so all the viewers need to do the same investment in receiving equipment: the set-up box.

This scenario architecture´s considers a DVB-S2 broadcast network but instead of an individual receiving at each house, it is done at a local substation that, after some signal processing in a transmodulator, re-transmits the signal locally using DVB-T, Figure 146. The consumers will enjoy the advantages of the digital signal without any extra investments in parabolic antennas or the need of a second antenna for several TV sets per home. The global architectural impact is also smoother in this case, Figure 146.

The digital signal is received in QPSK and converted to COFDM by using a transmodulator [117, 125]. In case of agreement with the Regulator the signal broadcast could be done in different channels per municipality to minimize the impact in neighbor municipalities, by using a multi frequency network, MFN and to be immune to potential far away signals that reach the area.

Concerning new investments for the operator there is the cost to take into account of new electronic equipment, building rental and human resource's maintenance of the local substation, but the consumers only have to acquire per TV a set-up box as in the first scenario with DVB-T.

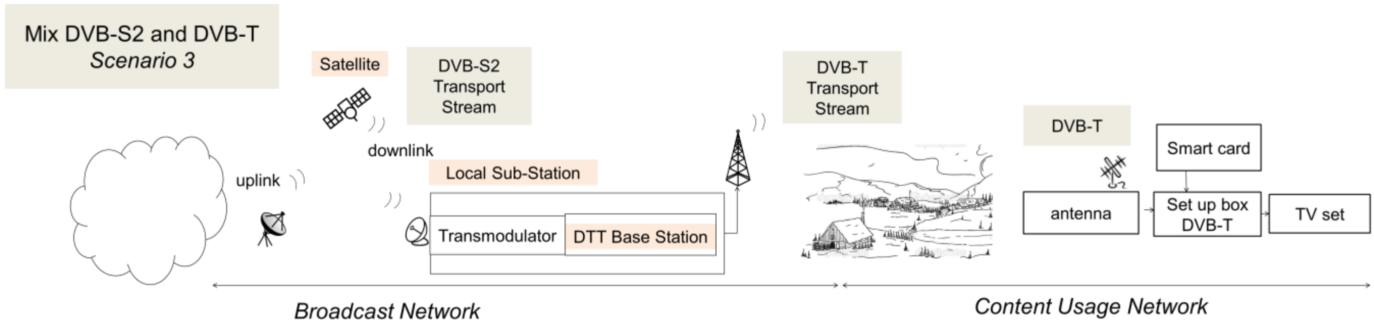


Figure 146 - Scenario 3, satellite DVB-S2 plus DVB-T broadcast network

<u>*The operator's point of view*</u>

Considering the previous techno-economic approaches, the financial analysis for each technical scenario is compared in Table 36.

The graphs depict per scenario type the Equipment Investment items that contribute for the major investments in fixed assets in the first year of the project. The second graph row presents, per scenario, the impact of those initial investments (black bar CAPEX or Equipment Investment) in a time frame of fifteen years and also compares, along the same period, the annual Cash Flow (CF) (grey bar), defined as CF=Revenues- Equipment Investment - Maintenance Investment. The line presents the cash Balance as the cumulative Cash Flow along the period. The last row presents the revenues for four TV channels along the fifteen years, assumed to be constant and the comparison with EBITDA as the difference between Revenues and the Maintenance Investment.

Operator Equipment Investment (1st year)

Scenario 1

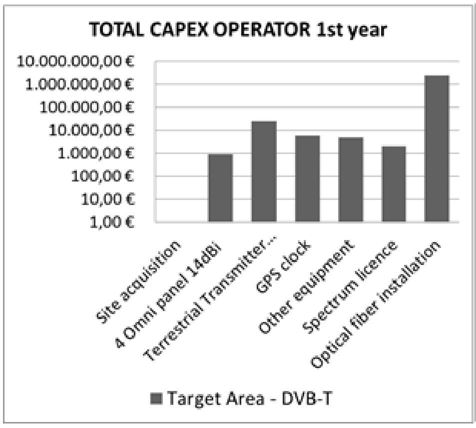
DVB-T (50% Duct share)

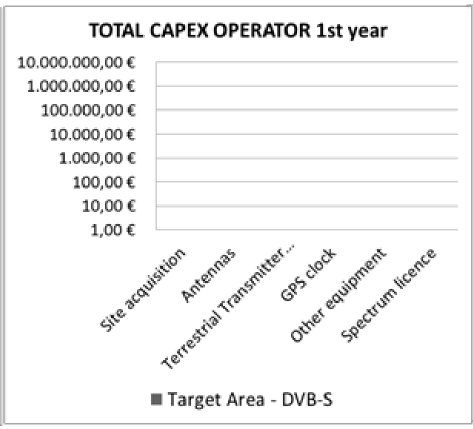
Scenario 2

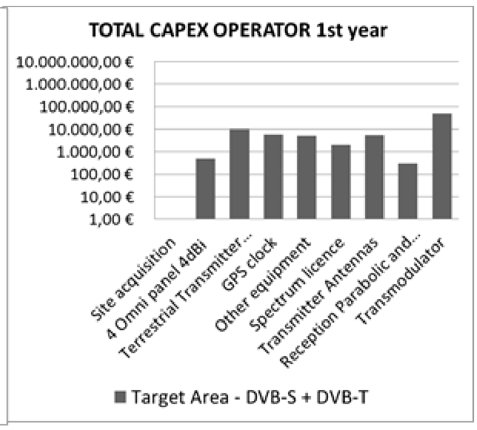
DVB-S2

Scenario 3

DVB-S2 & DVB-T







Operator Financial Summary - Cash Balance

Scenario 1

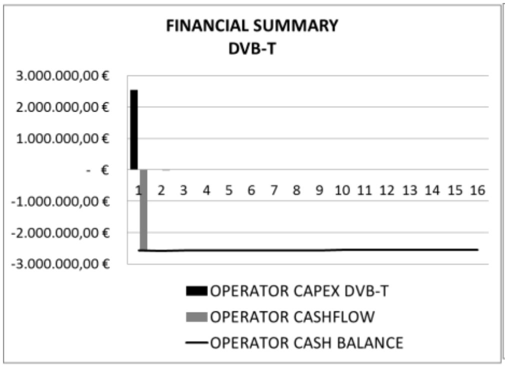
DVB-T (50% Duct share)

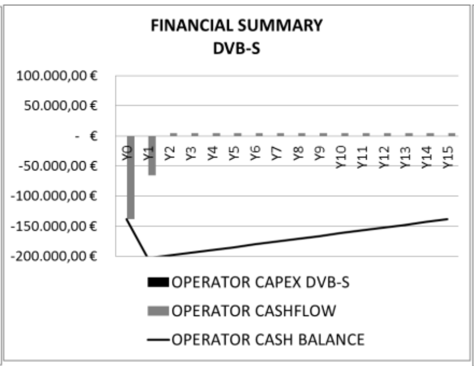
Scenario 2

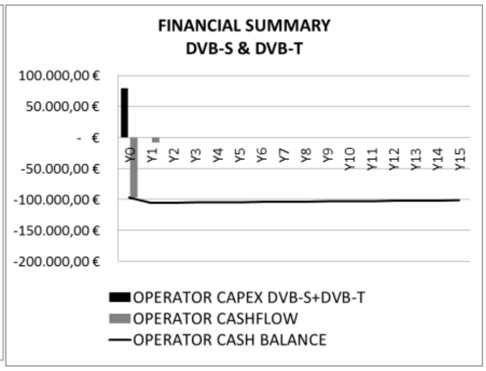
DVB-S2

Scenario 3

DVB-S2 & DVB-T

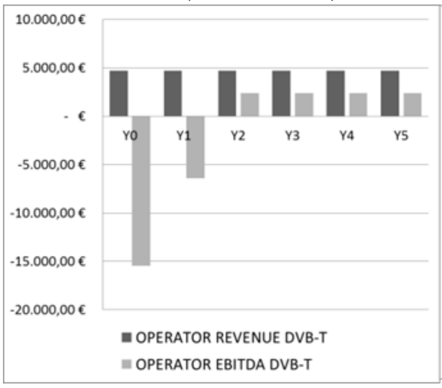




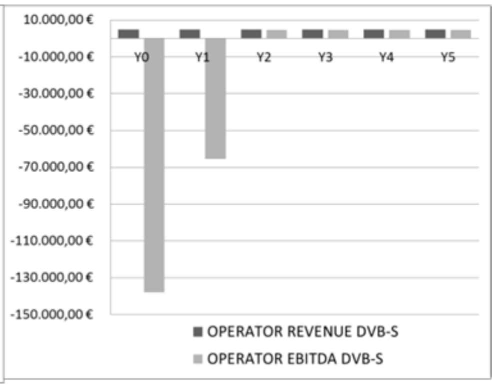


Operator Financial Summary – EBITDA

Scenario 1
DVB-T (50% Duct share)



Scenario 2
DVB-S2



Scenario 3
DVB-S2 & DVB-T

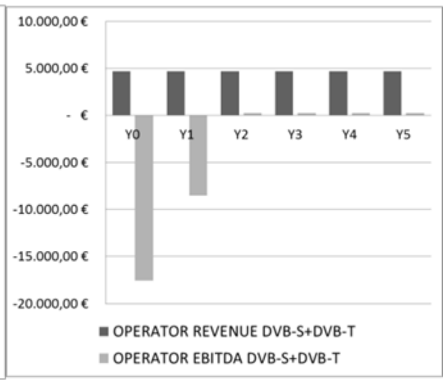


Table 36– Financial summary for Target Rural Area from the Operator point of view[20].

<u>*The impact of infrastructure investment in Scenario 1*</u>

It should be stated here that the operator could profit from sharing the infrastructure in certain scenarios. The impact of the civil works in the optical fiber deployment is widely known and studied [223, 224].

In scenario 1, DVB-T, the chosen solution for comparison was a 50% duct share. A 50% duct share means that the operator will invest 50% of the full cost of the infrastructure, 0% means full investment and 100% means that no civil work is required. Within this technology three different approaches were considered: 0%, 50% and 100% of duct share. The impact of this item in the global project is analyzed in Figure 147.

Operator Equipment Investment - (1st year)

Scenario 1.1
DVB-T | 0% Duct share

Scenario 1
DVB-T |50% Duct share

Scenario 1.2
DVB-T |100% Duct share

[20] The y-axis in row 1 is on a logarithmic scale.

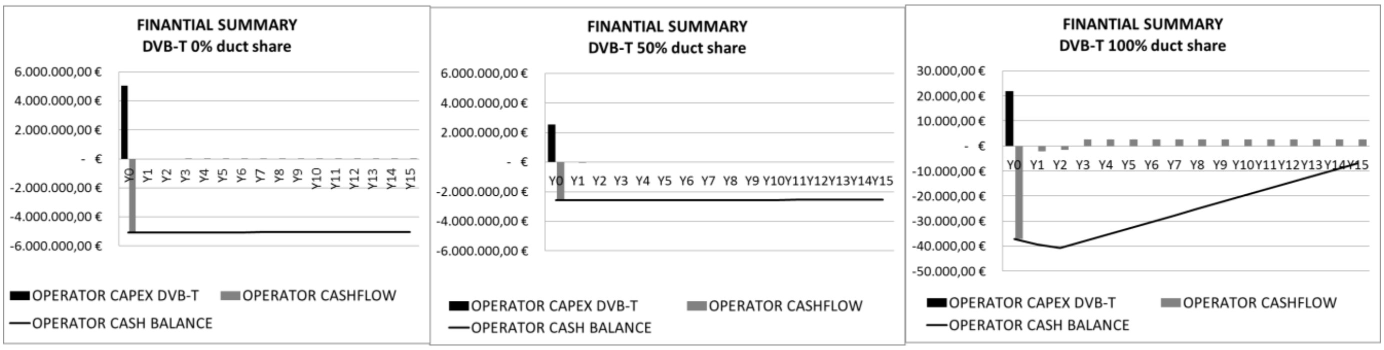


Figure 147 – Financial Summary comparison for DVB-T solution considering different levels of duct sharing.

Looking back to Equipment Investment results at Figure 147, row 1; it is clear that the rural area with DVB-T coverage, scenario 1, presents the worst results for the operator. This is related to the need of fiber deployment that demands high investments for civil works, even though in this scenario it is considered that there is a 50% share of the infrastructure. This initial investment will affect the business plan along the fifteen years project frame (the period of the broadcast license). Thus this approach of terrestrial broadcast is immediately eliminated for rural areas from the point of view of the operator. It is also interesting to see that if a 100% of duct share is possible, as seen in Figure 147, this solution might be attractive for the operator and consequently for the client due to the lower cost of receiver equipment needed in this case compared to the solution 2.

Scenario 2 is the one that presents the best results in terms of Equipment Investment for the operator; it is a turnkey solution where the broadcast service is sub rent to another service provider and does not evolved Equipment Investment. Due to this, this scenario is chosen by many operators to use in rural/shadow FTA´s areas.

The initial Equipment Investment operator's investment, per rural municipality, in scenario 3 is bigger than in scenario 2 due to the need of acquisition of new equipment for the signal's local distribution. Nevertheless since the distribution network is made by satellite communications rather than fiber, the initial cost of the civil work is irrelevant. As mentioned before, it is assumed that the DVB-T transmitter is collocated with an existing mobile telecommunication base-station site and therefore no investment in infra-structure is needed.

<u>The impact of number of television channels in the operator´s revenue</u>

In a single FTA business plan, the source of revenue in the telecommunication operator's comes from the leasing of the logical carriers to the TV operators. In this work it was assumed as initial condition the existence of four TV FTA channels. Figure 148 depicts the impact of that item in the operator´s revenue.

Operator CASHFLOW

Scenario 1 *DVB-T (100% Duct share) |4TV channels – 1MUX*	*Scenario 1* *DVB-T (100% Duct share)| 6TV channels – 1MUX*	*Scenario 1.2* *DVB-T (100% Duct share)| 10TV channels – 1MUX*

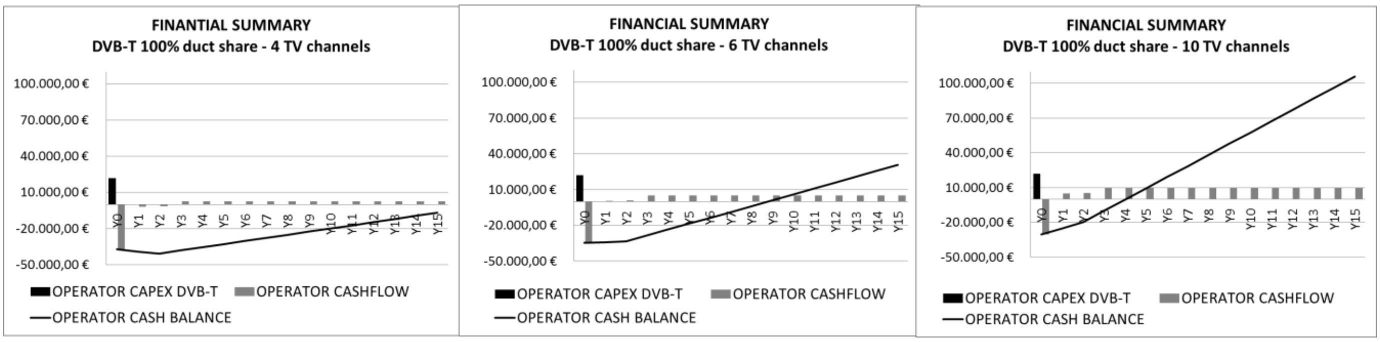


Figure 148 – Financial Summary comparison for DVB-T solution considering different levels of revenues depending on the number of TV channels in the bouquet.

Looking now to the second row of Figure 148, the cash balance of scenario 2 and 3 is affected in the first years by the need of reimbursement from the operator's point of view. This is more pronounced in scenario 2, as the reimbursement is proportional to the cost of the client equipment. In scenario 3 the Maintenance Investment value is moderate as it reflects higher maintenance cost associated with maintaining remotely located equipment. Nevertheless it is 1/3 of scenario 2, due to the lower cost of reimbursements.

If the EBIDTA is evaluated, the results are equivalent for the three cases in a long time frame, but scenario 2 is clearly worst in the first years, representing this way the impact of the transition period.

Even though all the three investment scenarios present a positive trend in long term Cash Balance evolution, that could be speed up if new forms of revenue were found by the operator mainly based on the increasing of channels to broadcast. Increasing from 4 to 6 channels in the solution DVB-T with 100% of duct sharing presents a profit in a ten year period, Figure 148 is possible. Other solutions that would increase this profit are the inclusion of other services offered to the client as pay-tv, video on demand, internet access, voice (phone).

<u>The client's point of view</u>

The following graphs in Figure 149, present the cost impact from the client, as a whole, for each one of the solutions adopted by the operator, in the period of the first five years after the analog switch off. It was decided to present the global amount of investment for sensitivity analysis to the global operator´s investment.

In this type of business relationship the client is always dependent on the technical decisions of the broadcast operator and therefore is obliged to adopt a certain receiver technology and consequent different amounts of investment. That can be seen in the first two graphs on the left, where the global investment of the inhabitants of the target area in study is 60% higher in the case of satellite coverage (in the legend as "Antenna+installation" and "set-up box)".

In all the graphs they are also included the indirect expenses due to the switch off, namely the amount of viewers that switch to pay TV subscription pressured by the inconvenient of the transition (in the legend as "Pay TV"), the amount of investment done in new TV receivers (in the legend as "Digital TV"). Even if it is not an expense due to the transition, the audio visual tax is also included in the graphs for qualitative comparison of the users total cost for free to air television service.

Final User Investment (society a whole)

Scenario 1 *DVB-T (50% Duct share)*

Scenario 2 *DVB-S2*

Scenario 3 *DVB-S2 & DVB-T*

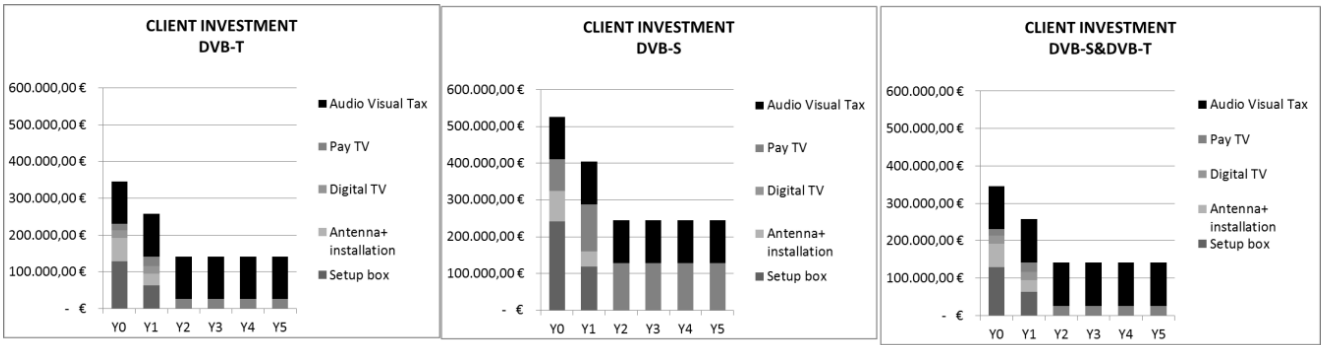


Figure 149 – Financial summary for Target Rural Area from the final user point of view, for the first five years after the switch off.

In Figure 149, the client perspective can be seen. It is clear that scenario 3 is the one that better suits the clients' interests, since it approaches the rural client to the urban solution.

The combination of DVB-T and DVB-S technologies is thus a potential technology to be used in Universal Service implementation, mainly in rural zones where the other technologies impose a higher cost.

6.4 Summary

The next Figures synthetize the investment cost per subscriber by Geotype and per technological solution, in the scenarios with and without universal service obligations (Figure 150 for LTE and Figure 151 and for GPON).

It can be seen that for Geotypes 10, 9, 8, 7, 6 and 5, the cost per user is theoretically reduced after the introduction of the Universal Service Obligations. This happens due to the fact that the investment is already done in the region and therefore more clients enhance the business raising the network efficiency.

For Geotypes inside the blue line, 4, 3, 2 and 1, the deployment is virtually done from the scratch increasing tremendously the cost of the subscriber. This trend can only be changed by the addition of new subscribers in the region.

INVESTMENT PER USER (@ end of project)
WITHOUT AND WITH UNIVERSAL SERVICE OBLIGATIONS
IN LTE

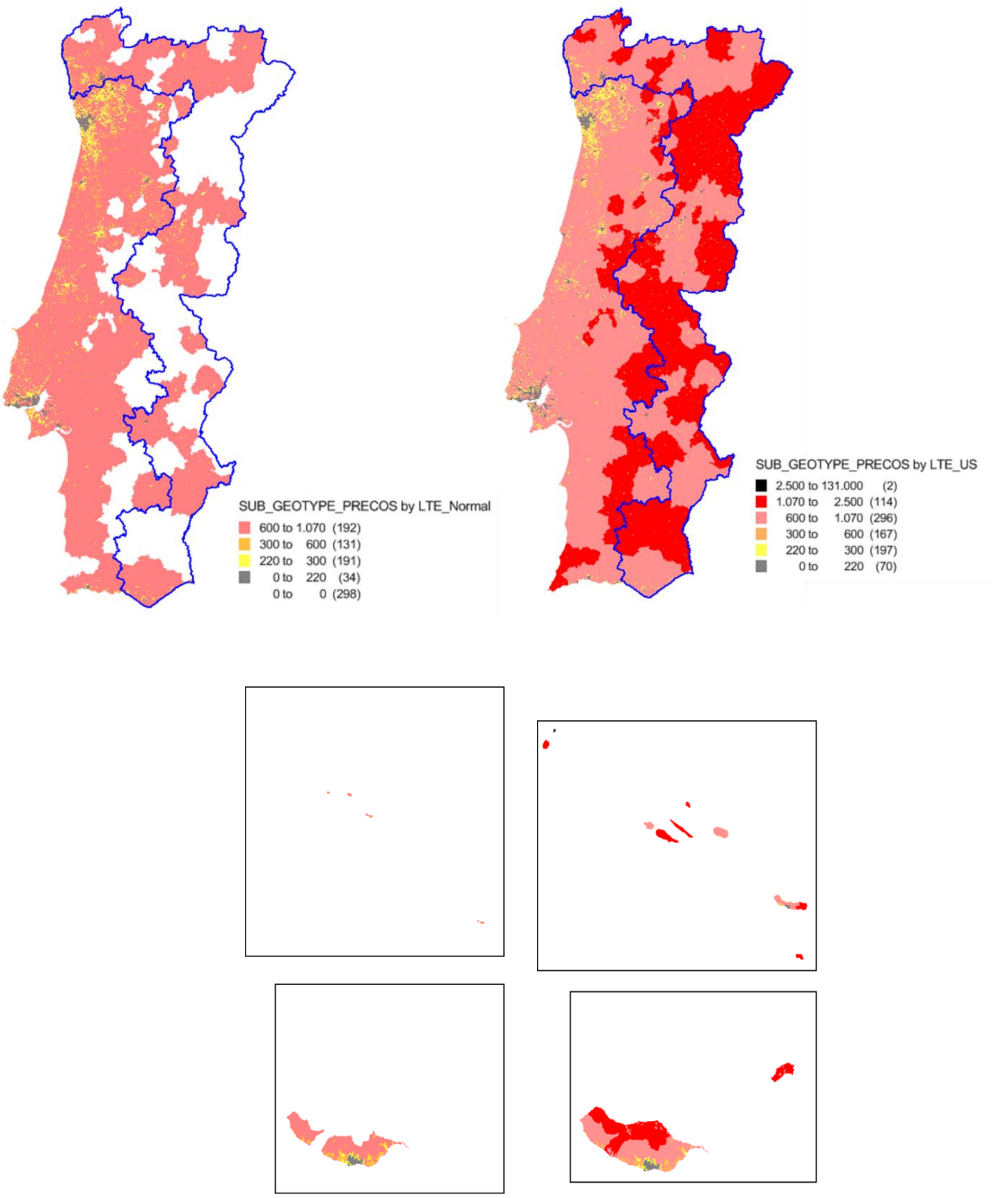


Figure 150 – Investment forecast per sub-Geotype without and with Universal Service Obligations in LTE.

INVESTMENT PER USER (@ end of project)
WITHOUT AND WITH UNIVERSAL SERVICE OBLIGATIONS
IN GPON

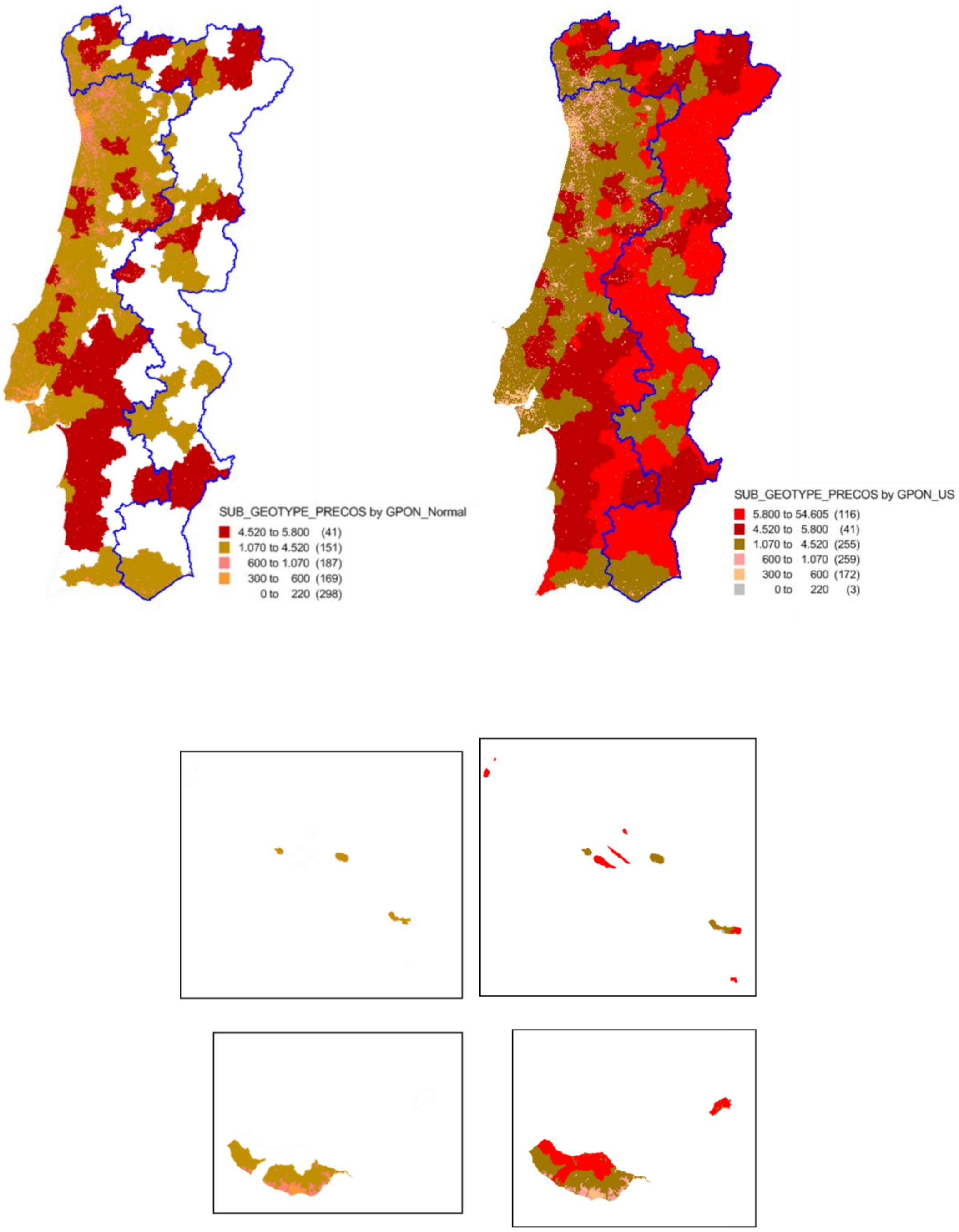


Figure 151 – Investment forecast per sub-Geotype without Universal Service Obligations in FTTH-GPON.

This chapter presents the simulation results obtained by the TENTUS tool for the wireline and wireless new generation networks. For the FTTH-GPON and for the LTE scenarios it is presented the investment distribution per environment and the financial analysis with and without Universal service obligations. The accumulated value per environment and per scenario is also reached for comparison purposes.

The dimension results for digital video broadcast dimension as data communication alternative solution are also presented. In this particular case it was calculated the cost for the operator and also for the subscriber of three scenarios: terrestrial broadcast, satellite broadcast and mixture of both.

Chapter 7. **CONCLUSIONS, FINDINGS AND FUTURE WORK**

In this chapter the questions raised in the introduction are going to be discussed based on the developed models described in Chapter 5 and using the results presented in Chapter 6.

The focus of this thesis is to evaluate the financial feasibility of the extension of the current voice telecommunications Universal Service to a combination of voice and broadband data services. The thesis subjects were centered in the network planning and dimensioning from a techno economic point of view[21].

The developed algorithm was based on the brownfield deployment of the technologies FTTH-GPON and LTE assuming the co-existence with other existent infrastructures and equipment availability. Two scenarios considering the existence or not of the Universal Service obligations were defined.

Although the telecommunication sector has high levels of competition in Portugal (see for eg. Figure 73), that atmosphere is not enough to guarantee the universal access to broadband communication at the individual level to levels much higher than those verified today, mostly at rural dispersed areas and between economically disadvantaged citizens. As a conclusion of this work it is a conviction of the author that the legal instrument Universal Service should be preserved in Portugal but its adoption should be weighted in time conditioned to financial availability.

The initial objectives are revisited at this moment to be discussed and analyzed.

7.1 Objectives Overview

The viewpoint followed in the debate of these hypotheses assumed the State (Government) as the prime promoter of the broadband universal service, launching periodically (periods of twenty, twenty five years) tenders for the selection of provider(s) of universal service of electronic communications where an existing private operator will be licensed as Universal Service Provider (USP). The main objective of the thesis was to provide technical solutions to support political and regulation decisions for short/medium term Portugal 1Mbps Broadband Universal Service implementation, based on a geographical financial analysis.

[21] The items part of the actual Universal Services definition as directories and public phones were not included in this work. These services became part on a separate public tender in the ANACOM´s tenders for the selection of provider(s) of Universal Service of electronic communications. Available on line, September 2013 @ http://www.anacom.pt/render.jsp?categoryId=346959.

In order to achieve that purpose, the secondary objectives were:

- The choice of the technology to implement the broadband universal service, according to the different geographical and social realities in Portugal.

The choice of the broadband universal service candidates was based on the technologic solutions successfully implemented in Portugal in particular in the last two decades. Their success is defined based on the number of subscriptions and network geographical expansion. Those solutions are therefore the wireless LTE as the next step of the 1990´s mobile successful heritage adding the broadband data to the mobile voice service; the fiber to the home optical network, following the cable television successful model incorporating both the broadband internet access and free voice communications and the universalized service of the television broadcast, that reaches more than 90% of the Portuguese population, Chapter 3 and Chapter 3.

- The definition of technology architecture and network planning based on the identified technologic solutions.

Using the defined technological solutions the typical architecture was defined for each network roll out in order to understand the equipment needs, specifications and constrains in a real environment. This step was fundamental to reach the real cost per network item in each type of region, Chapter 5.

- The quantification of the deployment cost of these technological solutions based in a theoretical business plan using real demographic and geographic data.

Each one of the adopted architectures was part of the inputs to the simulation tool developed to the financial analysis per technical solution and per sub-GEOTYPE. The sub-GEOTYPES are country's regions catalogued by real data variables, Chapter 5. Moreover a deployment cost strategy was defined in 4.8 to segregate the "profitable" to the "non-profitable" country areas.

- The calculation of a technical economical solution of the network implementation, from a private operator point of view; in order to give directions for the state subsidization policies.

The financial feasibility per technological solution was done at Chapter 6.

The financial indicators are observed considering that there is no own capital. For the LTE and FTTH-GPON solutions the adopted approach was based on the definition of two deployment scenarios: the first scenario is the typical private operator deployment, which accomplishes the regulators obligations but leaves aside some geographical areas. For this scenario a twenty five years business plan was defined. The second scenario is the same as the first one plus an extra obligation, due to the universal service obligation to potential reach any citizen anywhere in the country. The same business plan time frame was observed and compared to the first results to infer the universal obligations burden.

For the digital broadband television the approach was slightly different. It was analyzed (for the same time frame) the financial impact for the operator and also for the final subscriber based on the analog to digital transition done in Portugal by the time this thesis was developed. Two different technological solutions were implemented in different parts of the country with consequences in network architecture and type of reception equipment. Those regions are coincident to the two scenarios defined in the previous paragraph.

- Directions for a broadband universal service strategy to Portugal.

The directions for a global strategy for the implementation of the Universal Service are divided in two different points of view: the analysis of the strengths and weaknesses per studied technological solution and the implementation of the Universal Service per sub-GEOTYPE.

Item		*LTE*	*GPON-FTTH*	*Digital Broadcast*
Universal Service Candidate		OK	OK	OK
Technology Maturation Level (data)		Medium	Medium	Very Low
Technology Maturation Level (voice)		Very Low	Very Low	Extremely Low
Geographic Deployment	U	Medium/High	Medium	Very High
	SU	Medium	Low/Medium	
	R	Low	Very Low	
Uplink/Upstream debt (1Mbps reference)		Medium	High	Low
Downlink/Downstream debt (1Mbps reference)		Medium/High	High	Medium
Five year technical evolution forecast operator investment		Medium	Medium	High
Five year technical evolution forecast subscriber investment		Medium/High	Medium	Medium/High
Network investment versus Intangible gains		Comparable	Higher	Lower/Comparable
investment per subscriber (uban wireless reference)	U	Comparable	Comparable	Comparable
	SU	High	High	High
	R	Very High	Extremly High	Very High
Target population with economic and physical disabilities	U	High		
	SU			
	R			
Target population <u>without</u> any other internet access network <u>with</u> or <u>without</u> economic and physical disabilities	U	Low		
	SU	Medium/High		
	R	High/Very High		

Table 37 – Conceptual technology comparison for Universal Service.From the author.

For each technology, the integration of the results of the defined objectives leads to the following reflections, Table 37.

- Any of the solutions are candidates to short/medium term needs for broadband.
- The usage of the digital television broadcast was an issue widely studied some years ago but apparently abandoned, leading to the question: This was due to technical results or political decisions?;
- The usage of the digital television broadcast might need further investigation as a mean to delivery broadband universal internet;
- Any of them has potential to expand in case of other needs (geographic expansion, subscriber expansion).
- In five years from now the technical evolution for each one will punctual affect some equipments keeping the same type of architecture; with the exception of digital television, in case there is a standard change to DVB-T2 or higher.
- In case of major changes in the technical solution, the subscriber will always be affected and has to reinvest in new reception devices as set-up boxes, televisions, mobile phones of tablets (as always) and might be target to re-subsidization.

- The voice transmission in all the studied systems is done via IP. At this point of technology maturation the critical response is not as robust as today´s twisted pair solution.
- The forecast intangible gains (of ICT society) are in the same financial order of the wireless solution investment costs (LTE); which demonstrates an opportunity for a State subsidization.
- The existence of more than one technological solution will always originate a differentiation among access to technology:
    - The debts (upstream/uplink and downstream/downlink) are different and can be substantially different between technologic solutions questioning the equity of the access;
    - The access to each one of the solutions is done with different devices leading to different investments depending on the region;
    - In case of mobility (if someone changes home) the same equipment may not be adequate in the next geographical point;

- The wireless solution, as shared technological solution, is financial more attractive from the investment point of view leading to a value per subscriber lower than the wireline solution.
- In urban zones it is observed that all of the studied technologies are implemented and therefore are natural candidates for Universal Service Providers and the target subscribers is the population sector with economic and physical disabilities. Technological neutrality is then advised in urban zones.
- In suburban and rural zones the target population sector is the one <u>without</u> any other internet access network <u>with</u> or <u>without</u> economic and physical disabilities.

SWOT	***One country One solution***	***One country Several solutions (neutral solution per region)***
Strengths	• Equal technologic/services/debt opportunities to all universal service subscribers	• The implementation cost can be adapted to each reality to reduce State subsidization
Weaknesses	• The implementation cost in rural zones can lead from four to ten times more than an urban zone, leading to the increase of the State subsidization	• Different technical solutions lead to different types of speed access to the same service eventhought a minimum quality service per user is pre-defined (1Mbps)
Opportunities	• The widely usage of a certain technology can potentiate the cost reduction of the solution for the operator	• Reduction of the global amount of the State subsidization
Threats	• Few subscribers in certain zones might lead to gigantic investments, leading to an absence of competing operators, even with State subsidization	
	• Adoption of Regulation to balance the investment protection of the first investor in a certain rural area with a practice of infra-structure sharing and resource optimization	

Table 38 – Universal Strategies´ SWOT. From the author

After the reflection of the advantages or disadvantages per technological solution, the next step is the reflection on the adoption of a unique solution for all the country or the adoption of different solutions per geographic type, Table 38.

The adoption of the same solution for all the country, is a decision that goes against the technological neutrality referred as one of the main handicaps of today's Universal Service concept as it limits the subscriber choice and the involved operators;

This solution introduces higher level of perturbation in the telecommunication sector as only one type of operator´s can apply for the Universal service tender;

The adoption of different technological solutions per region drive to different reception devices and billing plans per zone, leading to different investments from the subscriber point of view. This situation might result in unbalanced investments among subscribers;

The urban cost per subscriber in LTE or FTTH-GPON is comparable but in suburban or rural the cost are substantially different, due to the costs of dispersion. A chart per zone might be developed to guarantee a minimum cost of subsidization per subscriber;

A neutral solution per region is the most balanced budget from the State intervention point of view as the implementation cost can be adapted to each reality to reduce State subsidization;

It is most important the adoption of suitable Regulation to balance the investment protection of the first investor in a certain rural area with infra-structure sharing and resource optimization;

The implementation of more than one Universal Service provider minimizes the potential perturbation of the market done by the State subsidization;

In the case that a region with potential few subscribers might lead to huge investments thus leading to an absence of competing operators for Universal Service, the State has to combine tender pairs of profitable/ non profitable regions.

7.2 Implicit questions

The research gap implicit in in this research is the adoption of an open concept but also realistic, suitable and affordable for Portugal. In this research are implicit the questions that are now answered.

One of the results of this work is that broadband availability is technically possible to be delivered to all Geotypes independent of the technology. This thesis discussed the use of GPON, LTE and DVB-T as technologic solutions for broadband delivered to each citizen/household.

7.2.1 The first question raised initially was “Which should be the new obligations of the Universal Service?”

All the above mentioned technologies are able to cope with existing Universal Service obligations (voice and functional internet) and also achieve theoretical data rates at a maximum rate of 30Mbps (peak values). LTE or GPON can even achieve higher values. The throughput of broadband Universal Service depends strongly on the investment on the deployment. The optical network was dimensioned based on that value per subscriber; the cellular network dimensioning imposed a 1Mbps per subscriber.

In this technological context the new Universal Service obligations should assure the access to basic data access. And which is, nowadays, the minimum data rate needed for the “basic data access”?

An approach to the calculation of this value can be observed in Table 39 for typical average forecast needs provided from telecom operator's real data. Surprisingly, as can be seen, the basic needs impose a maximum of 97Mbit during one hour, which is equivalent to 27kbps (at urban downlink, total data per user in busy hour).

Thus it can be concluded that any of the new generation technologies studied fulfills it.

Single User Throughput [Kbps]						
Single User Busy Hour Data	Urban		Suburban		Rural	
	UL	DL	UL	DL	UL	DL
VoIP	1401	1401	539	539	485	485
Web Browsing	2586	20689	776	6207	388	3103
E-Mail	849	2121	377	943	94	236
File Transfer	7071	35357	4714	23571	2357	11786
Chat	8	8	6	6	2	2
Streaming Media	227	36852	61	9827	61	9827
Total Data per User in Busy Hour(Kb) [Kb]	**12,142.32**	**96,428.69**	**6,472.94**	**41,093.31**	**3,387.10**	**25,439.18**
traffic per month	8,742,467.76	69,428,659.59	4,660,515.92	29,587,180.41	2,438,713.47	18,316,212.24
Single User Throughput (SUT) [Kbps] {Total Data / 3600 s}	**3.4**	**26.8**	**1.8**	**11.4**	**0.9**	**7.1**

Table 39 – Single user throughput forecast.

Nevertheless in order to guarantee 1Mpbs all the time to any subscriber in any part of the country this value was imposed for all the users as the single user throughtput. This value was chosen based on other countries definition and by the daily experience as a consumer. Technically any operator that supports LTE or GPON comply (under certain conditions) the minimum request for this single user throughtput. Moreover as was seen at Section 5.3.3 even a broadcast operator could in principle fulfill the same needs.

7.2.2 The second question was "Who should provide the Universal Service?"

It is the author belief that a public contest should be open, giving equal opportunity to any of the liberalized market operators to apply to it.

As an answer to the criticism of some observers related to the potential market perturbations from the state subsidies in the behalf of a particular operator, the proposal is to attribute the Universal Service to more than one operator, based on the Geotype coverage.

The market perturbation from a potential state grant is also taken into account as DL123/90, [225] sets out the system's general principles, namely the principles of competition, open access, non-discrimination, effectiveness and transparency; allowing the access of other operator´s to the financially supported infrastructure´s.

It also should be taken into account the grant of exploitation of a profitable Geotype zone with a less profitable zone to compensate the potential perturbation. Moreover, one can not forget that a network deployment in a non profitable reagion due to Universal Service obligations will in medium term absorb regular subscribers without any reduction fee that will facilitate the investment recovery.

7.2.3 The third question "How to finance the Universal Service?"

It is the author opinion that after this analysis that the Universal Service burden, in the limit could be absorb by the operator as this is a quite profitable business in long term. However understanding the negative impacts in short term it is assumed that the State could finance a percentage of the initial investment dependenig on current Funds Availability. Two perspectives should be taking into account.

The first one concerns the financial benefit gains forecasted by the new generation impact in the society. Retaking Figure 25 the mentioned three waves estimated savings around 2 000M€, based on optimization of resources and infrastructures in several areas: office/ school work; tourism and medicine. This value was calculated by replacing the spending money on transport, fuel or buildings on investment in new generation broadband infrastructure.

Comparing this value with the worst case presented by each one of the studied solutions, the value is quite comparable, Figure 152.

Scenario	***Savings/ Extra Investments***
NGN benefits (intangible)	*2 000M€*
Passive Optical Network	*5 200M€*
Wireless Network	*1 800M€*
Broadcasting	*6M€*

Figure 152 – Savings and Investment studied solutions comparison.From the author.

This data provide some confidence to the Government as an investor to provide means to be part of this broadband challenge.

The second point of view takes into account the reasonability of the subsidization. It is an expected conclusion that the investments in each technologic solution are highly dependent from the sharing conditions of the infra-structure. The reasonable values accepted are based on the evaluation of the difference between the rural and suburban cases. If we assume that the operators are willing to deploy a network in the urban or suburban area, this means that operators assume a profitable business. If the operator is not willing to assume the suburban/rural cost due to the high value of investment, then the state might subsidize the difference between the urban and rural network deployment in order to preserve the broadband Universal Service.

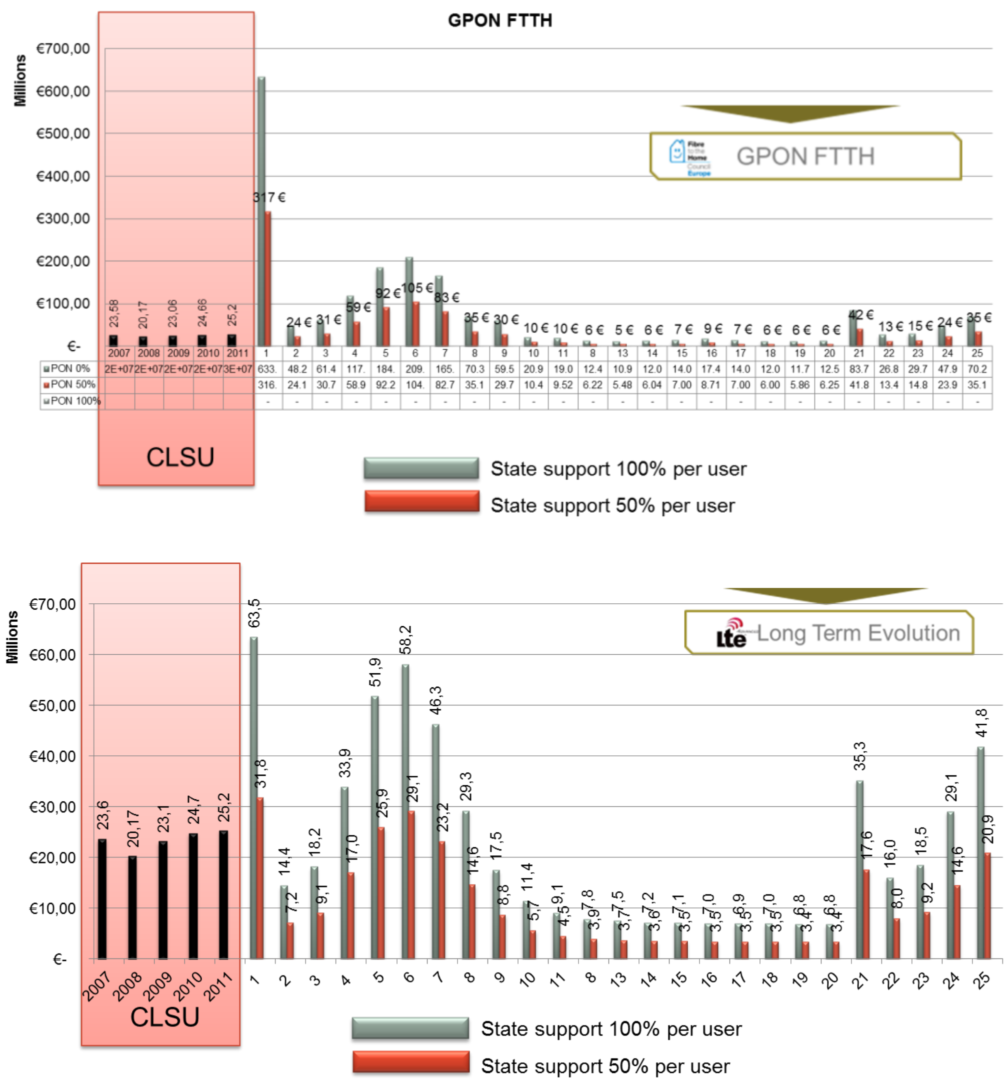


Figure 153 - State finantial support simulation for GPOn-FTTH (upper graph) and LTE (down).

In conclusion we can state a new definition of Universal Service subsidization as “the maximum percentage assumed by the state based on the cost of a subscriber in a typified region” The average calculated value up to 50% of cost per user in profitable zones and 100% in non-profitable zones, Figure 153.

7.3 Future Work

The future work is analysed considering two dimensions. The first one is evolution of the area of study of the author of the theis, and the second dimension is the legacy to others to continue to explore some open gaps due to this work.

7.3.1 Future work for the author

Concerning the future work for the author based on the devoloped work, the next step of analysis should be the impact of the Natural or Manmande Disasters in the telecommunication networks. In a moment of the humankid history faces high stress values of population towards limit ressources of our planet, can lead to unpredicted natural and non natural catastrophes committing human property and life itself.

The study to establish standards of interoperability and availability of emergency communications is an area of interest for the author to proceed her studies.The knowledge of each one of the architectures of the most common new generation networks made in this work are the basis for such a interoperability study.

7.3.2 Future work for the author and others

Assuming that the legacy of every thesis is the opppening of new areas of knowledge to others, some ideas based in the produced work are left for post graduate students.

Concerning the developed tool TENTUS

The developed tool was designed concerning the achievement of concrete objectives for the purpose of the develop theme. However as any other software tool, improvements and enhancements could increase both the performance as the user interface relation.

1. The input data concerning geographical and demographic values are likely to become outdated so its determinant its regular update.
2. A natural trend in the telecommunication sector is the decreasing of the equipment price´s as the technology matures. This effect will probably happen at the GPON networks; moreover as new optical technologies will emerge the re-evaluation of this access network for rural zones should be reviewed.
3. The subscriber forecast presented is purely an academic exercise. The accuracy of this forecast can be substantiated with a new module based on real and historical data of a real operator to tune the initial parameters.
4. The reuse and efficient factors were a strategy to simulate the random location of subscribers as well the random access to the service. This section can be done in a separate module based on statistical distribution and forecast.
5. The model assumes the churn coefficient as a constant. The effect of subscriber´s "lost and gain" can also be subject of study as part of the market´s game theory effect.
6. The tool was designed in a "raw" way, where all the inputs and assumptions are introduced in excel sheets, in specific cells, that are not intuitive to the general user. User interface enhancement can be a surplus to the widespread use of the tool.
7. The TENTUS tool can be found in the CD that complements this document.

Concerning the impact on the liberalized market dynamic´s

A mature liberalized market, as the telecommunication, depends on the independency of the players. The subsidization of the Universal Service to one or more operators can be interpreted as a distortion factor of the standard functioning of the market.

The effect of this disturbance can be subject of study based on the game theory behavioral interactions for a healthy liberalized market. Relevant contribution can outcome this study, concerning the true harmful effects of state subsidization and demystifying its effects.

Concerning the technology evolution

A natural trend in the telecommunication sector is the decreasing of the equipment price´s as the technology matures. This effect will probably happen at the GPON networks; moreover as new optical technologies will emerge the re-evaluation of this access network for rural zones should be reviewed.

Technology is growing continuously; the new trends are the convergence of mobile and fixed networks. One of those examples is the Cloud RAN. In this futuristic approach a mix of techno-economics from fixed and wireless should be reviewed, where the optical network will be responsible for the wide range data distribution and the wireless infra-structure will be strongly focused on low cost small cell planning. This will have a huge impact in the way the universal concept should be applied.

Concerning the geographic focus

With the Portuguese outer limits under revision for extend by the United Nations Oceans´ law of sea, the Portuguese nation will grow immensely in undersea geographical area. This fact reminds that the oceanic platform is also part of the nation and the sea communications might also be under the Universal Service scope. Thousands of men inhabit ships for several months in a row creating an attractive unexplored market share.

Thus, not only the cost but also the inherent technologies for this type of scenarios should be rethought.

Concerning the energy consumption and sustainability

As time goes by, more and more users subscribe telecommunication services, namely internet access, gaming or television services. Most of these services are time consuming and proportionally energy consuming as all this devices are always connected to the power network (as televisions or desktops) or at least from time to time (mobile phones, tablets and laptops).

This massive overload of the power network has certainly an impact on its own dimensioning, mainly in rural zones where only the basic services were specified at the roll out deployment. A deep analysis of the potential new devices connected to the power network and their average consumption might lead to some curious and relevant values.

Another point of view of the same problem might be the analysis of the impact on the power consumption of huge amounts of data exchange. A study can be made on the relevance of avoiding mails with attachements of several Megabits instead of small mails with dozens of bits. A confirmation of the impact of the size of the mail in the power consumption could lead to a new culture of restrain the content of the mail, not sharing big attachments. Those ones could became part of a sharing link at the cloud, instead.

PUBLICATIONS AND DELIVERIES

Book Chapter

Carvalho, J. et all, "Ocupação Dispersa- Custos e Benefícios, à Escala Local" (available in Portuguese). Cost and Benefits of Dispersed Occupation on a Local Scale2013: Direção-Geral do Território, ISBN 978-989-98156-0-5 @ http://www.dgterritorio.pt/produtos_e_servicos/publicacoes/outros_titulos/ocupacao_dispersa_custos_e_beneficios_a_escala_local__novo_/

Conference proceedings and presentations

Raquel Castro Madureira, A. Manuel de Oliveira Duarte, Raquel Matias-Fonseca, Carina Pais, Jorge Carvalho, "The impact of geography and demography on the economics of fibre optic access networks", ICSNC 2012, The Seventh International Conference on Systems and Networks Communications, Lisbon, Portugal. @ http://www.thinkmind.org/index.php?view=article&articleid=icsnc_2012_6_50_20195

Raquel Castro Madureira, A.M.d.O.D., Raquel Matias-Fonseca. "133 years of Telecommunications Universal Service in Portugal". A Century of Broadcasting. Proceedings IEEE HISTELCON'10, Madrid, Spain, 3-5 Nov. 2010, Page(s). 203-208.
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Invited speaker

Raquel Castro Madureira, IV Fórum Lusófono das Comunicações, "Que serviço para o Serviço Universal para o séc. XXI?" invited by ARCETEL-CPLP, 11 a 12 de Abril 2013, ISCTE-IUL, Lisboa, Portugal. @ http://www.arctel-cplp.org/noticias/detalhe/389/pt

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Journals

Raquel Castro Madureira, A. Manuel de Oliveira Duarte, Raquel Matias-Fonseca, "Digital terrestrial television: a golden or a missing opportunity? A reflection on the introduction of DTT in Portugal", Journal

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Raquel Castro Madureira, A. Manuel de Oliveira Duarte, Raquel Matias-Fonseca, "The Challenge of Universal Service in 21st Century Portugal", Technology and Society Magazine, IEEE, Volume: 31, Issue: 3 , Fall 2012, Page(s): 27 – 33 @ http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6313623

Raquel Castro Madureira, A. Manuel de Oliveira Duarte, Raquel Matias da Fonseca, "133 anos de História das Comunicações em Portugal", Revista do DETUA, Vol. 5, Issue 3, July 2011 @ http://revistas.ua.pt/index.php/revdeti/article/viewFile/2172/2043

Projects

Jorge Carvalho, et all, Projecto de investigação "Custos e Benefícios, à Escala Local, de uma Ocupação Dispersa", PTDC/AUR/64086/2006, chapter 3.9– "CUSTOS DE REDE DE TELECOMUNICAÇÕES", 2010-2011 @ http://www.ua.pt/ii/ocupacao_dispersa/PageText.aspx?id=13532&ref=ID0EACA/ID0EAACA

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LIST OF ACRONYMS

2G	-	Second generation of mobile communications systems (GSM)
3G	-	Third generation of mobile communications systems (UMTS)
3GPP	-	3rd Generation Partnership Project
3R	-	Re-Amplification, Re-Timing and Reshaping
A	-	Area
ABC	-	Activity Based Costing
ACLR	-	Adjacent Channel Leakage Ratio
ACS	-	Adjacent Channel Selectivity
ADSL	-	Asymmetric Digital Subscriber Line
ADSS	-	All-Dielectric Self-Supporting Aerial
AES	-	Advanced Encryption Standard
AH	-	Authentication Header
AM	-	Amplitude Modulation
A-MPR	-	Additional Maximum Power Reduction
AMPS	-	Advanced Mobile Phone System
ANACOM	-	Autoridade Nacional para as COMunicações
APC	-	Angled Physical Contact
APD	-	Avalanche Photo Diode
APON	-	ATM Passive Optical Network
APT	-	Arbitrage Pricing Theory
ARCTEL	-	Association of Communications and TELecommunications regulators
ARPU	-	Average Revenue per User
ARQ	-	Automatic Repeat reQuest
ASE	-	Amplified Spontaneous Emission
ASK	-	Amplitude Shift Keying
ASON	-	Automatically Switched Optical Network
ASTN	-	Automatic Switched Transport Network
ATB	-	Adaptive Transmission Bandwidth
ATDMA	-	Advanced Time Division Multiple Access
ATM	-	Asynchronous Transfer Mode
ATSC	-	Advance Television Systems Committee
AUC	-	Authentication Centre
AWG	-	Arrayed Waveguide Grating
AWGN	-	Additive White Gaussian Noise
BAK	-	Bill and Keep
BER	-	Bit Error Rate
BFWA	-	Broadband Fixed Wireless Access
BH	-	Busy Hour
BHSA	-	Busy Hour Sessions Attempts
BIAC	-	Broadband Internet Access Cost
BIC	-	Beginning of Confidential Information
BLER	-	Block Error Rate
BOM	-	Bill of Materials
BPON	-	Broadband PON
BPSK	-	Binary phase-shift keying
BS	-	Base Station
BS/PS	-	Burst Switching/Packet Switching
BS3	-	Burst Structure 3

BSC	-	Base Station Controller
BSS	-	Base Station Subsystem
BTS	-	Base Transceiver Station
BU-LRIC	-	Bottom-up - Long Run Incremental Costs (LRIC) model
BW	-	Bandwidth
BWA	-	Broadband Wireless Access
BWDM	-	Band Wavelength Division Multiplexing
CA	-	Carrier Aggregation
CAP	-	Code of Administrative Procedure
CAPEX	-	Capital Expenditure
CAPM	-	Capital Asset Pricing Method
CATV	-	Cable Television
CC	-	Component Carriers
CCA	-	Current Cost Accounting
CDMA	-	Code Division Multiple Access
CDR	-	Call data record
CET	-	Cell Edge Throughput
CH	-	Channel
CL	-	Central Local
CM	-	Cable Modem
CMTS	-	Cable Modem Termination System
CO	-	Central Office
COAX	-	Coaxial Cable
COFDM	-	Coded Orthogonal Frequency Division Multiplexing
COM	-	Operating Capital Maintenance
CoMP	-	Coordinated Multipoint transmission
CP	-	Cyclic Prefix
CPE	-	Customer Premises Equipment
CPLP	-	Comunidade dos Países de Língua Portuguesa
CPN	-	Consumer Premise Network
CPP	-	Calling Party Pays
CRC	-	Current Replacement Costs
CS	-	Circuit Switching
CSMA	-	Carrier Sense Multiple Acess
CSN	-	Cell Signaling Network
CSPF	-	Constrained Shortest Path First
CS-RZ	-	Carrier Suppressed Return to Zero
CS-SAP	-	Convergence Sub-layer – Service Access Point
CTE	-	Common Tracking Error
CU	-	Central Unit
CWDM	-	Coarse Wavelength Division Multiplexing
DA	-	Distribution Area
DAE	-	Digital Agenda for Europe
DBA	-	Dynamic Bandwidth Allocation
DBRu	-	Dynamic Bandwidth Report upstream
DBWS	-	Distributed Broadband Wireless System
DCCP	-	Datagram Congestion Control Protocol
DCF	-	Dispersion Compensation Fibre
DCS	-	Digital Cellular System
D-CWDM	-	Dense – Coarse Wavelength Division Multiplexing
DECT	-	Digital Enhanced Cordless Telecommunication
DES	-	Digital Encryption Standard
DFB	-	Distributed Feedback Laser

DG INFSO	-	Directorate General Information Society and Media
DGD	-	Differential Group Delay
D-ITG	-	Distribute Internet Traffic Generator
DIV	-	Diversity
DL	-	Downlink
DML	-	Direct Modulation Laser
DMT	-	Discrete Multi Tone
DNS	-	Domain Name Server
DOCSIS	-	Data Over Cable Service Interface Specification
DPSK	-	Differential Phase Shift Keying
DSF	-	Dispersion Shifted Fiber
DSL	-	Digital Subscriber Line
DSLAM	-	Digital Subscriber Line Access Multiplexer
DTTB	-	Digital Terrestrial Television Broadcasting
DTTV	-	Digital Terrestrial Television
DU	-	Dense Urban
DVB-RCS	-	Digital Video Broadcast – Return Channel System
DVB-RCT	-	Digital Video Broadcasting-Return Channel Terrestrial
DVB-T	-	Digital Video Broadcasting-Terrestrial
DWDM	-	Dense Wavelength Division Multiplexing
DXC	-	Digital Cross Connect
EAFRD	-	European Agricultural Fund for Rural Development
EAM	-	Electro-Absorption Modulator
EARFCN	-	E-UTRA Absolute Radio Frequency
EBITDA	-	Earnings Before Interest, Taxes, Depreciation and Amortization
EC		European Commission
ECI	-	End of Confidential Information
ECPR	-	Efficient Component Pricing Rule
ECPTA	-	European Conference of Postal and Telecommunications Administrations
EDC	-	Embedded Direct Costs
EDFA	-	Erbium Doped Fiber Amplifier
EDGE	-	Enhanced Data Rates for GSM/DCS Evolution
eDL-MIMO	-	Down Link Multiple Antenna
EDWA	-	Erbium Doped Waveguide Amplifiers
EFM	-	Ethernet in the First
EFM(A)	-	Ethernet in the First Mile (Alliance)
EIR	-	Equipment Identity Register
EIRP	-	Effective Isotropic Radiated Power
eMBMS	-	Multimedia Broadcast Multicast Service
EML	-	External Modulated Laser
eNB	-	Evolved Node B
EPC	-	Evolved Packet Core
EPMU	-	Equal Proportionate Mark-Up
EPON	-	Ethernet PON
EPRE	-	Energy Per Resource Element
ERDF	-	European Regional Development Fund
ERG	-	European Regulators Group
ESA	-	European Space Agency
eSGEI	-	Services of General Economic Interest in electronic communications
ESRI	-	Environmental Systems Research Institute
ETDM	-	Electrical Time Domain Multiplexing
ETSI	-	European Telecommunications Standards Institute
E-UTRA	-	Evolved Universal Terrestrial Radio

E-UTRAN	-	Evolved UTRA
EVA	-	Extended Vehicular A
EVDO	-	Evolution-Data Optimized
EVM	-	Error Vector Magnitude
f	-	Frequency
FBT	-	Fused Biconic Technology
FC	-	Ferrule Connector
FCM	-	Financial Capital Maintenance
FDC	-	Fully Distributed Costs
FDD	-	Frequency Division Duplex
FDDI	-	Fiber Distributed Data Interface
FDL	-	Fiber Delay Line
FDMA	-	Frequency Division Multiple Access
FDPS	-	Frequency Domain Packet Scheduling
FE	-	Fast Ethernet
FEC	-	Forward Error Correction
FFM	-	Fast Fading Margin
FFT	-	Fast Fourier Transform
FGL	-	Fiber Grating Laser
FIA	-	Functional Internet Access
FITL	-	Fiber in the Loop
FL-LRIC or LRIC	-	Long Run Incremental Costs
FM	-	Frequency Modulation
FMC	-	Fixed-Mobile Convergence
FP	-	Fabry Perot
FR	-	Frame Relay
FRC	-	Fixed Reference Channel
FRP	-	Fiber-Reinforced Polymer
FSAN	-	Full Service Access Network
FSK	-	Frequency Shift Keying
FT	-	Noise Total
FTE	-	Full-Time Equivalent
FTP	-	File Transfer Protocol
FTTB	-	Fiber to the Building
FTTC	-	Fiber to the Curb
FTTCab	-	Fiber to the Cabinet
FTTH	-	Fiber to the Home
FTTN	-	Fiber to the Node
FTTP	-	Fiber to the Premises
FTTx	-	Fiber to the x, where x can be filled in by home (H), curb (C) , building (B)…
FUTON	-	Fiber Optic Networks for Distributed and Extendible Heterogeneous Radio Architectures and Service Provisioning
FWA	-	Fixed Wireless Access
FWM	-	Four Wave mixing
G	-	Gain
GB	-	Guard Band
GE	-	Gigabit Ethernet
GEM	-	GPON Encapsulation Method
GEO	-	Geostationary Earth Orbital
G-EPON	-	Gigabit Ethernet Passive Optical
GERAN	-	GSM EDGE Radio Access Network
GFP	-	Generic Framing Procedure
GGSN	-	Gateway GPRS Support Node

GMSC	-	-Gateway MSC
GMSK	-	Gaussian Minimum Shift Keying
GoS	-	Grade of Service
GPON	-	Gigabit PON
GPRS	-	Evolution of the GSM system (General Packet Radio Service)
GSM	-	Global System for Mobile Communications
GTC	-	GPON Transmission Convergence
HAP	-	High Altitude Platform
HCA	-	Historical Cost Accounting
HD-FDD	-	Half- Duplex FDD
HDSL	-	High Bit-Rate DSL
HDTV	-	High Definition TV
HFC	-	Hybrid Fiber Coaxial
HH	-	Households
HLR	-	Home Location Register
HO	-	Handover
HOM	-	Higher Order Mode
HSCSD	-	High Speed Circuit Switched Data
HSDPA	-	High Speed Debit Packet Access
HSI	-	High Speed Internet
HSPA	-	High Speed Packet Access
HSUPA	-	High Speed Uplink Packet Access
HTTP	-	Hypertext Transfer Protocol
HW	-	Hardware
I	-	Interference
IA	-	Impact Assessment
ICP	-	Instituto das Comunicações de Portugal
ICP-ANACOM	-	Autoridade Nacional de Comunicações
ICT	-	Information and Communication Technologies
IDT	-	Inter Departure Time
IEEE	-	Institute of Electrical and
IETF	-	Internet Engineering Task Force
IM	-	Implementation Margin
IMEI	-	International Mobile Equipment Identity
IMSI	-	International Mobile Subscriber Identifier
IMT	-	International Mobile Telecommunication
InP	-	Indium Phosphide
IP	-	Internet Protocol
IPTV	-	Internet Protocol Television
ISDB-T	-	Integrated Services Digital Broadcasting-Terrestrial
ISDN	-	Integrated Services Digital Network
ISI	-	Inter Symbol Interference
ISP	-	Internet Service Provider
ITU	-	International Telecommunication Union
JPU	-	Join Process Units
LAN	-	Local Area Network
LC	-	Lucent Connector
LCAS	-	Link Capacity Adjustment Scheme
LCD	-	Long Constrained Delay data
LCE	-	Law of Electronic Communications
LCG	-	Large Hadron Collider Computing Grid
LEO	-	Low Earth Orbital
LHC	-	Large Hadron Collider

LMDS	-	Local Multipoint Distribution System
LNA	-	Low Noise Amplifier
LN-MZM	-	Lithium Niobate Mach-Zehnder Modulator
LOS	-	Line Of Sight
LRAIC	-	Long Run Average Incremental Costs
LRIC	-	Long Run Incremental Cost
LSP	-	Label Switched Path
LTE	-	Long Term Evolution
LTE or 4G	-	Long Term Evolution
MAC	-	Medium Access Control
MAL	-	Maximum Allowed Losses
MAN	-	Metropolitan Area Network
MAP	-	Mobile Application Part
MAPL	-	Maximum Admissible Path Loss
Market 7	-	Wholesale market of voice call termination on individual mobile networks
MAS	-	Medium Access Scheme
MCS	-	Modulation and Coding Scheme
MEA	-	Modern Equivalent Asset
MEMS	-	Micro-Electromechanical Systems
MGCP	-	Media Gateway Control Protocol
MG-OXC	-	Multigranular Optical Cross Connect
MGW	-	Media Gateway
MHA	-	Mast Head Amplifier
MHz	-	Mega Hertz
MIMO	-	Multiple Input Multiple Output
MISDN	-	Mobile Subscriber ISDN Number
mm	-	Millimeter
MME	-	Mobility Management Entity
MMF	-	Multimode Fiber
MoU's	-	Minutes of use
MPE-FEC	-	Multiprotocol Encapsulated FEC
MPEG2	-	Moving Picture Experts Group
MPR	-	Maximum Power Reduction
MRC	-	Maximum Ratio Combiner
MS	-	Mobile Station
MS	-	Member States
MSC	-	Mobile Switching Centre
MSD	-	Maximum Sensitivity Degradation
MSS	-	Mobile Switching Centre Server
MUX/DEMUX	-	Multiplexer/DE multiplexer
MVDS	-	Microwave Video Distribution System
MVNO	-	Mobile Virtual Network Operator
N	-	Noise
NBS	-	National Broadband Scheme
NDC	-	National Destination Code
NF	-	Noise Figure
NGA	-	Next Generation Access
NGN	-	Next Generation Networks
NG-SDH	-	Next Generation Synchronous Digital Hierarchy
NID	-	Network Interface Device
NIU	-	Network Interface Unit
NLOS	-	No-Line of Sight
NPV	-	Net Present Value

NRA	-	National Regulatory Authority
NRV	-	Net Realizable Value
NRZ	-	Non Return to Zero
NUTS		Nomenclature of Territorial Units for Statistics
OADM	-	Optical Add and Drop Multiplexing
OAM	-	Optical Absorption Modulator
OBS	-	Optical Burst Switching
OCDM	-	Optical Code Division Multiplexing
OCNG	-	OFDMA Channel Noise Generator
ODF	-	Optical-fiber Distribution Frame
ODN	-	Optical Distribution Network
OE	-	Opto-Electronic
OECD	-	Organisation for Economic Co-operation and Development
OFDM	-	Orthogonal Frequency Division Multiplexing
OFDMA	-	Orthogonal Frequency Division Multiple Access
OIF	-	Optical Internetworking Forum
OLT	-	Optical Line Terminal
OMC	-	Operation & Maintenance Centre
OMCI	-	ONT Management and Control
ONT	-	Optical Network Termination
ONU	-	Optical Network Unit
OOB	-	Out-of-band
OPEX	-	Operating Expenditure
OPS	-	Optical Packet Switching
OPT	-	OPTIMUS, Portuguese mobile operator
OSI	-	Open Systems Interconnection
OSP	-	Outside Plant
OSPF	-	Open Shortest Path First
OSS	-	-Operation and Support Subsystem
OTDM	-	Optical Time Division Multiplexing
OXC	-	Optical Cross Connect
P2MP	-	Point to Multipoint
P2P	-	P2P Point-to-Point
PA	-	Power Amplifier
PAN	-	Personal Area Network
PAPR	-	Peak to Average Power Ratio
PB3	-	Pedestrian B 3
PBx	-	Pedestrian B xKm/h
PC	-	Personal Computer
PCBd	-	Physical Level Control Block
PCN	-	Personal Communications Network
PCU	-	Packet Control Unit
PD	-	Point of Distribution
PDCCH	-	Physical Downlink Control Channel
PDH	-	Plesiochronous Digital Hierarchy
PE	-	Polyethylene
PG	-	Power Gain
PHY	-	PHYsical layer
PIN	-	Positive-Intrinsic-Negative
PKI	-	Public Key Infrastructure
PLC	-	Power Line Communication
P-MPR	-	Power Management Maximum Power
PMS	-	Significant Market Power

POD	-	Point of Optical Distribution
PON	-	Passive Optical Network
PON	-	Passive Optical Network
PoS	-	Power Splitter
POTS	-	Plain Old Telephone Service
Pr	-	Power received
PRB	-	Physical Resource Block
PS	-	Packet Switch
PSD	-	Power Spectral Density
PSK	-	Phase Shift Keying
PSTN	-	Public Switched Telecommunication Network
Pt	-	Power transmitted
PT	-	Portugal Telecom
PTC	-	PT Comunicações
QAM	-	Quadrature Amplitude Modulation
QoS	-	Quality of Service
QPSK	-	Quadrature Phase Shift Keying
R	-	Clutter Rural
RAA	-	Região Autónoma dos Azores |Azores´ Autonomous Region
RAM	-	Região Autónoma da Madeira |Madeira´s Autonomous Region
RAN	-	Radio Access Network
RAU	-	Remote Access Unit
RB	-	Resource Block
RCTT	-	Return Channel Terrestrial Terminal
RE	-	Resource Element
REFSENS	-	Reference Sensitivity power level
RF	-	Radio Frequency
RoF	-	Radio over Fiber
RPR	-	Resilient Packet Ring
RRM	-	Radio Resource Management
RS	-	Reed-Solomon
RT	-	Remote Terminal
RTT	-	Return-Trip-Time
Rx	-	Receiver
RZ	-	Return to Zero
S	-	Signal
SAN	-	Storage Area Network
SC-FDMA	-	Single Carrier Frequency Division Multiple Access
SCM	-	Sub-Carrier Multiplexed
SDH	-	Synchronous Digital Hierarchy
SDH/SONET	-	Synchronous Digital Hierarchy/Synchronous Optical Network
SDM	-	Space Division Multiplexing
SDMA	-	Space Division Multiple Access
SDR	-	Special Drawing Rights
SDSL	-	Symmetric Digital Subscriber Line
SDTV	-	Standard Definition TV
SDU	-	Service Data Unit
SF	-	System Frame
SFM	-	Slow Fading Margin
SFN	-	Single Frequency Network
SG	-	Scheduler Gain
SGEI	-	Services of General Economic Interest
SGSN	-	Serving GPRS Support Node

S-GW	-	Gateway Server
SHDSL	-	Single-pair High-speed Digital Subscriber Line
SIM	-	Subscriber Identity Module
SIM Card	-	Subscriber Identifier Module Card
SINR	-	Signal to Interference and Noise Ratio
SIP	-	Session Initiation Protocol
SISO	-	Single Input Single Output
SME	-	Small and Medium Enterprise
SMF	-	Single Mode Fiber
SMS	-	Short Message Service
SN	-	Subscriber Number
SNI	-	Server Network Interface
SNR	-	Signal to Noise Ratio
SOA	-	Semiconductor Optical Amplifier
SOHO	-	Small Office / Home Office
SON	-	Self Organizing Network
SONET	-	Synchronous Optical Network
SPC	-	Super Physical Contact
SPF	-	Shortest Path First
SR	-	Sub-Repartidor
SSMF	-	Standard Single Mode Fiber
SSS	-	Secondary Synchronization Signal
SSS_RA	-	SSS-to-RS EPRE ratio for
ST	-	Straight Tip (Connector)/ Square
STM	-	Synchronous Transport Module
STU	-	Set Top Unit
SU	-	Clutter Sub-Urban
SUT	-	Single User Throughput
SW	-	-Software
T	-	Temperature
TBS	-	Transport Block Size
TC	-	Transmission Convergence
T-CONT	-	Transmission Containers
TCP	-	Transfer Control Protocol
TCP/IP	-	Transmission control protocol/Internet protocol
TDD	-	Time Division Duplex
TDM	-	Time Division Multiplex
TDMA	-	Time Division Multiple Access
TELRIC	-	Total Element Long Run Incremental Cost
TENTUS		Techno-Economic access Network´s dimensioning Tool for Universal service
TFEU	-	Treaty on the Functioning of the European Union
TFF	-	Thin Film Filter
TIC	-	Technologies of Information and Communication
TIR	-	Taxa Interna de Rentabilidade
TMA	-	Tower Mounted Amplifier
TMN	-	TMN, Portuguese mobile operator
TRX	-	Transceiver
TS	-	Time Slot
TSLRIC	-	Total Service Long Run Incremental Cost
TTI	-	Time Transmission interval
Tx	-	Transmitter
U	-	Clutter Urban
UA	-	Universal Access

UAC	-	User Agent Client
UAS	-	User Agent Server
UDD	-	Unconstrained Delay data
UDP	-	User Datagram Protocol
UE	-	User Equipment
UHF	-	Ultra High Frequency
UL	-	Uplink
UL-MIMO	-	Up Link Multiple Antenna
UMTS	-	Universal Mobile Telecommunications System
UN	-	United Nations
UNI	-	User Network Interface
UPC	-	Ultra Physical Contact
UPT-5	-	Universal Personal Telecommunication
US	-	Universal Telecommunications Service
USD	-	Universal Service Directive
USO	-	Universal Service Obligations
USP	-	Universal Telecommunications Service Provider
USP	-	Universal Service Provider
UTRA	-	UMTS Terrestrial Radio Access
UTRAN	-	UMTS Terrestrial Radio Access Network
UWB	-	Ultra Wideband
VAT	-	Value Added Tax
VAx	-	Vehicular A xKm/h
VC	-	Virtual Container/Virtual Concatenation
VCAT	-	Virtual Concatenation
VCI	-	Virtual Circuit Identifier
VCSEL	-	Vertical Cavity Surface Emitting Laser
VDF	-	Vodafone, Portuguese mobile operator
VDSL	-	Very-High Data Rate DSL
VDSL2	-	Very-high bit rate Digital Subscriber Line
VHF	-	Very High Frequency
VLR	-	Visitor Location Register
VO	-	Virtual Organisation
VoD	-	Video-on-Demand
VoIP	-	Voice over Internet Protocol
VP	-	Virtual Path
VSAT	-	Very-small-aperture terminal
WACC	-	Weighted Average Cost of Capital
WAN	-	Wide Area Network
WCDMA	-	Wideband Code Division Multiple Access
WDM	-	Wavelength Division Multiplexing
WiFi	-	Wireless Fidelity – Any Kind of 802.11 Network
Wi-Fi	-	Wireless Fidelity
WiMax	-	Worldwide Interoperability for Microwave
WiMAX	-	Worldwide Interoperability for Microwave Access
WMAN	-	Wireless Metropolitan Area Network
WTO	-	World Trade Organization
xDSL	-	Digital Subscriber Line technologies, e.g. ADSL, ADSL2+,SDSL

LIST OF EQUATIONS

LIST OF FIGURES

LIST OF TABLES