University of Aveiro Department of Electronics, Telecommunications and Informatics
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Redes de Telecomunicações Móveis em Portugal: Análise Retrospectiva

Telecommunications Mobile Networks in Portugal: Retrospective Analysis

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia de Computadores e Telemática, realizada sob a orientação científica do Professor Doutor Aníbal Manuel de Oliveira Duarte, Professor Catedrático do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro e coorientação da Professora Doutora Raquel Matias da Fonseca, Professora Auxiliar do Departamento de Economia, Gestão e Engenharia Industrial da Universidade de Aveiro.

To Maria,

for being always with me.

o júri / the jury

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Palavras-chave Telecomunicações, Análise tecno-económica, sistemas de informação, mercado, concorrência, ferramentas de modelação

Resumo

Portugal é um dos países da *União Europeia* (UE) com maior taxa de penetração do *Serviço Telefónico Móvel* (STM) o que o torna num dos países mais interessantes para estudos relacionados com redes e serviços móveis.

Neste contexto os estudos de mercado para determinar a taxa de penetração de um novo serviço / tecnologia tornam-se decisivos para as empresas uma vez que podem implicar custos elevados por vezes muito difíceis de rentabilizar.

Apesar de já existir algum *software* que permite fazer modelação do comportamento de vários operadores de telecomunicações em determinados cenários, esses modelos têm em consideração padrões de comportamento teóricos e podem não estar inteiramente adaptados à realidade de cada mercado.

Este trabalho procura melhorar esses padrões de comportamento fazendo uma análise retrospectiva ao mercado do STM desde a sua introdução em Portugal, em 1989, e assim fornecer dados mais precisos às ferramentas de modelação.

Keywords

Telecommunications, techno-economic analysis, information systems, market, competition, modeling tools

Abstract

Portugal is one of the European Union (EU) countries with the highest penetration rate of Mobile Telecommunications Service (MTS) and that fact makes it one of the most interesting countries for conducting studies related to mobile networks and services.

In this context, doing market research to determine the penetration rate of a particular new service / technology becomes crucial for companies, since it may involve high costs sometimes very difficult to monetize.

Although there is already some software that models the behavior of several telecom operators in certain scenarios, these models take into account patterns of behavior based only on theory which may not be fully adapted to each market reality.

This work seeks to improve those patterns of behavior by a making a retrospective market analysis of the MTS, since its introduction in Portugal in 1989 thus providing more accurate data for modeling tools.

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List of Acronyms

1G First Generation

1xRTT 1x (single-carrier) Radio Transmission Technology

2.5G Second-generation enhanced

2G Second Generation

3G Third Generation

3GPP 3rd Generation Partnership Project

3GPP2 3rd Generation Partnership Project 2

4G Fourth Generation

ADM Add-drop multiplexer

ADSL Asynchronous Digital Subscriber Line

AMC Adaptive Modulation and Coding

AMPS Advanced Mobile Phone System

AMPU Average Margin Per User

ANACOM *Autoridade Nacional de Comunicações*

ANSI American National Standards Institute

ARD Advanced Receiver Design

ARPU Average Revenue Per User

ATM Asynchronous Transfer Mode

B-CDMA Broadband Code Division Multiple Access

CATV Community Access Television

CCITT *Comité Consultatif International Téléphonique et Télégraphique*

CCPU Cash Cost Per User

CDMA Code Division Multiple Access

CDMA2000 Code Division Multiple Access 2000

CDMAOne Code Division Multiple Access One

CEPT Conference of European Posts and Telecommunications

CMVM *Comissão do Mercado de Valores Mobiliários*

CTT *Correios de Portugal, S.A.*

D-AMPS Digital AMPS

DCHSPA Dual Carrier High Speed Packet Access

DECT Digital Enhanced Cordless Telecommunications

DOCSIS Data Over Cable Service Interface Specifications

DSL Digital Subscriber Line

DSLAM Digital Subscriber Line Access Multiplexer

EBITDA Earnings Before Interest, Taxes, Depreciation and Amortization

ECB European Central Bank

EDGE Enhanced Data GSM Environment

EMS Enhanced Messaging Service

ETSI European Telecommunications Standards Institute

EU European Union

EVDO 1x Evolution Data Optimized

FCS Fast Cell Search

FDD Frequency Division Duplex

FDM Frequency-division Multiplexing

FDMA Frequency Division Multiple Access

femtocell FemtoCell

FMC Fixed-Mobile Convergence

FOMA Freedom of Mobile Multimedia Access

FR Frame Relay

FTTB Fiber to the Building

FTTC Fiber to Curb/Cabinet

FTTH Fiber to the Home

FTTN Fiber to the Node

FTTP Fiber to the Premisses

FTTx Fiber to the x

GAAP Generally Accepted Accounting Principles

GPRS General Packet Radio Service

GSBL *Grupo de Sistemas de Banda Larga*

GSM Global System for Mobile communications

HARQ Hybrid Automatic Repeat Request

HFC Hybrid Fiber Coaxial Network

HSDPA High-Speed Downlink Packet Access

HSPA High-Speed Packet Access

HSPA Evolved High-Speed Packet Access Evolved

HSUPA High-Speed Uplink Packet Access

ICP *Instituto das Comunicações de Portugal*

ICT Information and Communication Technology

iDEN Integrated Digital Enhanced Network

IMF International Monetary Fund

IMT2000 International Mobile Telecommunications - 2000

IMTS Improved Mobile Telephone Service

IPTV Internet Protocol Television

ISDN Integrated Services Digital Network

ITU International Telecommunication Union

ITU-T ITU - Telecommunication Standardization Sector

LTE Long Term Evolution

LTE-Advanced Long Term Evolution - Advanced

MIMO Multiple-Input, Multiple-Output

MMS Multimedia Messaging Service

MPLS Multi-protocol Label Switching

MTS Mobile Telecommunications Service

MVNO Mobile virtual network operator

NVoIP Nomadic VoIP

NGA Next Generation Access Networks

NGN Next Generation Network

NMT Nordic Mobile Telephone system

NTT Nippon Telegraph & Telephone Corporation

OFDMA Orthogonal Frequency Division Multiple Access

PDA Personal Digital Assistant

PDC Personal Digital Cellular

PHP Personal Handy-Phone

PHS Personal Handy-phone System

POTS Plain Old Telephone Service

PSTN Public Switched Telephone Network

QAM Quadrature Amplitude Modulation

SDH Synchronous Digital Hierarchy

SIM Subscriber Identity Module

Smart-phone Smart-phone

SMS Short Message Service

STM *Serviço Telefónico Móvel*

TACS Total Access Communications System

TD-SCDMA Time Division Synchronous Code Division Multiple Access

TDD Time Division Duplex

TDMA Time Division Multiple Access

TLP *Telefones de Lisboa e Porto*

UC Ubiquitous Computing

UE *União Europeia*

UMTS Universal Mobile Telecommunications System

UWCC Universal Wireless Communication Consortium

VOD Video On Demand

VoIP Voice Over IP

WAP Wireless Application Protocol

WCDMA Wideband CDMA

WiMAX Worldwide Interoperability for Microwave Access

xDSL x Digital Subscriber Line

Chapter 1

Introduction

In this chapter we introduce the purpose, the objectives and the structure of this work.

1.1 Motivation

Information and Communication Technology (ICT) became an essential part of our lives as it represents our nature, as humans, to create, store and share information. ICT allows to foster prosperous and cohesive communities, offering a safer, healthier and more productive environment for all.

The natural evolution of information and communication technologies is to merge with individuals and organizations. The aim is to allow information processing available everywhere to everyone. The concept of pervasive or ubiquitous computing (often abbreviated to "ubicomp") refers to a new concept of computing as it merges technology with a user's life. As Jason Weiss wrote: "In ubiquitous computing, computers become a helpful but invisible force, assisting the user in meeting his or her needs without getting in the way" [145].

The MTS plays an important role in achieving that goal, because never before have mobile devices been so merged with one's life. It has become almost unthinkable to leave home without a mobile phone.

Being connected is now a bare necessity and telecom companies know this far too well. Over the years we have seen massive investments in telecom infrastructure and the offering of innovative services. This has happened every time a new technology matures enough to be invested in. As with (almost) all investments, sometimes it goes profitable quite rapidly, other times it does not. In spite all the economic research done before the adoption of a new technology and/or service, telecom companies face difficulties when it comes to predict how that technology and/or service will behave once it gets to market. One has to consider several aspects like competitors behavior, consumer trends and even political policies whenever there is a market regulator such as *Autoridade Nacional de Comunicações* (ANACOM).

The work in this document aims to lower the investment risk taken by the telecom industry by feeding some of the existing simulation software with more accurate input.

1.2 Objectives

The main objectives of this work are:

1. telecommunications networks technical study;
2. market analysis;
3. software testing;
4. conclusions and future work.

1.3 Thesis structure

This thesis is divided into six chapters. The order by which they are presented reflects the path taken during the work.

Chapter 1 - Introduction
This actual chapter, where it is described the purpose of this work and document structure.

Chapter 2 - State of the art
In this second chapter, we describe some telecommunications networks and technologies along with its evolution.

Chapter 3 - The Market
In this chapter, we will look at the Portuguese mobile market and know the players.

Chapter 4 - Analysis on market behavior
The fourth chapter will try to explain exactly how and why the market behaves when exposed to new products/services/technologies.

Chapter 5 - Simulation software tools
In this chapter and based on what was achieved, we conduct some testing using Vensim dynamic systems simulation tool.

Chapter 6 - Conclusions and future work
The final chapter is dedicated to discuss the results and future work.

Chapter 2

State of the art

In this chapter we get to know different types of telecommunication networks and technologies.

2.1 Telecommunication networks

2.1.1 The Network Structure

The Figure 2.1 shows a global telecommunications infrastructure model.

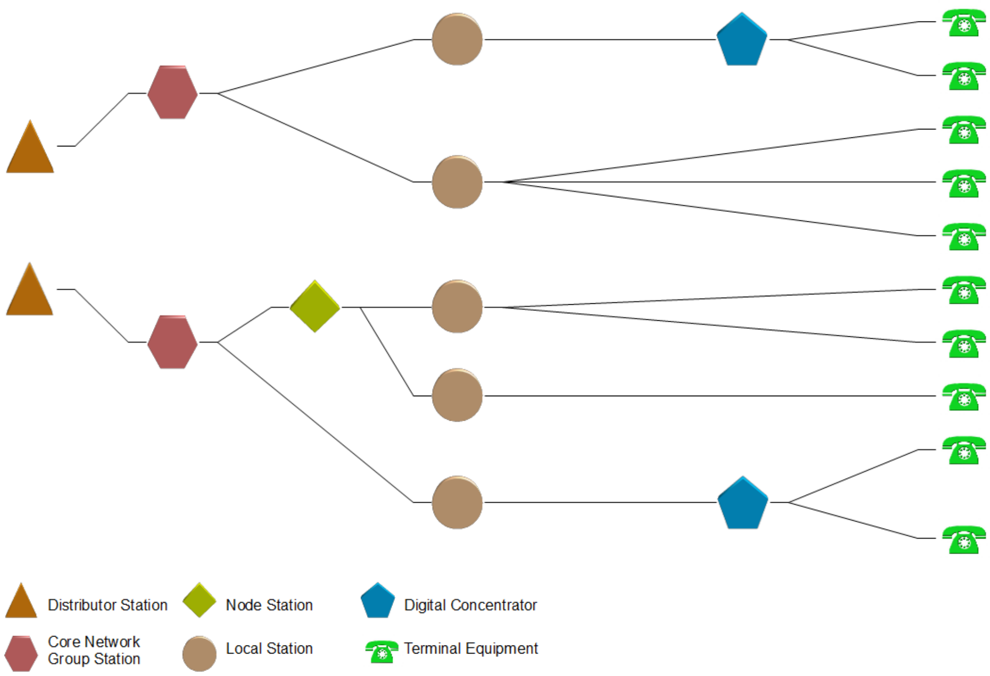

Figure 2.1: The Network Structure: Global Structure.[32]

The basic network infrastructure seen in Figure 2.2 can be split into three main segments:

Core Network, Access Network and Customer Network. On each one of these segments, several telecommunication technologies are used on data transmission, commutation and routing. There is also a number of services supported by these segments.

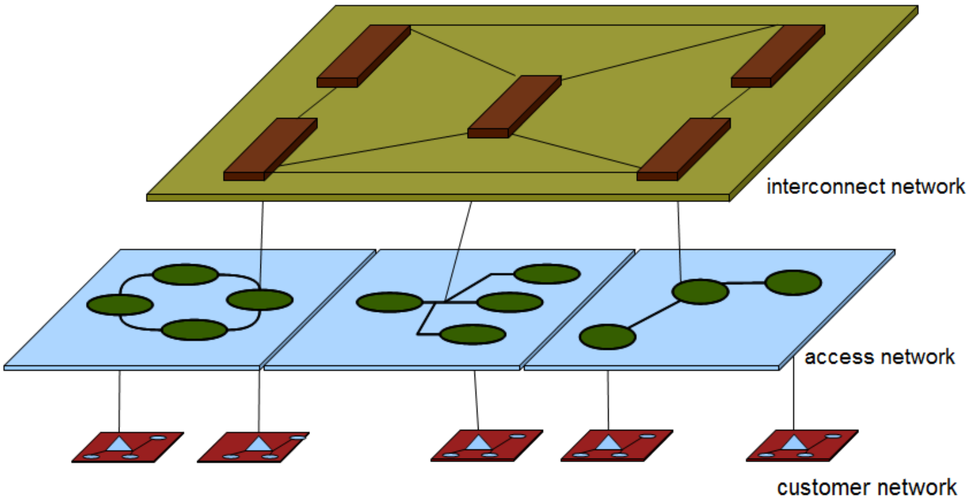

Figure 2.2: The Network Structure: Main segments.[32]

2.1.2 Core network

A core network is the central part of a telecommunications network, that provides the basic infrastructure supporting the interconnection of the access networks. It supports the various services to customers who are connected by the access network.

The most spread technology in use, on core networks, is the Synchronous Digital Hierarchy (SDH) technology. This is a standard technology for synchronous data transmission on electrical, optical and radio media. Transmission reliability and quality are assured by management and maintenance mechanisms that act on a physical level. In Figure 2.3, we can see a common SDH ring topology. This type of topology enables great network flexibility and protection. Figure 2.4 shows the SDH Hierarchy. The SDH frame encapsulates frames belonging to other technologies and therefor inside SDH there are different types of traffic. There are other technologies like Asynchronous Transfer Mode (ATM) and Frame Relay (FR) that are still used in core networks. These technologies usually use SDH by means of encapsulating onto SDH frames.

ATM is a dedicated-connection packet switching technology that organizes digital data into 53-byte cell units and transmits them over a physical medium using digital signal technology. ATM uses quality of service management mechanisms.

Frame relay technology is based on the older X.25 packet-switching technology which was designed for transmitting analog data such as voice conversations but, unlike X.25, frame relay is a fast packet technology, which means that the protocol does not attempt to correct

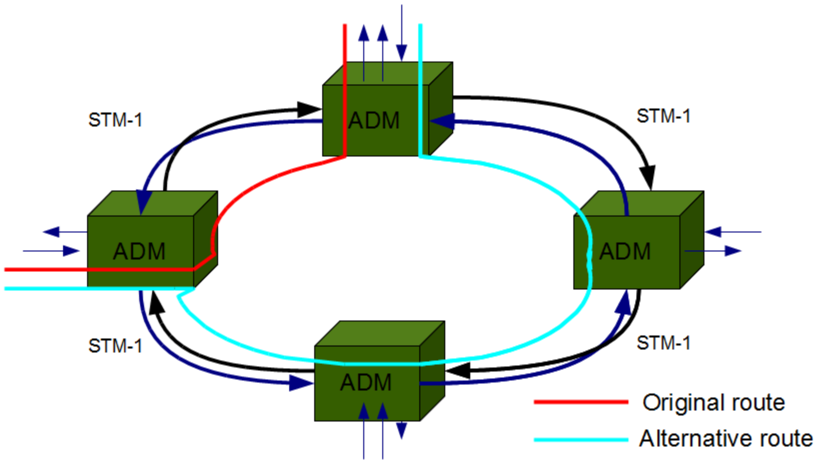

Figure 2.3: Core Network: SDH Ring.[32]

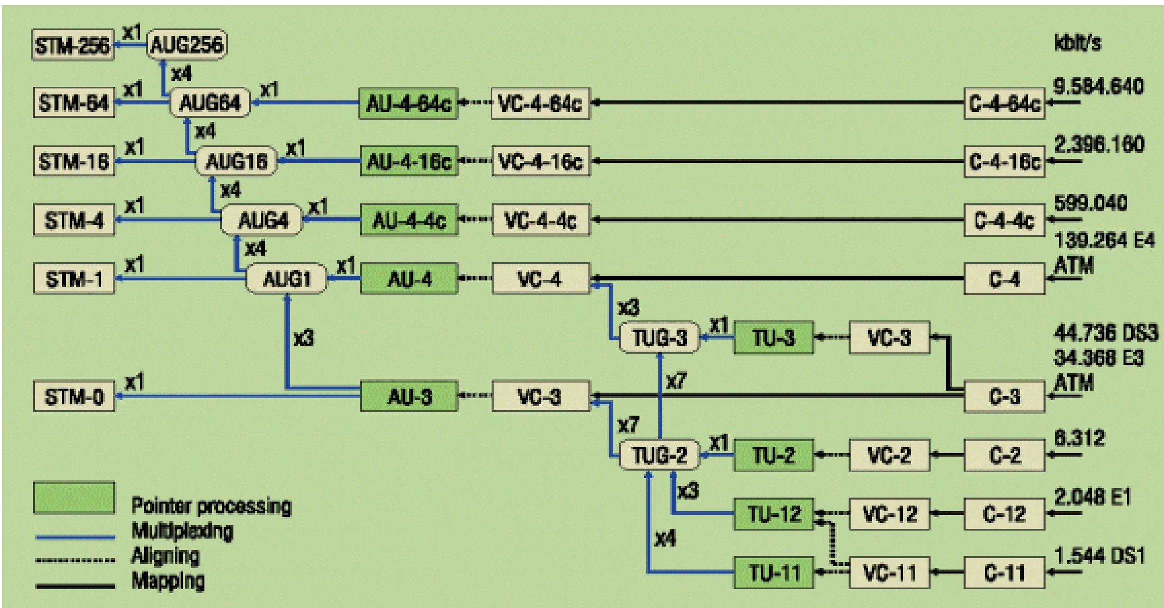

Figure 2.4: Core Network: SDH Hierarchy.[27]

any errors. When an error is detected in a frame, it is simply ”dropped”. The end points are responsible for detecting and retransmitting the dropped frames. Notice that the incidence of error in digital networks is extraordinarily small relative to analog networks.

Multi-protocol Label Switching (MPLS) is another technology used in core networks. MPLS works by initially setting up a specific path for a given sequence of packets, identified by a label put in each packet, thus saving the time needed for a router to look up the address to the next node to forward the packet to. MPLS is called a multi-protocol technology because it works with the IP, ATM, and Frame Relay network protocols. Figure 2.5 shows a AT & T MPLS commercial solution.

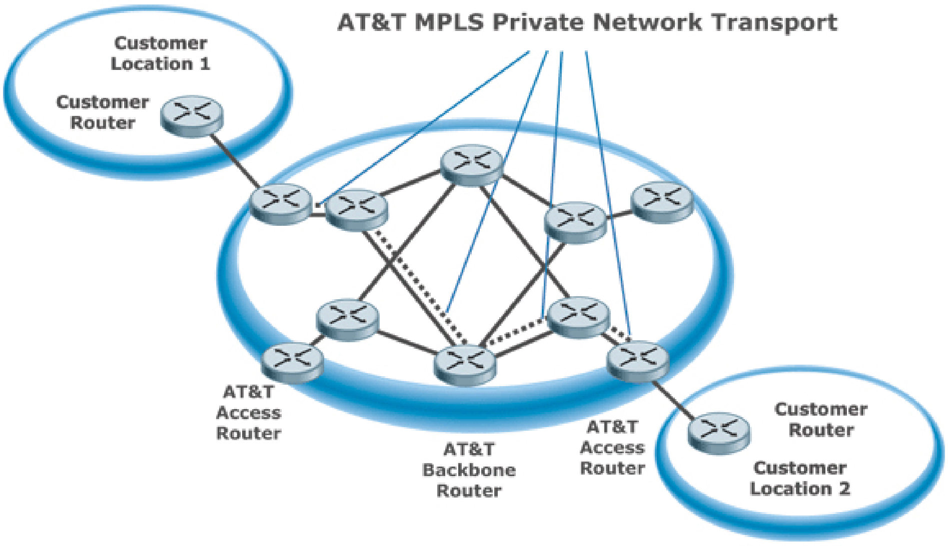

Figure 2.5: Core Network: MPLS AT&T network solution.[98]

2.1.3 Access network

An access network is the part of a telecommunications network which connects subscribers to their immediate service provider. These networks may be wired or wireless, using different types of transmission technologies. Most access network infrastructure is still based on pairs of copper wires and coaxial cables, using analog technology. This telephone inherence is a main cause for lower transmission speeds.

The most common technology on access networks is the x Digital Subscriber Line (xDSL). This technology establishes a dedicated circuit between the customer and the service provider, allowing for higher transmission rates. What began to be mainly voice, soon evolved to a mix of voice plus data thus making traffic equally distributed between the two types. This evolution motivated the coexistence of both data and voice dedicated circuit switching. Initially these switching technologies were analog, but soon became also digital with the arrival of the Integrated Services Digital Network (ISDN) technology.

Cable television access networks are, in most cases, a hybrid network also commonly known as Hybrid Fiber Coaxial Network (HFC) network. Using HFC, a local Community Access Television (CATV) company installs fiber optic cable from the distribution center to serving nodes located close to business and residential users and from these nodes uses coaxial cable to individual businesses and homes.

There are several types of media used in access networks:

- Copper twister wire pairs - Copper media comes in various flavors; being the most common, the twisted pair used in Plain Old Telephone Service (POTS) and DSL networks. Twisted pair cabling also comes in several different categories, the latest being category 6a (Augmented Category 6) - that is defined at frequencies up to 500 MHz (twice that of Cat. 6 cabling) - which is capable of carrying signals used in Gigabit Ethernet.

- Copper coaxial wire - Initially used for CATV, it is now also used for data and voice transmission.

- Wireless - Using radio transmission technologies such as GRAN (GSM Radio Access Network), GERAN (GSM EDGE Radio Access Network), UTRAN (UMTS Radio Access Network), Wi-Fi, WiMAX and LTE.

- Optical fiber - Initially used on core networks due to its high transmission rates, it has been increasingly approaching the customer network. Next Generation Networks (NGN) are to use this type of technology increasingly more.

The choice of technology, obviously, has to take into account bandwidth and distance requirements, and depending on those requirements one may even go for wireless if the requirement includes mobility.

Figure 2.6 shows the components of an optical fiber cable.

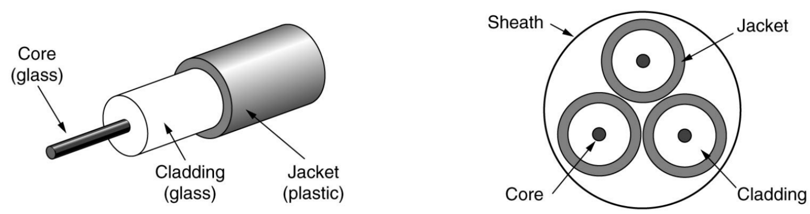

Figure 2.6: Access Network: Optical fiber.[65]

2.1.4 Customer network

Usually, these networks are small and confined to buildings. They establish the connection between the end user and the access network. Choosing the right technology to a customer network will depend on the distance (how far will the network spread), the number of users to be served and last, but not least, the purpose of the network.

These are mainly private managed networks and therefor limited in performance/reliability by the customer knowledge and purchase capacity. The network can be for a fixed telephone service, mobile telephone service, data service, radio broadcast or CATV. In the case of a fixed telephone service, the network uses circuit switching and the transmission is made through a copper twisted pair cable. On mobile telephone networks, the transmission is made through beam antennas to the base station that serves the customer location. Data networks use connectionless package switching through wireless, coaxial or UTP cables. Television networks use beam antennas or CATV coaxial cables. Figure 2.7 shows an example of a customer wired data network.

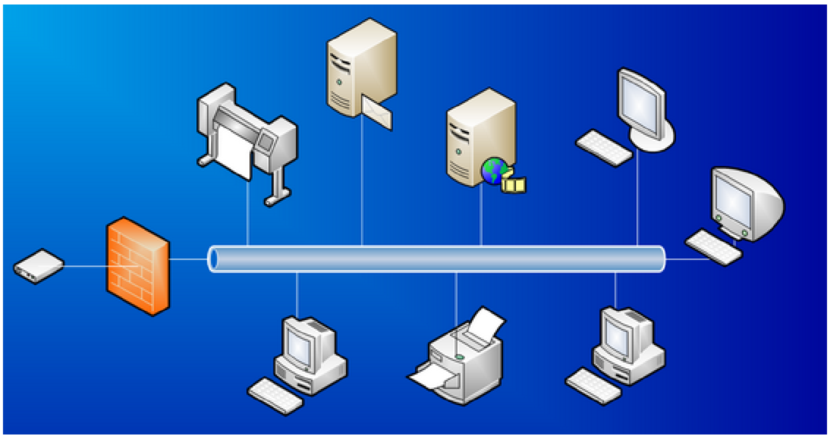

Figure 2.7: A Customer Network.[91]

2.2 Network access technologies

Access networks are under a huge bandwidth demand from users all over the world. This demand is directly related with the growing amount of information available on the Internet and also with the type of information being retrieved. Traffic as migrated rapidly from mainly text and image to cable Video On Demand (VOD), IPTV VOD, file sharing, VoIP, etc. as we can see on a forecast done by Cisco Systems on Figure 2.8 and in a more refined view through Figure 2.9.

As we can see on Figure 2.8, by 2015 total traffic will be 4 times larger than 2010. Amongst the reasons for such an increase in Internet traffic, we have to mention the rise of social networks thus making every one of their users a new Internet content maker i.e. posting and sharing photos, videos, etc.

Figure 2.10 allows us to get an idea on how much Internet traffic/volume of information has increased since 1995. Netcraft says that just between October and November 2011, the number count exceeded 22 million new additions. The number of active sites in Netcrafts survey stands now (November 2011) at 172 million [99].

The increasing number of active websites has a parallel on the number of Internet users. According to ITUs statistical information [84], the number of Internet users worldwide has doubled between 2005 and 2010, surpassing the 2 billion mark at the end of 2010.

The trend is to continue on this path. Not long ago, a simple modem with a (announced) speed of 56kbps would make web browsing a smooth experience and now new applications and services already require double digit Mbps. With the continuous growth of the ICT services worldwide over the last 10 years so does the amount of traffic. Fulfilling consumer bandwidth demand lead to the development of new networks - both access and core.

The ISDN technology started the bandwidth revolution in 1988 at the hands of the then *Comité Consultatif International Téléphonique et Télégraphique* (CCITT) (later renamed ITU - Telecommunication Standardization Sector (ITU-T) in 1992) by integrating both data

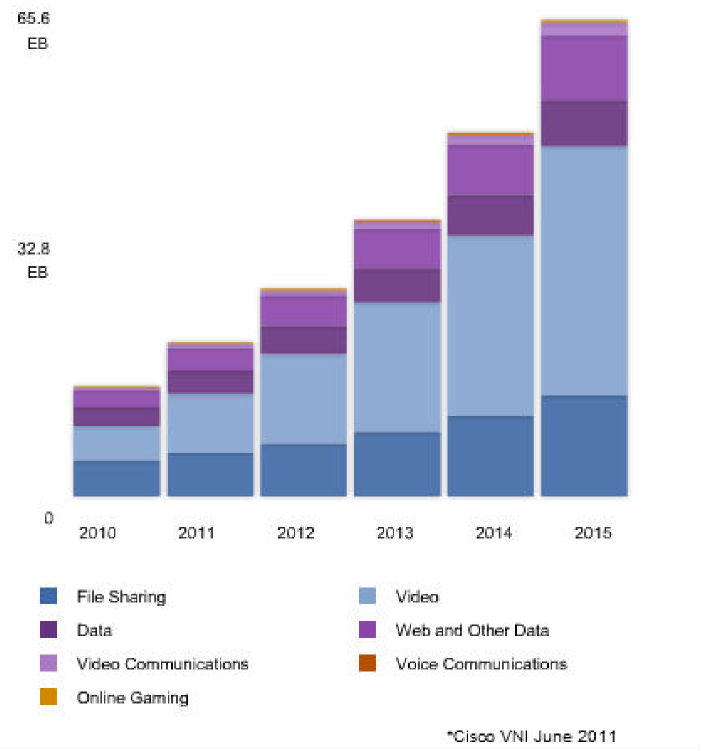

Figure 2.8: Internet consumption forecast 2010-2015.[26]
Units: Exabyte per month

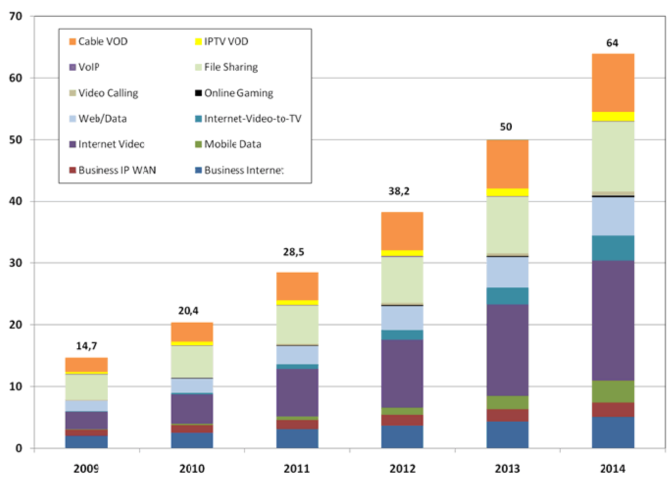

Figure 2.9: Internet consumption forecast per service 2009-2014.[4]
Units: Exabyte per month

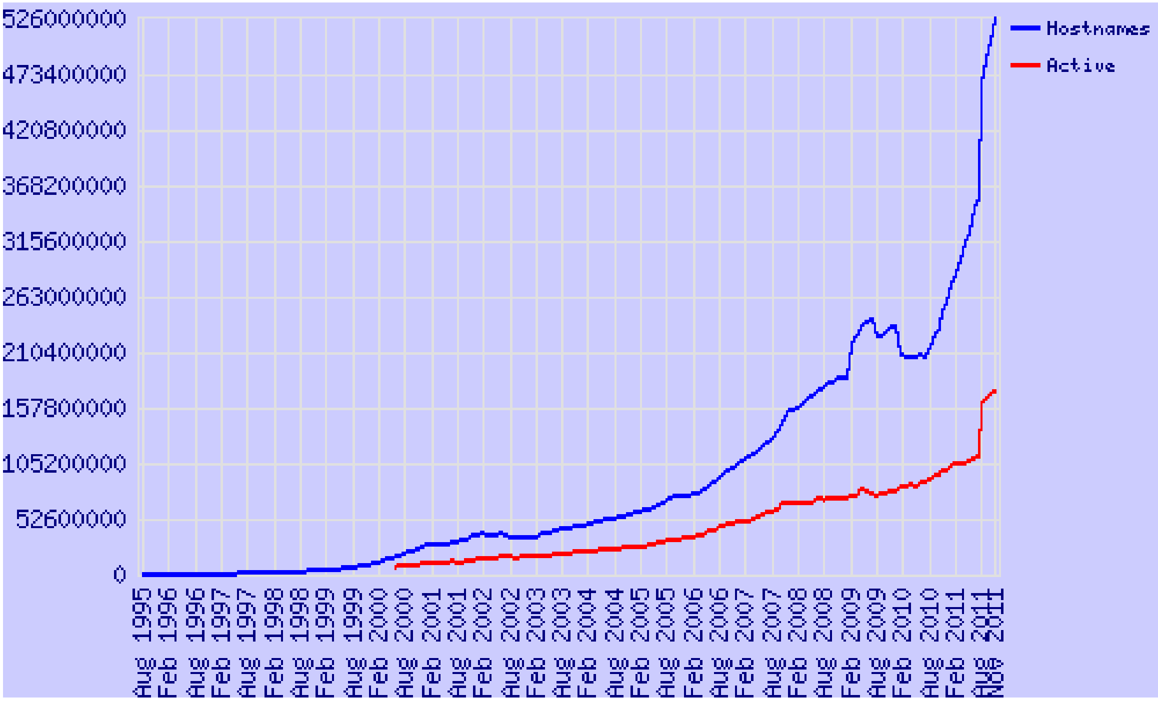

Figure 2.10: Total websites in all domains from August 1995 to November 2011 .[99]

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and voice communication over the same network. ISDN was a set of standards for digital transmission using common copper wiring and other media. For the home/small business user that migrated from a 56kps modem to a Basic Rate Interface (BRI) meant doubling the speed to 128kps (BRI consisted of: 2xB 64kps channels for voice/data + 1xD 16kbps channel for control and signalling information).

2.2.1 Twisted Copper Pair Access Networks

Fixed telephone access network

This network was initially designed to support voice only communications, also known as POTS, and used an infrastructure based on twisted par copper wiring - Public Switched Telephone Network (PSTN). The PSTN is the aggregation of circuit switching networks that has evolved since the first days of Graham Bell and Elisha Gray telephonic experiences in the 1870s. Today this network relies almost completely on digital technology with the exception of the final link connecting the user with its local telephone central.

xDSL

ISDN was the digital switched network technology that first made possible, the improvement of the voice and data transmission over the existing basic analog telephone network. While ISDN technology was an important step towards improving traditional copper lines, xDSL have pushed that bandwidth barrier even further. xDSL refers to the variations of DSL like ADSL, CDSL, DSL Lite, HDSL, IDSL, RADSL, SDSL, UDSL, VDSL, x2DSL, etc. xDSL has had a key advantage of making use of the existing copper network thus not requiring new cabling investment like, for instance, fibre optics.

Asynchronous Digital Subscriber Line (ADSL) began life as way for telephone companies to compete with the upcoming CATV offer, by delivering both TV and telephone services over their installed copper network. The technology was originally designed to work as a normal telephone line even in the event of a power failure. The Asymmetric part of xDSL means that the download link as much more allocated bandwidth than the uplink. As we can see on Figure 2.11, xDSL technologies make a more efficient use of the copper lines as it splits into different frequencies the data and voice channels.

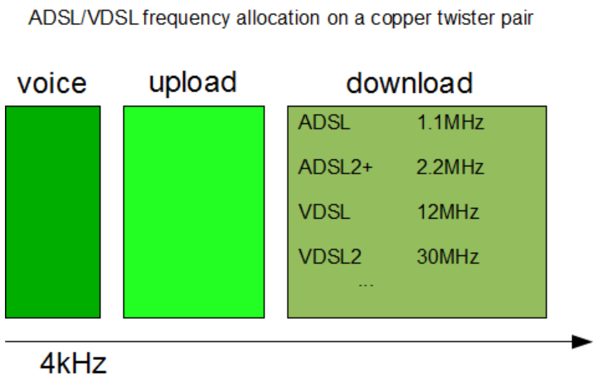

Figure 2.11: ADSL/VDSL frequency allocation

xDSL performance is influenced by the quality, gauge and material (there is some aluminum) of the telephone wire and the distance between the subscriber's equipment and the Digital Subscriber Line Access Multiplexer (DSLAM). The DSLAM splits the voice frequency signals from the high-speed data traffic, controlling and routing the traffic between the subscriber and the network service provider. Still on the subject of performance, since each line functions as a complete circuit to the central office of the operator, the bandwidth does not degrade with the number of subscribers in an area. This alone makes for one of xDSL's stronger points against, for instance, cable and wireless technologies. On this subject, wireless and cable subscribers can suffer from traffic congestion, once the allocated area bandwidth becomes overcrowded.

Although xDSL technology has proven itself to be a serious cable contender, the rate of xDSL deployments has always been dependent on the incumbent's operator will to open the local loop to competition, in a process known as Local Loop Unbundling (LLU).

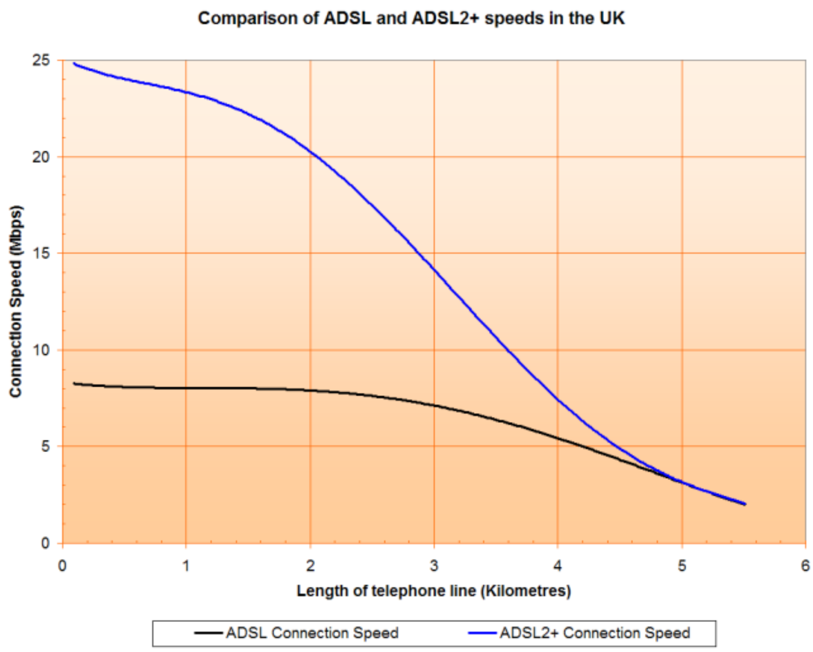

Figure 2.12: ADSL distance vs. rate.[121]

2.2.2 Coaxial access network

HFC

Cable networks were originally designed for video streaming and therefor cable companies would broadcast video over coaxial cabling to the subscriber's residence. These networks, however, have evolved to a multi-service platform, offering not only video signaling but also radio, telephone, internet access, etc. The physical network thus had to move from a broadcast only model to a fully two way network, with separate user communication so privacy would not be compromised. This capacity has been achieved by the use of new set of frequencies between 50 and 860MHz on the downlink and between 5 and 65MHz on the uplink [28]. Each downstream/upstream data channel uses a 6MHz window.

A hybrid fiber coaxial (HFC) network, as the name implies, is a technology in which optical fiber and coaxial cabling are used in different portions of a network, to carry the broadband content referred to earlier. Using HFC as we can see on Figure 2.13, a local CATV operator installs fiber optics from the cable head-end to serving-nodes located close to residential users, and from these nodes uses normal coaxial cable to the subscribers homes.

An advantage of HFC is that some of the characteristics of the fiber optic cable, like low noise and interference susceptibility (apart from the obvious high bandwidth), can be brought closer to the user without having to replace the installed coaxial cable that goes until the subscriber's home.

As with all networks, so has HFC continuously being upgraded to enhance the service offering and to increase capacity and efficiency. The most recent technology that cable operators are introducing is Data Over Cable Service Interface Specifications (DOCSIS) 3.0, released in 2006 by the CableLabs Consortium. DOCSIS specifies methods for transporting data over CATV networks using QAM and/or QPSK RF modulation techniques. A DOCSIS archi-

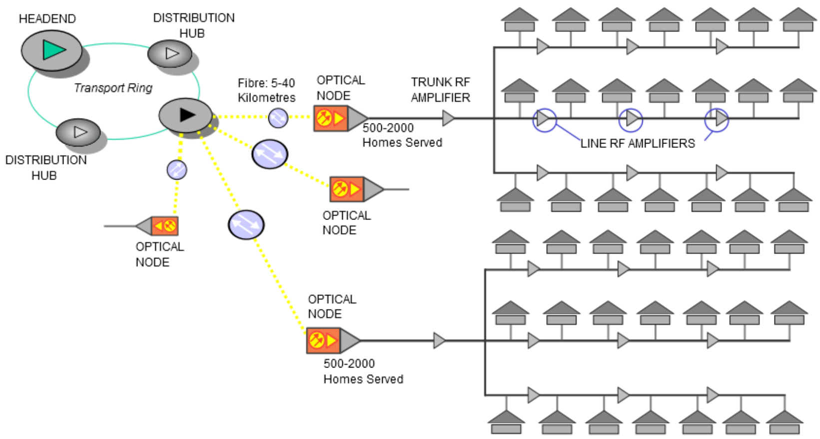

Figure 2.13: HFC Network Diagram.[149]

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tecture includes two primary components: a cable modem (CM) located at the subscriber's location, and a cable modem termination system (CMTS) located at the CATV head-end. Cable systems supporting on-demand programming, use a hybrid fiber-coaxial system. Fiber optic lines bring digital signals to the nodes in the system where they are converted into RF channels and modem signals on coaxial trunk lines, making it a point-multipoint communication system between the CMTS and the subscribers CMs. The CMTS is similar in function to a DSLAM used in xDSL systems. The number of users served by a node will have to take into consideration: thermal noise, ingress noise, common path distortion, etc [92].

2.2.3 Wireless access networks

It all began in the early summer of 1895, when Marconi was first to transmit a signal that was received at a distance of about 2km, despite a hill in its path [93].

Wireless communications is the fastest growing segment of the telecom industry. From the cellular systems that made the cellular phone a part of ones life to the WLANs that have replaced/complemented many wired networks in homes and businesses. Wireless networks make use of radio waves to transmit information and since the media is very sensible to radio-electric noise, the technology must rely heavily on error detection techniques.

GSM/GPRS

Global System for Mobile communications (GSM) is a digital mobile telephone system that is most commonly used in Europe. GSM uses a variation of Time Division Multiple Access (TDMA) and it is the most widely used of the three digital wireless telephony technologies (TDMA, GSM, and CDMA). GSM digitizes and compresses data before sending the information on a channel. Compared with the previous analog systems, GSM brought improvements concerning quality, safety and reliability. The system operates at either the 900 MHz or 1800 MHz frequency bands. General Packet Radio Service (GPRS) is a packet-based wireless communication service based on GSM communication and complements existing services such circuit-switched cellular phone connections and Short Message Service (SMS). Therefor, after the introduction of GPRS, there are two distinct networks operating at the same time:

GSM using circuit switching manages voice communication, and GPRS using packet switching handles the data communication. Speed for the GPRS data transmission may go up to 114kbps.

UMTS

Universal Mobile Telecommunications System (UMTS) is a third-generation (3G) broadband technology. It features packet-based transmission of text, digitized voice, video, and multimedia, at data rates up to 2Mbps. UMTS is the natural evolution of GSM and GPRS technologies in the sense that improves the other two significantly and allows for the coming of new services like video conference and Internet Protocol Television (IPTV). Previous cellular telephone systems (like GSM) were mainly circuit-switched and that meant connections were always dependent on circuit availability, whereas a packet-switched connection using the Internet Protocol (IP), means that a virtual connection will be always available to any other end point in the network.

HSPA

High-Speed Packet Access (HSPA) is a set of technologies that defines the migration path for 3G/WCDMA operators worldwide. Standardized by the 3GPP, HSPA uses the FDD transmission scheme and includes the variants: HSDPA (High Speed Downlink Packet Access), HSUPA (High Speed Uplink Packet Access) and HSPA Evolved. Unlike its predecessor (UMTS), HSPA provides very efficient voice services in combination with mobile broadband data, thus filling the UMTS broadband gap allowing the user to enjoy speeds of at least 1Mbps on the uplink and 14.4 Mbps on the downlink. HSPA Evolved introduces Multiple-Input, Multiple-Output (MIMO) capabilities and higher order modulation (64QAM), enabling greater throughput speeds of up to 21Mbps on the downlink.

LTE

Long Term Evolution (LTE) is a 4G wireless broadband technology developed by the 3GPP and it represents the next step in a progression from GSM, a 2G standard, to UMTS, the 3G technologies based upon GSM. LTE provides significantly increased peak data rates, with the potential for 100 Mbps downstream and 30 Mbps upstream, reduced latency, scalable bandwidth capacity, and backwards compatibility with existing GSM and UMTS technology. The upper layers of LTE are based upon TCP/IP, which will likely result in an all-IP network similar to the one we already have on our wired communications. LTE supports mixed data, voice, video and messaging traffic. LTE uses OFDM (Orthogonal Frequency Division Multiplexing) and MIMO (Multiple Input Multiple Output) antenna technology, similar to that used in the IEEE 802.11n wireless local area network (WLAN) standard. The higher signal to noise ratio (SNR) at the receiver enabled by MIMO, along with OFDM, provides improved coverage and throughput, especially in dense urban areas where signal is harder to propagate.

Although LTE aims for an all-IP simplified infrastructure, in reality LTE must be able to work with 3G networks, Internet Multimedia Subsystems (IMS), and other pre-existing elements as seen on Figure 2.14. This backwards compatibility with installed technologies will affect most the radio access network and the packet core network. Therefor the LTE Network consists of several updates and/or replacements for many of the components already

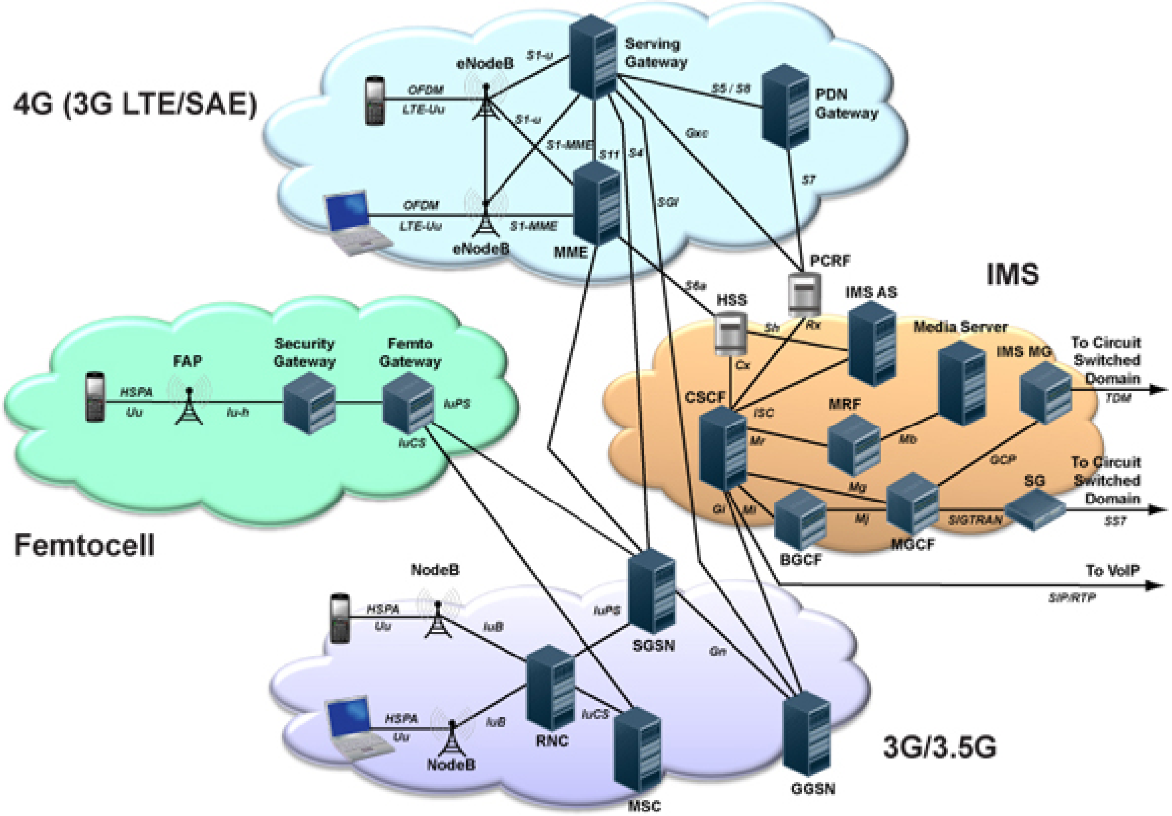


Figure 2.14: The 3G and LTE Network.[85]

deployed onto the wireless network. Using once more the Figure 2.14 we have for example [85]:

- eNodeB replaces the 3G base-station NodeB, to accommodate the change to E-UTRAN (Evolved UTRAN/RAN) from the older standard in the 2G and 3G Radio Access Networks.
- EPC (Evolved Packet Core, known also as SAE, System Architecture Evolution) replaces the General Packet Radio Services (GPRS) core network.
- The SAE Gateway is a new element that acts as a Serving Gateway and a Packet Data Network Gateway to handle traffic and data-plane aspects.
- Diameter signaling replaces SS7 signaling in the Home Subscriber Server (HSS), an existing element which is used by the new MME (Mobility Management Entity) node.

Wi-Fi

The Wi-Fi technology was first developed in order to allow low range on site communications i.e. subscribers houses or small businesses. Wi-Fi is a term, created by the Wi-Fi Alliance, for certain types of wireless local area networks (WLAN) that use specifications in the 802.11 family. The Wi-Fi Alliance oversees tests, that certify new products interoperability. Once a product passes all tests, the alliance grants a label "Wi-Fi certified" to the individual product. The wired LAN has been replaced by Wi-Fi in all kind of places, from homes to hotels, from schools to airports. The range varies from about 46m (150feet) indoors and 92m (300feet) outdoors. In terms of speed, 802.11n networks support approximately 300 Mbps of rated (theoretical) bandwidth under optimal conditions. Under "normal use" conditions the same 802.11n network will, unfortunately, operate at much lower speeds (130 Mbps or less). Speed will naturally depend on the quality of the antenna, the walls on the building, other objects on the way, etc. Unfortunately, the sad story does not end here since all users will share the same resource, thus making the speed of each link inversely proportional to the number of users. This technology is not used as an Access Network due to its lack of power (unlicensed spectrum), but is viewed as a complement to any Access Network.

WiMAX

Worldwide Interoperability for Microwave Access refers to the 802.16 standard developed by the IEEE to provide a broadband wireless access (BWA) coverage of up to 50km for fixed stations and 5-10 km for mobile stations. WiMAX is an IP based wireless broadband access technology that provides similar performance to 802.11/Wi-Fi networks with the coverage and quality of service of a cellular network. WiMAX operates in the 2 to 66 GHz range and enables connectivity without a direct line-of-sight to a base station. It provides shared data rates up to 70 Mbps.

Like the Wi-Fi, many factors affect range for any WiMAX broadband wireless product. Some of the factors include the terrain and density/height of tree cover; Hills and valleys that can block or partially reflect signals; rivers and lakes because are highly reflective of RF transmissions; the RF shadow of large buildings as they create dead spots directly behind them (particularly if license-free spectrums are being used i.e. Wi-Fi). Also like the Wi-Fi, all users share the same bandwidth, which means that the speed of each link gets inversely proportional to the number of users.

Wireless networks offer some good advantages over wired ones in terms of mobility, costs and flexibility but on the other hand these networks have problems when carrying big chunks of information over longer distances. These constraints cause wireless networks the inability to compete head-to-head with the most advance wired networks. They have however an important role in getting connectivity to remote areas, where wired networks are yet not installed or are too expensive to deploy. One can see that phenomenon on a larger scale with the adoption of WiMAX by some developing countries which have no previous broadband infrastructure [150].

2.2.4 Optical Fiber Access Network

The optical fiber network has been seen as a sort of ”holy grail” of the telecom industry for at least 20 years when, in 1990, Bell Labs was able to transmit a 2.5Gbps signal over a 7500 km section without the need for regeneration [44]. The goal ever since, has been getting the fiber to the subscribers homes thus delivering the promised high quality of service on voice and data.

FTTx

Fiber to the x is a generic term to describe any broadband architecture replacing all or part of the traditional local loop with optical fiber technology. The ”x” stands for the various possible fiber deployments: Fiber to the Home (FTTH), Fiber to the Building (FTTB), Fiber to the Premisses (FTTP), Fiber to Curb/Cabinet (FTTC) and Fiber to the Node (FTTN).

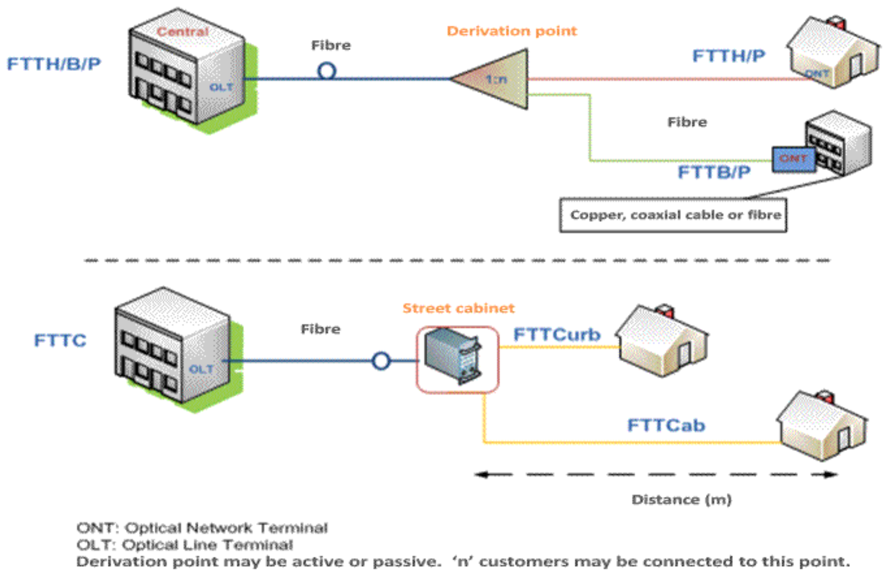


Figure 2.15: Struture of FTTH/B/P and FTTC.[5]

The first two definitions (FTTH/FTTB) were standardized in 2006 by the FTTH Councils for Europe, Asia and North America. The other definitions are not standardized but are commonly used by the industry.

- FTTH - *Is defined as a communications architecture in which the final connection to the subscriber's premises is Optical Fiber. The fiber optic communications path is terminated on or in the premise for the purpose or carrying communications to a single subscriber. In order to be classified as FTTH, the access fiber must cross the subscriber's premisses boundary and terminate:*

  - *(a) inside the premisses,or*
  - *(b) on an external wall of the subscriber's premisses, or*
  - *(c) not more than 2m from an external wall of the subscriber's premisses*

  [40]. This is the most expensive solution as the fiber goes directly to the subscriber without making any use of possible previously deployed networks.

- FTTB - *Is defined as a communications architecture in which the final connection to the subscriber's premisses is a communication medium other than fiber. The fiber communications path is terminated on the premisses for the purpose of carrying communications for a single building with potentially multiple subscribers. It is implicit that in order to be classified as FTTB, the fiber must at least:*

  - *(a) enter the building, or*
  - *(b) terminate on an external wall of the building, or*
  - *(c) terminate no more than 2m from an external wall of the building, or*
  - *(d) enter at least one building within a cluster of buildings on the same property, or*
  - *(e) terminate on an external wall of one building within a cluster of buildings on the same property, or*
  - *(f) terminate no more than 2m from an external wall of on building within a cluster of buildings on the same property.*

  [40]. This architecture is almost as expensive as the FTTH in the sense that the fiber reaches the building and only inside it is used a non optical network (copper/coaxial).

- FTTN/FTTCab - This concept is not defined by the FTTH Councils. In general, it refers to a system in which fiber is extended to a street-side or on-pole cabinet. The FTTH North America Council mentions distances within approximately 300m to 1500m of the average user. From that point forward, installations are to use xDSL technology or Ethernet (over copper or wireless) until it reaches the user [41].

- FTTCurb - This concept is also not defined by the FTTH Councils. They state that it is similar to FTTN with the exception that the fiber is brought much closer to the user's premises - *typically closer than approximately 300m and often closer than 1500m.* FTTC installations are to use either xDSL or Ethernet (over copper cable or wireless) to bring the signal from the fiber termination point (curb) to the user [41].

As we can see on Figure 2.15 FTTCurb and FTTN/FTTCab only differ on the distance to where the street cabinet is located.

These networks can be deployed using the following architectures:

1. ”Point-to-Point” architecture, comprises: one OLT port per one subscriber fiber. This means that for each subscriber there will be one laser transmitter and another receiver thus all the bandwidth provided to that fiber by the OLT will be available to that subscriber as seen on Figure 2.16.

2. ”Point-to-Multipoint” architecture, comprises: one OLT port for each N subscribers and is subdivided into Active Ethernet and PON networks as seen on Figure 2.17.

3. ”Ring” architecture provides a sequence of optical fiber paths in a closed loop that connects several communication nodes as seen on Figure 2.18.

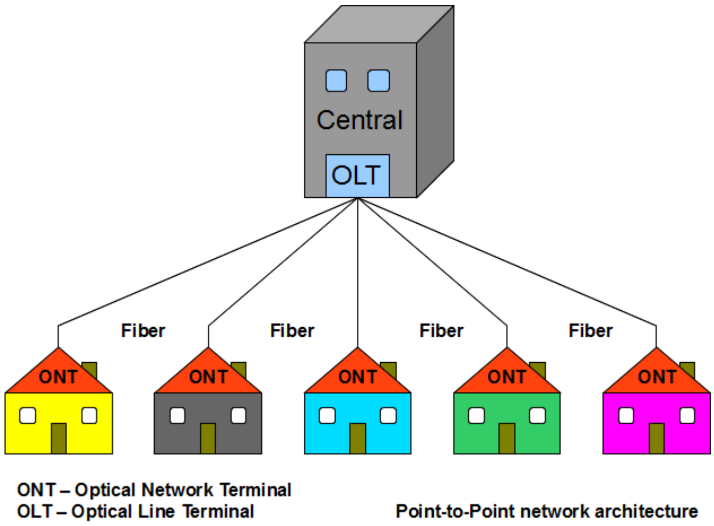


Figure 2.16: FTTH Point-to-point network architecture

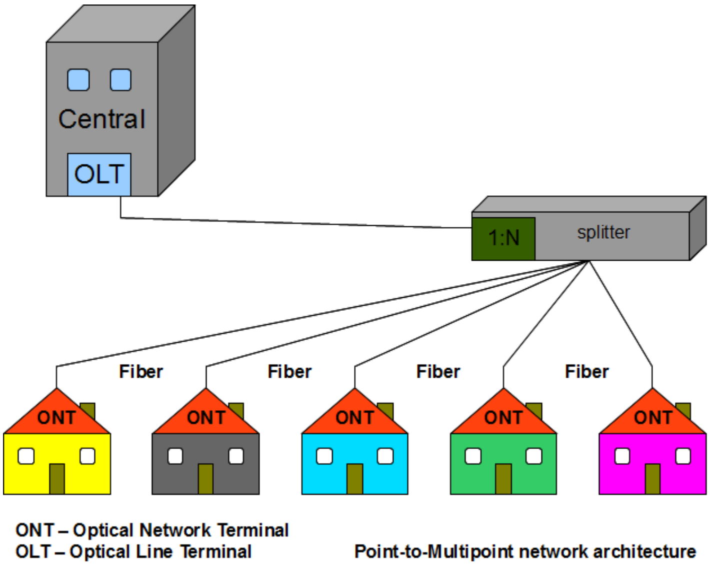


Figure 2.17: FTTH Point-to-multipoint network architecture

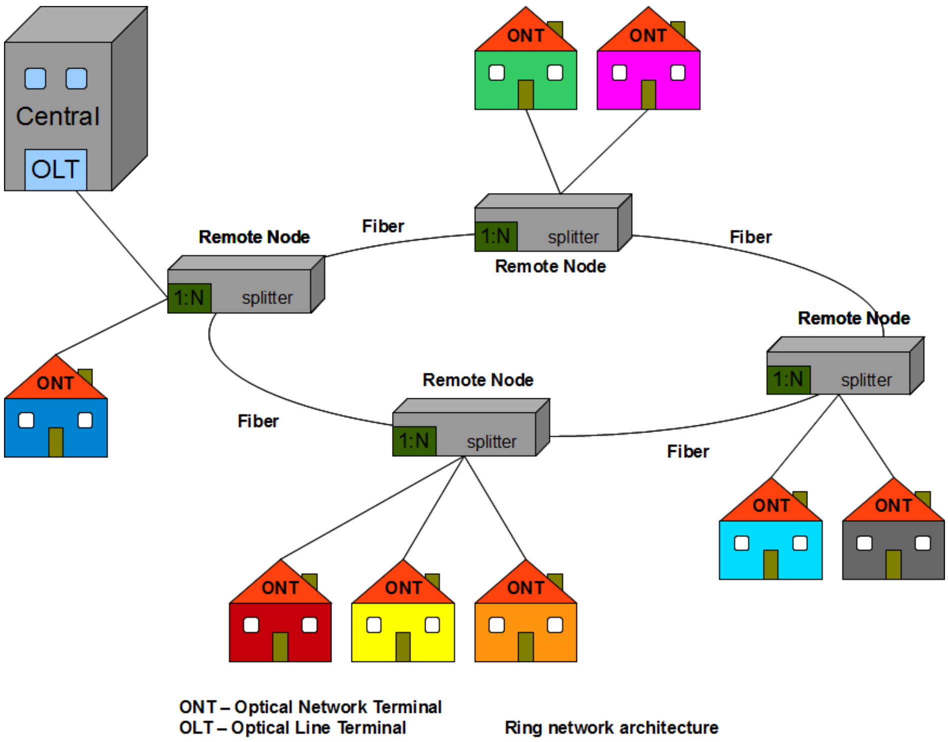


Figure 2.18: FTTH Ring network architecture

Global technology overview

The Figure 2.19 sums up the several network technologies and transmission medias available on market as well as their capabilities. It is clear to see how closer wireless technology has came, in terms of performance, to what the best wired technology can offer.

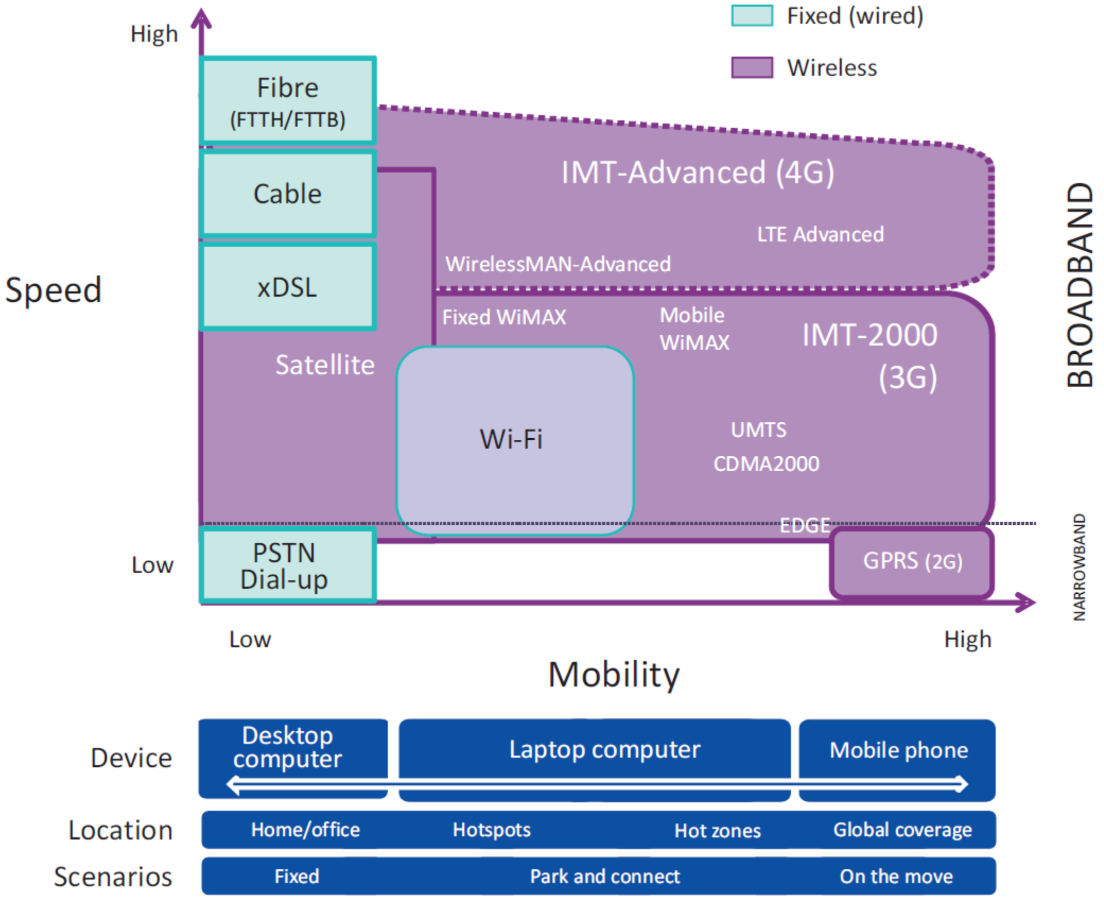


Figure 2.19: ITU - broadband technologies 2011.[76]

2.3 The mobile telecommunications service

Figure 2.20: Mobile phone user, Chicago, Il, 1947.[15]

The MTS is, by definition, a public communications service that allows signal transmission through core terrestrial networks. The subscribers access is made through a non-fixed type of system, using radio-electric propagation through the air.

The MTS was first introduced to the market in 1946, just after World War II, in the US and its purpose was to allow car drivers, access to a public fixed network as depicted in Figure 2.20 [15]. In those days, there were only a few channels available and the calls were set up by a human operator.

Twenty years later, a new system called Improved Mobile Telephone Service (IMTS) developed by Bell System, introduced some improvements like direct dialing and a higher bandwidth. The first analog cellular systems that were based on that technology came out between the late 1960s and early 1970s.

2.3.1 First Generation

The first generation (1G) analog system for mobile communications saw two key improvements during the 1970s that were, the invention of the microprocessor and the digitization of the control link between the mobile phone and the cell site. The appearance of the ”cellular” nomenclature was due to the fact that coverage areas were split into smaller ones or ”cells” that used low power receivers/transmitters [70].

Still, the big boom for MTS came with the introduction of the Advanced Mobile Phone System (AMPS) in 1981. This technology allowed users to continue their conversations seamlessly as they passed from cell to cell. AMPS used Frequency-division Multiplexing (FDM), a technology in which each mobile phone call would use separate frequencies or channels.

2.3.2 Second Generation

The Second generation (2G) digital cellular systems were first developed at the end of the 1980s. 2G technologies can be divided into two main groups: TDMA-based and Code Division Multiple Access (CDMA)-based, depending on the type of multiplexing they use. The main standards are:

- GSM - A TDMA based system developed in Europe in the 1980's through a pan-European initiative, involving the European Commission, equipment manufacturers and telecom operators. The European Telecommunications Standards Institute (ETSI) was the responsible for the standardization. Mobile services based on GSM technology were first launched in Finland in 1991.

- Integrated Digital Enhanced Network (iDEN) - A Motorola proprietary network used by Telus Mobility in Canada and Nextel in the US. It was also TDMA based.

- Digital AMPS (D-AMPS) - Also known as IS-136 (Interim standard-136) from Electronics Industries Association / Telecommunication Industries Association (EIA/TIA). Another TDMA based system.

- Personal Digital Cellular (PDC) - A TDMA based system that was developed and deployed in Japan in 1994. By November 2001 there were over 66 million PDC subscribers in Japan.

- Code Division Multiple Access One (CDMAOne) - It was a CDMA based technology also known as ITU IS-95. It was first commercially deployed in North America and South Korea.

There was also the Personal Handy-phone System (PHS), which was a digital system used in Japan and that came to market in 1995, seen as a cheaper alternative to cellular systems. Its technology lay somewhere between cellular and cordless. It had an inferior coverage area and limited usage on moving vehicles. Japan had, by November 2001, 5.68 million PHS subscribers [78].

2.3.3 "2.5" Generation

Although the terms "2G" and "3G" are officially defined, the term "2.5G" was created only for marketing purposes. The term 2.5G was seen as a stepping stone between the second and third cellular wireless technologies. The term is used to describe second generation systems which have added a packet switched domain to the existing circuit switch. 2.5G offers some of the benefits of 3G - like packet-switching - without changing the existing 2G infrastructure in GSM and CDMA networks. GPRS is a commonly known technique to achieve faster transmission rates and it was the precursor for 3G.

2.3.4 ”2.75” Generation

Just before 3G, came another marketing word. This time it was the ”2.75G”. Protocols like Enhanced Data GSM Environment (EDGE) for GSM and CDMA2000 qualified as 3G services, mainly because they had a data rate above 144Kbps, but since they were still under the ”true” 3G service speeds, the term ”2.75G” appeared.

2.3.5 Third Generation

The 3G mobile phone technology promised the ability to transfer both voice and non-voice data such as information downloading, email exchange and instant messaging.

It was in the mid-1980s that the concept for International Mobile Telecommunications - 2000 (IMT2000), ”International Mobile Telecommunications”, was born at the International Telecommunication Union (ITU) as the third generation system for mobile communications. One of its key visions was to provide seamless global roaming, and to enable users to move across borders while using the same number and handset. The system envisaged a platform for distributing converged fixed, mobile, voice, data, Internet and multimedia services.

After over ten years, came a unanimous approval of the technical specifications for third generation systems under the brand IMT-2000. The entire telecommunication industry gave a concerted effort to avoid the fragmentation that had before characterized the mobile market and this meant that for the first time, full interoperability and interworking of mobile systems could finally be achieved. The standard was the result of collaboration of many entities inside and out the ITU scope. Among those entities were ITU-Radiocommunication Sector and ITU-Telecommunication Standardization Sector, 3GPP, 3GPP2, Universal Wireless Communication Consortium (UWCC) and others[72].

The IMT-2000 had the following goals:

- Affordable - The industry agreed that in order to obtain the general adoption of 3G systems, they would undoubtedly have to be affordable both to operators and consumers.
- Flexible - In order to reduce costs, the telecom industry wanted to avoid having to deal with a wide range of interfaces and technologies. This concern came in a time when the mobile industry saw the spread of mergers, consolidations and the expansion of business to new foreign markets. The standard issued these problems by proposing a flexible system, able to support a wide range of services and applications. Five radio interfaces were possible within the standard, all of which based on just three different access technologies: CDMA, TDMA and Frequency Division Multiple Access (FDMA).
- Scalable - The new systems had to be able to expand easily and at a low cost in order to accommodate new services, users and coverage areas.
- Legacy - The new standard had to ensure backward compatibility of services with legacy systems. 2G systems would continue to exist in some parts of the world and there was the need to assure a seamless migration to the new standard.

Like in so many good histories, what at first were good intentions soon came to an end. The 3G world was supposed to be a single and unified one, but ended up being split into three different areas.

- UMTS - The European term for the 3G mobile cellular systems based on the Wideband CDMA (WCDMA) standard. (The Freedom of Mobile Multimedia Access (FOMA) -

was NTT DoCoMo brand name for its 3G service and although the system was also based on the WCDMA standard, it was not compatible with UMTS.)

- Code Division Multiple Access 2000 (CDMA2000) - A CDMA version of ITUs IMT-2000 standard. Based on Qualcomm technology, it was first launched in South Korea by SK Telecom.
- Time Division Synchronous Code Division Multiple Access (TD-SCDMA) - It is a less known standard developed by the China Academy of Telecommunications Technology (CATT) in collaboration with Datang and Siemens. It combines TDMA with a synchronous-mode CDMA component.

2.3.6 "3.5" Generation

3.5G is another marketing created term, to name the use of HSPA set of technologies which include High-Speed Downlink Packet Access (HSDPA), High-Speed Uplink Packet Access (HSUPA) and High-Speed Packet Access Evolved (HSPA Evolved)/HSPA+.

2.3.7 Fourth Generation

The fourth generation is composed of two main standards: WiMax and LTE.

The LTE is a 4G wireless broadband technology developed by 3GPP. The name "LTE" came as it was seen as the next step in the mobile network technology succeeding the 2G GSM/EDGE and the 3G UMTS/HSxPA network technologies. The need for a new standard came from more demanding services and applications, and LTE provides for such demand by offering increased peak data rates, potentially up to 100Mbps on downstream and 30Mbps upstream.

Technically, LTE incorporates MIMO combined with Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink and Single Carrier FDMA in the uplink to provide high levels of spectral efficiency, coupled with major improvements in capacity and reductions in latency. It supports channel bandwidths from 1.4 MHz to 20 MHz and both FDD and TDD operation. On December 14^{th} 2009, TeliaSonera became the first mobile operator worldwide to commercially deploy 4G/LTE services in both Sweden and Norway.[119]

The LTE-Advanced is an upgrade to LTE technology. The targeted peak data rate is 1Gbps.[58] It is able to increase data rates by incorporating higher order MIMO antenna techniques and allowing multiple carriers to be bonded together into a single stream. LTE-Advanced also intends to use other innovations including the ability to use non-contiguous frequency ranges, with the intent that this will alleviate frequency range issues in an increasingly crowded spectrum, self back-hauling base station and full incorporation of FemtoCell (femtocell) using Self-Organizing Network techniques.

Worldwide Interoperability for Microwave Access (WiMAX) is also a 4G wireless broadband technology but based upon the IEEE 802.16 standard. The IEEE 802.16 standard was developed to deliver non-line-of-sight (LoS) connectivity between a subscriber station and base station with typical cell radius of three to ten kilometers.

LTE vs WiMAX

Although both LTE and WiMAX use the OFDMA air interface, there are some advan-

Figure 2.21: HTC ThunderBolt 4G - Verizon Network (US): CDMA 800/1800 MHz EvDO rev.A, LTE 700 MHz.[62]

Figure 2.22: HTC EVO 4G - Sprint Network (US): CDMA 800/1900 MHz EvDO Rev.A, WiMAX (802.16e).[62]

tages/disadventures from both sides. In Robb Henshaw's article "Why the WiMAX vs. LTE Battle Isn't a Battle" [64] he claims that the 4G future is not the kingdom of one sole technology and that therefor WiMAX and LTE are to walk together. This author foresees four possible scenarios:

1. At location A, where people will have only access to WiMAX;
2. At location B, where people will have only access to LTE;
3. At location C, where people will have the choice of either one, since both are available.
4. At location D, where people will have WiMAX as a wireless backhaul - making the connection with the core - and LTE providing the access.

The main idea being that both technologies will have to coexist in the global market, and apparently he is right.

The 4G Race

Figure 2.23: LTE vs WiMAX

Deployment

WiMAX got to market first and that has given it a small edge. This is specially seen in countries which do not have a previously installed GSM network, mainly because LTE has backward compatibility with existing GSM technology.

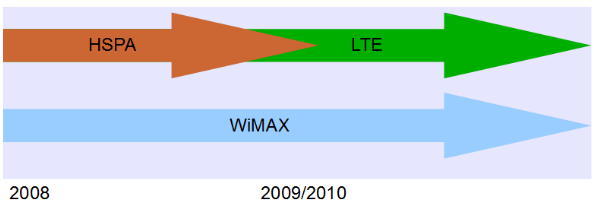


Figure 2.24: LTE vs WiMAX - Commercial Deployment

WiMAX - World Status

The map on Figure 2.25 includes several levels of deployment status: In Deployment, In Service, Licence Awarded and Planned. The map shows WiMAX per operator.

LTE - World Status

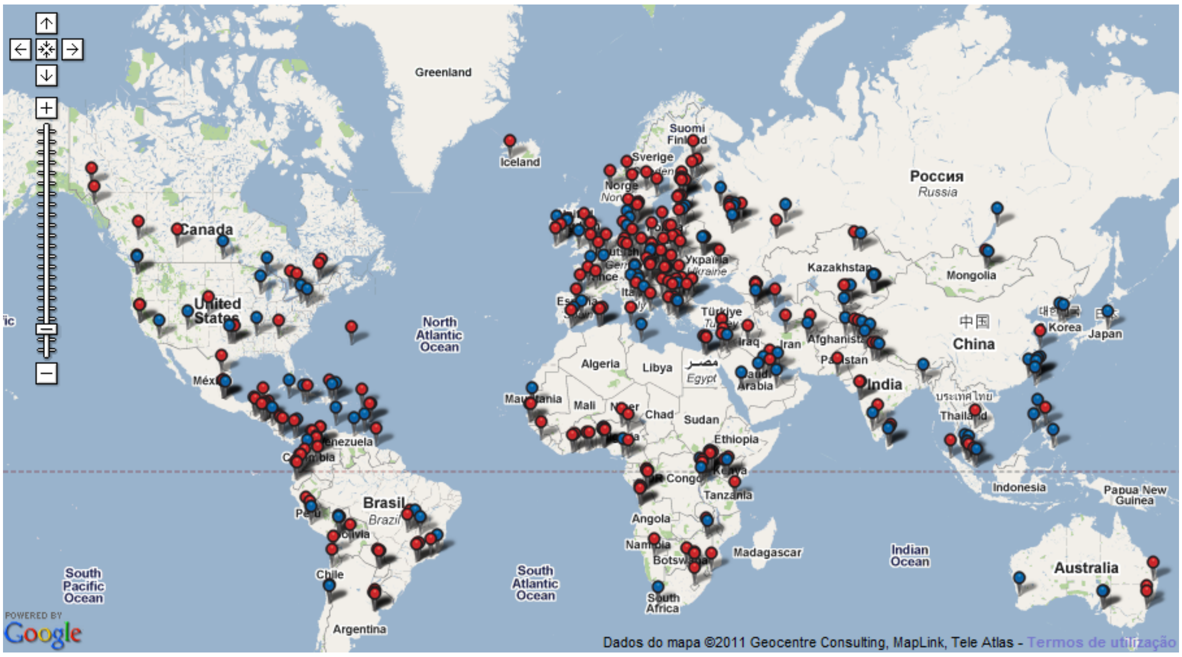


Figure 2.25: WiMAX - World Status, January 2011.[150]

Figure 2.26: LTE - World Status, 2011.[90]

The map on Figure 2.26 shows global LTE deployments commitments, stating and quote [90]: *"It includes a variety of commitment levels including intentions to trial, deploy, migrate, etc."* The blue markers on the map show actual deployments and red ones show commitments. From the next map, we can obtain a more precise view of the LTE deployment status.

After seeing the WiMAX map on Figure 2.25 and comparing it with the map on Figure

2.26, we confirm the edge deployment of WiMAX over LTE, the idea that both technologies will coexist and that Africa will be the only continent that has clearly preferred just one technology. Until the 11^{th} May 2011 there were 20 commercially active LTE networks in 14 countries [45]. It is easy to see that Africa is biased towards WiMAX technology.

Country	Operator	Launched
Norway	TeliaSonera	15.12.09
Sweden	TeliaSonera	15.12.09
Uzbekistan	MTS	28.07.10
Uzbekistan	UCell	09.08.10
Poland	Mobyland & CenterNet	07.09.10
USA	MetroPCS	21.09.10
Austria	A1 Telekom Austria	05.11.10
Sweden	TeleNor Sweden	15.11.10
Sweden	Tele2 Sweden	15.11.10
Hong Kong	CSL Limited	25.11.10
Finland	TeliaSonera	30.11.10
Germany	Vodafone	01.12.10
USA	Verizon Wireless	05.12.10
Finland	Elisa	08.12.10
Denmark	TeliaSonera	09.12.10
Estonia	EMT	17.12.10
Japan	NTT DoCoMo	24.12.10
Germany	Deutsche Telekom	05.04.11
Philippines	Smart Communications	16.04.11
Lithuania	Omnitel	28.04.11

Table 2.1: LTE - Commercial LTE network launches, May 2011.[45]

Region	Deployments	Countries
CALA	120	33
Africa	117	43
Asia-Pacific	98	23
Eastern Europe	86	21
Western Europe	77	18
North Anerica(USA/Canada)	56	2
Middle East	29	10

Table 2.2: WiMAX - Commercial WiMAX network launches, May 2011.[147]

When compiling the data from Table 2.2 and Table 2.1 into a new one 2.3, it becomes possible to compare the global presence of both technologies. WiMAX does have a leading edge over LTE.

Region	Countries	
	LTE	WiMAX
CALA	0	33
Africa	0	43
Asia-Pacific	4	23
Eastern Europe	2	21
Western Europe	8	18
North America(USA/Canada)	1	2
Middle East	0	10

Table 2.3: WiMAX vs. LTE - Global commercial presence, May 2011.[147][45]

Technology advantages and drawbacks

LTE Advantages:
It has the advantage of being backwards compatible with existing GSM and HSPA networks, enabling mobile operators deploying LTE to continue providing a seamless service across LTE and existing deployed networks.

WiMAX Advantages:
"A single upgrade move to WiMAX technology's all IP architecture is a direct step to 4G. It can provide a less costly long term approach compared to LTE and HSPA+ and also provides a significant Time to Market advantage"[146].

LTE disadvantages:
It is seen as a more expensive alternative on the long run. As seen by some WiMAX supporters: *"LTE is not a simple 3G upgrade as LTE represents a major upgrade from CDMA-Based HSPA (or EvDO); it is not and never was a "simple" software upgrade"*[146].

WiMAX disadvantages:
The most disadvantage of WiMAX is its installation and operational cost. Due to heavy structure, tower, antennas, etc., makes the WiMAX network a collectively high cost network.

2.3.8 Global technology overview

We can see on Figure 2.27, a comparison between the existing broadband technologies, wired and wireless, available and its forecast until 2015. The speeds exemplified are the current maximum values achieved under ideal conditions, i.e. good propagation conditions, reduced network load and a low retention rate. As for cable and wireless networks, speeds are shared among multiple users connected to a given "cell". Notice the gap between FTTH and LTE.

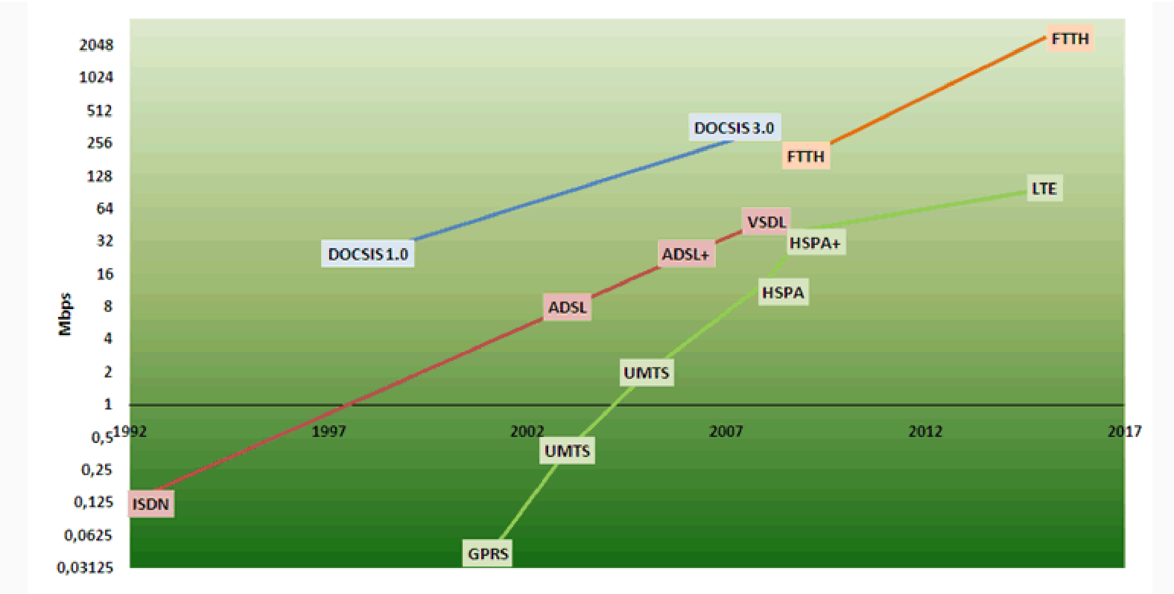


Figure 2.27: Evolution in fixed and mobile access networks.[9]

2.4 The Portuguese Mobile Telecommunications Service

2.4.1 MTS history

The first mobile operator was created in 1989 by a joint-venture between two public owned companies: *Correios de Portugal, S.A.* (CTT) and *Telefones de Lisboa e Porto* (TLP). This joint-venture offered 1G services based on C-450 technology. In March 1991, TMN was formed to take over the business and a year later it got the second GSM licence from ICP. TMN assured the analog service until the 30^{th} of October 1999.

The first GSM licence was granted to Telecel - Comunicações Pessoais, S.A. in October 1991, thus becoming the second mobile operator in Portugal. It began its commercial operation on the 18^{th} October 1992. In 2001, after being acquired by the Vodafone Group Plc., changed its commercial name to Vodafone Portugal.

Optimus was the third operator to arrive. In 1997, was the only contender to the GSM licence being offered by the ICP and it began its commercial activity in August 1998.

On December 2000, four companies disputed the new 3G/UMTS licences. The fourth company was Oniway-Infocomunicações, S.A.. Oniway tried to offer GSM services using the other operators network resources, but due to commercial conflict (i.e. access conditions) with those operators, it had to fold back and eventually had its licence revoked in January 2003.

Indirect access became available on the 31^{st} March 2000, due to regulation.

In 2001, operators started to offer Enhanced Messaging Service (EMS) and Multimedia Messaging Service (MMS) services to the public.

Operator portability began on the first day of 2002.

3G/UMTS offering only began in 2004. First on a experimental basis and then on the 21^{st} of April, TMN began the commercial offer, followed by Vodafone on the 4^{th} of May and Optimus on the 4^{th} of June.

In 2006, started to come out services based on HSPA. In March, the services based in HSDPA offered speeds up to 1,8Mbps and later that year, in September, came Personal Computer Memory Card International Association (PCMCIA) boards with speeds up to 3,6Mbps. 2006 saw yet another speed increase up to 7,2Mbps downstream and 1,4Mbps upstream. On the 20^{th} of July, Vodafone had its licence renewed for a period of 15 years, until the 19^{th} of October 2021.

2007 saw the first MVNO operator entering the Portuguese market. That operator carried the brand *"Phone-ix"* and it was Group CTT's mobile operator. The project *Phone-ix* was born after a contract was signed with the physical network provider TMN. A licence renewal, was obtained in 2007 by TMN that extended its GSM operations until the 16^{th} of March 2022.

ZON mobile, the second MVNO arrived to market in October 2008 using Vodafone's network resources. One month later began commercial operations. The regulator also emitted commercial authorizations for two other MVNOs: Companhia Portuguesa de Hipermercados, S. A. (Auchan) and ACP - Comunicações Electrónicas, Unipessoal, Lda., but since these companies did not initiated their activities in 2008, their licence was revoked.

The European Commission, through its GSM Directive, opened in 2009 the possibility for operators to use 3G/UMTS services in the 900MHz frequency - initially reserved for 2G/GSM technologies. Two years earlier, the three Portuguese operators began 3G/UMTS technical experiences using the 900MHz frequency.

2009 saw the mobile broadband market introduction of HSPA+ technology, with theoretical speeds of up to 56Mbps downstream and 22Mbps upstream. Femtocell was also introduced in 2009, allowing for signal amplification on indoor environments by installing new equipments "on site" (client facilities). ZON Multimédia and CTT began their mobile broadband offer.

In 2010, the HSPA+ allowed for another increment in speed, this time enabling up to 43,2Mbps on downstream. That year also saw the first LTE experiences. The city of Aveiro saw one 4G event, where TMN showcased some of the new features using the technology. The three operators showed their commitment to the new technology. Public demonstrations have reached speeds up to 150Mbps[109].

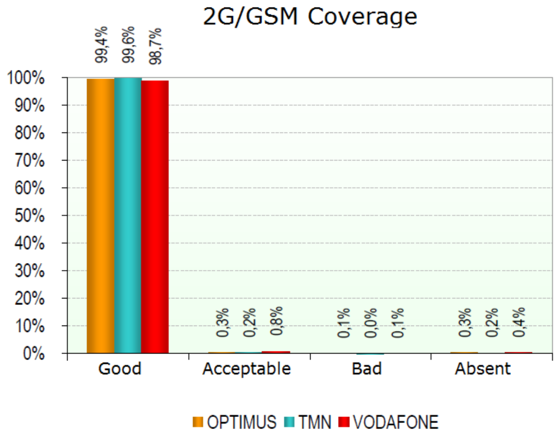
2011 marks the commercial launch of the first 4G-ready mobile broadband equipments by TMN. The new boards can deliver speeds of up to 100Mbps on the downlink and 50Mbps on the uplink, once the network becomes available. Several experiments and public demonstrations have taken place in Cascais and Braga, including the first trials on real urban scenarios.

2.4.2 MTS Coverage

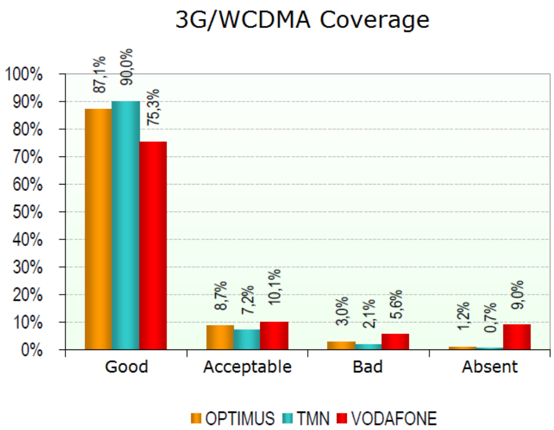
The MTS service is now at near 100% values. All major cities have 3G coverage. Exceptions are some of the main roads which still have inferior coverage.

As one can see on Figure 2.29, major cities have nearly 100% 2G/3G coverage. Optimus shows the best performance with 98,2%, followed by TMN with 97,5% and Vodafone with 97,1%.

On major roads, 3G/WCDMA coverage shows some deficiencies. As one can see on Figure 2.28 there are significant differences between the three operators. TMN has the best result with 90% of the measurements showing good coverage levels, Optimus drops in performance at 87,1% and Vodafone comes last with a worrying 75,3%. Clearly Vodafone has not invested enough to improve its 3G/WCDMA coverage on major roads. Figures 2.30 and 2.31 show respectively, the cities and roads involved in ANACOM's study.

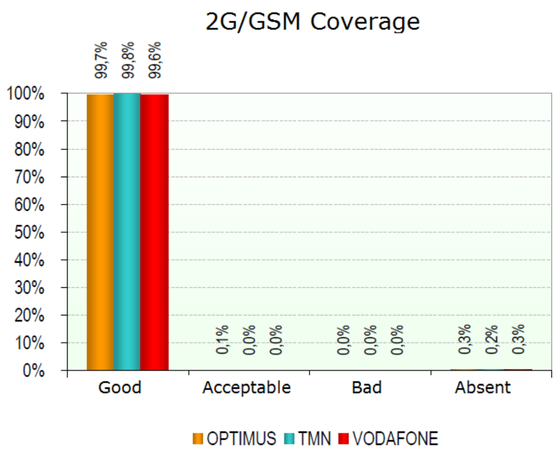


(a) 2G Coverage

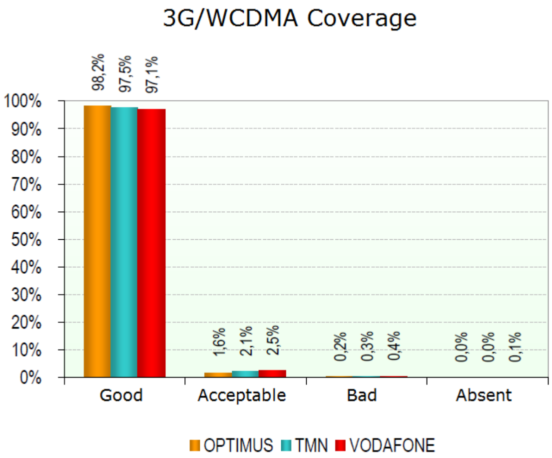


(b) 3G Coverage

Figure 2.28: 2G/3G - Major Roads Coverage, December 2010.[10]



(a) 2G Coverage



(b) 3G Coverage

Figure 2.29: 2G/3G - Major Cities Coverage, December 2010.[10]

Cities	
Aveiro	Lisboa
Beja	Amadora
Braga	Cascais
Bragança	Loures
Castelo Branco	Oeiras
Coimbra	Sintra
Évora	Almada
Faro	Seixal
Guarda	Odivelas
Leiria	
Portalegre	Porto
Santarém	Gondomar
Setúbal	Maia
Viana do Castelo	Matosinhos
Vila Real	Vila Nova de Gaia
Viseu	

Living Population: 4.287.788

Figure 2.30: Coverage Assessment - Major Cities, December 2010.[10]

Major Roads	[Km]
Aveiro-Viseu-Vilar Formoso (A25)	200
Chaves-Vila Real-Figueira da Foz (A24 / IP3 / A14)	285
Lagos-Vila Real de Sto. António-Faro-Lagos (A22 / EN125)	275
Lisboa-Algarve (A2)	245
Lisboa-Cascais-Sintra-Lisboa (A5 / A16 / IC19)	60
Lisboa-Évora-Elvas (A12 / A2 / A6)	220
Lisboa-Leiria-Aveiro (A8 / A17)	245
Lisboa-Porto (A1)	310
Maia-Guimarães-Braga-Esposende (A41 / A42 / A11)	120
Oeiras-Castelo Branco-Guarda (A9 / A10 / A1 / A23)	330
Porto-Bragança (A4 / IP4)	260
Porto-Braga-Valença-Viana do Castelo-Porto (A3 / A28)	230
Póvoa de Varzim-Vila Pouca de Aguiar (A7)	110
Total	2.890

Figure 2.31: Coverage Assessment - Major Roads, December 2010.[10]

As one can see on Figure 2.32, Portugal comes 10^{th} on the list with 98% of the population well above the 89,9% average.

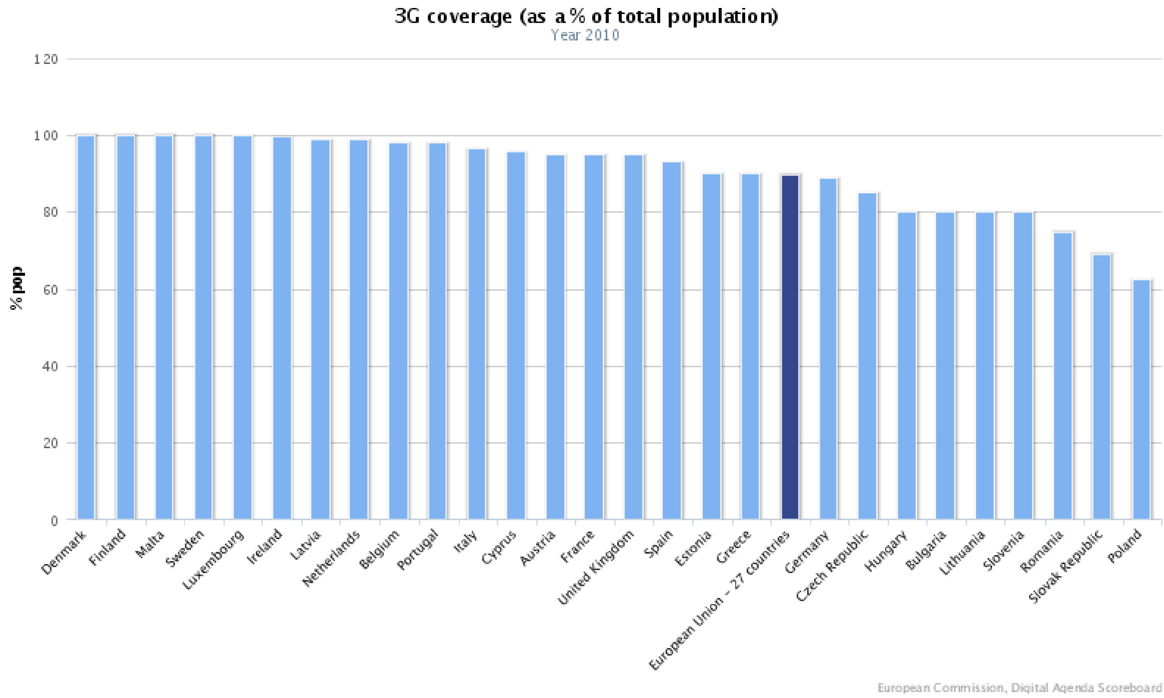


Figure 2.32: 3G Coverage in the EU27 - 2010.[30]

Chapter 3

The Market

In this chapter we will get to know the Portuguese market and its MTS players.

3.1 Portugal

Portugal is a country with a little over 10,5 million residents [69] and a population density of 115 people per km^2 [67]. The GDP per capita in 2010 was 17.645 euros which placed the country on the 57^{th} place worldwide [20].

In terms of mobile subscribers, Portugal comes in second when comparing with the EU27 countries. Italy comes first with 154% and Finland third with 152% of market penetration [31].

The Human Development Index (HDI) is a statistic tool used to rank countries by level of human development - life expectancy, literacy, education and standards of living. Portugal ranked 41^{st} in the 2011 HDI evaluation. When comparing with Italy and Finland in terms of HDI, we find that Italy ranks at 24^{th} and Finland at 22^{nd}[123]. Even more surprising is to find Norway, which leads the HDI list, with "only" 110% MTS penetration.

Portugal during 2010 saw an increment in Mobile Broadband/3G users to 63,7% of the total number of MTS subscribers - ranking 7^{th} in the EU27 -, but only 24,8% are in fact active users of those services [3]. This means that although these subscribers are able to use the services, almost one fourth does not. The reason for that disparity may be found on the latest census report made in 2011 by the Instituto Nacional de Estatística(INE). According to that census, 22.79% of the active population has only been through elementary school[68]. This comes in line with the latest report from ANACOM [12] that confirms age and education levels as key elements to the MTS penetration. On that report MTS penetration scores higher on ages between 15 to 34 - although it is spreading through all ages - and people with high-school or higher education levels, usually also from higher social classes.

3.2 The players

There are currently five independent MTS operators in Portugal. Three of them are physical network operators:

1 TMN - Telecomunicações Móveis Nacionais, S.A. (branded: TMN) Network Prefixes: 96, 9240 to 9244, 925, 926 and 927

2 Vodafone Portugal - Comunicações Pessoais, S.A. (branded: Vodafone) Network Prefixes: 91 and 921

3 Optimus - Telecomunicações, S.A. (branded: Optimus) Network Prefix: 93

These MNOs have their own network infrastructure and spectrum allocation. The other two are virtual network operators:

4 CTT - Correios de Portugal, S.A. (branded: Phone-ix) Network Prefixes: 9220 to 9222

5 ZON - TV Cabo Portugal, S.A (branded: ZON Mobile) Network Prefixes: 9290 to 9294

Being a Mobile virtual network operator (MVNO), means that each on of these operators make use of contracts with MNOs in order to support their offer. CTT uses TMN's physical network and ZON uses the Vodafone's network. Their relation with subscribers is ruled by the same principles as any other operator. CTT (Phone-ix), for instance, has its own customer call center running independently from TMN. Notive that the three MNOs have their own discount/low cost brands:

- TMN has *"Uzo"*
- Vodafone has *"Vodafone Directo"*
- Optimus has *"Rede4"*

These brands and some others (i.e. Worten mobile, etc.) that exist on the market, are not considered by the regulator ANACOM as MVNO activities, because the brands do not have an issued MTS licence and therefor are excluded from this work. In the case of the Worten mobile brand, the technical resources come from Optimus and Sonaecom, its parent company.

3.3 Operator information

- **TMN - Telecomunicações Móveis Nacionais, S.A.**
  Address: Rua Andrade Corvo, 6, 4^{th} floor ,1050-009 LISBON
  Phone No. 217 914 601
  Fax No. 215 005 304
  Website: `http://www.tmn.pt`
  Chairman of the Board: Zeinal Bava
  Share Capital 47 000 000 euros
  Shareholders:(31.12.2009)

  - PT Portugal, SGPS, S.A. 100%

  Turnover:(31.12.2009) 1 499 349 998,00 euros
  Number of Employees:(31.12.2009) 1 004
  Authorized Electronic Communications Networks and Services

  1 Internet Access Service, date of authorization 1.06.2004

  2 Voice Transport Service in CUG, date of authorization 1.01.2000

  3 Mobile Telephone Service (GSM/UMTS), date of authorization 8.07.2010

4 Public Communications Network, date of authorization 19.11.1999

5 Telephone Service at a Fixed Location, date of authorization 19.11.1999

- **Vodafone Portugal - Comunicaçẽs Pessoais, S.A.**
  Address: Av. D. João II - Lote 1.04.01, 8^{th} floor - Parque das Nações, 1998-017 LISBON
  Phone No. 210 915 000
  Fax No. 210 915 200
  Website: `http://www.vodafone.pt`
  Chairman of the Board: António Rui de Lacerda Carrapatoso
  Share Capital:(31.03.2011) 91 068 253 euros
  Shareholders:(31.03.2011)

  – Vodafone Holdings Europe B.V. 61,37%

  – Vodafone Group Plc 38,63%

  Group Turnover:(31.12.2010) 13 850 000 000 euros
  Number of Employees: (31.03.2011) 1 536
  Authorized Electronic Communications Networks and Services:

  1 Data Transmission Services, date of authorization 3.05.1999

  2 Internet Access Service, date of authorization 3.05.1999

  3 Virtual Phone Card Service, date of authorization 29.09.1999

  4 Telephone Service at a Fixed Location, date of authorization 29.09.1999

  5 Fixed Wireless Access (FWA), date of authorization 23.11.2006

  6 Voice over Internet Nomadic Service (VoIP,) date of authorization 25.03.2008

  7 Distribution of Signal of Television Service, date of authorization 31.08.2009

  8 Mobile Telephone Services (GSM/UMTS), date of authorization 8.07.2010

  9 Public Communications Network, date of authorization 9.10.1998

- **Optimus - Comunicações, S.A.**
  Address: Rua Henrique Pous ao 432, 4460-191 SENHORA DA HORA - Matosinhos
  Phone No. 931 002 000
  Fax No. 220 111 847
  Website: `http://www.optimus.pt/`
  Chairman of the Board:(30.06.2011) Paulo Teixeira de Azevedo
  Share Capital:(30.06.2011) 366 246 868 euros
  Shareholders:(30.06.2011)

  – Sonaecom, SGPS, S.A. 53,17%

  – Free Float 20.95%

  – Atlas Services Belgium 20.00%

  – BCP, S.A. 3.41%

  – Sonaecom SGPS (own shares) 2.47%

  Turnover:(30.06.2011) 209 600 000 euros

Number of Employees: (30.06.2011) 2 066
Authorized Electronic Communications Networks and Services:

1 Public Communications Network, date of authorization 16.08.1999
2 Virtual Phone Card Service, date of authorization 16.08.1999
3 Fixed Wireless Access (FWA), date of authorization 23.11.2006
4 Distribution of Signal of Television Service, date of authorization 15.11.2005
5 Voice Over Internet Nomadic Services (VoIP), date of authorization 6.05.2008
6 Mobile Telephone service (GSM/UMTS), date of authorization 8.07.2010
7 Voice Transport Service (CUG), date of authorization 31.07.1997
8 Data Transmission Services, date of authorization 31.07.1997
9 Telephone Service at a Fixed Location, date of authorization 16.08.1999
10 Internet Access Service, date of authorization 22.12.1995

- **CTT - Correios de Portugal, S.A.**
  Address: Rua de S. José, 20, 1166-001 LISBON
  Phone No. 213 227 400
  Fax No. 213 227 744
  Website: `http://www.phone-ix.pt/`
  Chairman of the Board:(30.09.11) Pedro Amadeu de Albuquerque Santos Coelho
  Share Capital:(30.09.11) 87 325 000 euros
  Shareholders:(30.09.11)

  – Portuguese State 100%

  Turnover:(31.12.2010) 650 626 000 euros
  Number of Employees:(31.12.2010) 12 473
  Authorized Electronic Communications Networks and Services:

  1 Mobile Telephone Service (MVNO), date of authorization: 01.10.2007

  Physical Network: TMN - Telecomunicações Móveis Nacionais, S.A.

- **ZON - TV Cabo Portugal, S.A.**
  Address Av. 5 de Outubro, 208, 11^{th} floor, 1069-203 LISBON
  Phone No. 217 824 700 — 217 914 800
  Fax No. 217 824 710
  Website: `http://www.zon.pt`
  Chairman of the Board: Rodrigo Costa
  Share Capital 25 477 270 euros
  Shareholders:(31.12.2009)

  – Zon Televisão por Cabo SGPS, S.A. 100%

  Turnover:(31.12.2009)679 203 736,00 euros
  Number of Employees: (31.12.2009) 639
  Authorized Electronic Communications Networks and Services:

1 Cable Distribution Network, date of authorization 19.05.1994
2 Mobile Telephone Service (MVNO), date of authorization 26.05.2008
3 Telephone Service at a Fixed Location, date of authorization 4.10.2008
4 Data Transmission Services, date of authorization 26.05.2008
5 Public Communications Network, date of authorization 18.11.1999
6 Public Communications Network, date of authorization 18.04.2002
7 Voice over Internet Nomadic Services (VoIP), date of authorization 28.11.2006
8 Internet Access Service, date of authorization 20.10.1999
9 Telephone Service at a Fixed Location, date of authorization 30.05.2006
10 VoIP Services Without Numbering, date of authorization 22.03.2006
11 Short Data Messages Service, date of authorization 26.05.2008

Physical Network: Vodafone Portugal - Comunicações Pessoais, S.A.

3.4 Players history

3.4.1 TMN

TMN - Telecomunicações Móveis Nacionais S.A. was born on the 22^{nd} March 1991, and it is the current Portugal Telecom mobile operator. TMN toke over the analog mobile business launched in 1989 by the CTT and TLP - Telefones de Lisboa e Porto, both public owned companies. The CTT and TLP initially shared 50% of TMN until December 1991, when CPRM - Companhia Portuguesa Rádio Marconi became a new shareholder, splitting the share capital into three equal parts. In March 1992, the ICP granted TMN with a MTS licence to operate both the analog and digital networks. The analog service (1G) was active until the 30^{th} of October 1999. The first GSM call is made on the 17^{th} of May 1992. The commercial offer begins later on the 8^{th} of October [114].

3.4.2 Vodafone

Vodafone Portugal - Comunicações Pessoais, S.A. was born Telecel - Comunicações Pessoais, S.A. in 1991. Later that year, in October, was the first to get a GSM licence. It began commercial operations about one year later on the 18^{th} October 1992. This company made it to telecom history by making the fastest GSM deployment ever recorded. It took just one year after the GSM licence being granted, and the network already was covering 57% of the territory and 83% of the population. The final rebranding to Vodafone happened in October 2001, about a year later after the Vodafone Group had bought the remaining 49% of shares that were at the time on open market [127].

3.4.3 Optimus

Optimus Telecomunicações S.A. was born from the union of Sonae Group and (at the time of its launch) Orange/France Telecom. In November 1997 ICP granted Optimus with a GSM licence. The commercial launch was a few months later on the 15^{th} September 1998. It is the current Sonae Group mobile operator [100].

3.4.4 CTT

CTT - Correios de Portugal, S. A. was born from the Administração Geral dos Correios Telégrafos e Telefones. On the 10^{th} November 1969 was created the public owned company CTT - Correios e Telecomunicações de Portugal, E. P., initiating operations on the 1^{st} January 1970. On 15^{th} December 1992, with the creation of the former Telecom Portugal, S.A., and scission of Correios e Telecomunicações de Portugal, S.A., the company adopted its current denomination CTT - Correios de Portugal, S.A. CTT have launched its MVNO service on the 30^{th} November 2007 carrying the *Phone-ix* brand and the 922 prefix. It was the first MVNO to get to market. It uses the TMN telecommunication infrastructure [22].

3.4.5 ZON

PT Multimedia was founded in July 1999 as a part of the Portugal Telecom Group strategy to split its core telecommunications business from the cable tv and media production/distribution. On the 7^{th} November 2007, PT Multimedia underwent a spin-off from its parent company which led to a significant change in ownership structure. Prior to the spin-off, on 21^{st} September, the new Executive Management Team was appointed and the organization entered a new phase of development as an independent company. Zeinal Bava left the company to become Portugal Telecom CEO and Rodrigo Costa took his place as the new PT Multimedia CEO. To mark the birth of the new independent business strategy and identity, on the 31^{st} January 2008, the shareholders approved a change of corporate name to ZON Multimédia - Serviços de Telecomunicações e Multimédia, SGPS, S.A. completing the scission process from Portugal Telecom. ZON launched its MVNO business, using the Vodafone infrastructure, on the 28^{th} September 2008, initiating the commercial offer to private customers a month later [156] .

Chapter 4

Analysis on market behavior

This chapter presents some data and reflections on the behavior of the Portuguese MTS market. The objective is to gather as much information as possible and correlate it with engineering decisions associated with the release of new products, services and technologies.

4.1 Operators behavior

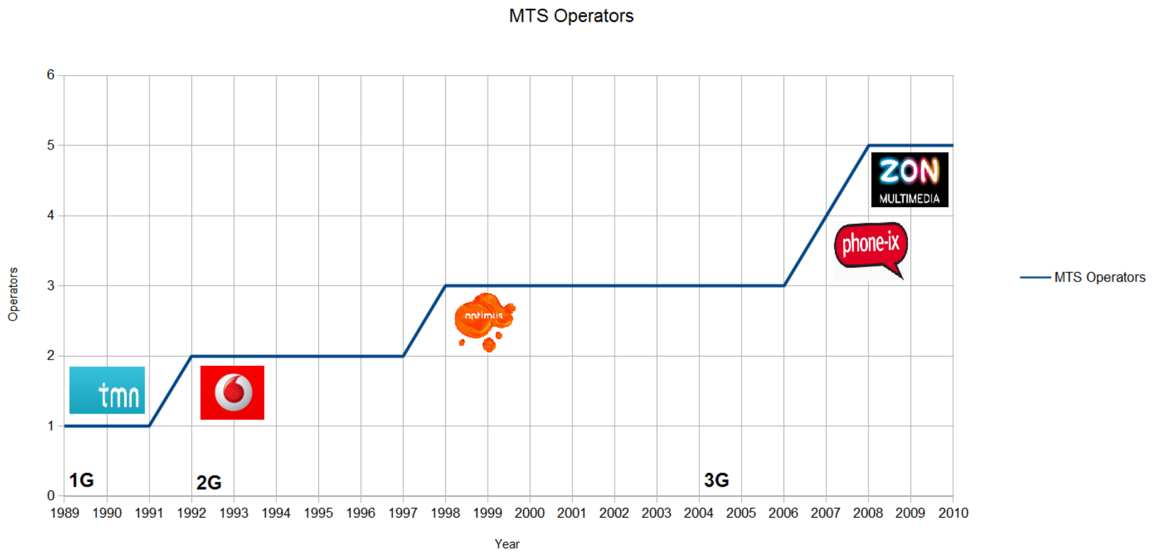


Figure 4.1: Operators market entry

4.1.1 TMN

The incumbents mobile operator TMN was the first to arrive to market in 1989, thus achieving a key role among the public. Figure 4.2 shows how its number of subscribers has increased over the years.

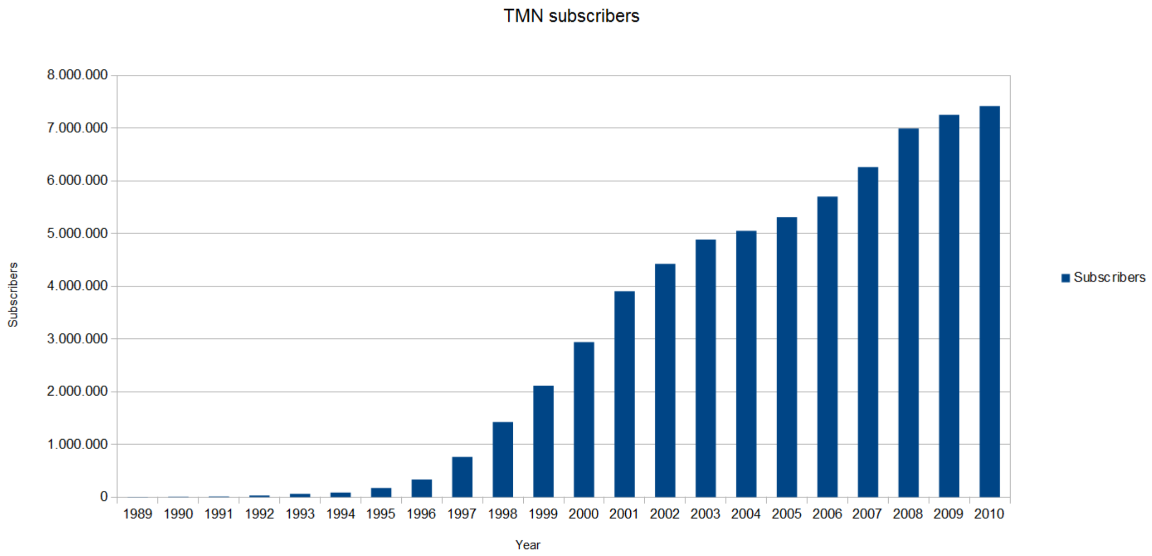


Figure 4.2: Subscribers

As we can see in Figure 4.3, the company has been able to maintain a stable market share since 1994. From that year until the entrance of the third operator, the market split in half. TMN issued a fast recovery from the arrival of Vodafone mainly due to the launch of *MIMO* - the worlds first prepaid plan in September 7^{th} 1995 - that revolutionized the market and gave the company the innovator image it needed at the time. Vodafone - then Telecel - since it entered the market carried a fresher and innovative image, notoriously marked by the 1995 *'Tou Xim'* television commercial. It took more than one year for Vodafone to present its *Vitamina T* prepaid plan in November 1996. The arrival of a third player in 1998 did not affected the company's share the way the first competitor's arrival did, presumably because it targeted a different customer base.

TMN's Earnings Before Interest, Taxes, Depreciation and Amortization (EBITDA) numbers show the good performance and competitiveness of the company throughout the years. TMN achieves a remarkable performance even in years when there is a negative GDP growth, such as 2003. From 2004, EBITDA numbers have remained almost constant, making it the best performer of the 5 operators currently in business. The fact that it still is the incumbent's mobile operator, probably benefits the company's management decisions.

In Figure 4.5 it gets clear the impact of new players into the market. Vodafones arrival in 1992 and Optimus in 1998 affected severely the growth rate of the company as it would be expected. The 1993 downfall may be a consequence of the bad economic period at the time - GDP rate that year was at -2.0%. The introduction of the *MIMO* prepaid plan in 1995 enabled more than 100% subscriber growth that year. The next year was probably affected by the launch of the competitor's *Vitamina T* prepaid plan. Growth rates continued to fall as market approached maturity.

Average Revenue Per User (ARPU) numbers have been decreasing throughout the years as a direct result of the market competitiveness. Optimus's aggressive price campaign during its launch pushed ARPU values below 29€ in 1999. It was the lowest ARPU of the three.

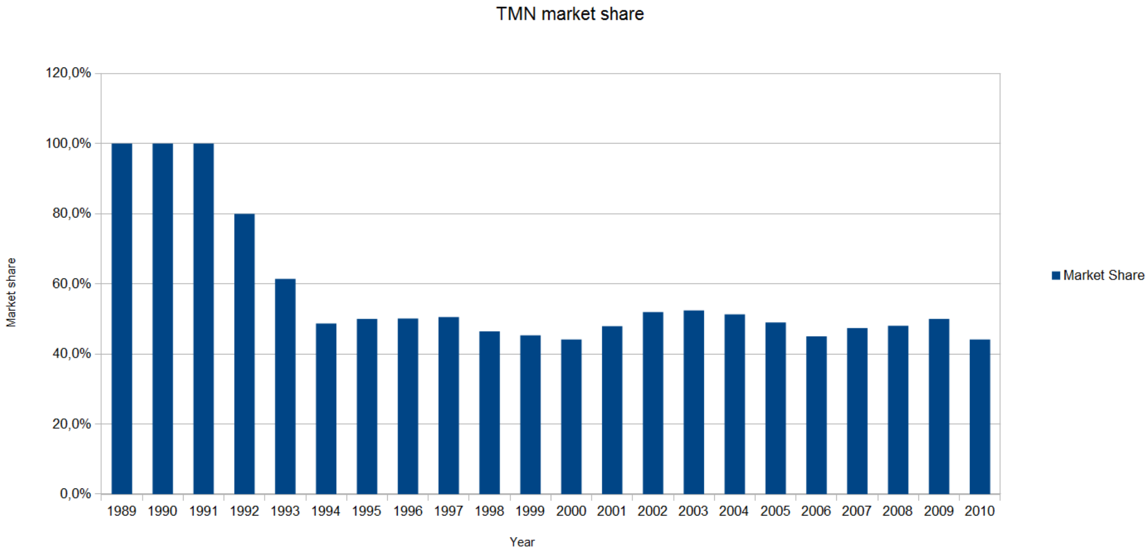


Figure 4.3: Market share

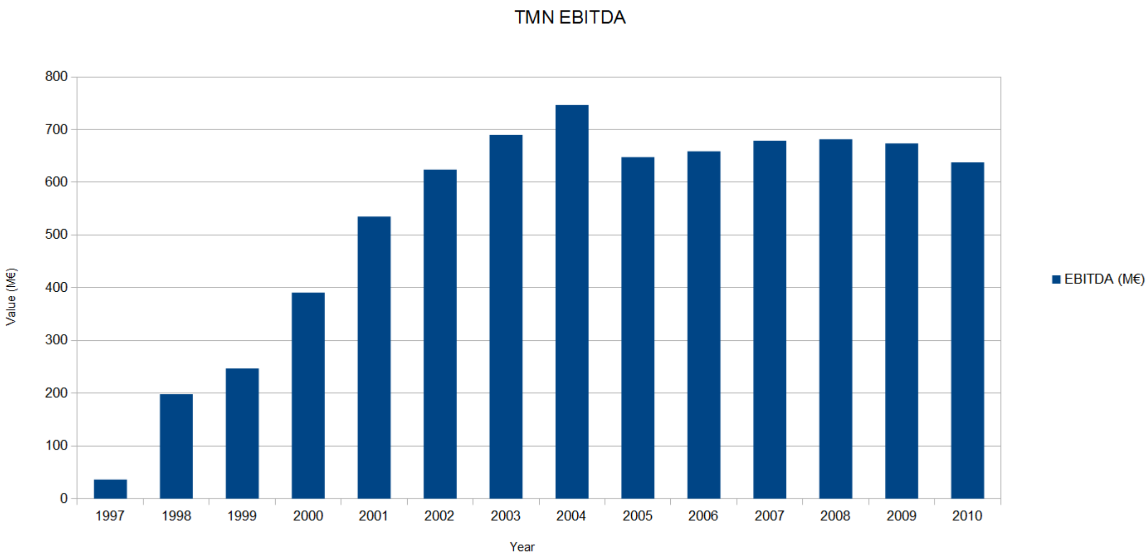


Figure 4.4: EBITDA behavior

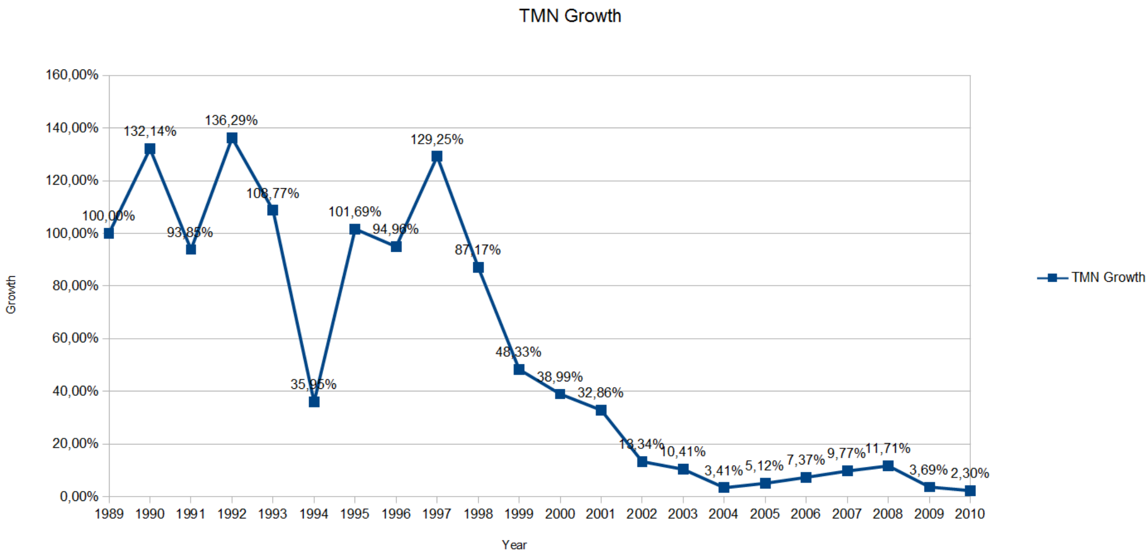


Figure 4.5: Growth behavior

In 1996, three years earlier, the ARPU value was above 61€. Since 2000 its value has been decreasing almost linearly, on par with the other competitors. The latest trend of tribal plans will likely take ARPU values even lower.

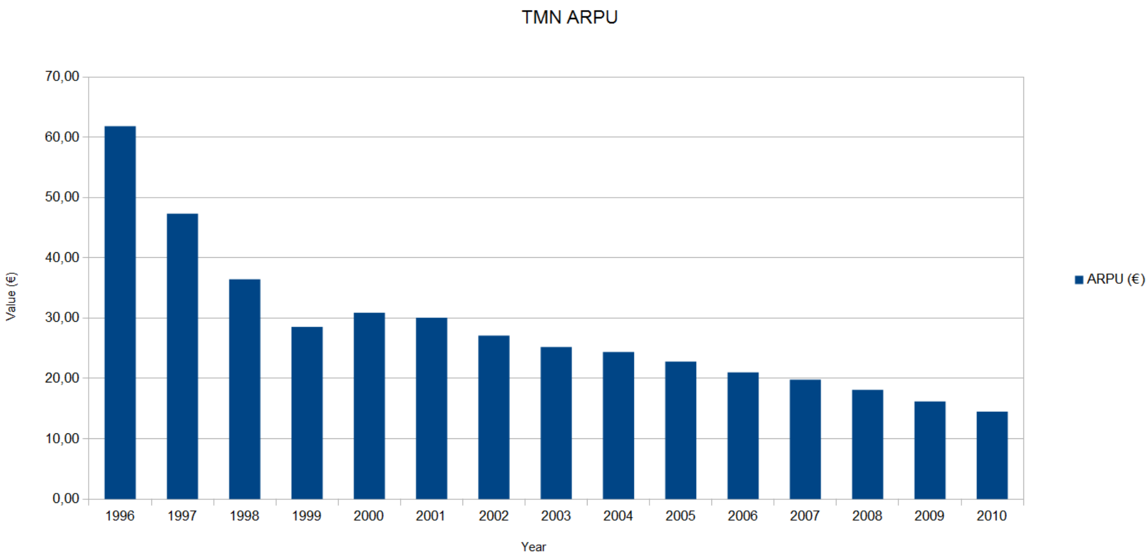


Figure 4.6: ARPU behavior

Figures 4.7 and 4.8 show that although the Cash Cost Per User (CCPU) has decreased over time, the pressure on prices have pulled down ARPU values faster than CCPU could match, thus bringing the Average Margin Per User (AMPU) to a steady decrease.

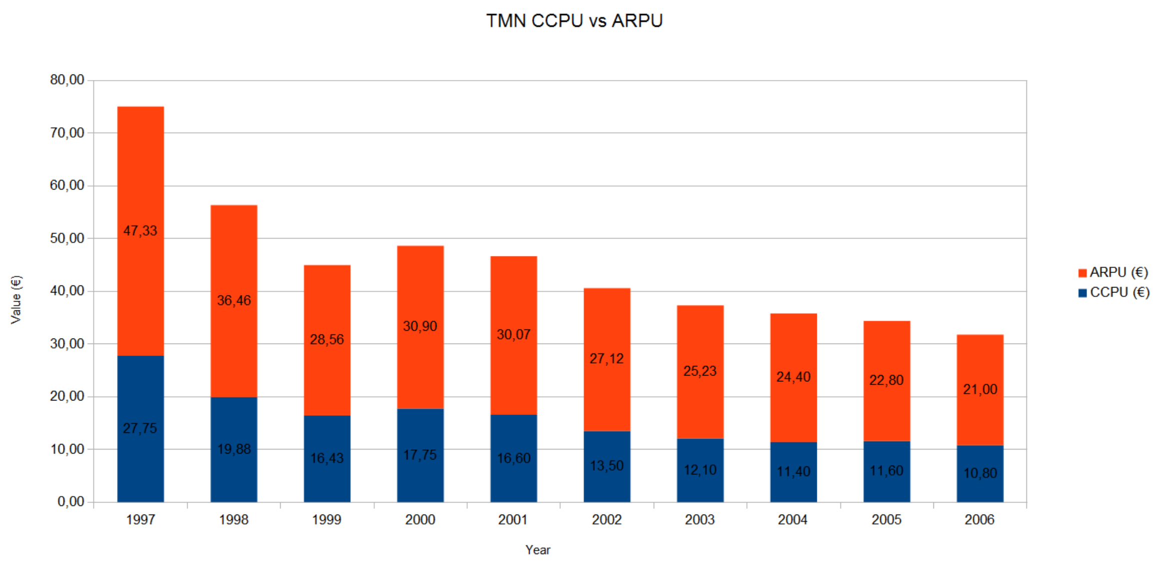


Figure 4.7: CCPU versus ARPU behavior

Note the almost half cut on AMPU value between 1997 and 2010 as well as the pressure of the third competitor in 1999.

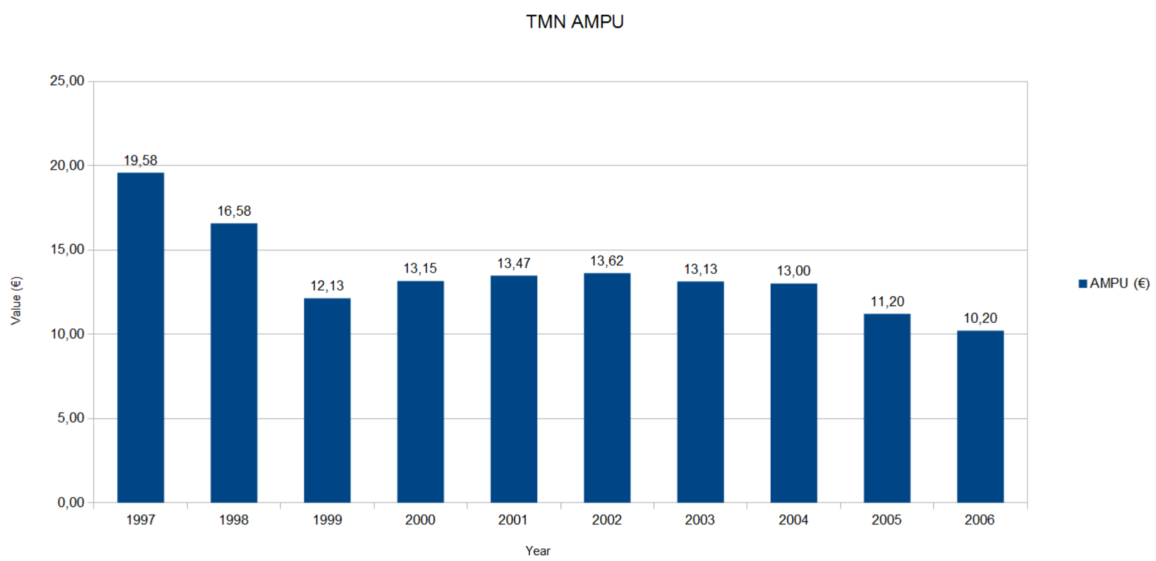


Figure 4.8: AMPU behavior

4.1.2 Vodafone

Vodafone shows a good performance in terms subscribers number, as seen in Figure 4.9. Like main rival TMN, it has been able to increase its customer base.

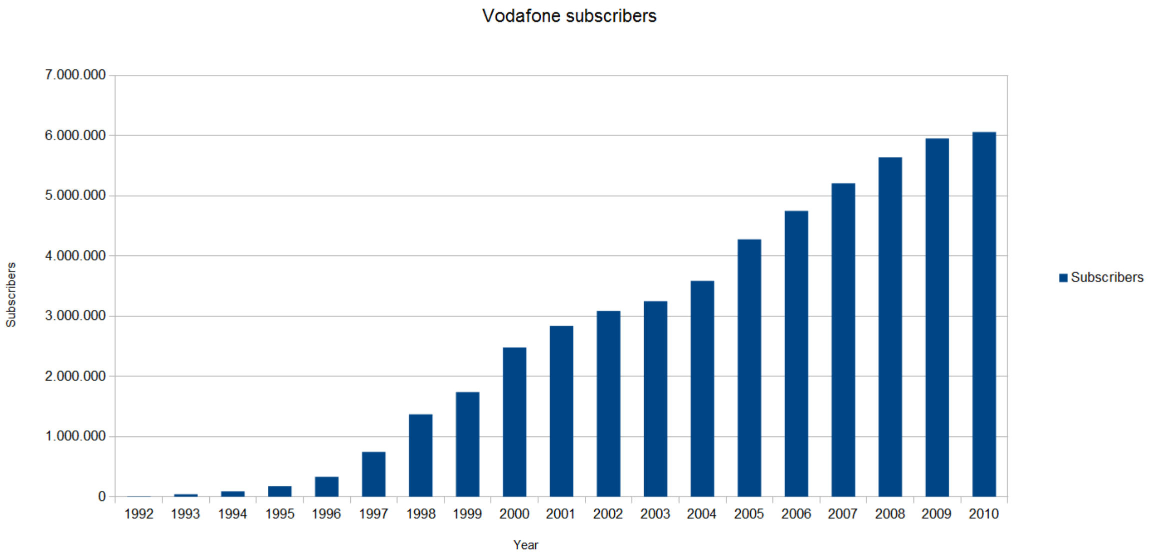


Figure 4.9: Subscribers

Figure 4.10 clearly shows the impact of Optimus in Vodafone's market share. There is a clear cut in share starting in 1998. One may assume that both companies where targeting the same customers. The brand changing campaign from 'Telecel' to 'Vodafone' that started in 2000 with the acquisition of the company by the Vodafone Group, may have led some customers off the operator.

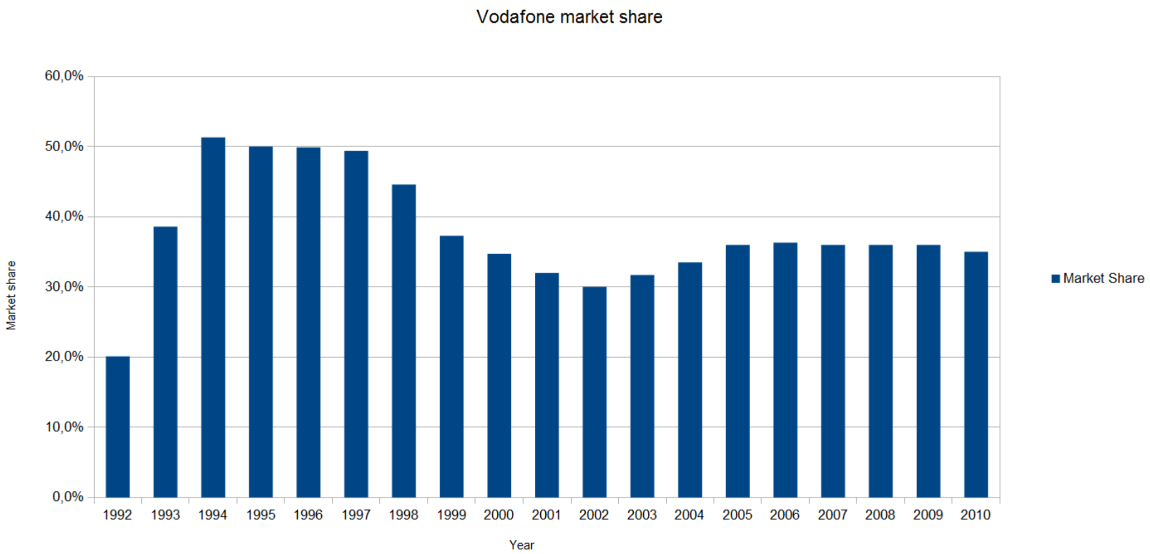


Figure 4.10: Market share

EBITDA results, shown on Figure 4.11, state a generally good management of the company. Perhaps, like TMN, benefiting from its parent company worldwide expertise. The downfall in 2010 - similar to TMN's - may be a consequence of the country's bad economic performance.

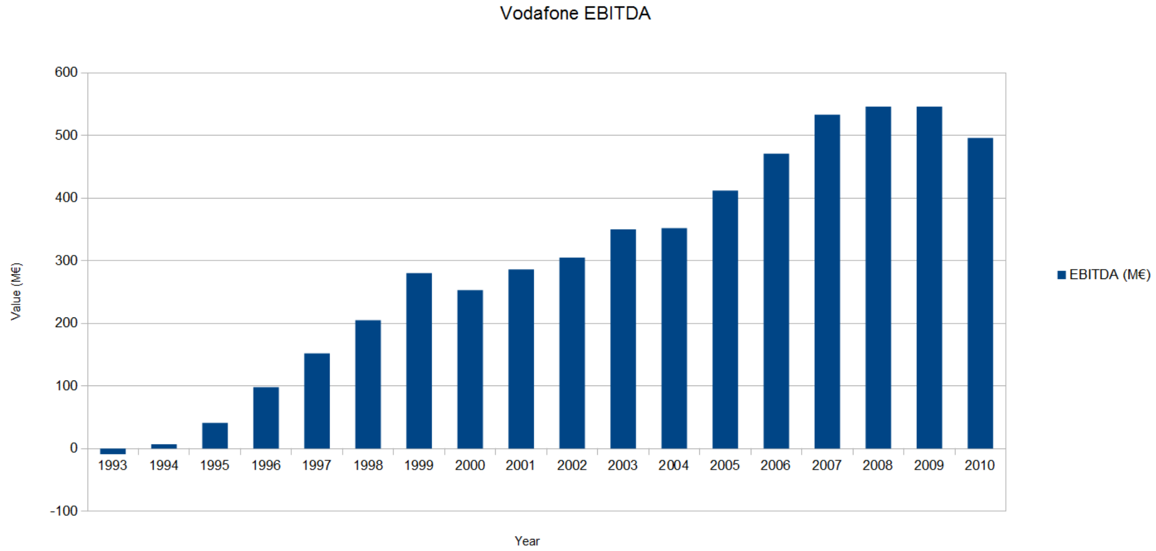


Figure 4.11: EBITDA behavior

The company's growth, after the initial novelty effect, declined to a little over 125% in 1994. Apart from the third operator arrival, it has been on par with the others.

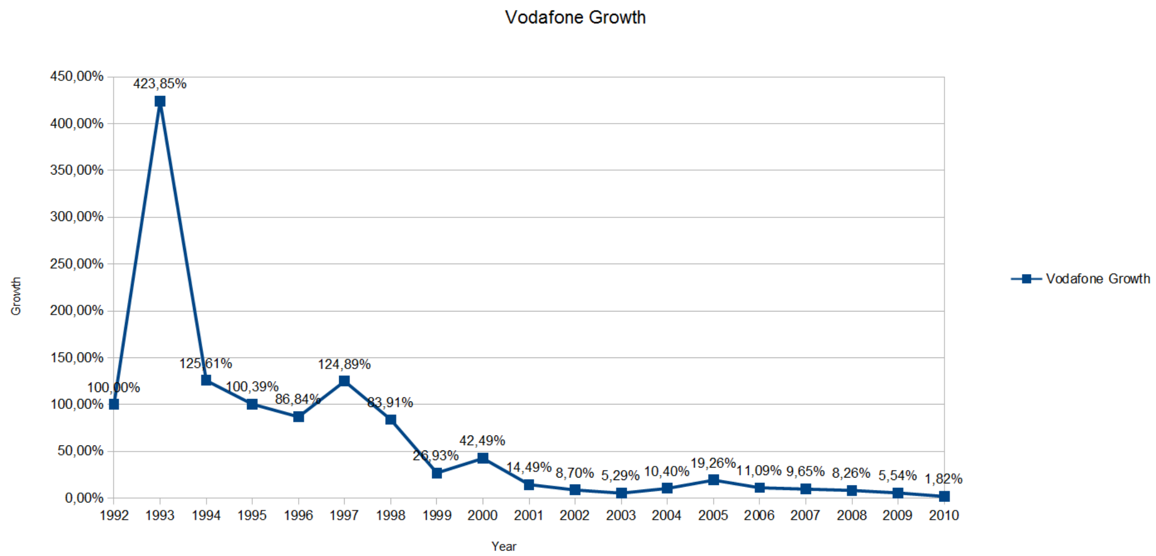


Figure 4.12: Growth behavior

Like TMN, also Vodafone suffered the effects of the aggressive price policy made by Optimus in 1998. ARPU values since then have been steadily decreasing.

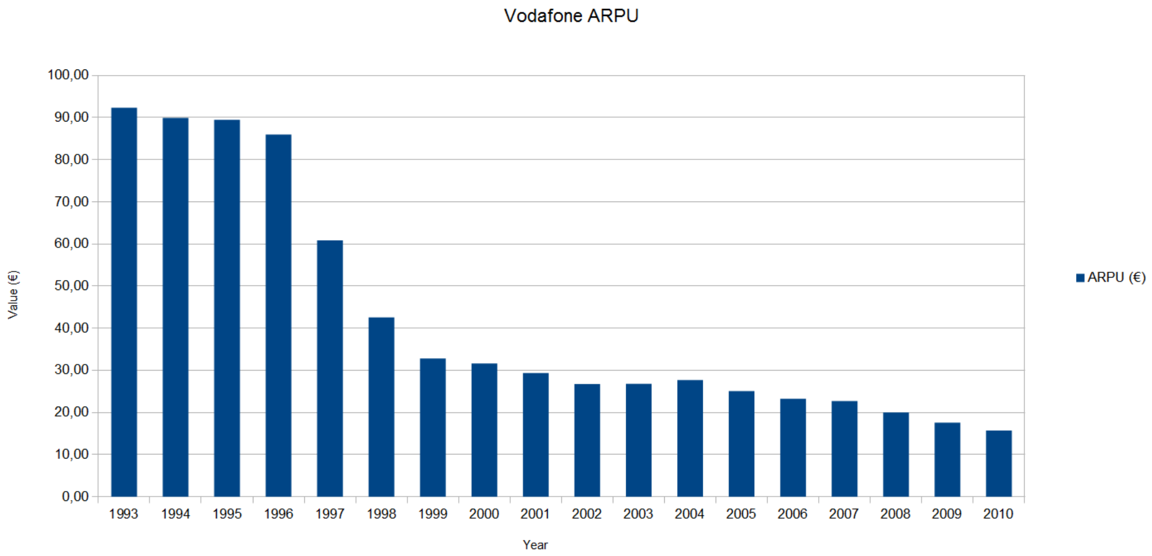


Figure 4.13: ARPU behavior

With the arrival of the 3G technology in 2004, Vodafone was able to increase its ARPU performance in order to compensate the higher CCPU value at the time.

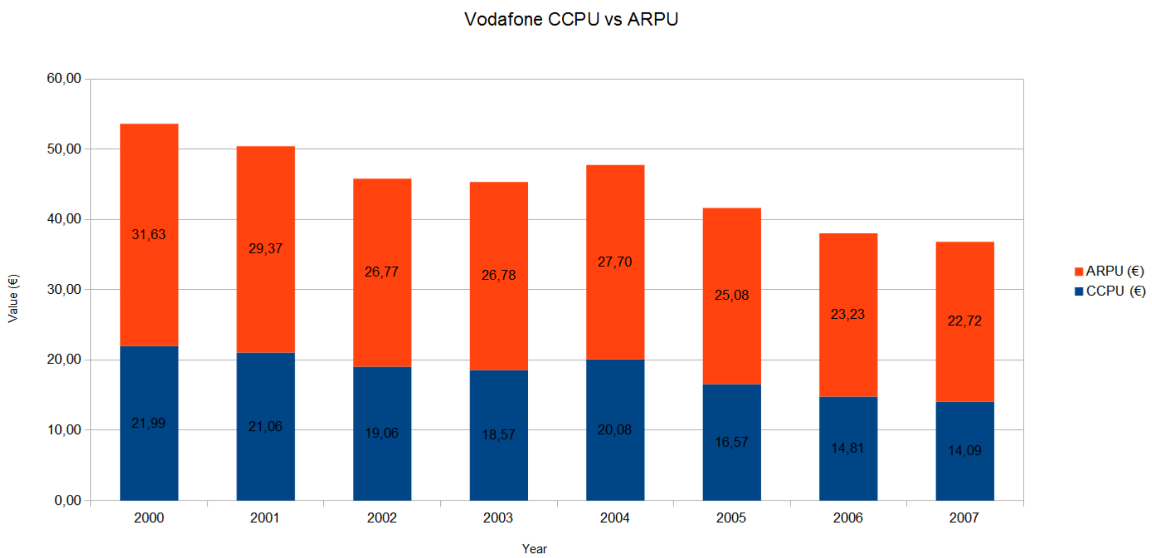


Figure 4.14: CCPU versus ARPU behavior

Figure 4.15 shows how steady Vodafone has been able to kept its AMPU values between 2000 and 2007.

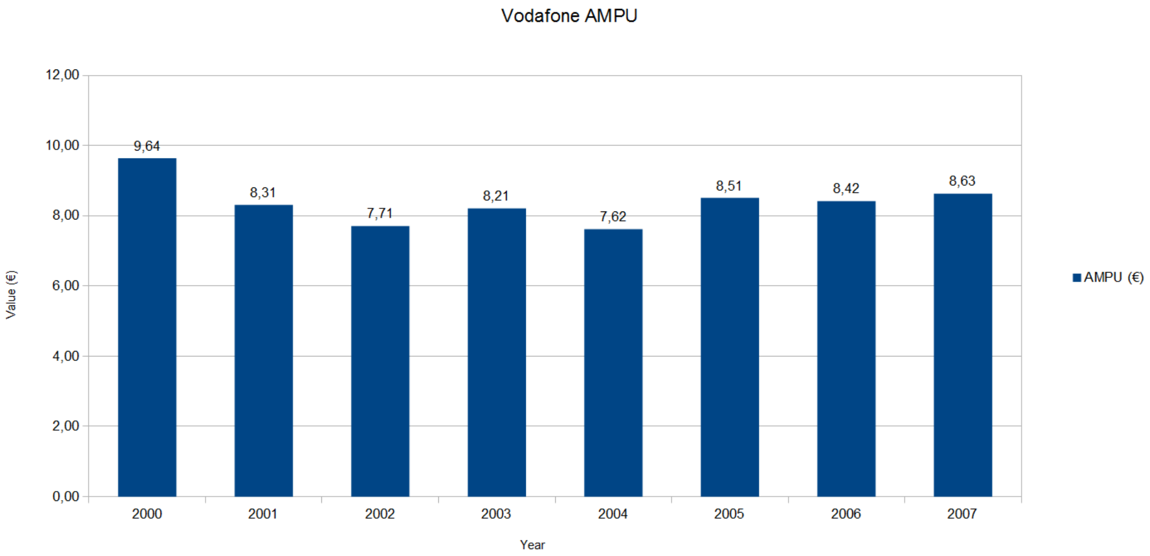


Figure 4.15: AMPU behavior

4.1.3 Optimus

Optimus has been growing in subscribers since its arrival. 2004 saw an awkward decrease in spite the successful launch of a new product called *Optimus Home*, targeting the incumbents fixed telecommunications customers - remains its main rival.

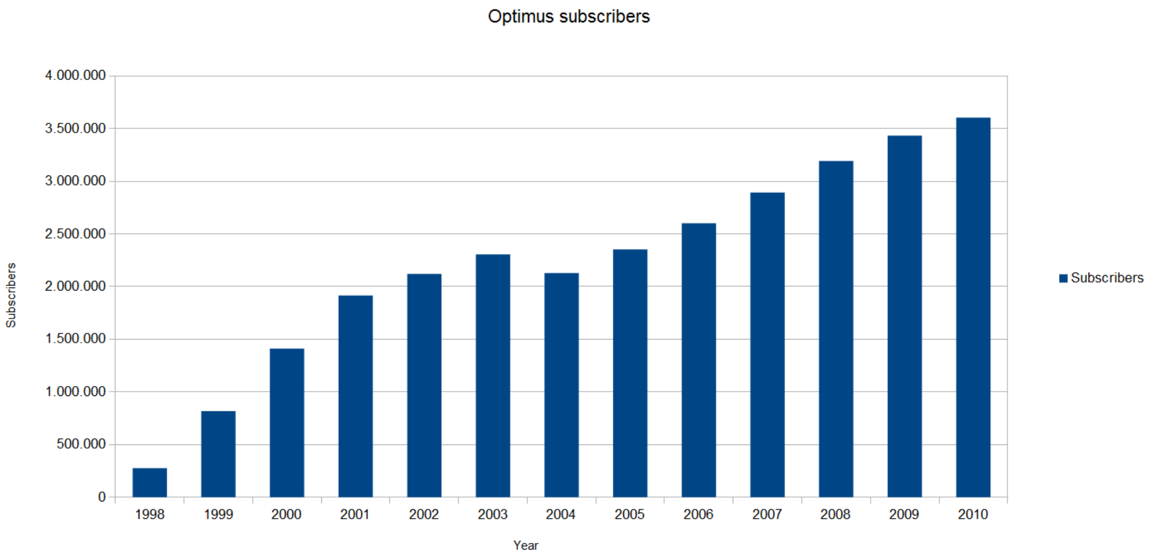


Figure 4.16: Subscribers

Figure 4.17 shows a company that remains relatively stable around a 20% market share until 2004 and then entered a lowering path until 2010 - the lowest result since 1998. In 2004 was probably punished by customers for the delay in adopting the 3G technology. Some of those customers may have gone to its rivals. 2008 and 2009 saw yet another decrease in share, perhaps due to the joint effort of the two new MVNOs: *ZON mobile* from ZON Multimédia and *Phone-ix* from CTT. None of them using Optimus's infrastructure.

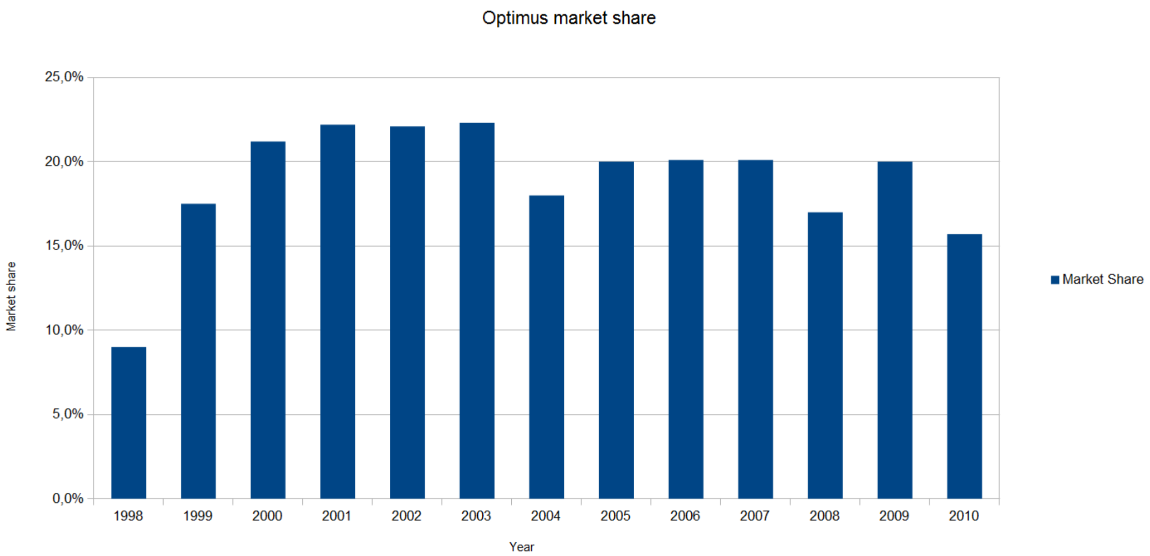


Figure 4.17: Market share

Optimus's EBITDA performance has been a mix of results. It showed an increase from its inception until 2004 and then a decrease until 2008, returning to rise in 2009 and 2010.

Subscriber's growth rate has declined from 1999, had a surprising regression in 2004 - probably, as stated before, due to 3G lag - and from 2005 has been stable between 5% and 11%.

Optimus's ARPU values follow the others trend which is to decrease over time. Notice the years 2000 value, that perhaps can be explained by the operator's first introduction into market of WAP technology and the first web portal *Optimus Zone*.

Figure 4.21 shows how Optimus has been able to reduce its CCPU, at the same time not being able to retain ARPU values.

The AMPU values in Figure 4.22 show exactly the apparent problem Optimus has in retaining a stable AMPU value over the years. Since 2004 - the *Optimus Home* product launch -, these values have been decreasing to a somewhat alarming 3,40€ in 2007.

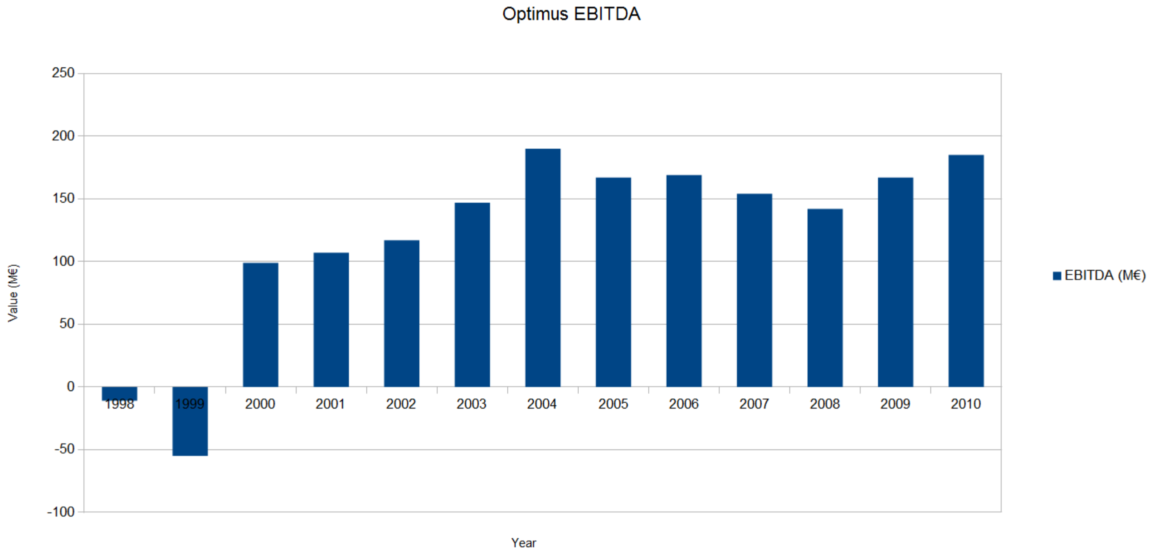


Figure 4.18: EBITDA behavior

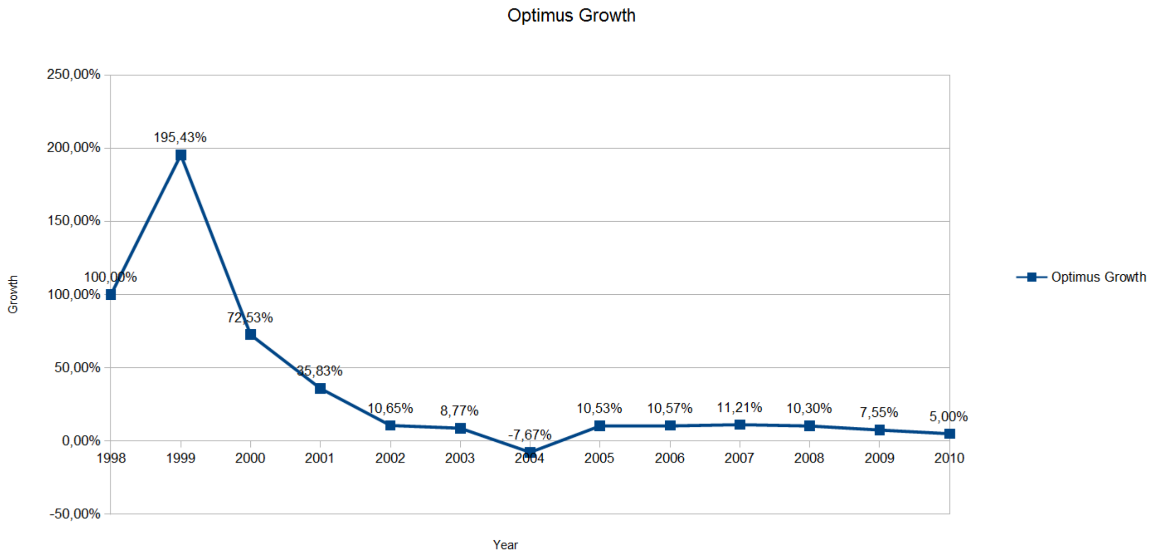


Figure 4.19: Growth behavior

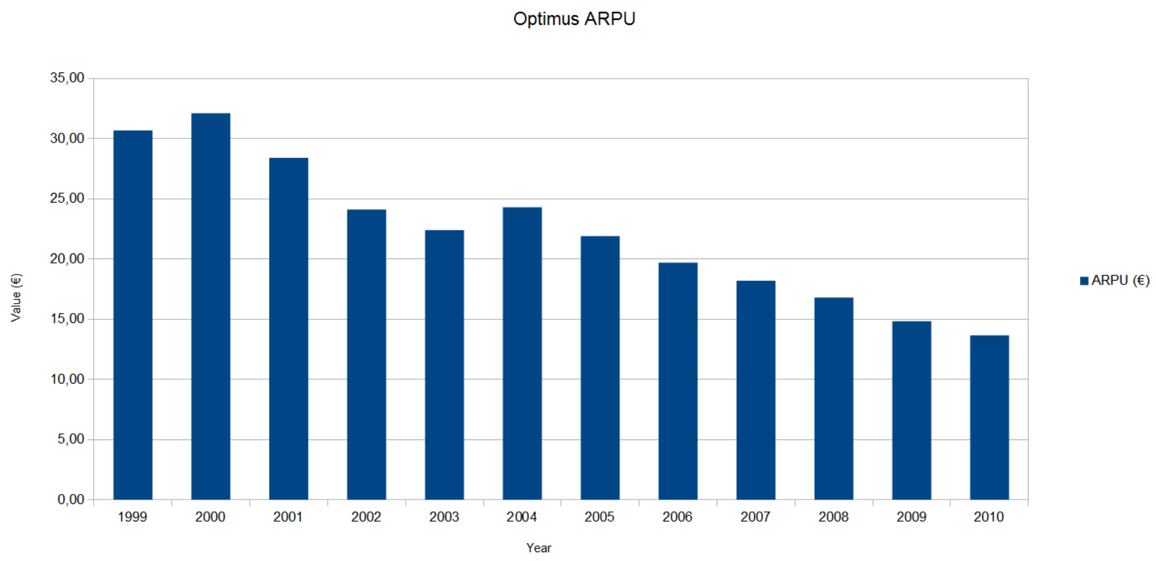


Figure 4.20: ARPU behavior

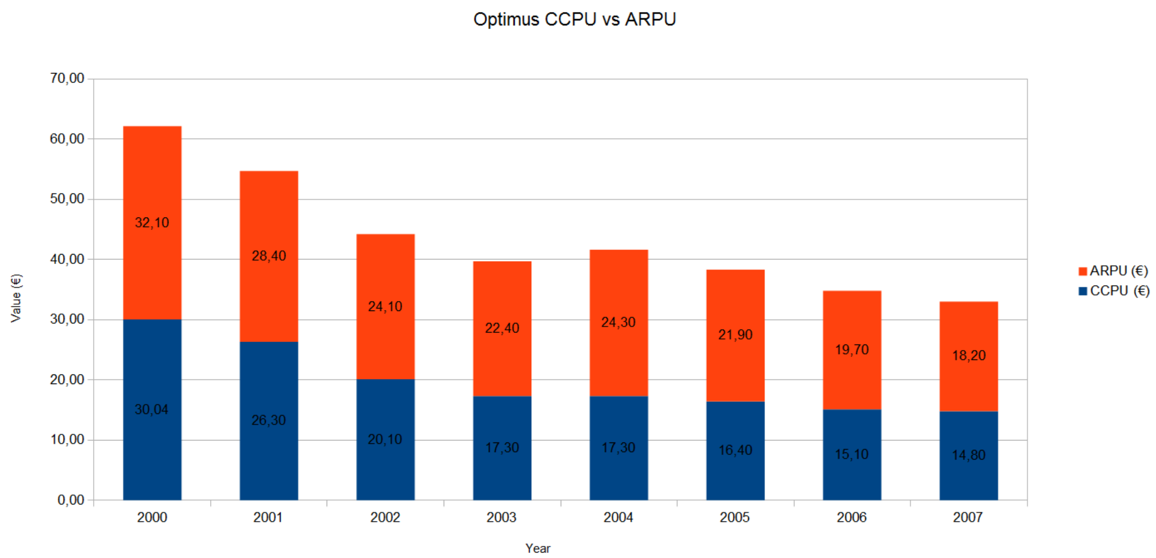


Figure 4.21: CCPU versus ARPU behavior

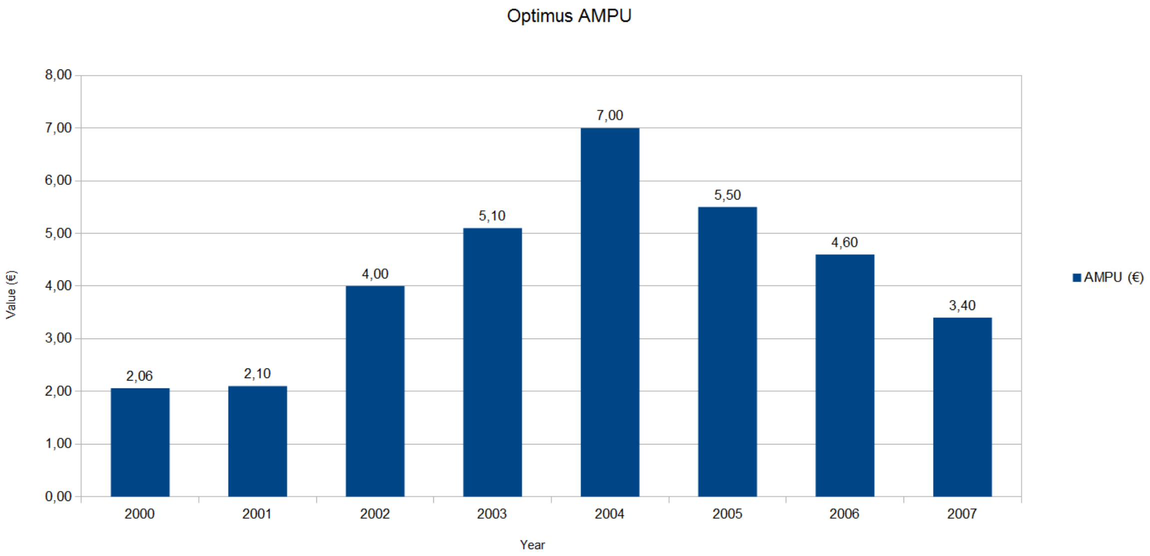


Figure 4.22: AMPU behavior

4.1.4 ZON mobile

ZON mobile has the merit of having gained some thousands subscribers in such hard market. ZON mobile enters a market that in 2008 had 140.3% service penetration. The fact that ZON Multimédia was the former PT Multimédia, perhaps helps to explain some of the company's mobile division success. ZON Multimédia does not hide its intention of using a leading position in cable TV subscriptions to increase its mobile customer base. ZON Multimédia had in 2010 over 1,5 million customers. It is only natural for the company's management to try to seize those customers into ZON Mobile subscribers. Therefor, marketing its mobile products also to their cable TV customers has allowed ZON mobile to increase its still small market share.

Figure 4.25 shows the usual good start followed by a more "normal" 56,60% subscribers growth rate in 2010. Early values from 2011 show over 163.000 mobile subscribers which represents a 51,25% growth from 2010. It is expectable that more pay TV customers will become ZON mobile subscribers thus maintaining a considerable growth rate.

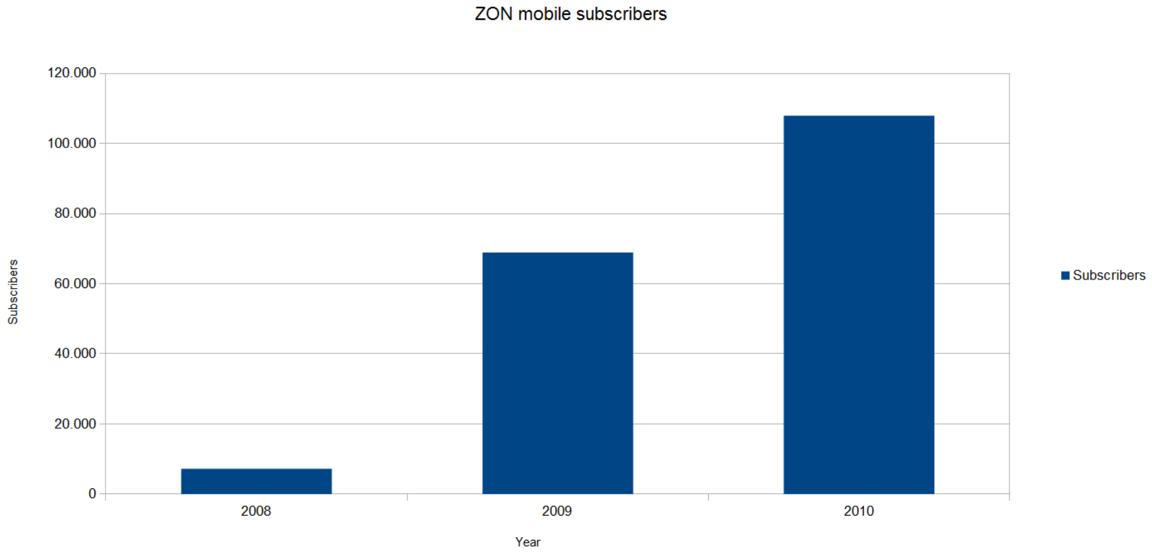


Figure 4.23: Subscribers

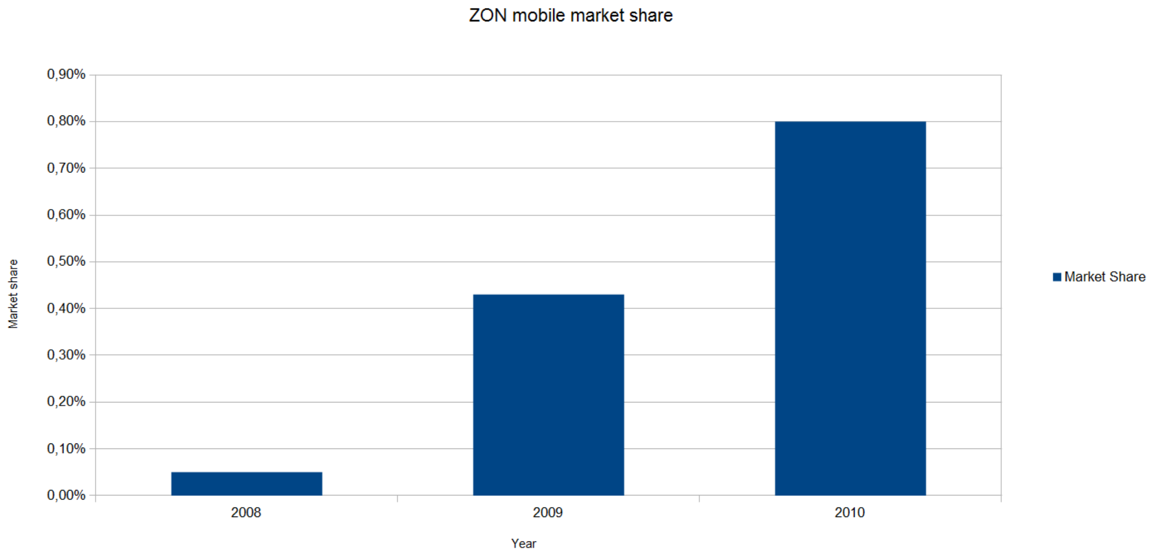


Figure 4.24: Market share

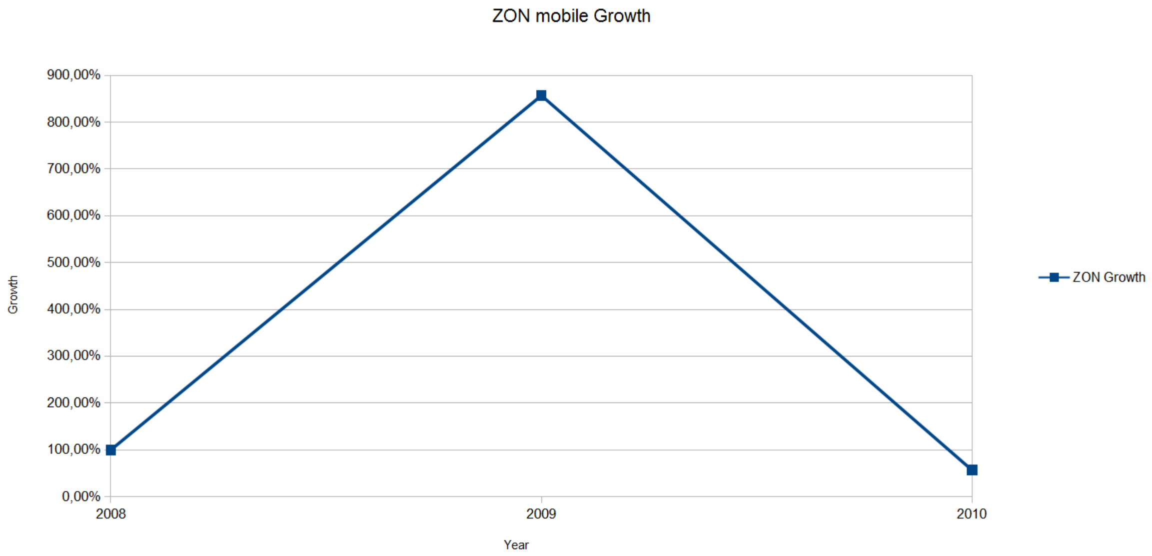


Figure 4.25: Growth behavior

4.1.5 Phone-ix

CTT's Phone-ix brand has started well as seen on 4.26, reaching in 2008 a reported number of 120.000 subscribers. That value has since then been decreasing, probably due to the lack of marketing investment from its parent company. CTT is currently on a government's privatization list as part of the financial agreement between the Portuguese government and the IMF, ECB and EC.

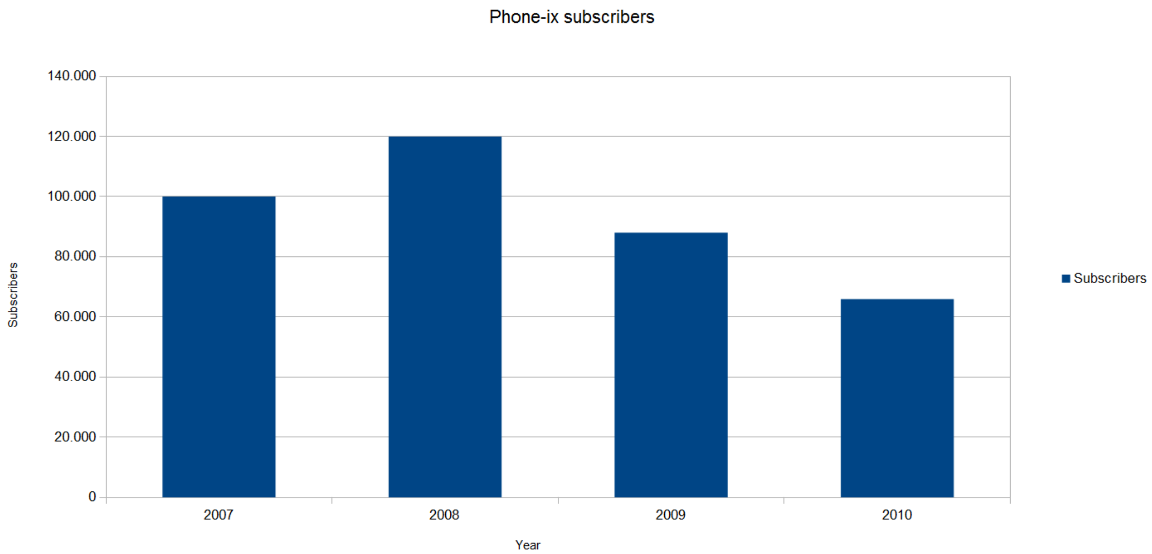


Figure 4.26: Subscribers

Unlike ZON Mobile, Phone-ix does not have a targeted customer base thus it is forced to compete without any advantage with the three MVNOs belonging to TMN, Vodafone and Optimus. Not surprisingly, its market share has been decreasing since 2008 and prospects are not good.

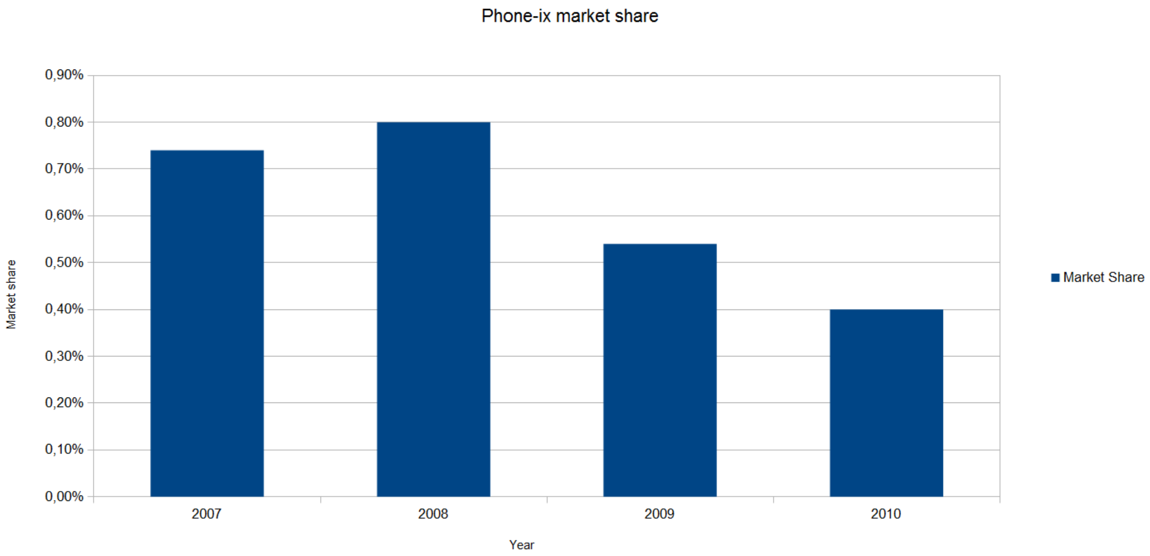


Figure 4.27: Market share

Figure 4.28 just states the obvious. The brand has started to loose customers.

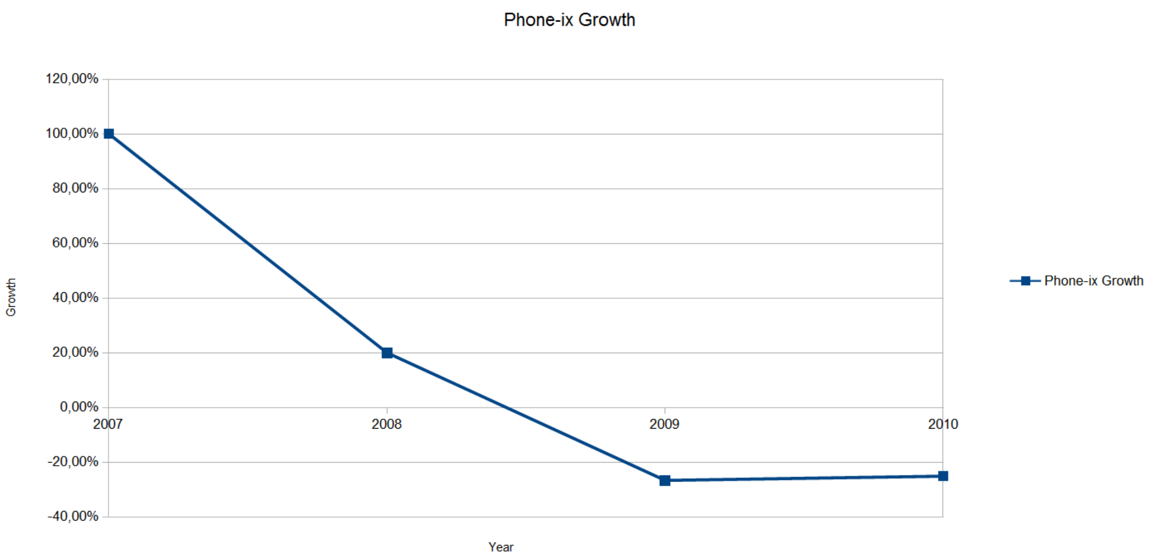


Figure 4.28: Growth behavior

4.2 Subscribers behavior

Figure 4.29 shows how the average price decrease [61] influenced the time spent on each call. Notice that from 2002 the number of calls has been relatively stable as the number of minutes continued to rise. The current trend is to increase the gap between the number of calls and number of minutes due to the rapid spread of tribal plans i.e. Optimus's *TAG* and others. These plans allow subscribers to talk between members of their "tribe" for "free". The word "free" is in between commas because there is an activation fee i.e. 5€ allows the plan to remain active for 12 days; 10€ for 24 days and so forth until a maximum of 60 days. Although all operators state that this fee is entirely converted to services credit, what the subscriber is actually doing - like all prepaid plans - is lending money to its operator.

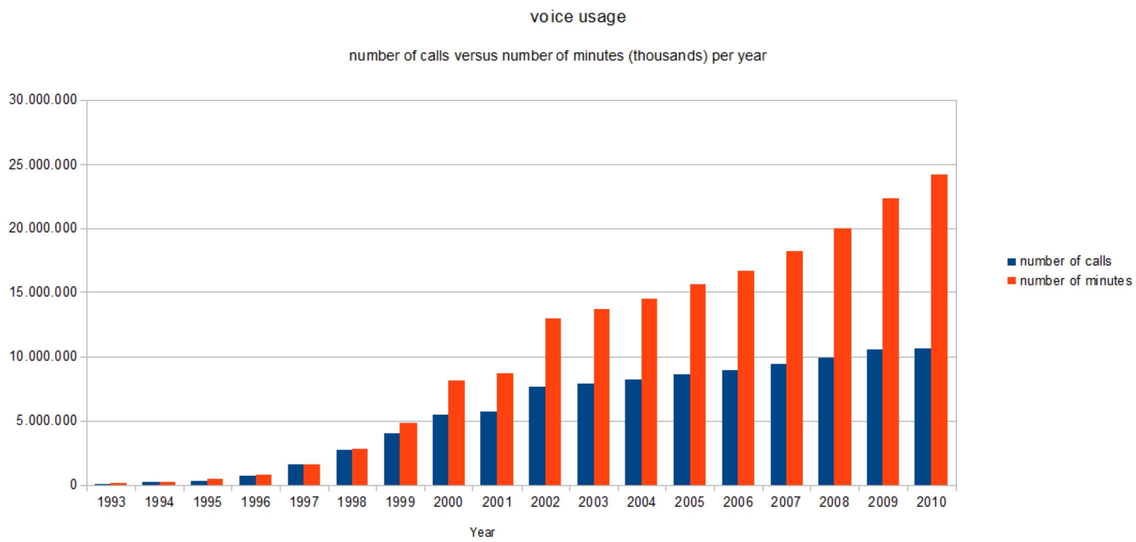


Figure 4.29: Subscriber calls versus minutes behavior

The Figure 4.30 shows how the entrance of Optimus in the market with its campaign *Pioneiros* changed the trend on the number of minutes spent on each call. Until 1998 the trend was to decrease the time on a call, but with the third player the trend inverted and is going towards 1993 values of 2 minutes and 36 seconds.

The number of SMS per year has surged from 2005 onwards. The reason for the popularity has been SMS price reduction and even the offer of free SMS packages. Like voice calls, SMS packages appear as being free inside the new tribal plans. As with voice calls, the subscribers of such plan have unlimited and free SMSs between members of their "tribe".

Figure 4.32 demonstrates exactly that. In 2010, each subscriber sent an average 1596 SMSs, thus meaning that every day he or she sent more than 4 SMSs.

MMS messaging follows the same SMS trend but on a different league. It is true that its number has been increasing consistently but it wont match the number of SMSs any time soon. The main reason may lay on the practicality of the SMS as it is just a simple text message. The fact that both devices must be fully compatible with the technology may detract a few as well. The cost factor may no longer apply as it did in the recent past because, once more, the new tribal plans include free limitless MMSs between "tribe" members. Still, and using

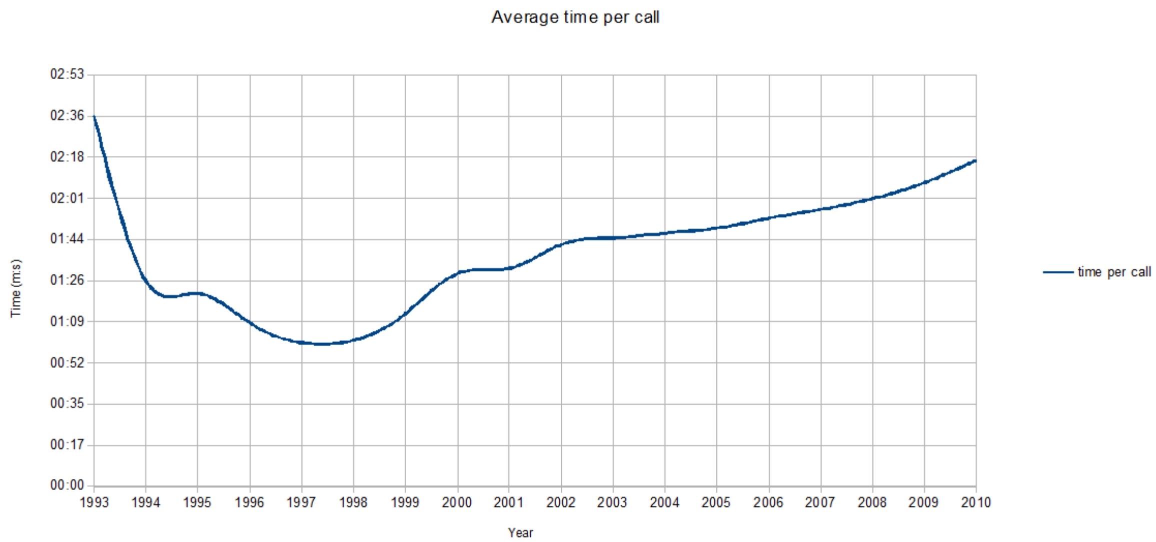


Figure 4.30: Average time per voice call

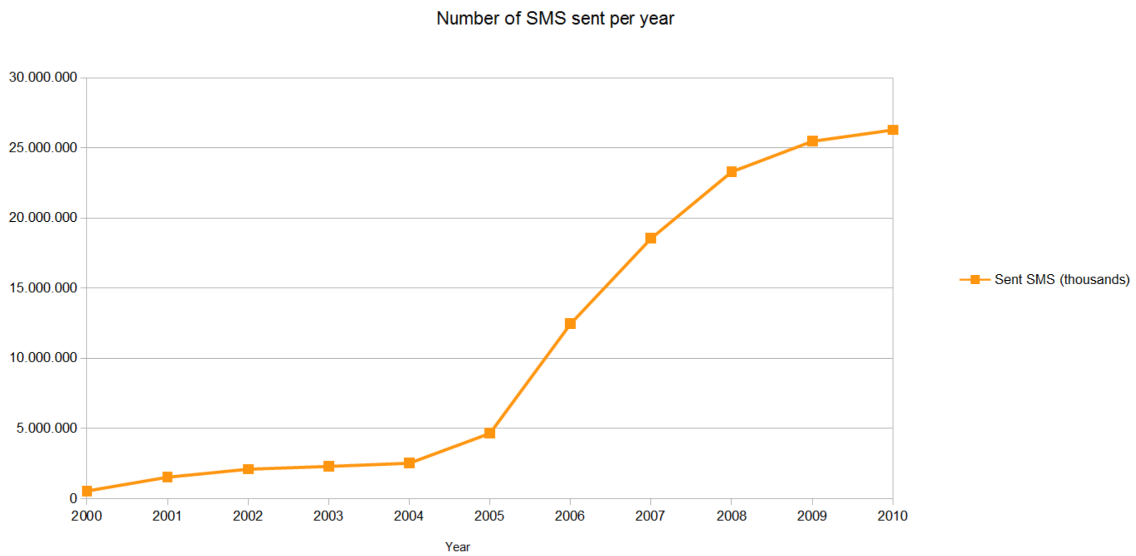


Figure 4.31: SMS per year

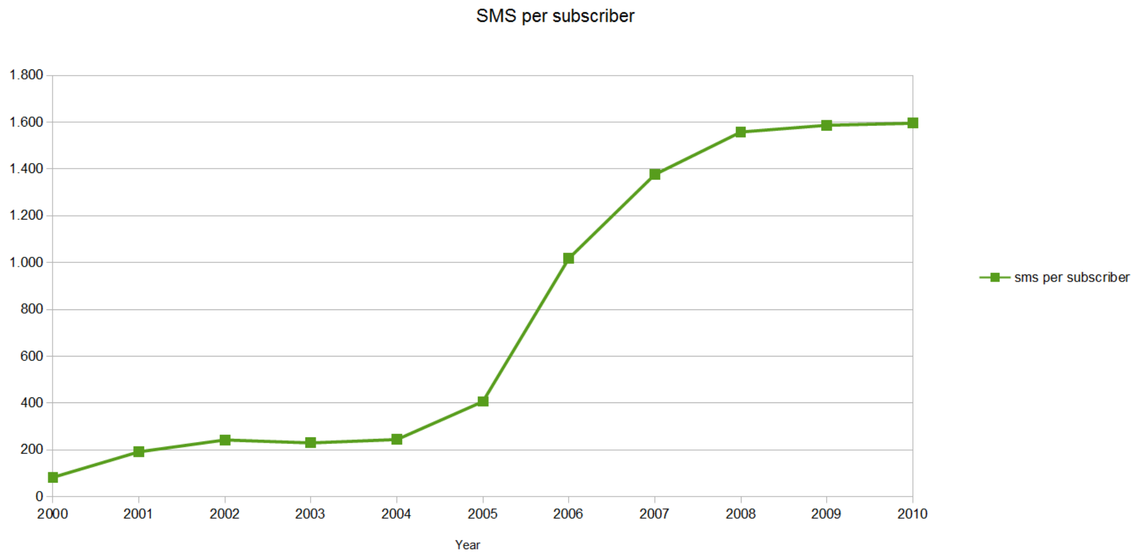


Figure 4.32: SMS per subscriber

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as reference the *TAG* plan, we see that sending an MMS to a different plan within Optimus or to a different network costs 42,3 cents.

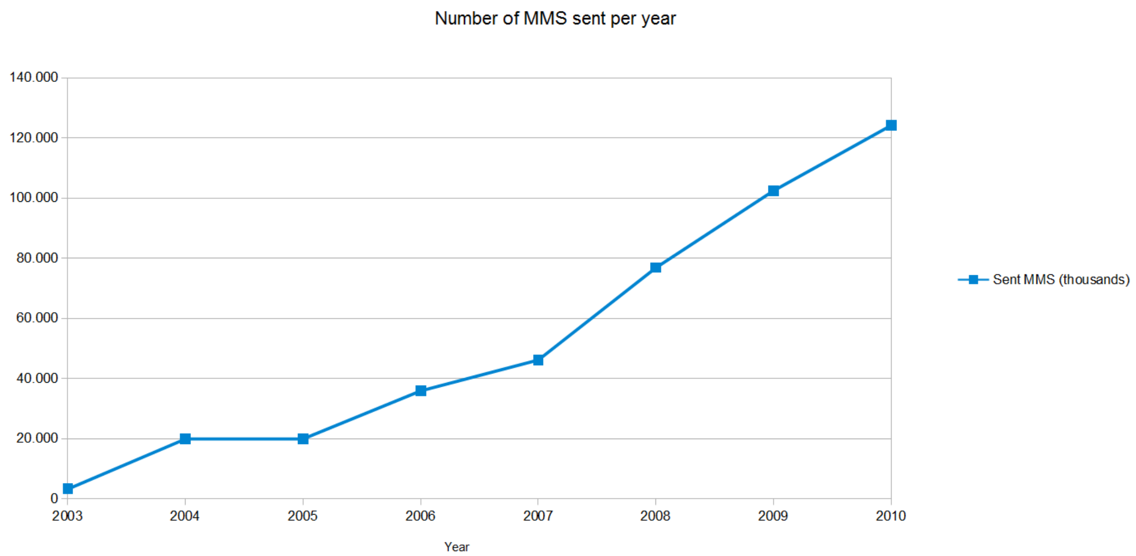

Figure 4.33: Subscriber MMS per year

Video calls follow an interesting pattern, as the number of calls has even decreased from 2009 to 2010. As with MMSs, video calls are also included on the tribal plans. This by itself excludes some of the cost factor from the equation, remaining the question of why the difference in behavior. And it excludes some of the cost factor, because like with the MMS and using the same Optimus plan with the same conditions, a video call costs 65 cents per minute. The answer - besides the price - may lay on the subscriber's need to use the service and on the quality of the WCDMA coverage on main roads, as stated by the regulator [12]. Like with MMS service, both devices must be fully compatible with the technology, and not all phones have the ability to perform video calls.

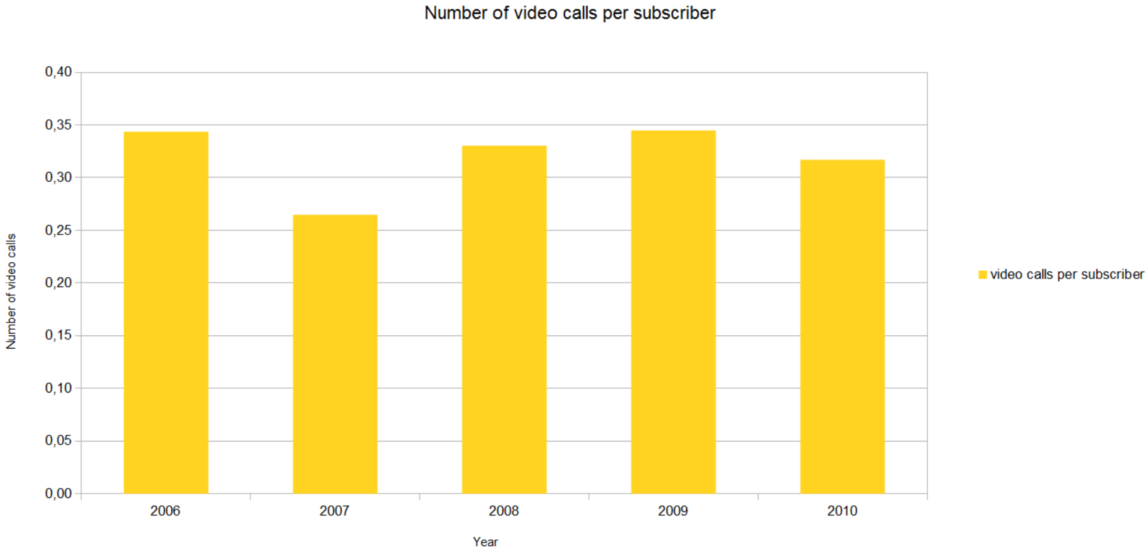

Figure 4.34: Video calls per subscriber

Notice the fact that in 2010, the average video call lasted longer than a simple voice call, topping almost 4 minutes. This means that a video call service user, is willing to pay more for this particular service.

Figure 4.36 shows the difference in duration of voice and video calls thus proving that whoever uses video call service is willing to spend more time (and money) on a call.

This Figure 4.37 describes a similar situation to that seen with the number of voice calls versus number of minutes. As we can see, the number of calls remain stable while the duration of the call increases to a maximum in 2009 and remains high in 2010.

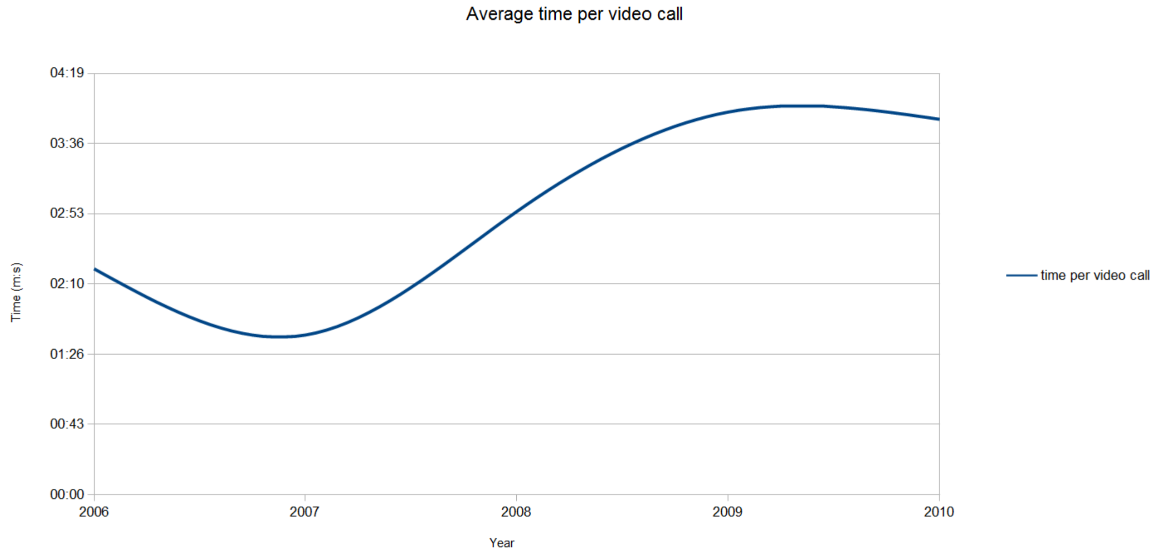

Figure 4.35: Average time per video call

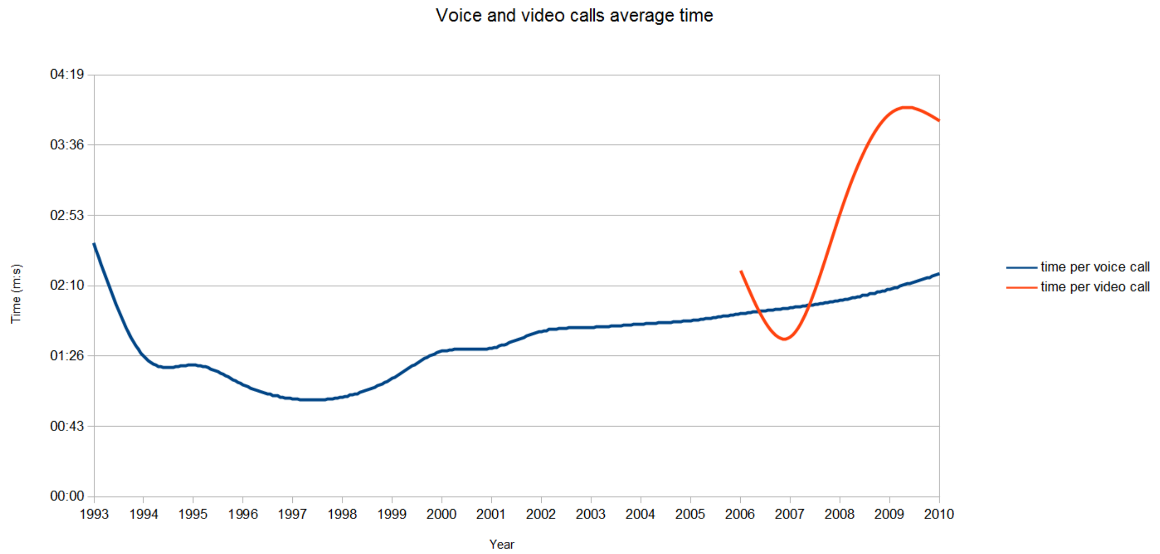

Figure 4.36: Average time in voice and video calls

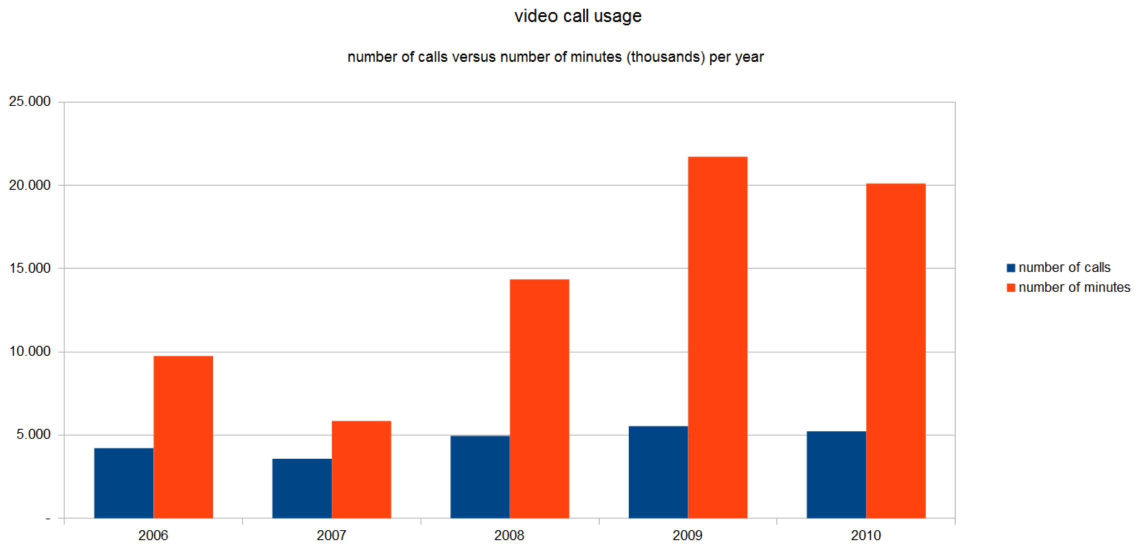

Figure 4.37: Subscriber video calls versus minutes behavior

4.3 Market

Portuguese MTS penetration remains one of the highest in the EU27. In 2010 it rated 154,9 per 100 inhabitants, only second to Italy on the list and in front of Finland. Still, as we can see on Figure 4.38, Portugal is not an isolated case. The EU27 average is not far behind although the gap between them has been increasing to a 2010 record 26,9%.

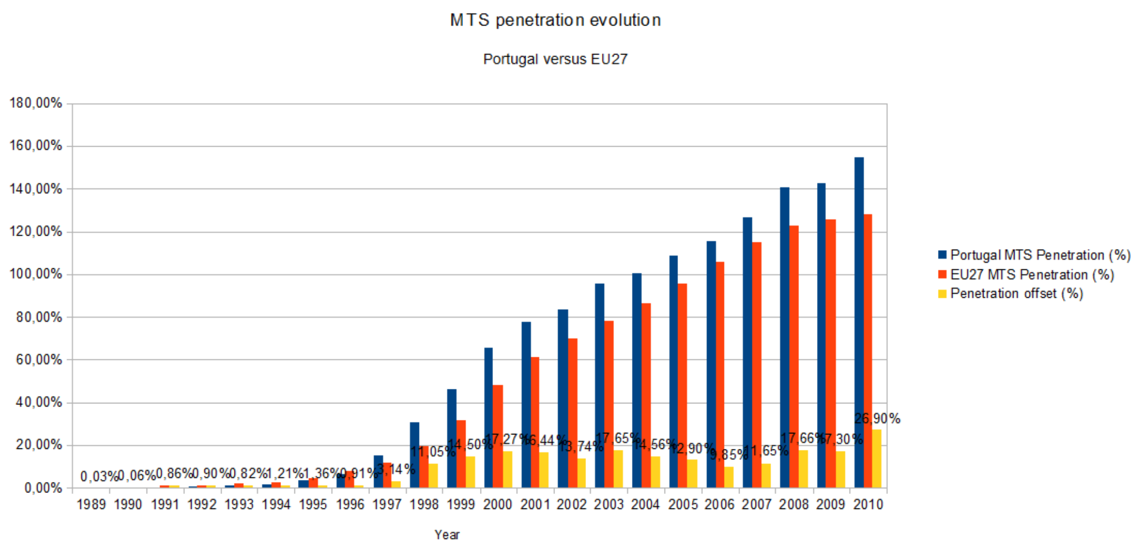

Figure 4.38: Market penetration: Portugal versus EU27.[151]

Figure 4.39 shows that after the third operator entrance in 1998, subscriber growth rate has been decreasing over the years and that the arrival of the two new NVNOs have not really affected the market.

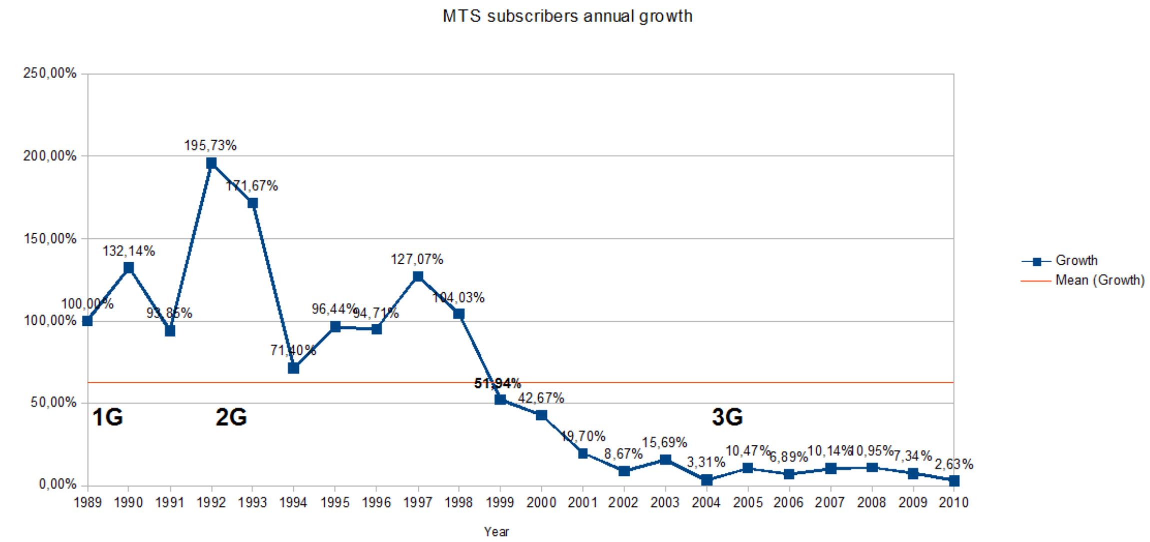

Figure 4.39: Subscribers growth behavior

Figures 4.40 and 4.41 do tend to relate the country's economic health with the subscriber growth rate. 2004 marks the 100% penetration attainment, so it is normal to have a slower growth rate around that period and obviously from there forth.

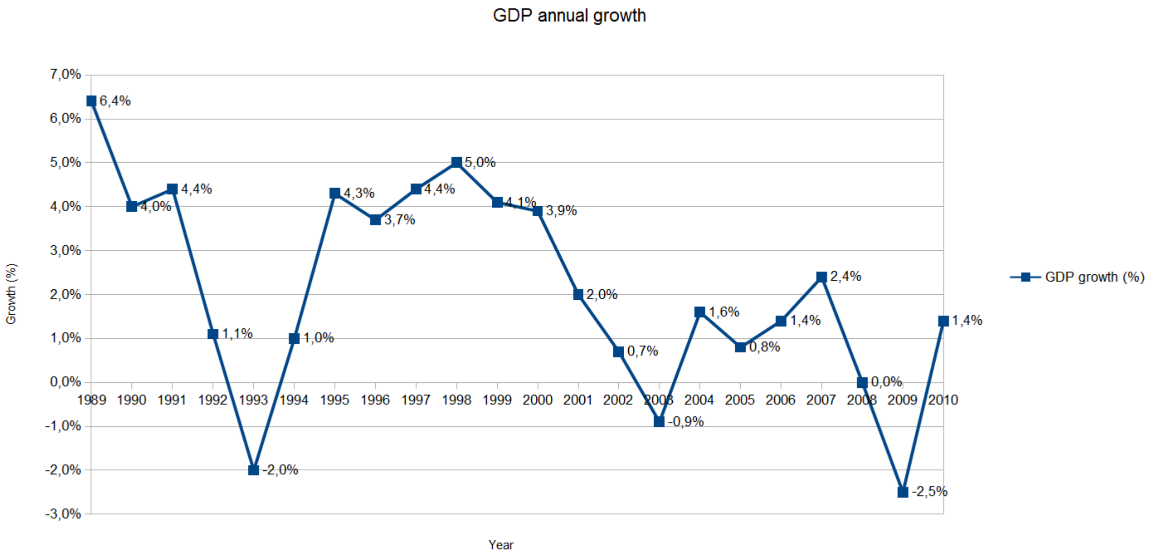

Figure 4.40: GDP growth behavior.[152]

In Figure 4.42 we can see proof of the proliferation of more than one SIM per subscriber,

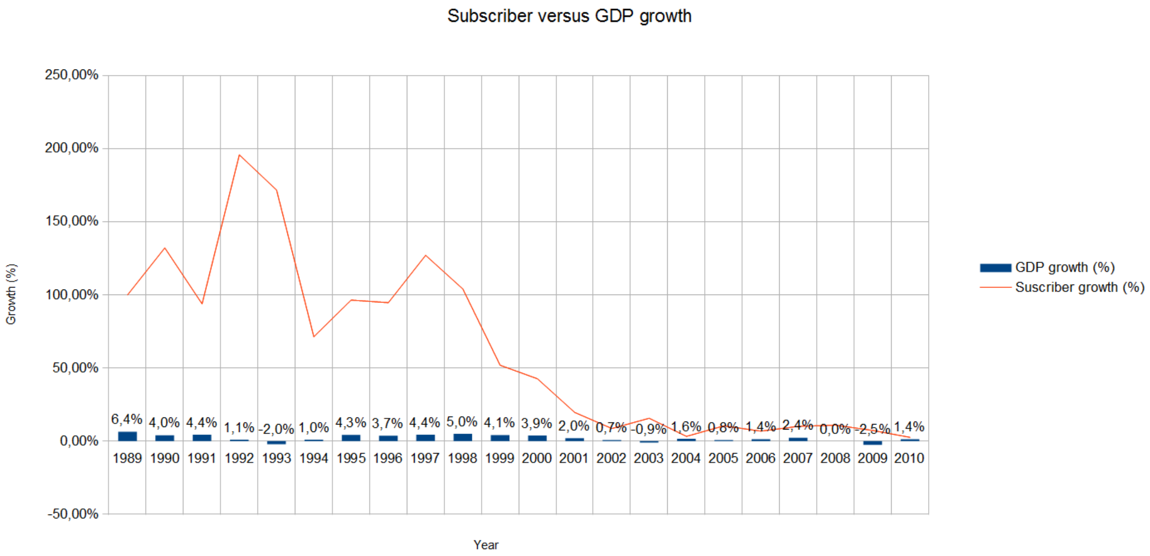

Figure 4.41: GDP versus Subscriber growth behavior

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as the number of subscribers surpasses the number of inhabitants.

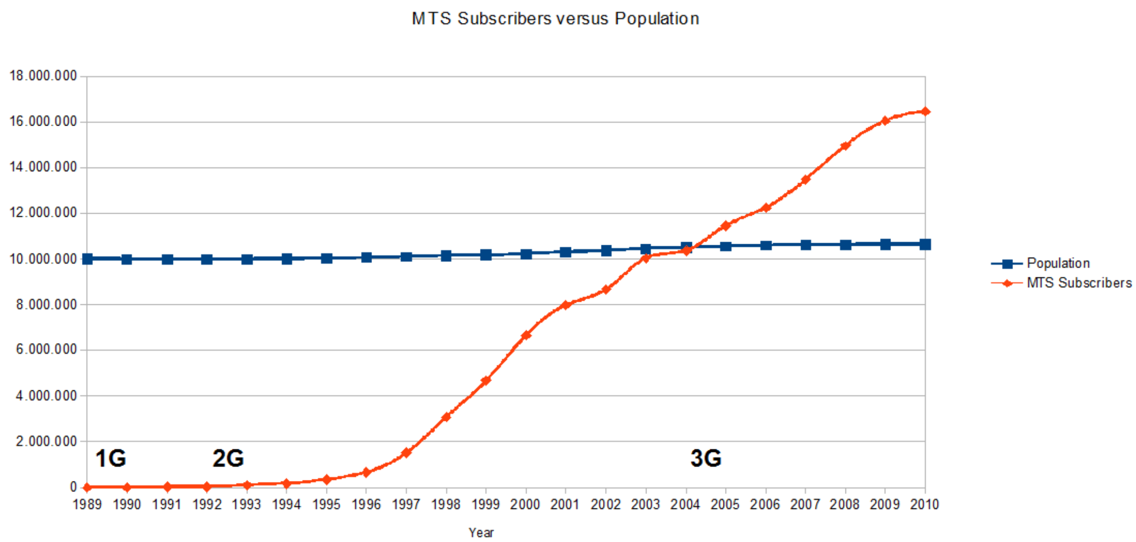

Figure 4.42: Portuguese population versus MTS subscribers

This particular Figure 4.43 is quite interesting, because it shows how the third operator affected the other two competitors. As we know, from 1989 to 1992, TMN had no competition. When in 1992, Vodafone entered the market we can see how little effect it had on the existing operator. TMN and Vodafone continued to grow their subscriber number until 1998. Notice how the lines are almost undistinguishable during that period. When Optimus came, it affect most the growth of Vodafone.

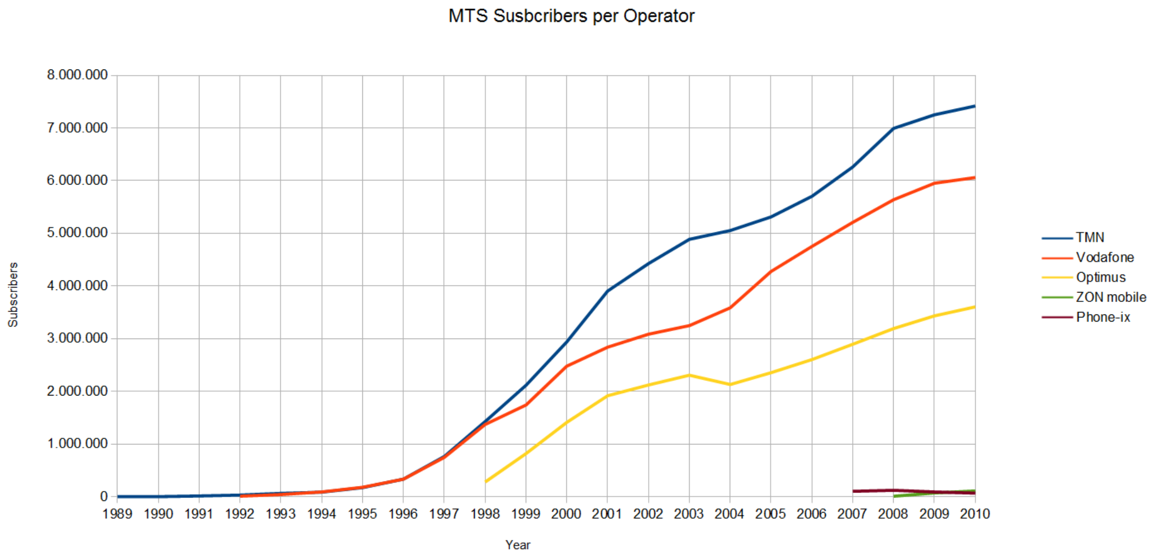

Figure 4.43: Subscribers per operator

The Figure 4.44 illustrates the previous point. Notice how in 1998, Optimus has an ascending line and Vodafone on the other hand has the worst performance. From 2001 the three maintain the same behavior until 2010. Once more, the entrance of the two MVNO's did not affected the MNO's growth behavior considerably.

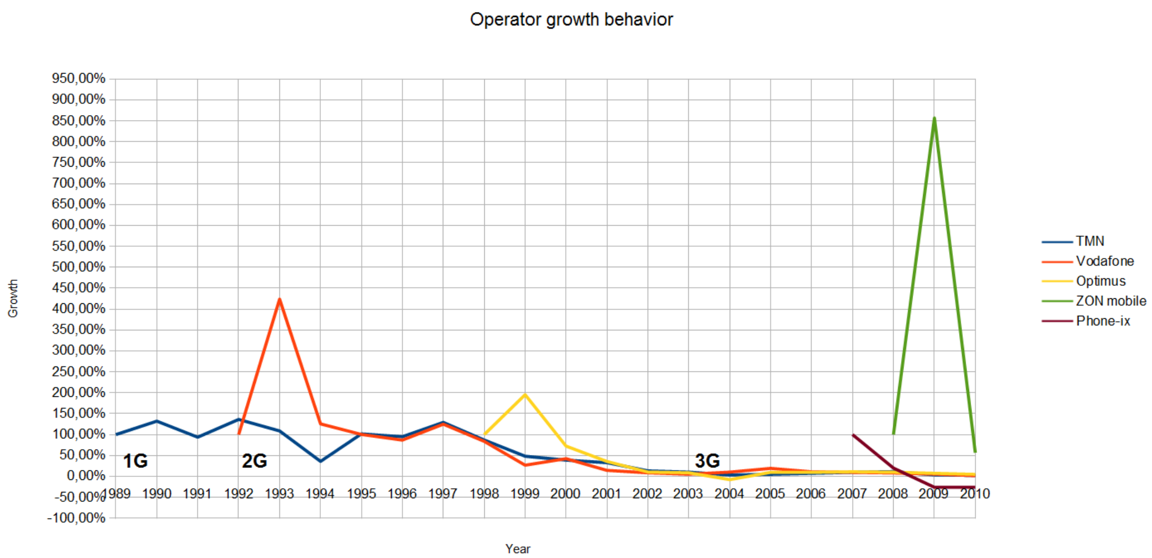

Figure 4.44: Operators growth behavior

This Figure 4.45 shows a half split of the market from 1994 to 1998 - almost theoretical perfection - and an asymmetric split from 1998. What it probably means is that Optimus directly competes for the same customers as Vodafone. Notice once more, how TMN remains around the 50% share mark.

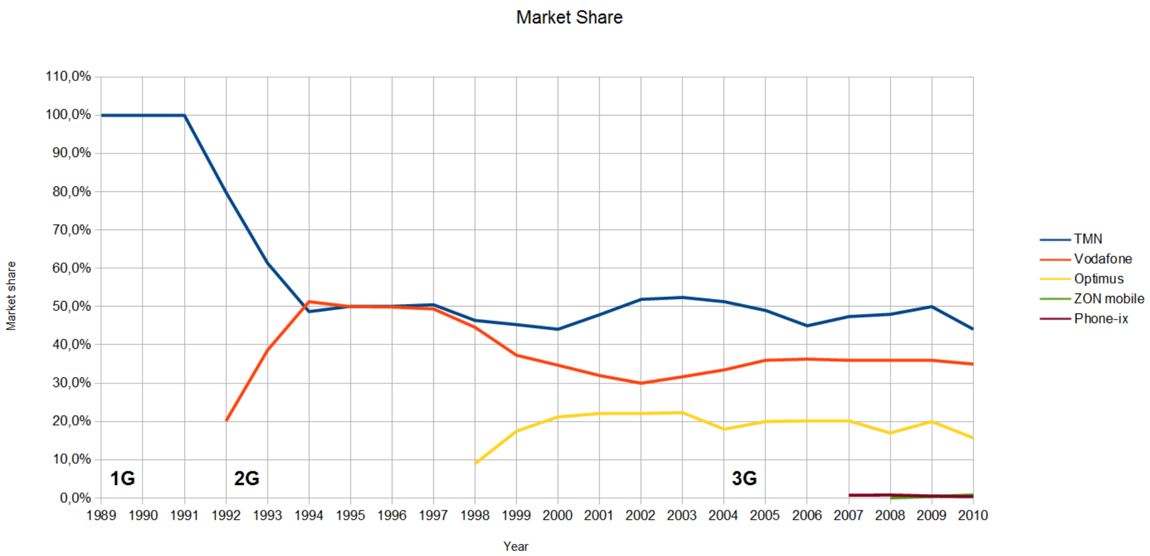

Figure 4.45: Operators market share

Plan types remain biased towards the prepaid with more than 70% share. Cost control remains the main reason for the prepaid success. Notice that postpaid plans continue to have more offers at lower prices than prepaid. In 2009 there were four offers on postpaid plans at around 15€ and six offers on prepaid plans at around 30€ [12].

Although percentages on prepaid plans are quite high in Portugal, they are still on par with the other European countries, as they also prefer prepaid plans. What Portuguese consumers probably are unaware is that Portuguese prepaid plans - unlike postpaid - are, on average, cheaper than the average EU countries as seen on Figure 4.47.

Figure 4.48 still shows a large gap between those "able to use 3G services" subscribers and those who actually use them. From the 10,5 million 3G able subscribers, only 4 million use 3G services i.e Mobile TV, Video call, Internet access, etc. and from those 4 millions, 1,2 million are computer broadband access boards. Notice that the e-Government initiative i.e. *e-escola, e-professores, etc.* contributed to the increase of the 3G active users number. These programs have since been suspended by the current government, therefor it is expectable for 3G user growth to be affected. Growth has already decelerated as seen on Figure 4.49.

Figure 4.50 shows how all operator keep ARPU values closer together. What is noticeable is that between 1993 and 1996, ARPU values remained abnormally high in spite the supposed competition from the two existing operators. TMN was notably faster to react to the Optimus's entry.

Although it would be interesting to observe CCPU behavior, these values were only published between 1997 and 2007. During those 10 years, they have decreased considerably. In the case of TMN, there has been almost a 3 fold cost decrease. These values are even more surprisingly when we compare both Vodafone's and Optimus's with TMN's. There is almost

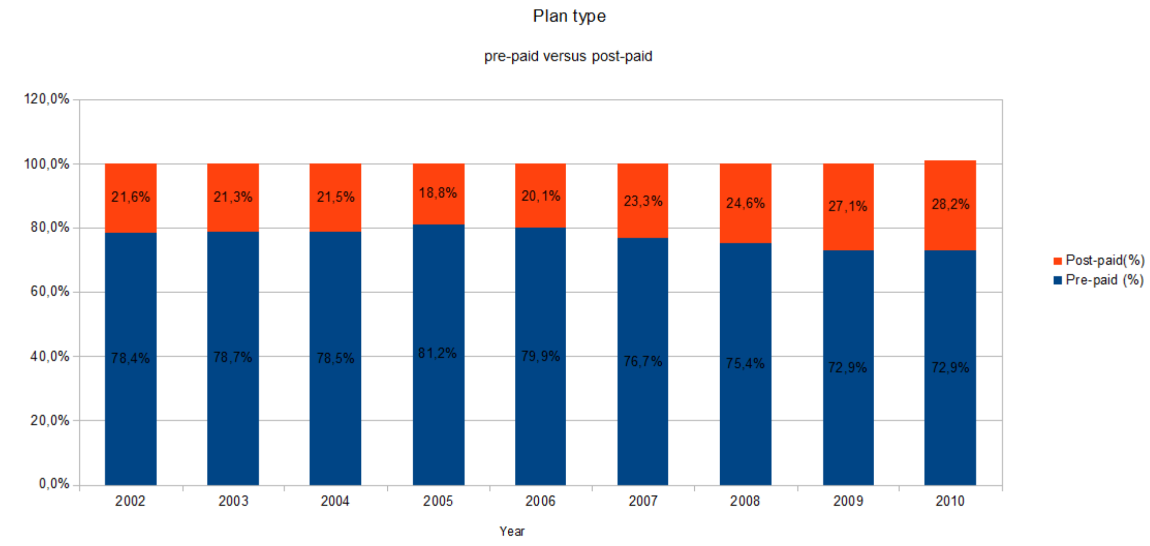

Figure 4.46: Prepaid versus postpaid plans

Profile / Plan	Low usage	Average usage	High usage
Prepaid	21,3%	29,8%	42,6%
Pospaid	-3,3%	-5,2%	0,6%

Figure 4.47: Prepaid and postpaid versus EU average prices.[12]

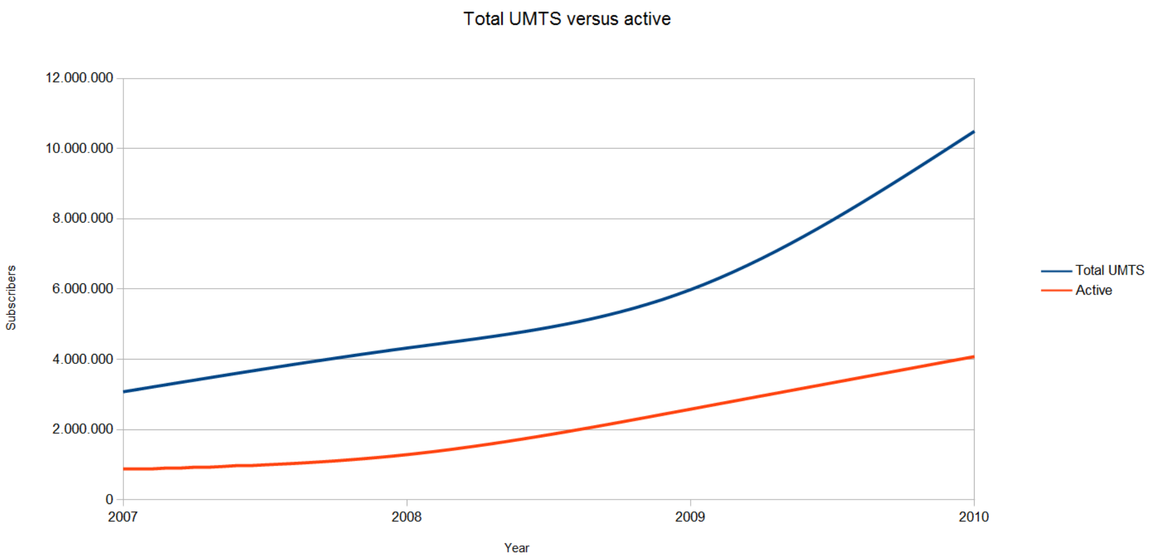

Figure 4.48: Total UMTS subscribers versus active subscribers

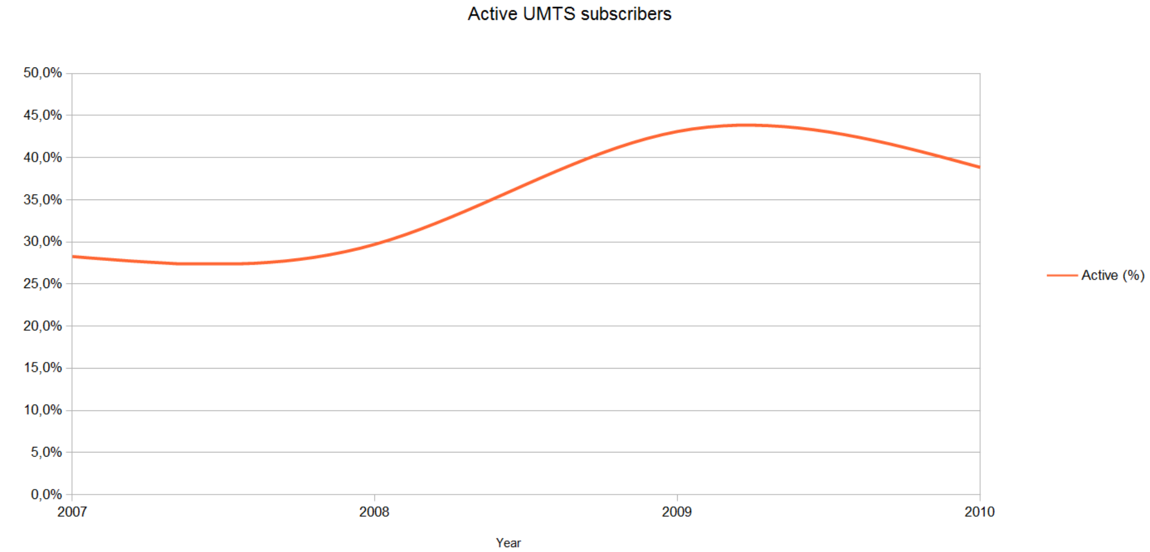

Figure 4.49: Active UMTS subscribers behavior

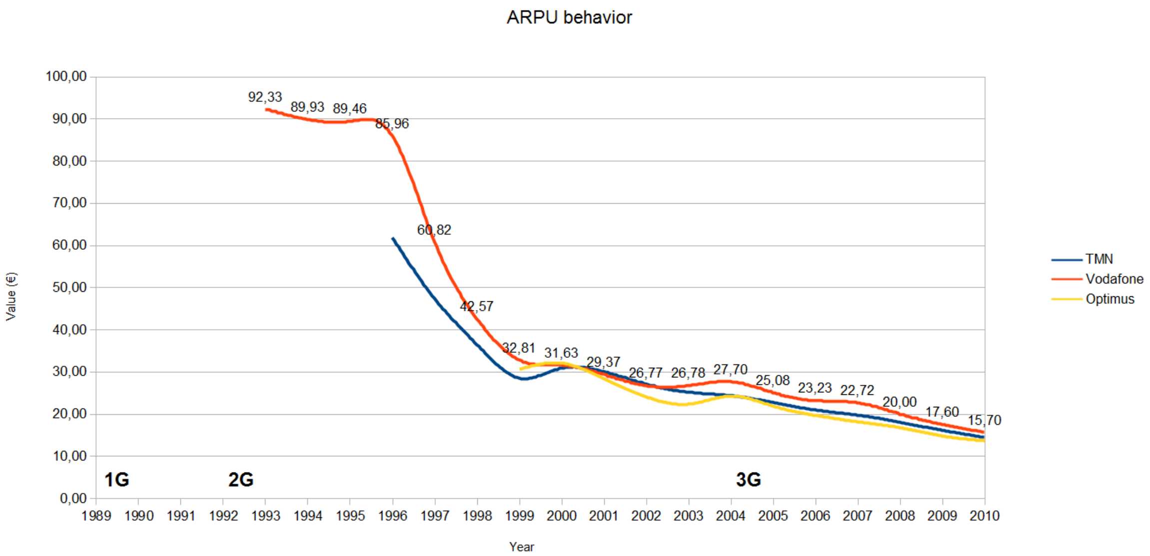

Figure 4.50: ARPU behavior

a 4€ gap between them.

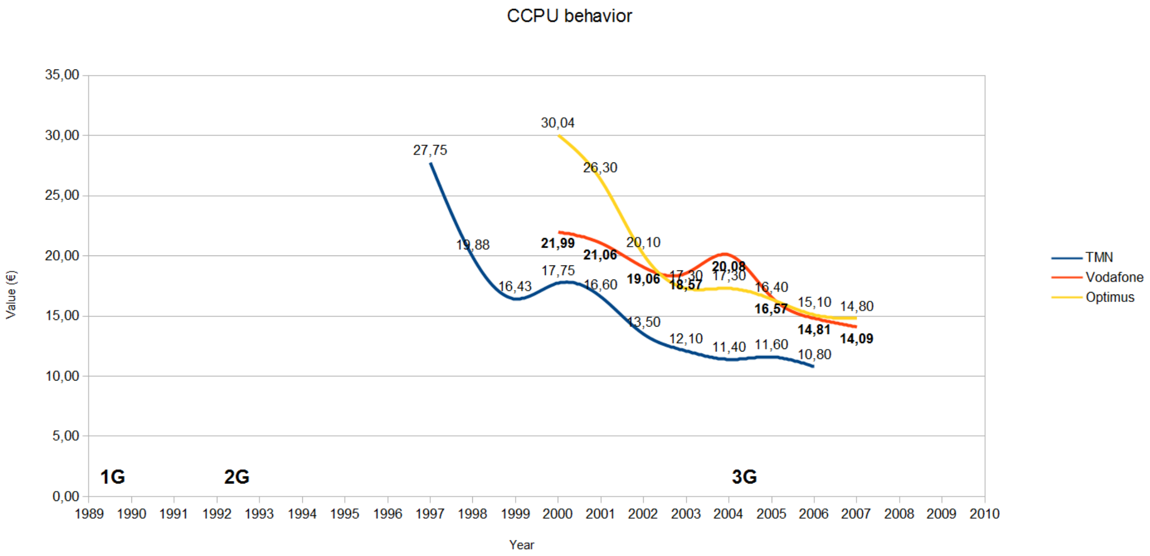

Figure 4.51: CCPU behavior

Figure 4.52 shows several things. It shows how tight was Optimus AMPU in 2000 with 2,06€ and again in 2007 with 3,40€. It shows how much money TMN was making in 1997 - almost 20€ per subscriber. And it also shows how Vodafone has been increasing its margin since 2002.

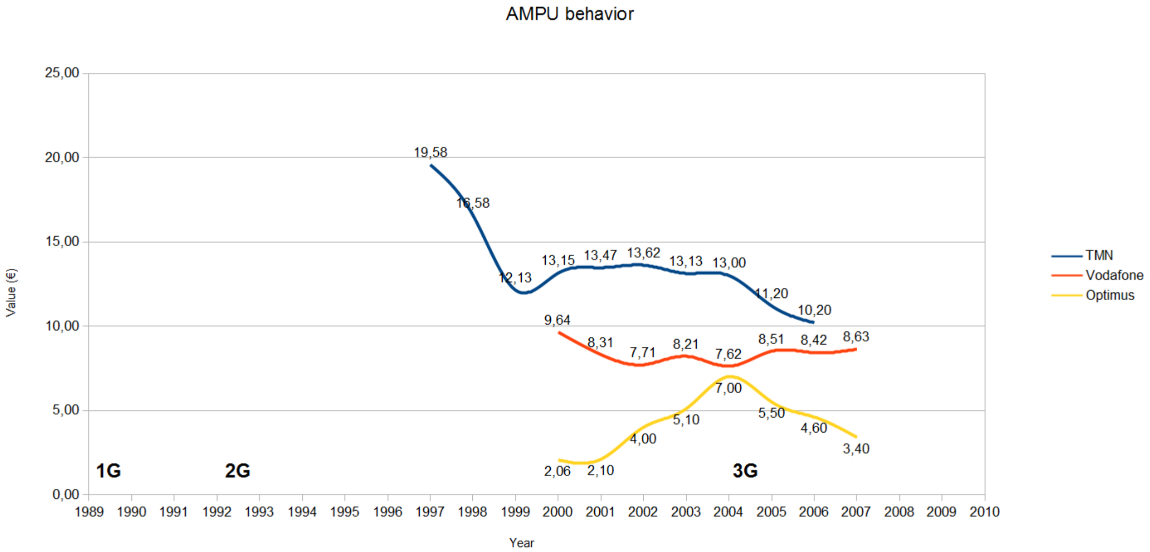

Figure 4.52: MNO AMPU behavior

EBITDA values on Figure 4.53 show the market ability to maintain the existing 3 MNOs healthy in business.

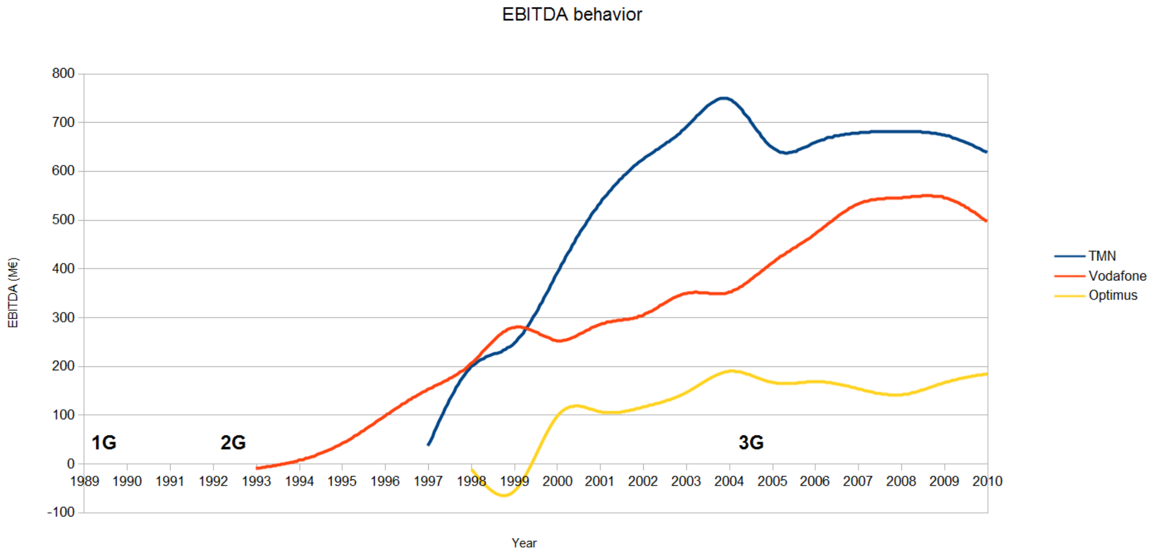

Figure 4.53: MNO EBITDA behavior

4.4 Overview

TMN gained market share by being the first to arrive to market and maintained its position by having an innovative posture - courtesy of its parent company's innovation center: PTInovação S.A..

The arrival of vodafone in 1992, followed a theorized market split in two halfs. There were minor variations between the two until 1998.

In 1998 the market share changed in an interesting way. The entry of Optimus in the market, thus splitting it asymmetrically, suggests an interaction between Vodafone and the newly arrived. It seems to indicate that the offering from those two companies can be substitutes thus targeting the same customer base.

The interaction between TMN and the other two MNOs from 1998 until 2010, suggests that the offering carried out by the incumbent's mobile operator is in fact complementary to Vodafone's and Optimus's.

The entry of a new player in 1992 and 1998 has caused significant cost reduction in order to improve competitiveness. The AMPU values and in particular the ones reported by TMN, suggest that the Optimus entry caused a major decrease in prices. In 1998, TMN officially reported a price decrease in services costs by 26%. [115].

Vodafone points out some reasons for the late ARPU decrease: Macroeconomic; regulation; competition and new tribal plans [29].

The entry of two MVNOs, Phone-ix in 2007 and ZON mobile in 2008, apparently had no influence on market behavior.

ZON mobile intends to grow by first targeting their cable customers. Its 1,5 million clients target is reachable due to highly competitive bundle offers. There are customers outside its cable subscribers, but are negligible and highly volatile to the other operators MVNO offerings such as UZO, Rede4, Vodafone Directo, etc.

CTT aims at big corporate clients by offering them a very close relationship with the operator, i.e. it has deployed 17 big account managers. Although they have captivated some private customers, these customers are dispersed throughout the other networks MVNO offerings, i.e. UZO, Rede4, etc.

The three MNOs continue to report good EBITDA reports in spite a low subscriber growth rate during recent years.

The absence of CCPU values from the operators indicates that such information was corporate sensitive.

Subscribers are spending more time on each voice and video call. They are also sending more SMSs and MMSs each year.

The Portuguese MTS market evolution is not that different from the EU27 average.

Apparently there is a relation between the country's GDP performance and the MTS market behavior.

2G technologies continue to dominate the mobile services.

The paper *Entry, Costs Reduction, and Competition in the Portuguese Mobile Telephony Industry* [61] published in 2005, states that *"Mobile telephony is a luxury good and demand increases over time"*. This may justify the increasing gap over the years between UMTS capable devices and UMTS service usage, meaning the purchase of technologic sophisticated mobile phones as part of a social statement and not necessarily to make use of its capabilities. When we look at some data from Italy - The number one country on MTS penetration in 2010 - we see some of its fashion industry targeting the mobile phone as a seasonable item like for instance a handbag. There is a web site [153] with a dedicated section to Top Designer Cell Phones, here we can find some of Italy's most famous brands i.e. Armani, Prada, Dolce& Gabanna, etc. selling mobile phones. These brands, although not creating directly new subscribers are somehow forcing the ones who do not own a mobile phone to be compelled to do so. Operators, therefor, can make profit from launching these devices. Italy, maybe, should be looked more closely as the trend leader to follow.

The full liberalization of the telecommunications industry imposed by the EU in 1998 and applied in Portugal in 2000 - via derogation (decision 97/310/EC), meant that any company licensed by the regulator could offer its services. To the customers this meant the arise of new players in the fixed telecommunications services. These new players could use their own infrastructures or lease the existing ones by making contracts with their owners. The global behavior of the three companies show no signs of having been influenced by this measure.

Chapter 5

Simulation software tools

We can model the Portuguese MTS market as a dynamic system. In order to do so, in this chapter, we will focus on Vensim dynamic systems simulation tool, developed by Ventana Systems Inc.. The simulations in this chapter are based upon versions of a dynamic system model developed by the *Grupo de Sistemas de Banda Larga* (GSBL) [42].

5.1 Vensim

Vensim is a very light simulation software made by Ventana Systems, Inc. based in Harvard, Massachusetts (USA). The name *"Vensim"* stands for VENtana SIMulation environment and it is an integrated framework for conceptualizing, building, simulating, analyzing, optimizing and deploying models of dynamic systems [124]. With this tool it is possible to simulate the dynamic behavior of complex systems thus introducing improvements upon those systems. Simulated situations may come from different sectors such as economics, business, science, environment, health care and many others. Its current version is 5.11 and is available for both Windows (XP/Vista/7) and Macintosh OSX machines [125].

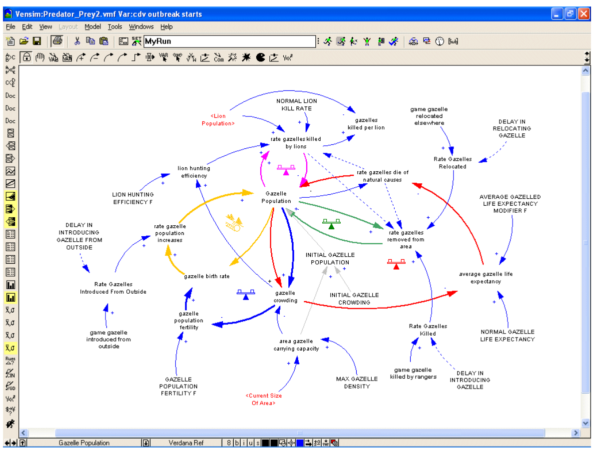

Figure 5.1: Vensim - Predator/Prey Simulation.[124]

On Figure 5.1 it is possible to see how a complex Predator/Prey dynamic system looks like.

5.2 Simulations

Two simple simulations were made in order to discuss the retrieved data in this work. The two will try to model subscriber adherence to operators during a period of years using just one quality differentiator. The difference between them will be the market expansion. On the first simulation we will consider a natural supply of new subscribers, that operators will try to seize and add to the ones conquered from the others. The second simulation will consider a non supply of new subscribers in order to focus the operator growth on the ability to conquer competition subscribers. The first simulation is naturally closer to reality than the second. Concerning both simulations, we considered the MTS market in the period from 2000 to 2006. This was done for two main reasons. The first reason being the existence of three important types of values during that period - ARPU, CCPU and AMPU - from the three main operators. The second reason being the existence of one MVNO in 2007 with ARPU values diluted between the consolidated business of the company and therefor not comparable. The quality differentiator between operators was the ARPU. The reason for choosing the ARPU measurement relates to each subscribers monthly spent value.

5.2.1 Scenario one - expansible market

In this scenario we will have three operators: Operator A (TMN), Operator B (Vodafone), and Operator C (Optimus). Each operator will start with a subscribers base which is equal to its subscribers number in 2000. The variable **M** will define the initial number of subscribers. Therefor we will have:

- M_A = 2.939.268
- M_B = 2.478.800
- M_C = 1.410.408

All operators offer the same service but each one will have its own quality level. As stated before, we will consider their ARPUs as the quality differentiator. The variable **Q** will be used to define this characteristic. Therefor, we will have for each operator, and for the considered period, the following list of values:

Q_A = 30,90€; 30,07€; 27,12€; 25,23€; 24,40€; 22,80€; 21,00€
Q_B = 31,63€; 29,37€; 26,77€; 26,78€; 27,70€; 25,08€; 23,23€
Q_C = 32,10€; 28,40€; 24,10€; 22,40€; 24,30€; 21,90€; 19,70€

We can also see the input as the following Table 5.1:

Operator/Year	2000	2001	2002	2003	2004	2005	2006
Q_A	30,90	30,07	27,12	25,23	24,40	22,80	21,00
Q_B	31,63	29,37	26,77	26,78	27,70	25,08	23,23
Q_C	32,10	28,40	24,10	22,40	24,30	21,90	19,70

Table 5.1: Operator quality value per year

Figure 5.3 shows how the ARPU evolved between 2000 and 2006. This behavior will influence the subscribers decision towards an operator.

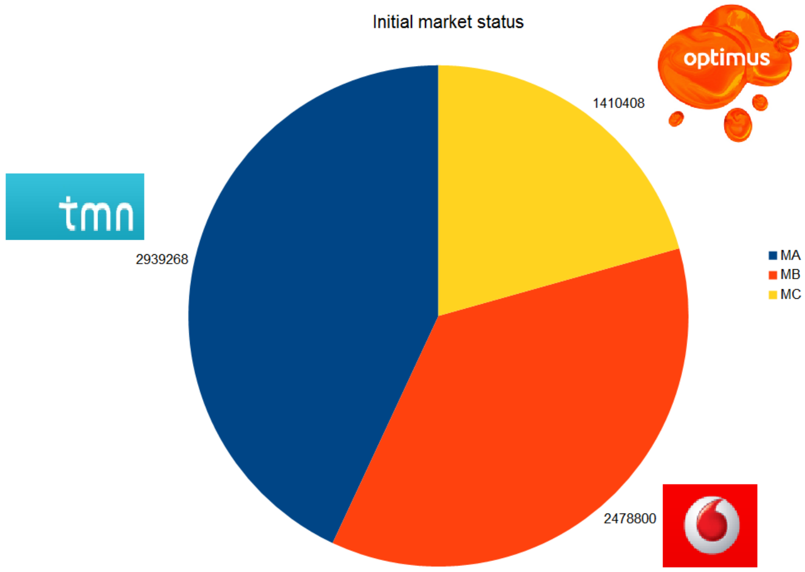

Figure 5.2: Vensim - Scenario one - initial state (subscribers)

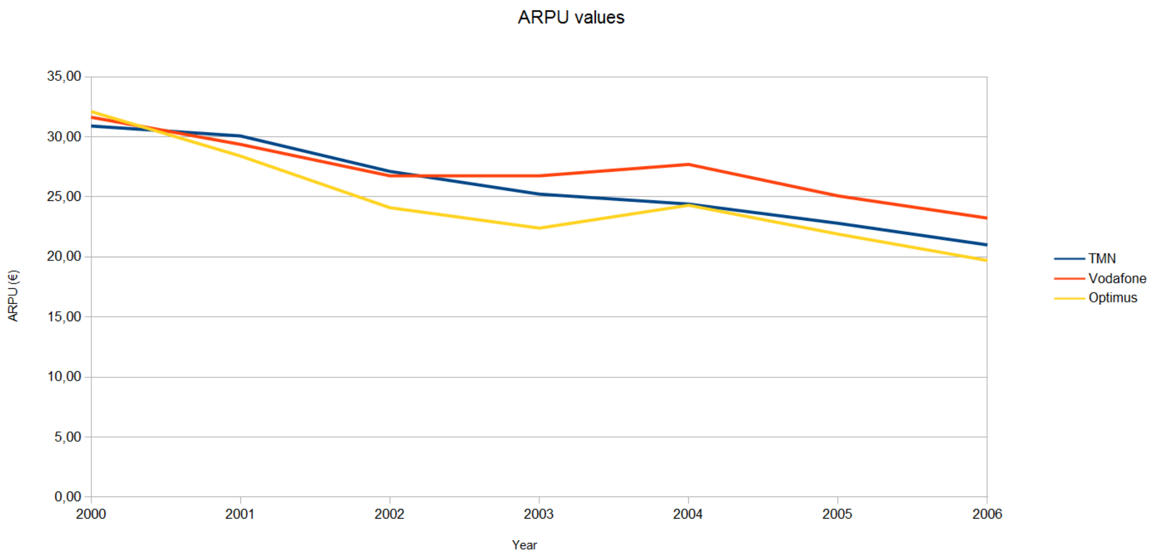

Figure 5.3: Scenario one - ARPU

When someone is shopping for a new service or trying to decide if it stays with the same service provider, usually compares services or the quality of its service with the market average to make its decision. In this case it can be defined through Equation (5.1).

$$Q = \frac{Q_A \times M_A + Q_B \times M_B + Q_C \times M_C}{M_A + M_B + M_C} \tag{5.1}$$

The relative quality of each operator towards the market can be defined through Equations (5.2),(5.3) and (5.4).

$$QR_A = \frac{Q_A}{Q} \tag{5.2}$$

$$QR_B = \frac{Q_B}{Q} \tag{5.3}$$

$$QR_C = \frac{Q_C}{Q} \tag{5.4}$$

What this means is that each operator's relative quality is nothing more than its absolute value divided by the average market quality.

If we define quality elasticity as the percentage market growth, divided by the quality percentage growth and for this simulation we will consider an elasticity of 1, we will have Equation (5.5).

$$E_Q \equiv \frac{dM}{dQ} = 1 \tag{5.5}$$

Having that value for elasticity, we can move on to calculate market changes given by Equations (5.6),(5.7) and (5.8).

$$dM_A = E_Q \times QR_A - 1 \tag{5.6}$$

$$dM_B = E_Q \times QR_B - 1 \tag{5.7}$$

$$dM_C = E_Q \times QR_C - 1 \tag{5.8}$$

Since elasticity values are defined as percentage, also these results come as percentage representing an increase or decrease in subscribers. The following three dynamic Equations (5.9),(5.10) and (5.11) define the behavior of each operator.

$$M_A t = M_A t - 1 + dM_A(t-1) \tag{5.9}$$

$$M_B t = M_B t - 1 + dM_B(t-1) \tag{5.10}$$

$$M_C t = M_C t - 1 + dM_C(t-1) \tag{5.11}$$

5.2.2 Scenario one: model

Figure 5.4 shows the model constructed for this simulation. As mentioned before, this model is feed of with new subscribers in order to bring the simulation closer to reality. The system variable *Time* controls both the feed of ARPU values and the flow of new subscribers. The amount of new subscribers being feed to the model each year was calculated using real data gathered from the regulator.

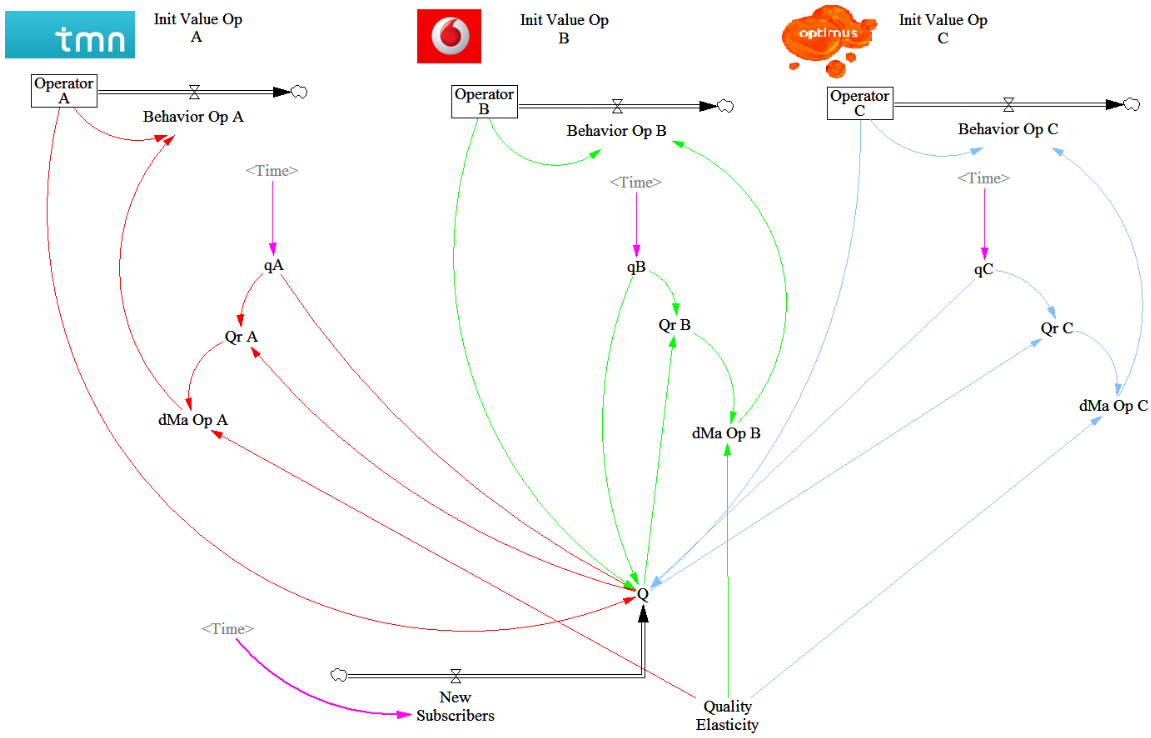

Figure 5.4: Vensim - Scenario one - model

5.2.3 Scenario one: results

Figure 5.8 shows how the operators evolved their subscriber's base and Figure 5.9 shows how they really evolved in those considered years. In the model it is interesting to see that the lower prices of Optimus boosted its customer base from 2000 to 2003 and that the same happened, on a much lower scale, in reality. Vodafone's curve is very similar in behavior but the model ended up with more than a 10% difference. TMN also has a similar curve with the interesting aspect of having lost share in the model and in reality it was the other way around with a 1% increase.

Figure 5.10 shows how the market was before the simulation and Figure 5.11 shows how the market ended after the simulation.

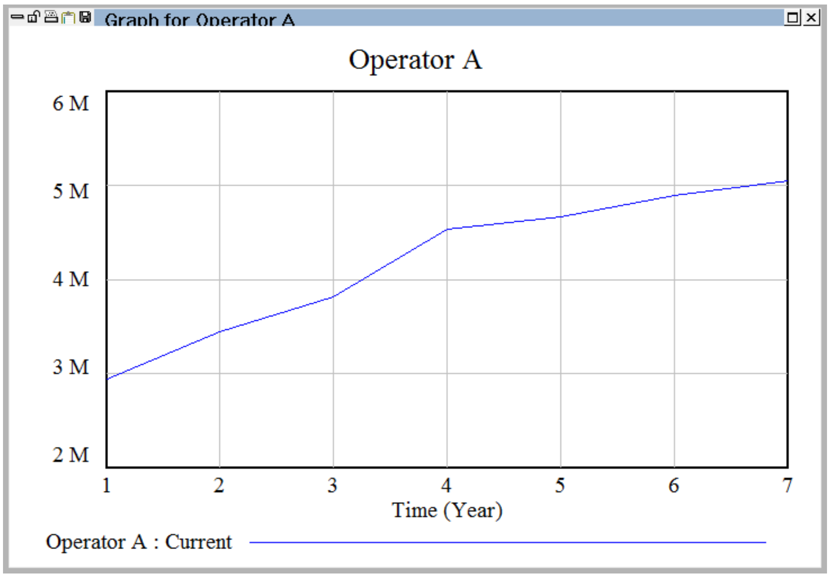

Figure 5.5: Vensim - Scenario one - TMN results

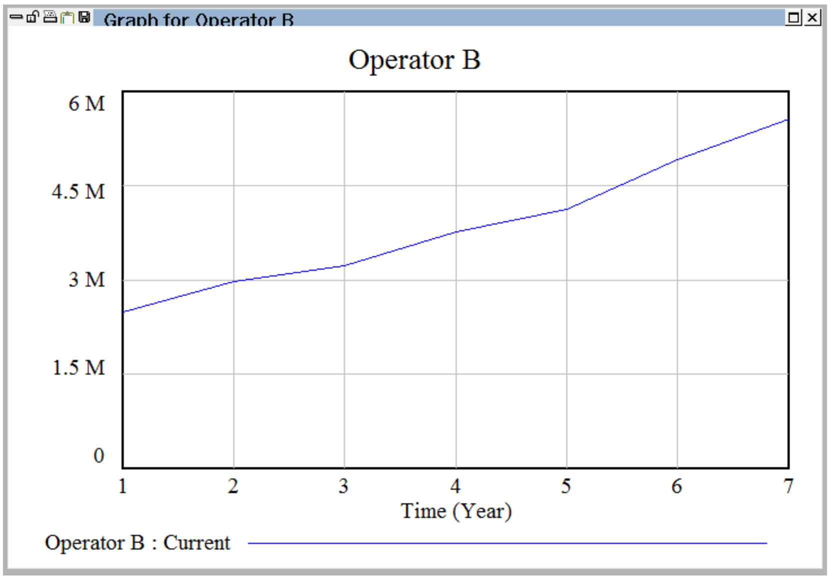

Figure 5.6: Vensim - Scenario one - Vodafone results

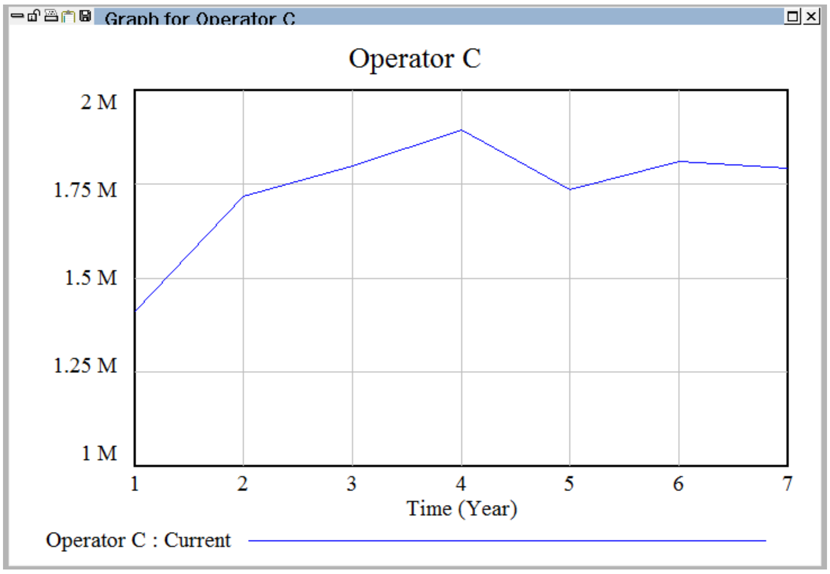

Figure 5.7: Vensim - Scenario one - Optimus results

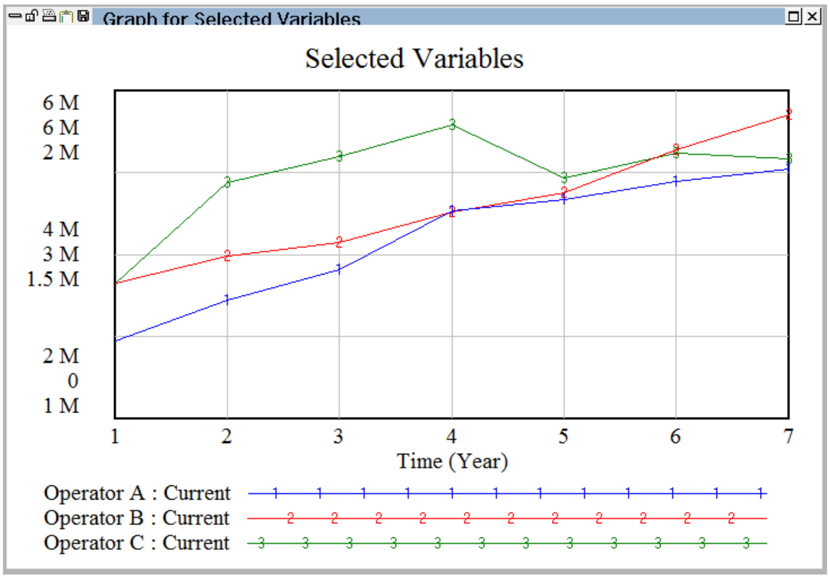

Figure 5.8: Vensim - Scenario one - results

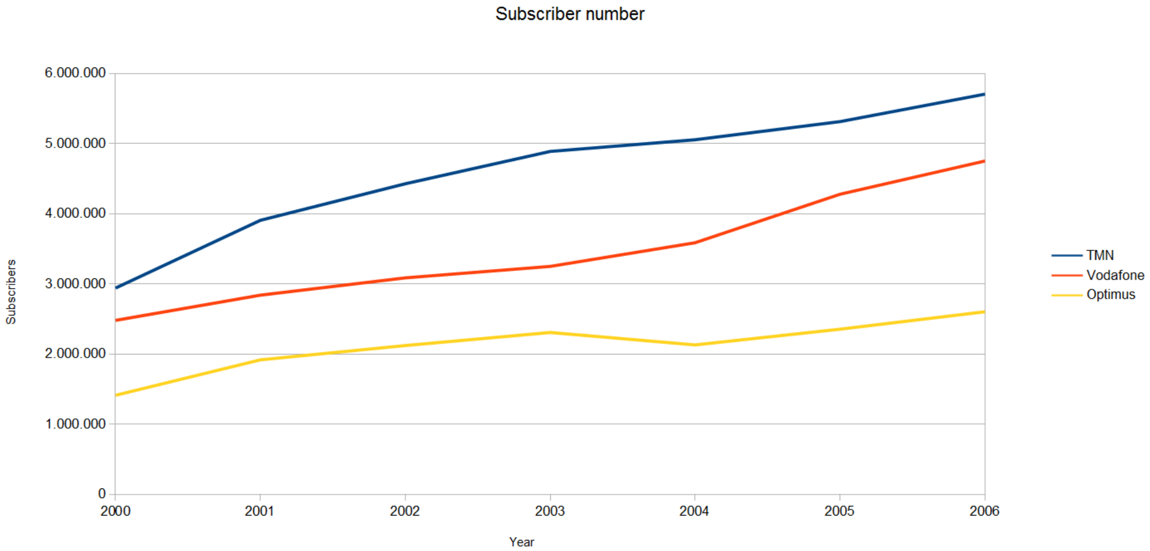

Figure 5.9: Scenario one - real evolution

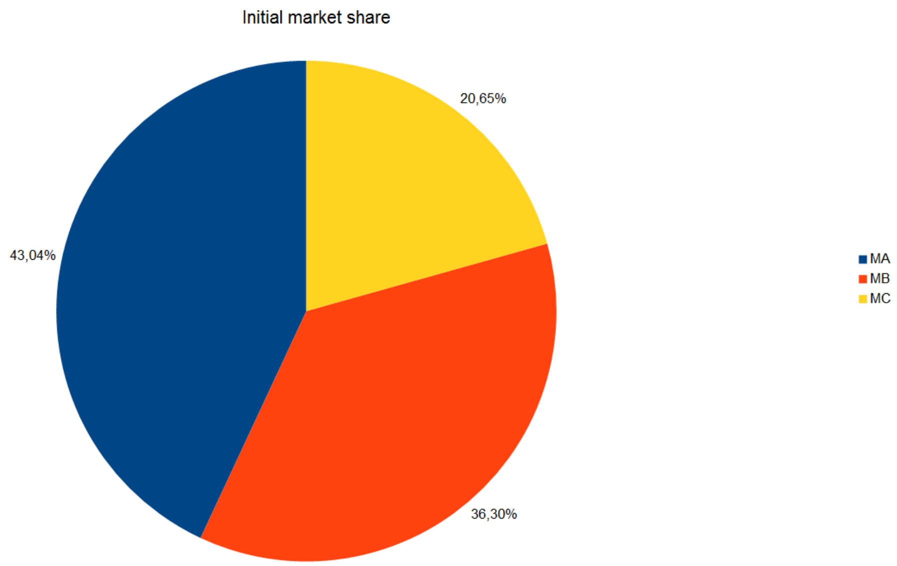

Figure 5.10: Vensim - Scenario one - initial share

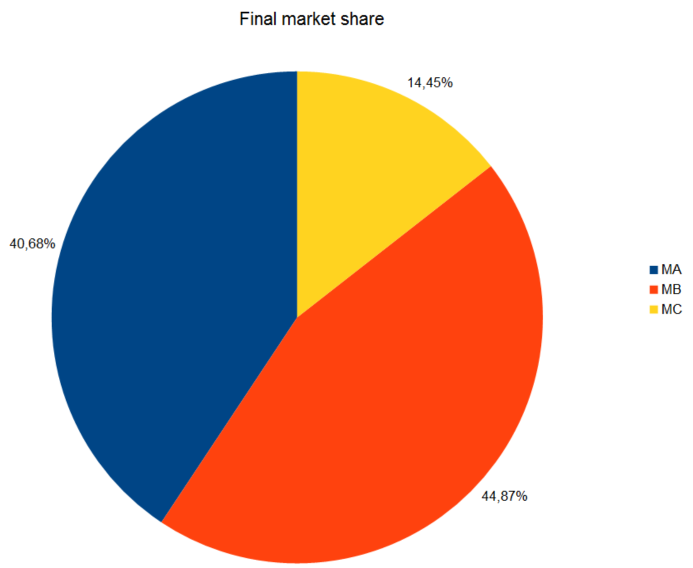

Figure 5.11: Vensim - Scenario one - final share

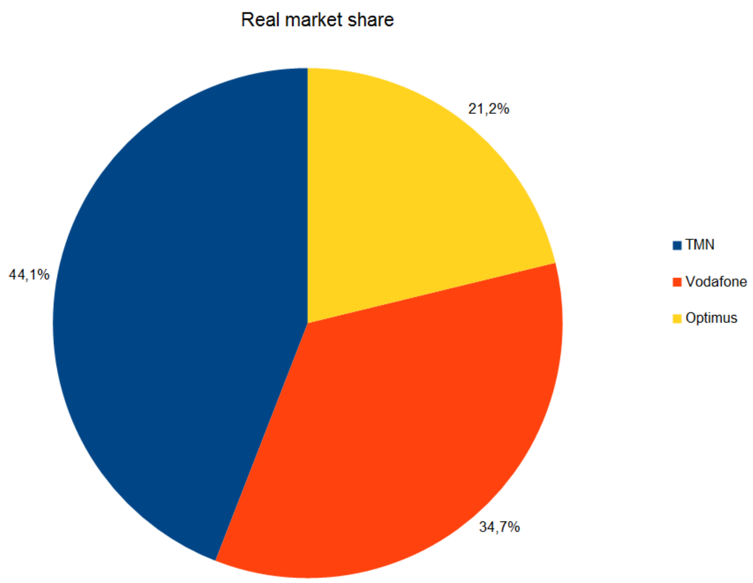

Figure 5.12: Scenario one - real share

5.2.4 Scenario two - non-expansible market

As mentioned before, this second scenario is more simple than the previous one in the way that it assumes the total number of subscribers to be constant over the simulation period. However, this simulation may be used to highlight which operator is more aggressive seizing competition customers.

5.2.5 Scenario two: model

Figure 5.13 shows the new model without the feed of new subscribers into the market.

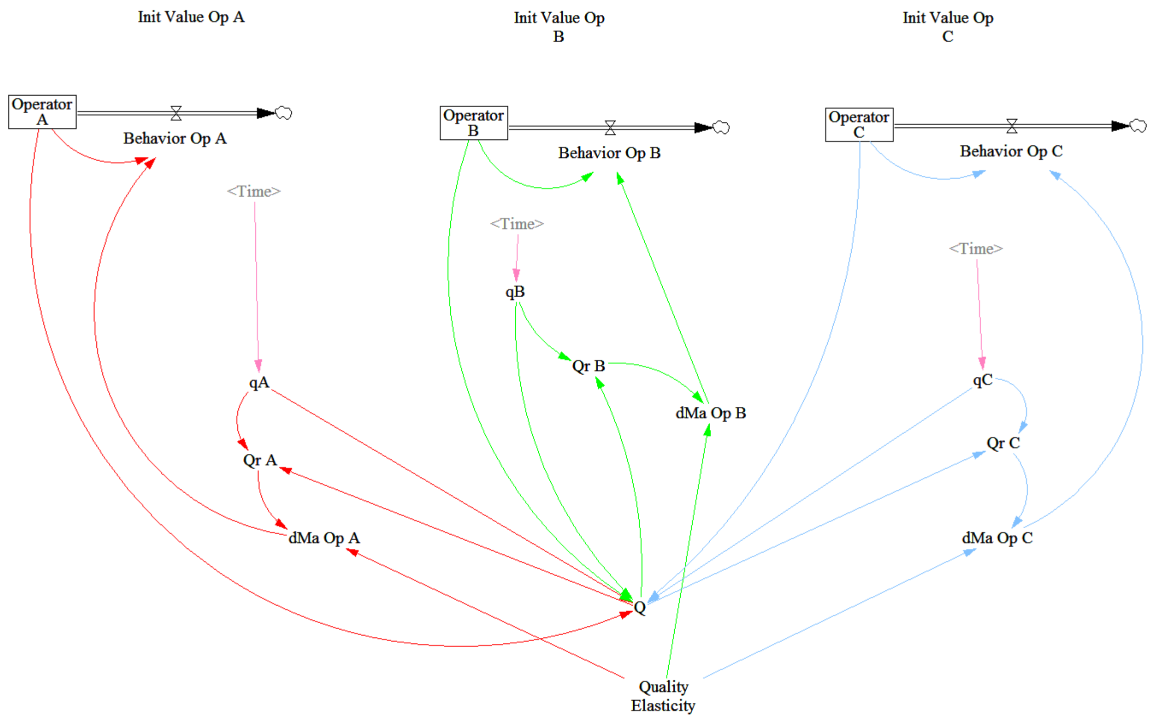

Figure 5.13: Vensim - Scenario two - model

5.2.6 Scenario two: results

In Figure 5.17 it is possible to see how each of the operators fight for the existing subscribers.

The end result in terms of market share is the same, but without the market expansion. As expected, the behavior of the three operators is highlighted and it is possible to see the subscriber behavior through the years.

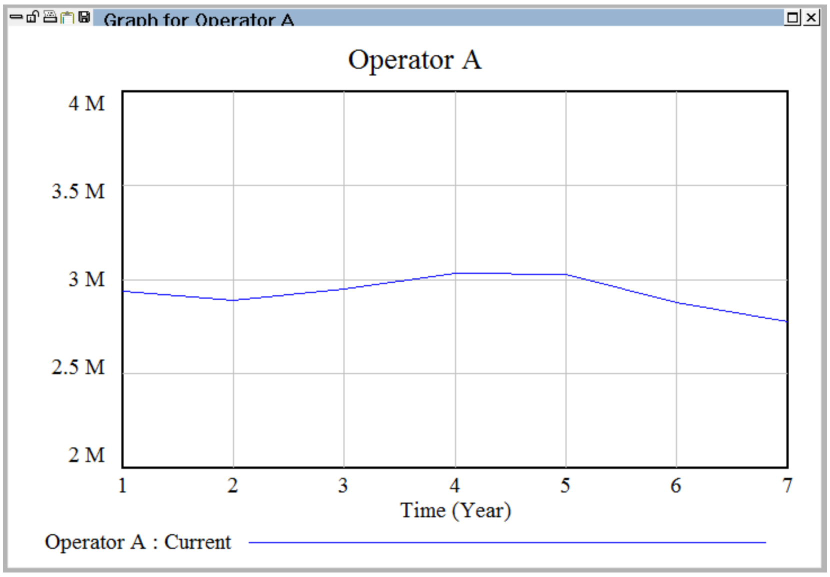

Figure 5.14: Vensim - Scenario two - TMN results

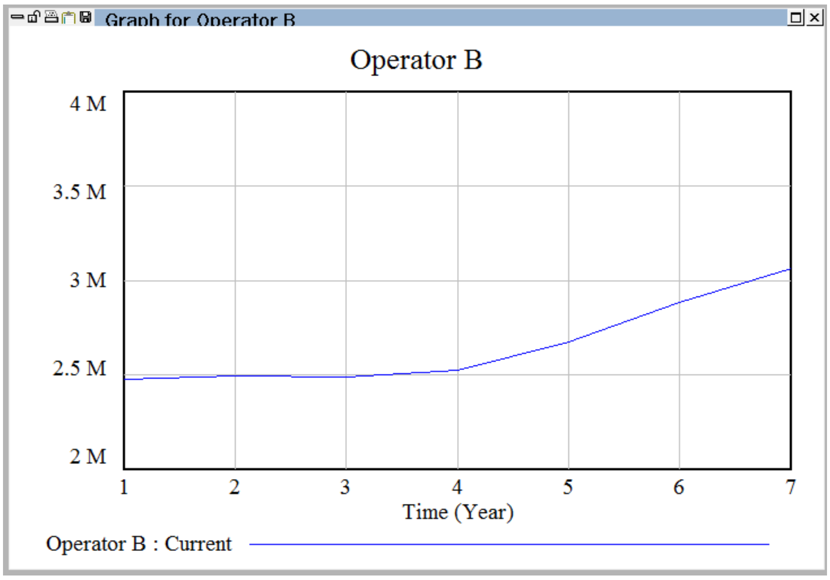

Figure 5.15: Vensim - Scenario two - Vodafone results

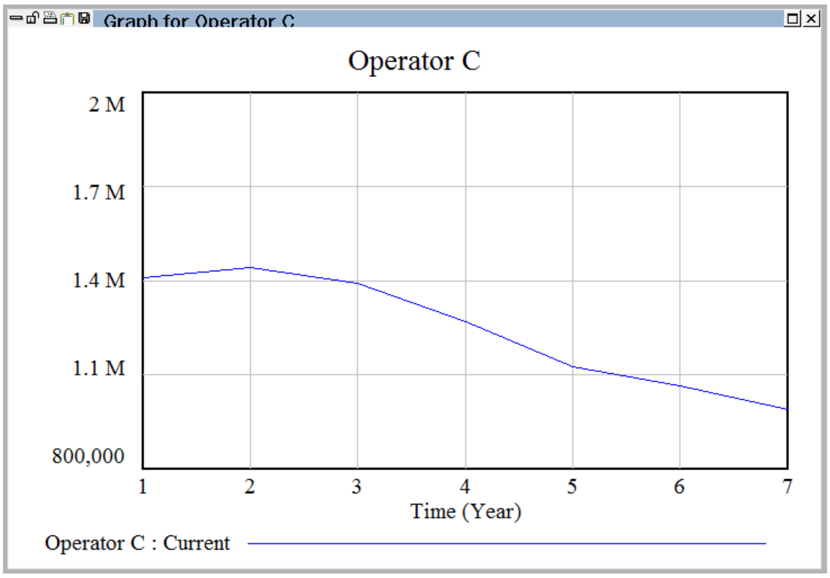

Figure 5.16: Vensim - Scenario two - Optimus results

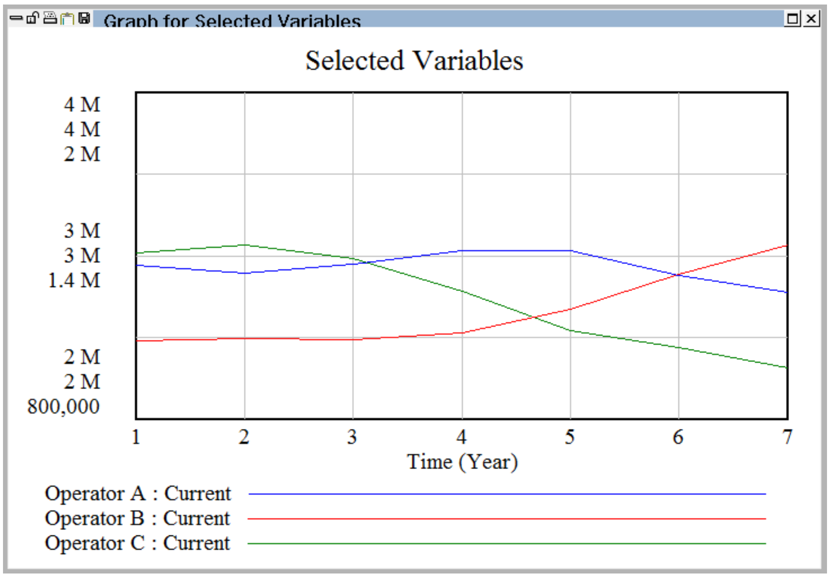

Figure 5.17: Vensim - Scenario two - results

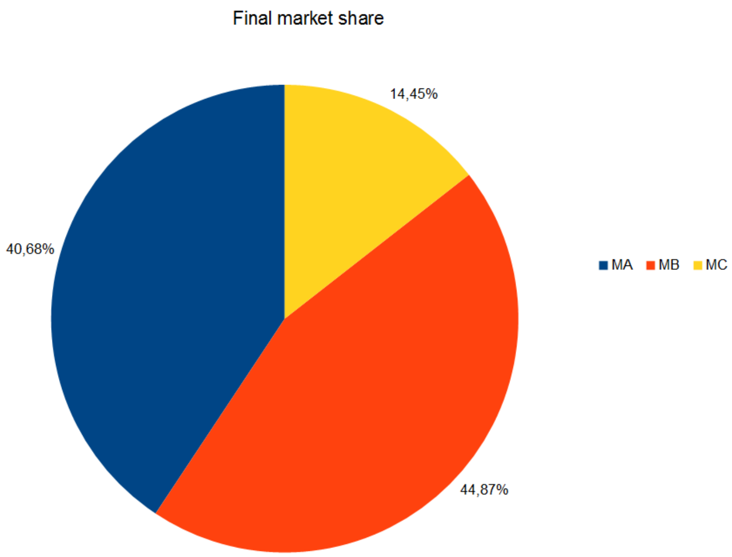

Figure 5.18: Vensim - Scenario two - final share

5.3 Overview

This chapter demonstrates that it is possible to see, even with a simple Vensim model, that the operators behavior was similar to the real one experienced during that considered period of time. The simulated values are also not very far from the real ones. Keeping in mind that there was only one quality differentiator. With more complex models and more imputed information it is expectable for the accuracy to naturally improve.

Chapter 6

Conclusions and future work

This chapter exposes some reflections about the work done, and also does some considerations on future work developments.

6.1 Conclusions

This work aimed at the gathering of techno-economic information, by doing a retrospective analysis into the Portuguese mobile telecommunications networks, so that the retrieved data could later be used to perfect existing and future telecom market simulations.

In order to achieve that goal, the first task was to get familiarized with the *State of the art* in terms of existing network technologies. Therefor, chapter two focused on four topics:

- Get to know the three types of telecommunications networks: Core, Access and Customer;
- explore Access Network technologies;
- see the technical differences between mobile network generations;
- contextualize the mobile telecommunications service in Portugal.

From this chapter, it was possible to conclude that Portugal has technologically advanced telecommunications networks and that its companies are determined to continue to invest on the development of those infrastructures.

Chapter 3 had two objectives. The first was to compare the country and it's people against some reference countries and the twenty seven country European Union, in terms of human development and economy. The second was to know the existing players, their services and history. The first objective completion gave important clues on why some more sophisticated 3G services have so little active users. Clues like the a low education rate among active workers and low GDP rate. From the second objective completion, came information on how and when the players entered the market. It suggests that arriving first and before a market becomes saturated are key points in order to be successful. It gave also information on the high number of services currently being offered by each of the contenders. This apparently points out that the more services a company offers the more likely it is to increase customer appeal.

Chapter 4 aimed at gathering as much information as possible from the Portuguese MTS market. Its completion provided valuable information on the market, on each operator's market behavior and also provided information on subscribers usage of the existing services.

On chapter 5, it was expected the use of some of the retrieved data using a software simulation tool such as Vensim. Two simulations were done for two different scenarios - one with an expanding market and the other with a static one. Using just one differentiator, it was possible to show the importance of the gathered data and the potential in this kind of dynamic models. Results looked promising as simulated behavior came very close to the real one.

Overall, I have found this work very satisfying. The knowledge that came with the making of this dissertation, has given me new perspectives on how telecommunication networks work and specifically on how the mobile market developed.

Interesting times are surely ahead, as the new licences for 4G technology have been sold. The new question is how will the market react to 4G services.

6.1.1 Market developments

During the making of this work and in the middle of a European financial crisis, Portugal was obliged to sign a *Memorandum* with the EU, European Central Bank (ECB) and International Monetary Fund (IMF) in order to get a long term loan. The *Memorandum Of Understanding On Specific Economic Policy Conditionality* signed on the 17^{th} May 2011 ([33]) between the Portuguese government and the EU, ECB and IMF and its later update from September the first 2011 ([34]) have a specific target regarding the Portuguese telecommunications and postal services. The targeted objectives are:

1. Increase market competition
2. Facilitate access to network infrastructure
3. Reenforce ANACOM power

These three objectives carry significant changes to a small and saturated mobile telecommunications market such as the Portuguese.

The document aims at an increase in market competition and forces the government execute a list of measures (summarized and only concerning the MTS):

- Implement the new Directive on EU electronic communications regulatory framework Directive 2009/140/EC (also known as "Better Regulation" Directive [39]) to, among other things, enhance the independence of ANACOM [Q3-2011]. Under current implementation and with expected visible results by Q1-2012 [13].

- Facilitate market-entry by lowering mobile termination rates [Q3-2011] and by launching the auction of spectrum for broadband wireless access.[Q4-2011] This is under current analysis by the regulator as the auction as ended. Among other suggested measures, the auction regulation includes reserve prices and new entrant price discounts - Memorandum point 5.17 (line iv) on auction tender.

- Monitoring and enforcement mechanism to guarantee the effective implementation of the obligations to negotiate fair and reasonable access to national roaming and mobile virtual network operator (MVNO) agreements, ensuring timely access and reasonable prices. The mechanism was to be defined by [Q4-2011] and it is mentioned in the auction regulation [2]- article 35 *Obrigações de acesso à rede* - Network access conditions.

- The review of the current fee values on the use of frequencies to ensure that they are *"justified, transparent, non-discriminatory and proportionate in relation to their intended purpose"*. Such review was to be announced in the auction tender [Q4-2011], but it wasn't.

Figure 6.1 shows what was available to the possible candidates. Categories B,C,D,E and G have spectrum caps in order to restrain purchase by only one candidate. All granted licences are valid through a 15 year period and can be revalidated.

Category	Frequency	Available lots description	Available number of lots	Reserve price per lot (M€)
A	450 Mhz	455.80625 - 457.45 MHz 465.80625 - 467.45 MHz	1 lot of 2 × 1.25 MHz	2
B	800 Mhz	791-821 MHz 791-821 MHz	6 lots of 2 × 5 MHz	45
C	900 Mhz	880-890 MHz 925-935 MHz	2 lots of 2 × 5 MHz	30
D	1800 Mhz	1710 – 1785 MHz 1805 – 1880 MHz	9 lots of 2 × 5 MHz	4
E	1800 Mhz	1710 – 1785 MHz 1710 – 1785 MHz	3 lots of 2 × 4 MHz	3
F	2,1 Ghz	1900-1910 MHz	2 lots of 5 MHz	2
G	2,6 Ghz	2500-2570 MHz 2620-2690MHz	14 lots of 2 × 5 MHz	3
H	2,6 Ghz	2570-2595 MHz	1 lot of 25 MHz	3
I	2,6 Ghz	2595-2620 MHz	1 lot of 25 MHz	3

Figure 6.1: ANACOM Q4-2011 Frequency Auction.[2]

The auction mentions that winning candidates have to 3 years from the licence issue to start commercial operations. The time is reduced to 1 year to candidates awarded a 900MHz licence that already have one of those licences.

The deadline for the candidates to present their proposals ended on the 11^{th} November 2011 after a 3 day extension published on the 3^{rd} the same month. The auction itself started on the 28^{th} November and ended two days later on the 30^{th}. A surprise to some, only TMN, Vodafone and Optimus have participated on the auction. Table C.1 in appendix C, shows the final results of the auction. Overall, the event has generated the Portuguese government an 372M€ income out of the 429M€ available if all lots had been purchased. Vodafone was the one spending more on the auction with 146M€. Optimus and TMN have only spent 113M€. The reason for the value disparity in this awkward auction - since the lots were purchased by their base value - can be found in the operators press releases: Vodafone states that the now acquired spectrum on the 800MHz, 1800MHz and 2600MHz will allow the company to deliver 4G/LTE services and that the 900MHz licence will enable better coverage and service quality for 3G/HSPA, mainly inside buildings [143]; TMN, through its parent company Portugal Telecom, states that has acquired the maximum amount of spectrum allowed in order to fulfil its commitment with the deployment of 4G/LTE technology [111]; Optimus in its press release stated that it had acquired all the relevant spectrum for 4G/LTE deployment [107].

It was expected, with this auction, the entrance of new players into the market. ZON mobile was a certain bet until the last minute. The company had presented itself to the regulator as an interested party and had received permission to be in the auction, but then decided to quit its presence at the event. In a news published on *Económico* online newspaper [37], it is cited a company spokesperson saying that Zon is still interested on buying frequencies that will allow them to have their own mobile network operation. On a note [157] sent to the stock market regulator *Comissão do Mercado de Valores Mobiliários* (CMVM) two days before the start of the auction, ZON states that under the auction conditions it was commercially unviable for the company to present itself as a new MNO operator. The company also states in the same note that national 3G roaming (of data and voice) conditions were not guaranteed on a technical and commercial level.

This last note from ZON Multimédia is quite interesting as it reminds us of another case a few years back when Oniway faced roaming difficulties with the existing operators. The auction outcome was overall disappointing as it was expected the entrance of a new player.

6.2 Future work

The gathered information is now available in this dissertation and can be used to perfect MTS market software simulation. There are still some information gaps to be filled. Some of those gaps were not made available by the operators, while others may remain hidden on the regulator's, not so user friendly, web site.

There is also work to be done in terms of analyzing from other points of view the collected information and to establish new links and relations between the data.

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Glossary

1G First Generation
The first generation of analogue mobile phone technologies including AMPS, TACS and NMT. [46]

1xRTT 1x (single-carrier) Radio Transmission Technology
The first in a family of CDMA2000 1x digital wireless standards designed to extend and replace the IS-95 CDMA standard. 1xRTT is sometimes referred to as a ”2.5G” standard. When compared to the IS-95 CDMA technology it replaces, 1xRTT offers increased network voice capacity. This benefit requires support on both the base station (tower) and handset (phone). If everyone using a given tower has a 1xRTT phone, twice as many people can use that tower at the same time, compared to the old IS-95 standard. 1xRTT also offers much faster data speeds. The initial release - release 0 (zero) - supports data speeds peaking at 144 kbps.[116]

2.5G Second-generation enhanced
Name given to enhanced 2G networks, like GPRS and CDMAOne. [71]

2G Second Generation
The second generation of digital mobile phone technologies including GSM, CDMA IS-95 and D-AMPS IS-136. [47]

3G Third Generation
Third-generation mobile network or service.Generic name for third-generation networks or services under the IMT-2000 banner, for example WCDMA. [72]

3GPP 3rd Generation Partnership Project
A grouping of international standards bodies, operators and vendors with the responsibility of standardizing the WCDMA based members of the IMT-2000 family.[48]

3GPP2 3rd Generation Partnership Project 2
The counterpart of 3GPP (spearheaded by ANSI) with the responsibility for standardizing the CDMA2000-based members of the IMT-2000 family.[49]

4G Fourth Generation
Fourth-generation mobile network or service. According to the ITU, a new 4G network requires a mobile device to be able to support data exchange at 100 Mbit/sec. ITU has determined that the designation IMT-Advanced (considered 4G) should be accorded to ”LTE-Advanced” and ”WirelessMAN-Advanced” technologies. The term ”4G” has since been extended to include previous versions of these technologies such as LTE, WiMax, and other evolved 3G technologies that made substantial level of improvement

in performance and capabilities when compared to initial third generation systems now deployed. The detailed specifications of the IMT-Advanced technologies will be provided in a new ITU-R Recommendation expected in early 2012.[73] 4G is expected to change the way people use mobile broadband in their lives. When fully deployed, people will be able to enjoy a state of permanent high quality link to the network with seamless hand-offs while traveling.

ADM Add-drop multiplexer
A multiplexer combines several lower-bandwidth streams of data into a single beam of light. An add-drop multiplexer also has the capability to add one or more lower-bandwidth signals to an existing high-bandwidth data stream, and at the same time can extract or drop other low-bandwidth signals, removing them from the stream and redirecting them to some other network path. [148]

AMC Adaptive Modulation and Coding
In order to improve system capacity, peak data rate and coverage reliability, the signal transmitted to and by a particular user is modified to account for the signal quality variation through a process commonly referred to as link adaptation. Traditionally, CDMA systems have used fast power control as the preferred method for link adaptation. Recently, Adaptation Modulation and Coding (AMC) have offered an alternative link adaptation method that promises to raise the overall system capacity. AMC provides the flexibility to match the modulation-coding scheme to the average channel conditions for each user. With AMC, the power of the transmitted signal is held constant over a frame interval, and the modulation and coding format is changed to match the current received signal quality or channel conditions. In a system with AMC, users close to the Node B are typically assigned higher order modulation with higher code rates (e.g. 64 QAM with R=3/4 turbo codes), but the modulation-order and/or code rate will decrease as the distance from Node B increases.[95]

AMPS Advanced Mobile Phone System
The analogue mobile phone technology used in North and South America and in around 35 other countries. Operates in the 800MHz band using FDMA technology. [50]

AMPU Average Margin Per User
AMPU is a measure of profitability used by the telecom industry. AMPU is equal to total revenue minus total costs divided by the number of users.[87]

ANACOM *Autoridade Nacional de Comunicações*
According to its web site [11] , this organization describes itself as the postal and electronic communications national regulator. Among its responsibilities are:

- Market Regulation - Ensures fair network access to operators, promoting a healthy competition and the development of the communications market. Manages phone numbering and the radio-electric spectrum, coordinating all civil, military and paramilitary communications.
- Market Oversight - Operator contract and technical compliance with existing laws. Consumer protection, namely the ones under the universal service, by encouraging operators to apply transparency policies.

- Industry Representative - Represents the Portuguese interests internationally by attending meetings with other regulatory entities. Promotes technical standardization with international organizations.

ANSI American National Standards Institute
As the voice of the U.S. standards and conformity assessment system, the American National Standards Institute (ANSI) empowers its members and constituents to strengthen the U.S. marketplace position in the global economy while helping to assure the safety and health of consumers and the protection of the environment. The Institute oversees the creation, promulgation and use of thousands of norms and guidelines that directly impact businesses in nearly every sector: from acoustical devices to construction equipment, from dairy and livestock production to energy distribution, and many more. ANSI is also actively engaged in accrediting programs that assess conformance to standards - including globally-recognized cross-sector programs such as the ISO 9000 (quality) and ISO 14000 (environmental) management systems. Its Mission is to enhance both the global competitiveness of U.S. business and the U.S. quality of life by promoting and facilitating voluntary consensus standards and conformity assessment systems, and safeguarding their integrity.[14]

ARD Advanced Receiver Design
ARD describes the technical architecture for MIMO receivers. The architecture includes advanced DSP techniques and ASIC technology.[122]

ARPU Average Revenue Per User
The monthly revenue generated by a single customer or unit.[88]

ATM asynchronous transfer mode
ATM is a dedicated-connection switching technology that organizes digital data into 53-byte cell units and transmits them over a physical medium using digital signal technology. Individually, a cell is processed asynchronously relative to other related cells and is queued before being multiplexed over the transmission path. Because ATM is designed to be easily implemented by hardware (rather than software), faster processing and switch speeds are possible. The pre-specified bit rates are either 155.520 Mbps or 622.080 Mbps. Speeds on ATM networks can reach up to 10 Gbps. Along with Synchronous Optical Network (SONET) and several other technologies, ATM is a key component of broadband ISDN (BISDN).[116]

CATV Community Access Television
CATV (originally "community antenna television," now often "community access television") is more commonly known as "cable TV." In addition to bringing television programs to those millions of people throughout the world who are connected to a community antenna, cable TV is an increasingly popular way to interact with the World Wide Web and other new forms of multimedia information and entertainment services.[116]

CCPU Cash Cost Per User
"CCPU" is a non-GAAP financial measure and includes all network and general and administrative costs as well as the subsidy loss on equipment (handsets and accessories) sales unrelated to customer acquisition. This measure is calculated as a per month

average by dividing the total costs for the specified period by the average total customers during the period and further dividing by the number of months in the period.[18]

CDMA Code Division Multiple Access
CDMA is based on ”spread” spectrum technology and since it is suitable for encrypted transmissions, it has long been used for military purposes. CDMA increases spectrum capacity by allowing all users to occupy all channels at the same time. Transmissions are spread over the whole radio band, and each voice or data call are assigned a unique code to differentiate them from the other calls carried over the same spectrum. CDMA allows for a ”soft hand-off”, which means that one terminal can communicate with several base stations at the same time. The dominant radio interface for third-generation mobile, or IMT-2000, is a wide-band version of CDMA with three modes (IMT-DS, IMT-MC and IMT-TC).

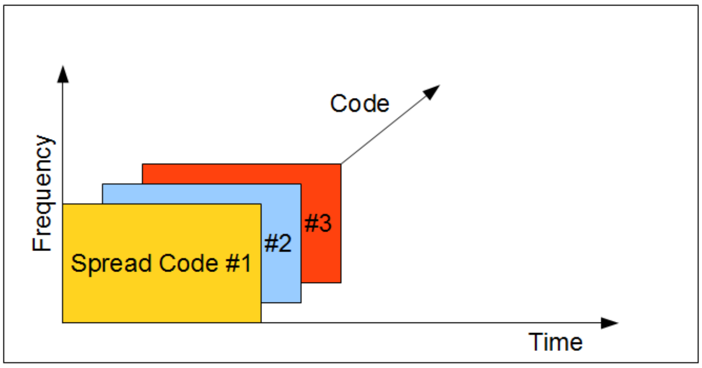

Figure 6.2: CDMA

CDMA2000 Code Division Multiple Access 2000
CDMA2000, also known as IMT-CDMA Multi-Carrier or 1xRTT, is a CDMA version of the IMT-2000 standard developed by the ITU. The CDMA2000 standard is a 3G mobile wireless technology. The world’s first 3G commercial system was launched by SK Telecom (South Korea) in October 2000, using CDMA2000 1X. CDMA2000 supports mobile data communications at speeds ranging from 144 Kbps to 2 Mbps. Versions have been developed by Ericsson and Qualcomm.[116]

CDMAOne Code Division Multiple Access One
CDMA One, refers to the original ITU IS-95 (CDMA) wireless interface protocol that was first standardized in 1993. It is considered a 2G mobile wireless technology.[116]The first commercial CDMA cellular system was deployed in North America and South Korea.

CEPT Conference of European Posts and Telecommunications
A organization of national posts, telegraphs and telephone administrations. Until 1988, when this work was take over by ETSI, the main European body for telecommunications standardization. CEPT established the original GSM standardization group.

CMVM *Comissção do Mercado de Valores Mobiliários*
The CMVM is the national stock market regulator. It is an independent public institu-

tion, with administrative and above all financial autonomy that derives from supervision fees. Established in April 1991, it holds task of supervising and regulating securities and other financial instruments markets as well as the activity of all those who operate on the stock market.[21]

CTT *Correios de Portugal, S.A.*
A state owned company that begun life offering postal services. The CTT Group, has now several other companies under its control: CTT Correios: national and international regular mail delivering company; CTT Expresso: national and international express mail service; Mailtec: management and information systems research & development company; PostContacto: non addressed mail delivering company; PayShop: utility services pay net service; Phone-ix: mobile communications operator; EAD: document management ; Tourline Express: express mail service (Spain).[23]

D-AMPS Digital AMPS
D-AMPS (Digital-Advanced Mobile Phone Service), sometimes spelled DAMPS, is a digital version of AMPS, the original analog standard for cellular telephone phone service in the United States. D-AMPS added TDMA to AMPS to get three channels for each AMPS channel, tripling the number of calls that can be handled on a channel. D-AMPS is Interim Standard-136 from the Electronics Industries Assocation/Telecommunication Industries Assocation (EIA/TIA).[116]

DCHSPA Dual Carrier High Speed Packet Access
Dual Carrier HSPA technology (a.k.a. Dual-Cell HSPA) is the next step in 3G/HSPA development. The basic idea underneath the multi-carrier feature is to achieve better resource utilization and spectrum efficiency, across the downlink/uplink carriers, by relying on the aggregation of two adjacent radio channels.[113]

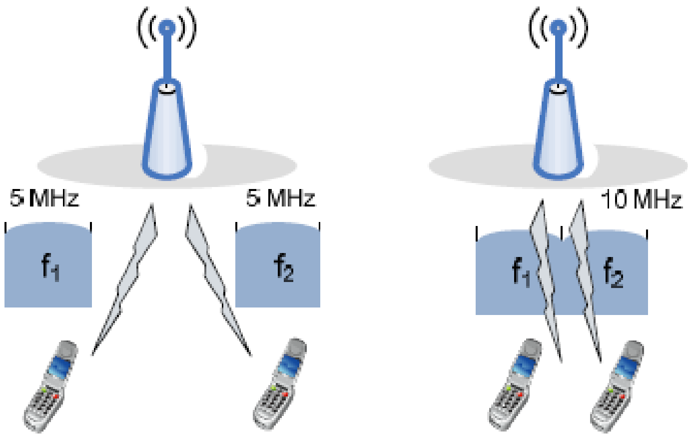

Figure 6.3: Single-Carrier versus Dual-Carrier Transmission.[113]

DECT Digital Enhanced Cordless Telecommunications
A second generation digital cordless technology standardized by ETSI. DECT is a standard for short-range cordless communications, which can be adapted to many applications and can be used to operate on unlicensed frequency allocations world-wide.

DECT is suited to voice (including PSTN and VoIP telephony), data and networking applications with a range up to 500 meters. DECT dominates the cordless residential market and the business PABX (Private Automatic Branch eXchange) market.[36] The ETSI Technical Committee DECT (TC DECT) has the overall responsibility over the technology.

DSL Digital Subscriber Line
A technology for bringing high-bandwidth information to homes and small businesses over ordinary copper telephone lines. Assuming your home or small business is close enough to a telephone company central office that offers DSL service, you may be able to receive data at rates up to 6.1 Mbps (of a theoretical 8.448 Mbps), enabling continuous transmission of motion video, audio, and even 3-D effects. A DSL line can carry both data and voice signals and the data part of the line is continuously connected. DSL competes with the cable modem and satellite transmission for high-bandwidth information reception.[116]

DSLAM Digital Subscriber Line Access Multiplexer
A DSLAM is a network device, usually at a telephone company central office, that receives signals from multiple customer Digital Subscriber Line (DSL) connections and puts the signals on a high-speed backbone line using multiplexing techniques. Depending on the product, DSLAM multiplexers connect DSL lines with some combination of asynchronous transfer mode (ATM), frame relay, or Internet Protocol networks.[116]

EBITDA Earnings Before Interest, Taxes, Depreciation and Amortization
EBITDA is an indicator of a company's financial performance which is calculated using the following formula: **EBITDA = Revenue - Expenses (excluding tax, interest, depreciation and amortization)** EBITDA is essentially net income with taxes, interest, depreciation, and amortization added back to it, and can be used to analyze and compare profitability between companies and industries because it eliminates the effects of financing and accounting decisions. [86]

EDGE Enhanced Data GSM Environment
EDGE (a 2G technology) is a faster version the GSM wireless service and it has been designed to deliver data at rates up to 384 Kbps. Enables the delivery of multimedia and other broadband applications to mobile phones and laptops. The EDGE is built on the existing GSM standard, using the same TDMA frame structure and existing cell arrangements. EDGE became commercially available in 2001 and it was regarded as an evolutionary standard on the way to UMTS.[116]

EMS Enhanced Messaging Service
EMS is an improved message system for GSM mobile phones. It was developed by the 3GPP from the basic SMS text messaging for use in the 2G networks. EMS enabled mobile phone users to send and receive pictures (including .gif animations) and sounds along with formatted text message. The message could contain just one or all of these elements: picture, sound or text. If by any chance, messages were to exceed the length of a single SMS then they would be decomposed by the system into several concatenated SMS messages and sent to its destination phone. The EMS system enabled operators raise extra revenue by offering paid products such as phone wallpapers, screen savers or ring tones. As with most technologies, EMS only works between EMS capable devices

DSL Type	Description	Data Rate Downstream; Upstream	Distance Limit	Application
IDSL	ISDN Digital Subscriber Line	128 Kbps	18,000 feet on 24 gauge wire	Similar to the ISDN BRI service but data only (no voice on the same line)
CDSL	Consumer DSL from Rockwell	1 Mbps downstream; less upstream	18,000 feet on 24 gauge wire	Splitterless home and small business service; similar to DSL Lite
DSL Lite (same as G.Lite)	"Splitterless" DSL without the "truck roll"	From 1.544 Mbps to 6 Mbps downstream, depending on the subscribed service	18,000 feet on 24 gauge wire	The standard ADSL; sacrifices speed for not having to install a splitter at the user's home or business
G.Lite (same as DSL Lite)	"Splitterless" DSL without the "truck roll"	From 1.544 Mbps to 6 Mbps , depending on the subscribed service	18,000 feet on 24 gauge wire	The standard ADSL; sacrifices speed for not having to install a splitter at the user's home or business
HDSL	High bit-rate Digital Subscriber Line	1.544 Mbps duplex on two twisted-pair lines; 2.048 Mbps duplex on three twisted-pair lines	12,000 feet on 24 gauge wire	T1/E1 service between server and phone company or within a company; WAN, LAN, server access
SDSL	Symmetric DSL	1.544 Mbps duplex (U.S. and Canada); 2.048 Mbps (Europe) on a single duplex line downstream and upstream	12,000 feet on 24 gauge wire	Same as for HDSL but requiring only one line of twisted-pair
ADSL	Asymmetric Digital Subscriber Line	1.544 to 6.1 Mbps downstream; 16 to 640 Kbps upstream	1.544 Mbps at 18,000 feet; 2.048 Mbps at 16,000 feet; 6.312 Mpbs at 12,000 feet; 8.448 Mbps at 9,000 feet	Used for Internet and Web access, motion video, video on demand, remote LAN access
RADSL	Rate-Adaptive DSL from Westell	Adapted to the line, 640 Kbps to 2.2 Mbps downstream; 272 Kbps to 1.088 Mbps upstream	Not provided	Similar to ADSL
UDSL	Unidirectional DSL proposed by a company in Europe	Not known	Not known	Similar to HDSL
VDSL	Very high Digital Subscriber Line	12.9 to 52.8 Mbps downstream; 1.5 to 2.3 Mbps upstream; 1.6 Mbps to 2.3 Mbps downstream	4,500 feet at 12.96 Mbps; 3,000 feet at 25.82 Mbps; 1,000 feet at 51.84 Mbps	ATM networks; Fiber to the Neighborhood

Figure 6.4: DSL Summary table.[117]

and as such if the destination phone is not capable of handling an EMS, the received message will be displayed as a 'normal' plain SMS text.[120]

ETSI European Telecommunications Standards Institute
The European group responsible for defining telecommunications standards. ETSI produces globally-applicable standards for Information and Communications Technologies (ICT), including fixed, mobile, radio, converged, broadcast and internet technologies.[35]

We are officially recognized by the European Union as a European Standards Organization. The high quality of our work and our open approach to standardization has helped us evolve into a European roots - global branches operation with a solid reputation for technical excellence.

ETSI is a not-for-profit organization with more than 700 ETSI member organizations drawn from 62 countries across 5 continents world-wide.

EvDO 1x Evolution Data Optimized
EvDO is a 3G wireless radio broadband data standard that enables faster speeds than are available in existing CDMA networks or other 2G services, such as GPRS or EDGE. EvDO is the next step in the evolutionary path of CDMA standards, following CDMA2000 and 1xRTTC. EV-DO was developed by Qualcomm in 1999 to meet a transmission speed target, set by IMT-2000, of over 2 Mbps for stationary communications. In practice, mobile EvDO users can expect download speeds of 400-700 kbps, although speeds over 2 Mbps are possible in areas of high signal strength and low interference. Download speeds are also affected by signal strength. EvDO can enable zones of near pervasive computing, in which multiple devices are seamlessly networked with a constant high-speed Internet connection. A user might have constant access to rich media applications and services like IPTV and VoIP. EvDO also optimizes VPNs (virtual private networks). Where EvDO service is not available, EvDO-enabled handsets or PCI cards automatically switch to 1xRTT or CDMA coverage. The primary competition for EvDO in 3G mobile telephony networks in the U.S.A. was HSDPA, which (unlike EvDO) enabled the transmission of voice and data simultaneously.[116]

FCS Fast Cell Search
FCS is an algorithm adopted by the 3GPP committee as the method for establishing initial synchronization between a base station and a mobile station.[25]

FDD Frequency Division Duplex
A radio technique which uses paired spectrum. FDD uses two separate frequency bands, allowing the terminal to emit in one frequency and transmit using the other. The frequency by which the base station transmits is known as the downlink and the terminal transmission frequency is known as the uplink. UMTS has an FDD element.[126]

FDMA Frequency Division Multiple Access
FDMA is the most common analog system. It is a technique whereby spectrum is divided up into frequencies and then assigned to users. With FDMA, only one subscriber at any given time is assigned to a channel. The channel therefore is closed to other conversations until the initial call is finished, or until it is handed-off to a different channel. A "full-duplex" FDMA transmission requires two channels, one for transmitting and another for receiving. FDMA has been used for first generation analog systems.[74]

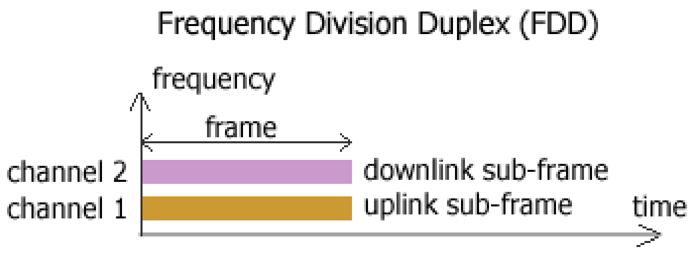

Figure 6.5: Frequency Division Duplex (FDD).[126]

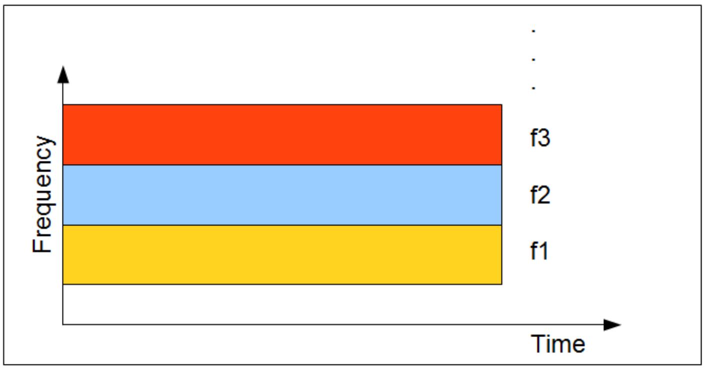

Figure 6.6: FDMA

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femtocell FemtoCell

Femtocells are low-power wireless access points that operate in licensed spectrum to connect standard mobile devices to a mobile operator's network using residential DSL or cable broadband connections.[43]

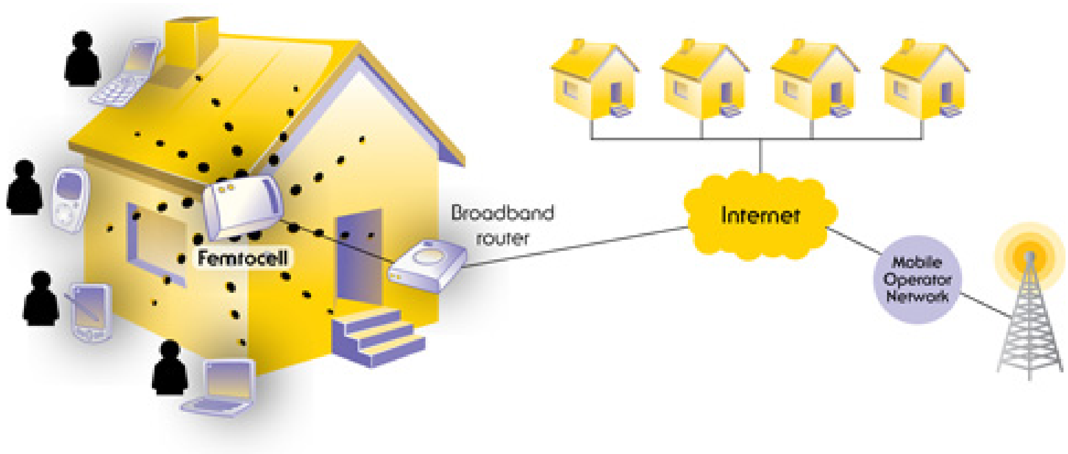

Figure 6.7: Femtocell House Diagram.[43]

FMC Fixed-Mobile Convergence

FMC means that users can use one terminal, one number and only need to pay one bill to smoothly switch between fixed-line network and mobile network.[63]

FOMA Freedom of Mobile Multimedia Access
FOMA is a 3G service and was launched in the fall of 2001 by the Japanese telecom NTT DoCoMo.[96]

FR Frame Relay
Frame relay is a telecommunication service designed for cost-efficient data transmission for intermittent traffic between local area networks (LANs) and between end-points in a wide area network (WAN). Frame relay puts data in a variable-size unit called a frame and leaves any necessary error correction (retransmission of data) up to the end-points, which speeds up overall data transmission. For most services, the network provides a permanent virtual circuit (PVC), which means that the customer sees a continuous, dedicated connection without having to pay for a full-time leased line, while the service provider figures out the route each frame travels to its destination and can charge based on usage. A company can select a level of service quality - prioritizing some frames and making others less important. Frame relay is offered by a number of service providers, including AT&T. Frame relay is provided on fractional T-1 or full T-carrier system carriers. Frame relay complements and provides a mid-range service between ISDN, which offers bandwidth at 128 Kbps, and Asynchronous Transfer Mode (ATM), which operates in somewhat similar fashion to frame relay but at speeds from 155.520 Mbps or 622.080 Mbps.[116]

GAAP Generally Accepted Accounting Principles
A widely accepted set of rules, conventions, standards, and procedures for reporting financial information, as established by the FASB (Financial Accounting Standards Board).[89]

GPRS General Packet Radio Service
Standardized as part of GSM Phase 2+, GPRS represents the first implementation of packet switching within GSM, which is a circuit switched technology. GPRS offers theoretical data speeds of up to 115kbit/s using multi-slot techniques. GPRS is an essential precursor for 3G as it introduces the packet switched core required for UMTS. [53] The higher data rates allowed MTS subscribers, through portable devices such as Smart-phones, PDAs or notebooks, to take part in video conferences and interact with upgraded multimedia web sites and similar applications.

GSM Global System for Mobile communications
The second generation digital technology originally developed for Europe but which now has in excess of 71 per cent of the world market. Initially developed for operation in the 900MHz band and subsequently modified for the 850, 1800 and 1900MHz bands. GSM originally stood for *Groupe Speciale Mobile*, the CEPT committee which began the GSM standardization process. [54] GSM uses a variation of TDMA. GSM digitizes and compresses data, then sends it down a channel with two other streams of user data, each in its own time slot. It operates at either the 900 MHz or 1800 MHz frequency band. It was first commercially deployed in 1991 in Finland.[116]

HARQ Hybrid Automatic Repeat Request
HARQ is a retransmission strategy which allows to perform possible retransmissions

directly at physical/MAC layer, without involving higher layer mechanisms and so reducing the delay.[17]

HFC Hybrid Fiber Coaxial Network
Fiber cable and coaxial cable are used in different portions of a network to carry broadband content (such as video, data, and voice). 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. Both cable TV and telephone companies are using HFC in new and upgraded networks and, in some cases, sharing the same infrastructure to carry both video and voice conversations in the same system. Scientific Atlanta lists four reasons why cable TV and telephone companies are upgrading facilities to HFC:

- 1) The use of fiber optic cable for the backbone paths allows more data to be carried than coaxial cable alone.
- 2) The higher bandwidth supports reverse paths for interactive data flowing back from the user.
- 3) That portion of the infrastructure with fiber optic cable is more reliable than coaxial cable. Reliability is perceived as more important in an interactive environment.
- 4) Fiber optic cable is more efficient for interconnecting cable TV or phone companies that are consolidating with geographically adjacent companies.

[116]

HSDPA High-Speed Downlink Packet Access
HSDPA is a packet-based mobile telephony protocol used in 3G UMTS radio networks to increase data capacity and speed up transfer rates. HSDPA, which evolved from the WCDMA standard, provides download speeds at least five times faster than earlier versions of UMTS, allowing users of HSDPA networks a broader selection of video and music downloads. HSPDA specifies data transfer speeds of up to 14.4 Mbps per cell for downloads and 2 Mbps per cell for uploads.[116] HSDPA implementations include Adaptive Modulation and Coding (AMC), MIMO, Hybrid Automatic Repeat Request (HARQ), fast cell search and advanced receiver design.

HSPA High-Speed Packet Access
Standardized by 3GPP, HSPA is the set of technologies that defines the migration path for 3G/WCDMA operators worldwide. HSPA, which uses the FDD transmission scheme, includes HSDPA, HSUPA and HSPA Evolved. These are also known as 3GPP Releases 5 through to 8. Unlike many other mobile broadband technologies, HSPA provides very efficient voice services in combination with mobile broadband data. In most HSPA networks, the end-user can expect to enjoy speeds of at least 1Mbps upwards, depending upon the peak speed of the network (anywhere from 1.8Mbps to 14.4 Mbps) with peak uplink speeds of up to 5.7Mbps.[55]

HSPA Evolved High-Speed Packet Access Evolved
HSPA Evolved introduces MIMO capabilities and higher order modulation (64QAM), enabling greater throughput speeds and higher performance.[116]

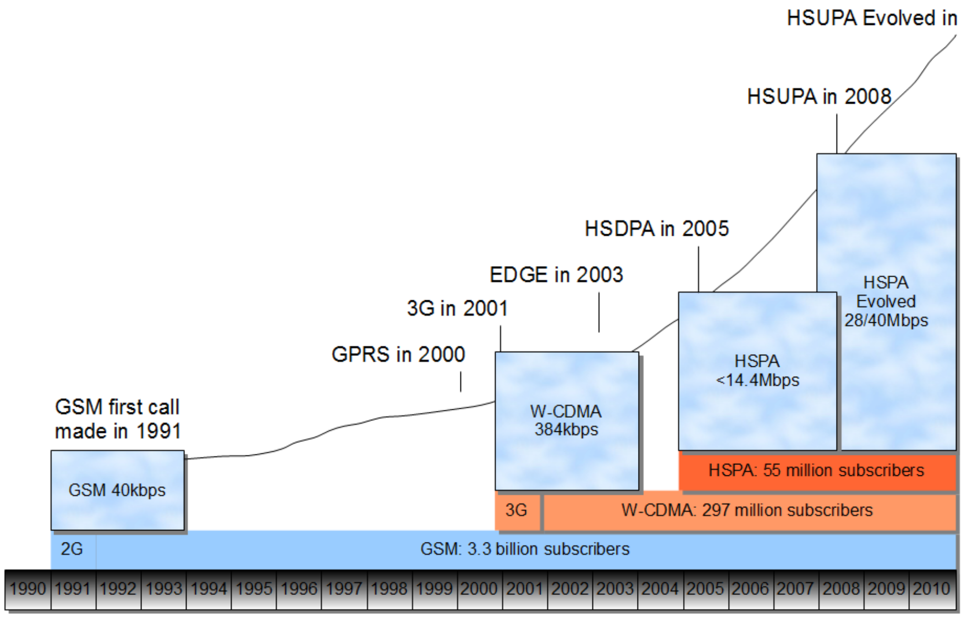

Figure 6.8: The GSM Family.[55]

HSUPA High-Speed Uplink Packet Access
HSUPA is a UTMS/WCDMA uplink evolution technology from 3GPP. It is directly related to HSDPA, and the two are complimentary to one another. Both technologies are very similar as they employ the same modulation procedures to allow a better use of the existing infrastructure. HSUPA enhances the uplink speed of UMTS / WCDMA networks and is the natural step after HSDPA. HSUPA improves advanced person-to-person data applications with higher and symmetrical data rates, like real-time person-to-person gaming.[116]

ICP *Instituto das Comunicações de Portugal*
The former existing regulator, later renamed ANACOM.

iDEN Integrated Digital Enhanced Network
iDEN is a wireless technology from Motorola combining the capabilities of a digital cellular telephone, two-way radio, alphanumeric pager and data/fax modem in a single network. iDEN operates in the 800 MHz, 900MHz, and 1.5 GHz bands and is based on TDMA and GSM architecture. It uses Motorola's Vector Sum Excited Linear

Predictors (VSELP) vocoder for voice compression and Quadrature Amplitude Modulation (QAM) modulation to deliver 64 Kbps over a 25 KHz channel.iDEN was designed to give the mobile user quick access to information without having to carry around several devices.[116]

IMT2000 International Mobile Telecommunications - 2000
The family of third generation technologies approved by the ITU. There are five members of the family [56]:

- IMT-DS(Direct Spread) - WCDMA-FDD
- IMT-MC(Multi-Carrier) - CDMA2000
- IMT-SC(Single Carrier) - EDGE
- IMT-TC(Time Code) - TD-SCDMA e WCDMA-TDD
- IMT-FT(Frequency Time) - DECT

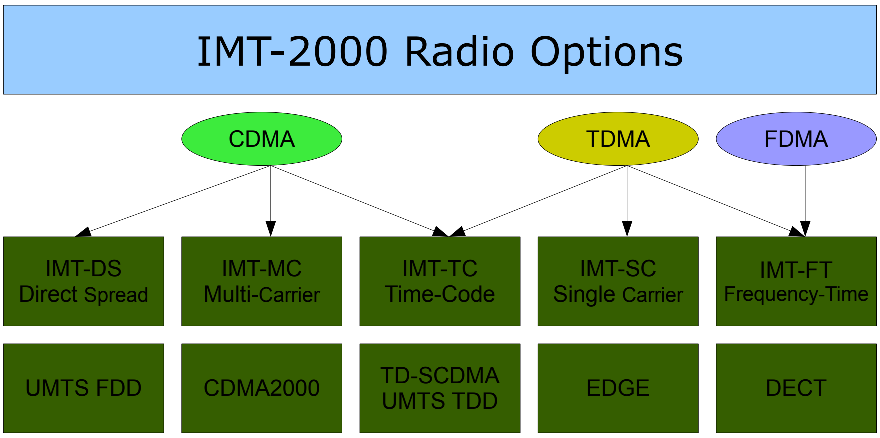

Figure 6.9: IMT 2000 Options

IMTS Improved Mobile Telephone Service
Also known as "0G" is a pre-cellular VHF/UHF radio system that connects to the PSTN. The system was just an enhancement of the existing Mobile Telephone System. The IMTS was released in 1964 and was the first full duplex mobile system. It was introduced as a replacement to MTS and improved on most MTS systems by offering direct-dial rather than connections through an operator.[75]

ISDN Integrated Services Digital Network
ISDN is a set of CCITT/ITU standards for digital transmission over ordinary telephone copper wire as well as over other media. Home and business users who install an ISDN adapter (in place of a telephone modem) receive Web pages at up to 128 Kbps compared with the maximum 56 Kbps rate of a modem connection. ISDN requires adapters at both ends of the transmission so your access provider also needs an ISDN adapter. ISDN is generally available from your phone company in most urban areas in the United States and Europe. In many areas where DSL and cable modem service are now offered, ISDN is no longer as popular an option as it was formerly.There are two levels of service: the Basic Rate Interface (BRI), intended for the home and small enterprise, and the Primary Rate Interface (PRI), for larger users. Both rates include a number of B-channels and a D-channels. Each B-channel carries data, voice, and other services. Each D-channel carries control and signaling information. The Basic Rate Interface consists of two 64 Kbps B-channels and one 16 Kbps D- channel. Thus, a Basic Rate user can have up to 128 Kbps service. The Primary Rate consists of 23 B-channels and one 64 Kpbs D-channel in the United States or 30 B-channels and 1 D-channel in Europe. ISDN in concept is the integration of both analog or voice data together with digital data over the same network.[116]

ITU International Telecommunication Union
ITU is a United Nations agency for information and communication technology issues. It is an important agency for governments and the private sector in developing networks and services. It has coordinated the shared global use of the radio spectrum, promoted international cooperation in assigning satellite orbits, worked to improve telecommunication infrastructure in the developing world, established the worldwide standards that foster seamless interconnection of a vast range of communications systems. ITU also addresses other problems such as mitigating climate change and strengthening cybersecurity. ITU is based in Geneva, Switzerland, and its membership includes 192 Member States and more than 700 Sector Members and Associates.[83]

LTE Long Term Evolution
LTE is the next step from 3G/WCDMA and HSPA for many already on the GSM technology curve but also for others too, such as CDMA operators. This radio access technology is optimized to deliver very fast data speeds of up to 100Mb/s downlink and 50Mb/s uplink (peak rates).[57]

LTE-Advanced Long Term Evolution - Advanced
LTE-Advanced extends the technological principles behind LTE into a further step change in data rates by incorporating higher order MIMO (4x4 and beyond) and allowing multiple carriers to be bonded together into a single stream. Up to 1Gbps target peak data rates, have been set.[58]

MIMO Multiple-Input, Multiple-Output
Is an antenna technology for wireless communications in which multiple antennas are used at both the source (transmitter) and the destination (receiver). The antennas at each end of the communications circuit are combined to minimize errors and optimize data speed. MIMO is one of several forms of smart antenna technology, the others being MISO (multiple input, single output) and SIMO (single input, multiple output). MIMO

technology has aroused interest because of its possible applications in digital television (DTV), wireless local area networks (WLANs), metropolitan area networks (MANs), and mobile communications.[116]

MMS Multimedia Messaging Service
Sometimes called Multimedia Messaging System - is a communications technology developed by 3GPP (Third Generation Partnership Project) that allows users to exchange multimedia communications between capable mobile phones and other devices. An extension to the Short Message Service (SMS) protocol, MMS defines a way to send and receive, almost instantaneously, wireless messages that include images, audio, and video clips in addition to text. A common current application of MMS messaging is picture messaging (the use of camera phones to take photos for immediate delivery to a mobile recipient).[116]

MPLS Multi-protocol Label Switching
Multi-protocol Label Switching (MPLS) is a standards approved technology for speeding up network traffic flow and making it easier to manage. MPLS involves setting up a specific path for a given sequence of packets, identified by a label put in each packet, thus saving the time needed for a router to look up the address to the next node to forward the packet to. MPLS is called multi-protocol because it works with the Internet Protocol (IP), Asynchronous Transport Mode (ATM), and frame relay network protocols. With reference to the standard model for a network (the Open Systems Interconnection, or OSI model), MPLS allows most packets to be forwarded at the Layer 2 (switching) level rather than at the Layer 3 (routing) level. In addition to moving traffic faster overall, MPLS makes it easy to manage a network for quality of service (QoS).[116]

MTS Mobile Telecommunications Service
Telecommunications service in which the subscriber's access is made through a non-fixed type of system, using radio-electric propagation through the air.[7] Disambiguation with Mobile Telephone Service, which was a pre-cellular VHF radio system that linked to the Public Switched Telephone Network (PSTN).The protocol replaced by the Improved Mobile Telephone Service (IMTS).

MVNO Mobile virtual network operator
An operator which does not own a licensed spectrum and generally without their own telecommunications infrastructure. MVNOs resell wireless services under their brand name, using normal telecom operators network with which they have business arrangements. Usually they buy minutes of network use from the licensed telecom operator and then resell those minutes of usage to their own customers.[118]

Netbook Netbook
A smaller, and usually cheaper, laptop computer used mostly for web browsing.

NGA Next Generation Access Networks
NGA is the next step in access networks evolution.It aims at the provision of advanced electronic communication services, including the delivery of a high level of bandwidth customers. This evolution, independent of the technologies and topologies of the networks involved, is essentially characterized by the deployment of fibre optic until the final customers home, known as FTTH: Fibre To The Home.[8]

NGN Next Generation Network
A Next Generation Network is a packet-based network able to provide services including Telecommunication Services and able to make use of multiple broadband, QoS-enabled transport technologies and in which service-related functions are independent from underlying transport-related technologies. It offers unrestricted access by users to different service providers. It supports generalized mobility which will allow consistent and ubiquitous provision of services to users. The NGN is characterized by the following fundamental aspects:

- Packet-based transfer
- Separation of control functions among bearer capabilities, call/session, and application/service
- Decoupling of service provision from network, 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 multimedia)
- Broadband capabilities with end-to-end QoS and transparency
- Interworking with legacy networks via open interfaces
- Generalized mobility
- Unrestricted 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/Mobile
- Independence of service-related functions from underlying transport technologies
- Compliant with all Regulatory requirements, for example concerning emergency communications and security/privacy, etc.

[77]

NMT Nordic Mobile Telephone system
An analogue cellular technology deployed in the Nordic countries in the late 1970's; variations were also deployed in the Benelux countries and in Russia. NMT operated in the 450 and 900MHz bands and was the first technology to offer international roaming, albeit only in the Nordic countries.[59]

NVoIP Nomadic VoIP
The use of a VoIP application with a mobile data SIM card.

OFDMA Orthogonal Frequency Division Multiple Access
OFDM is a method of digital modulation in which a signal is split into several narrowband channels at different frequencies. The technology was first conceived in the 1960s and 1970s during research into minimizing interference among channels near each other in frequency. In some respects, OFDM is similar to conventional frequency-division multiplexing (FDM). The difference lies in the way in which the signals are modulated

and demodulated. Priority is given to minimizing the interference, or crosstalk, among the channels and symbols comprising the data stream. Less importance is placed on perfecting individual channels.OFDM is used in European digital audio broadcast services. The technology lends itself to digital television, and is being considered as a method of obtaining high-speed digital data transmission over conventional telephone lines. It is also used in wireless local area networks.[116]

PDA Personal Digital Assistant
A portable electronic notebook: a small hand-held computer with facilities for taking notes, storing information such as addresses, and keeping a calendar, usually operated using a stylus rather than a keyboard.[94]

PDC Personal digital cellular
PDC is a Japanese standard that uses TDMA. The technology was used in the 800 MHz and 1.5 GHz bands.[116]

Penetration Rate
The penetration rate is the number of subscribers per 100 inhabitants.

PHP Personal Handy-Phone
Same as Personal Handy-phone System. See PHS.

PHS Personal Handy-phone System
A digital cordless technology developed in Japan which achieved great success. Deployed by Nippon Telegraph & Telephone Corporation (NTT) and other Japanese operators PHS offered two-way communications, data services and Internet access and eventually won some 28 million customers. Started to decline as cellular's wide area capabilities offer better service.It was discontinued in January 2008.[97]

POTS Plain Old Telephone Service
POTS is a term sometimes used in discussion of new telephone technologies in which the question of whether and how existing voice transmission for ordinary phone communication can be accommodated. For example, Asymmetric Digital Subscriber Line (ADSL) and Integrated Services Digital Network (ISDN) connections provide some part of their channels for "plain old telephone service" while providing most of their bandwidth for digital data transmission.[116]

PSTN Public Switched Telephone Network
The public telephone network that delivers fixed telephone service.[80]

QAM Quadrature Amplitude Modulation
QAM is a method of combining two amplitude-modulated (AM) signals into a single channel, thereby doubling the effective bandwidth. QAM is used with pulse amplitude modulation (PAM) in digital systems, especially in wireless applications.[116]

SDH Synchronous Digital Hierarchy
SDH is a standard technology for synchronous data transmission on optical media. It is the international equivalent of Synchronous Optical Network. Both technologies provide faster and less expensive network interconnection than traditional PDH (Plesiochronous Digital Hierarchy) equipment. In digital telephone transmission, "synchronous" means

the bits from one call are carried within one transmission frame. "Plesiochronous" means "almost (but not) synchronous," or a call that must be extracted from more than one transmission frame. SDH uses the following Synchronous Transport Modules (STM) and rates: STM-1 (155 megabits per second), STM-4 (622 Mbps), STM-16 (2.5 gigabits per second), and STM-64 (10 Gbps).[116]

SIM Subscriber Identity Module
SIM is a smart card that stores data for GSM cellular telephone subscribers. Such data includes user identity, location and phone number, network authorization data, personal security keys, contact lists and stored text messages. Security features include authentication and encryption to protect data and prevent eavesdropping.[116]

Smart-phone Smart-phone
A mobile phone that offers more advanced computing ability and connectivity than a contemporary feature phone. We may think of a smart-phone as a feature phone with added features usually found on a PDA or Netbook.

SMS Short Message Service
Is a service for sending short messages of up to 160 characters (224 characters if using a 5-bit mode) to mobile devices, including cellular phones, smart-phones and PDAs. SMS is similar to paging. However, SMS messages do not require the mobile phone to be active and within range and will be held for a number of days until the phone is active and within range. SMS messages are transmitted within the same cell or to anyone with roaming service capability.[116]

Subscriber
A subscriber is a person that has a contractual relationship with an MTS operator. This relation may be in the form of a prepaid or postpaid plan.

TACS Total Access Communications System
An AMPS variant deployed in a number of countries principally the UK.[60]

TD-SCDMA Time Division Synchronous Code Division Multiple Access
TD-SCDMA is a mobile telephone standard for wireless network operators who want to move from a 2G wireless network to a 3G one. Supporting data transmission at speeds up to 2 Mbps, TD-SCDMA combines support for both circuit-switched data, such as speech or video, and also packet-switched data from the Internet. The standard combines TDMA with an adaptive, synchronous-mode CDMA component. TD-SCDMA was developed by the China Academy of Telecommunications Technology (CATT) in collaboration with Datang and Siemens.[116]

TDD Time Division Duplex
A radio technology for use in unpaired spectrum. In TDD one uses the same frequency band for both transmit and receive but using, as the name implies, different time slots. The main advantage of this technology comes from the possibility on dynamically allocate bandwidth between the downlink and uplink. WCDMA/UMTS includes a band for TDD mode usage. PHS, DECT and Bluetooth use this technology.[126]

TDMA Time Division Multiple Access
TDMA improves spectrum capacity by splitting each frequency into time slots. TDMA

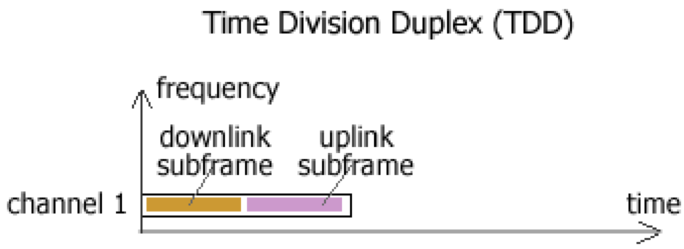

Figure 6.10: Time Division Duplex (TDD).[126]

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allows each user to access the entire radio frequency channel for the short period of a call. Other users share this same frequency channel at different time slots. The base station continually switches from user to user on the channel. TDMA is the dominant technology for the second generation mobile cellular networks.[81]

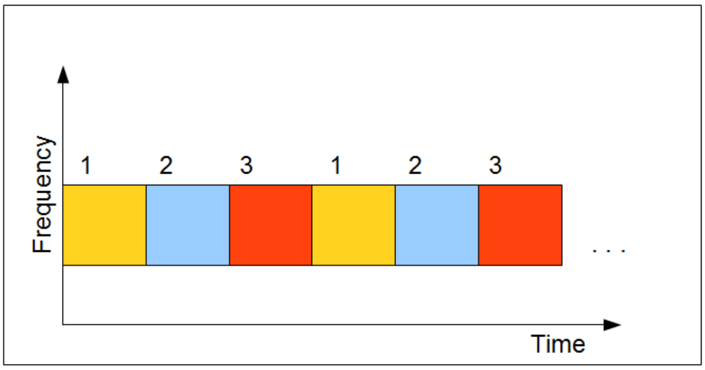

Figure 6.11: TDMA

TLP *Telefones de Lisboa e Porto*
A former, state owned, telecom company that was later dissolved to form Portugal Telecom.

UC Ubiquitous Computing
"Its highest ideal is to make a computer so exciting, so wonderful, so interesting, that we never want to be without it. A less-traveled path I call the "invisible"; its highest ideal is to make a computer so imbedded, so fitting, so natural, that we use it without even thinking about it." [144]

UMTS Universal Mobile Telecommunications Service
The European term for 3G mobile cellular systems or IMT-2000 based on the WCDMA standard. It allows for data rates up to 2Mbps.[82]

UWCC Universal Wireless Communication Consortium
The UWCC is a consortium of over 100 telecommunications carriers and vendors of wireless products and services. It was created in 1996 and dissolved in 2001 that supported the IS-41 (WIN) information and control system and EDGE enhancements for

increased data rates. UWCC completed its goals of developing and promoting TDMA standards in the wireless industry. 3G Americas, its successor trade organization, was founded in January 2002.[154] The UWCC Board Members included: Alcatel USA, Argentina TDMA Association, AT&T Wireless Services (USA), BellSouth Cellular Corp. (USA), Cellcom (Israel), Celumovil (Colombia), Compaq Computers Corporation, Ericsson Radio Systems, HongKong Telecom CSL (China), Hughes Network Systems, Industar Digital PCS (USA), Lucent Technologies, Mobikom SDN BHD (Malaysia), Motorola, Movilnet (Venezuela), Nokia Mobile Phones, Nortel Networks, Rogers Cantel (Canada), Southwestern Bell Mobile Systems (USA), Telecom New Zealand, VimpelCom (Russia).

VoIP Voice over IP
A digital telephone service that uses the public Internet and private backbones for call transport. Support for the PSTN is also provided so that VoIP calls can originate and terminate from regular telephones. Customers are required to have broadband Internet access (i.e cable, DSL,...).[155]

WAP Wireless Application Protocol
WAP (Wireless Application Protocol) is a specification for a set of communication protocols to standardize the way that wireless devices, such as cellular telephones and radio transceivers, can be used for Internet access, including e-mail, the World Wide Web, newsgroups, and instant messaging. While Internet access has been possible in the past, different manufacturers have used different technologies. The WAP layers are:

- Wireless Application Environment (WAE)
- Wireless Session Layer (WSL)
- Wireless Transport Layer Security (WTLS)
- Wireless Transport Layer (WTP)

The WAP was conceived by four companies: Ericsson, Motorola, Nokia, and Unwired Planet (now Phone.com). The Wireless Markup Language (WML) is used to create pages that can be delivered using WAP. There are other approaches to an industry standard besides WAP, including i-Mode.[116]

WCDMA Wideband CDMA
WCDMA is an ITU standard derived from CDMA. It is officially known as IMT-2000 direct spread and is a 3G mobile wireless technology. WCDMA can support mobile/portable voice, images, data, and video communications at up to 2 Mbps (local area access) or 384 Kbps (wide area access). The input signals are digitized and transmitted in coded, spread-spectrum mode over a broad range of frequencies. A 5 MHz-wide carrier is used, compared with 200 KHz-wide carrier for narrow band CDMA.[116]

WiMAX Worldwide Interoperability for Microwave Access
WiMax is a wireless industry union that aims the development of the IEEE 802.16 standards for broadband wireless networks.[116]

xDSL x Digital Subscriber Line
A term for any of the various types of DSL.[116]

Appendix A

MTS information tables

Information gathered from the operators *Report & Accounts* documents and regulator's reports.

Technology	Year	Portugal					EU27 MTS Penetration (%)	Penetration offset (%) Portugal vs EU27	Portugal GDP growth (%)
		MTS Subscribers	MTS Growth	MTS Operators	MTS Penetration (%)	Population			
1G	1989	2.800	100,00%	1	0,03%	10.005.000	?	?	6,4%
	1990	6.500	132,14%	1	0,06%	9.983.218	?	?	4,0%
	1991	12.600	93,85%	1	0,13%	9.967.878	0,99%	0,86%	4,4%
2G	1992	37.262	195,73%	2	0,4%	9.969.953	1,27%	0,87%	1,1%
	1993	101.231	171,67%	2	1,0%	9.982.591	1,84%	0,84%	-2,0%
	1994	173.508	71,40%	2	1,8%	10.004.081	2,95%	1,15%	1,0%
	1995	340.845	96,44%	2	3,4%	10.030.376	4,76%	1,36%	4,3%
	1996	663.651	94,71%	2	6,7%	10.057.861	7,51%	0,81%	3,7%
	1997	1.506.958	127,07%	2	15,1%	10.091.120	11,80%	3,30%	4,4%
	1998	3.074.633	104,03%	3	30,8%	10.129.290	19,30%	11,50%	5,0%
	1999	4.671.458	51,94%	3	46,8%	10.171.949	31,42%	15,38%	4,1%
	2000	6.665.000	42,67%	3	65,0%	10.225.836	47,91%	17,09%	3,9%
	2001	7.978.000	19,70%	3	81,0%	10.292.999	61,06%	19,94%	2,0%
	2002	8.670.000	8,67%	3	83,0%	10.368.403	69,88%	13,12%	0,7%
	2003	10.030.000	15,69%	3	95,5%	10.441.075	78,15%	17,35%	-0,9%
3G	2004	10.362.000	3,31%	3	100,4%	10.501.970	86,10%	14,30%	1,6%
	2005	11.447.000	10,47%	3	108,3%	10.549.424	95,61%	12,69%	0,8%
	2006	12.236.104	6,89%	3	115,4%	10.584.344	105,66%	9,74%	1,4%
	2007	13.477.414	10,14%	4	126,7%	10.608.335	115,15%	11,55%	2,4%
	2008	14.953.227	10,95%	5	140,3%	10.622.413	122,70%	17,60%	0,0%
	2009	16.051.044	7,34%	5	146,2%	10.632.482	125,45%	20,75%	-2,5%
	2010	16.473.690	2,63%	5	154,9%	10.637.346	128,00%	26,90%	1,4%

Figure A.1: Information on Portugal and EU27

Technology	Year	Plans			UMTS			Mobile tv users
		All Plans	Pre-paid	Post-paid	Total	Active	Active (%)	
1G	1989							
	1990							
	1991							
2G	1992							
	1993							
	1994							
	1995							
	1996							
	1997							
	1998							
	1999							
	2000							
	2001	?	?	?				
	2002	8.528.900	6.690.200	1.838.700				
	2003	9.350.600	7.359.700	1.990.800				
3G	2004	9.960.000	7.817.800	2.142.200	na	na	na	
	2005	11.448.000	9.291.000	2.157.000	?	?	?	na
	2006	12.226.400	9.770.800	2.455.600	2.220.000	?	?	?
	2007	13.450.900	10.319.800	3.131.000	3.074.000	869.000	28,3%	?
	2008	14.325.000	10.799.000	3.526.000	4.320.000	1.284.000	29,7%	?
	2009	16.051.044	11.702.094	4.348.950	5.984.000	2.580.000	43,1%	?
	2010	16.296.240	11.879.544	4.594.146	10.496.000	4.078.000	38,9%	57.400

Figure A.2: Information on subscribers

Technology	Year	Voice (thousands)		time per voice call (m:s)	Sent SMS (thousands)	Sent MMS (thousands)	Video Calls (thousands)		time per video call (m:s)
		number of calls	number of minutes				number of calls	number of minutes	
1G	1989								
	1990								
	1991								
2G	1992	na	na	na					
	1993	52.642	136.565	02:36					
	1994	177.071	254.514	01:26					
	1995	323.193	435.555	01:21					
	1996	687.835	786.804	01:09					
	1997	1.545.718	1.549.662	01:00					
	1998	2.707.006	2.758.300	01:01					
	1999	3.984.161	4.804.903	01:12	na				
	2000	5.467.017	8.126.270	01:29	549.748				
	2001	5.711.599	8.690.978	01:31	1.528.897				
	2002	7.645.000	12.916.000	01:41	2.101.000	na			
	2003	7.881.000	13.672.000	01:44	2.302.600	3.200			
3G	2004	8.191.000	14.487.000	01:46	2.528.800	19.900			
	2005	8.657.450	15.615.900	01:48	4.652.031	19.861	na	na	na
	2006	8.901.770	16.677.200	01:52	12.457.856	35.863	4.206	9.743	02:19
	2007	9.405.990	18.197.700	01:56	18.554.867	46.140	3.569	5.842	01:38
	2008	9.917.700	19.941.900	02:01	23.298.749	76.846	4.942	14.352	02:54
	2009	10.530.730	22.359.700	02:07	25.472.917	102.444	5.535	21.717	03:55
	2010	10.592.840	24.152.500	02:17	26.284.396	124.183	5.222	20.102	03:51

Figure A.3: Information on calls

Technology	Year	TMN						
		TMN Subscribers	TMN Growth	Economic data				Market Share
				CCPU (€)	ARPU (€)	AMPU (€)	EBITDA (M€)	
1G	1989	2.800	100,00%	?	?	?	?	100,0%
	1990	6.500	132,14%	?	?	?	?	100,0%
	1991	12.600	93,85%	?	?	?	?	100,0%
2G	1992	29.772	136,29%	?	?	?	?	79,9%
	1993	62.155	108,77%	?	?	?	?	61,4%
	1994	84.498	35,95%	?	?	?	?	48,7%
	1995	170.422	101,69%	?	?	?	?	50,0%
	1996	332.263	94,96%	?	61,85	?	?	50,1%
	1997	761.706	129,25%	27,75	47,33	19,58	36	50,5%
	1998	1.425.676	87,17%	19,88	36,46	16,58	198	46,4%
	1999	2.114.679	48,33%	16,43	28,56	12,13	247	45,3%
	2000	2.939.268	38,99%	17,75	30,90	13,15	391	44,1%
	2001	3.905.250	32,86%	16,60	30,07	13,47	535	47,9%
	2002	4.426.049	13,34%	13,50	27,12	13,62	624	51,9%
	2003	4.886.651	10,41%	12,10	25,23	13,13	690	52,4%
3G	2004	5.053.425	3,41%	11,40	24,40	13,00	747	51,3%
	2005	5.312.284	5,12%	11,60	22,80	11,20	648	49,0%
	2006	5.703.700	7,37%	10,80	21,00	10,20	659	45,0%
	2007	6.261.000	9,77%	?	19,80	?	679	47,4%
	2008	6.994.000	11,71%	?	18,10	?	682	48,0%
	2009	7.252.000	3,69%	?	16,20	?	674	50,0%
	2010	7.419.000	2,30%	?	14,50	?	638	44,1%

Figure A.4: Information on TMN

Technology	Year	Vodafone						
		Vodafone Subscribers	Vodafone Growth	Economic data				Market Share
				CCPU (€)	ARPU (€)	AMPU (€)	EBITDA (M€)	
1G	1989						0	
	1990						0	
	1991	na	na	na	na	na	0	na
2G	1992	7.489	100,00%	?	?	?	?	20,1%
	1993	39.231	423,85%	?	92,33	?	-9	38,6%
	1994	88.508	125,61%	?	89,93	?	7	51,3%
	1995	177.360	100,39%	?	89,46	?	41	50,0%
	1996	331.388	86,84%	?	85,96	?	98	49,9%
	1997	745.252	124,89%	?	60,82	?	152	49,4%
	1998	1.370.566	83,91%	?	42,57	?	205	44,6%
	1999	1.739.647	26,93%	?	32,81	?	280	37,3%
	2000	2.478.800	42,49%	21,99	31,63	9,64	253	34,7%
	2001	2.838.015	14,49%	21,06	29,37	8,31	286	32,0%
	2002	3.084.788	8,70%	19,06	26,77	7,71	305	30,0%
	2003	3.247.895	5,29%	18,57	26,78	8,21	350	31,7%
3G	2004	3.585.711	10,40%	20,08	27,70	7,62	352	33,5%
	2005	4.276.345	19,26%	16,57	25,08	8,51	412	36,0%
	2006	4.750.557	11,09%	14,81	23,23	8,42	471	36,3%
	2007	5.209.195	9,65%	14,09	22,72	8,63	533	36,0%
	2008	5.639.293	8,26%	?	20,00	?	546	36,0%
	2009	5.951.500	5,54%	?	17,60	?	546	36,0%
	2010	6.060.000	1,82%	?	15,70	?	496	35,0%

Figure A.5: Information on Vodafone

Technology	Year	Optimus						
		Optimus Subscribers	Optimus Growth	Economic data				Market Share
				CCPU (€)	ARPU (€)	AMPU (€)	EBITDA (M€)	
1G	1989							
	1990							
	1991							
2G	1992							
	1993							
	1994							
	1995							
	1996							
	1997	na	na	na	na	na	na	na
	1998	276.716	100,00%	?	?	?	-11	9,0%
	1999	817.505	195,43%	?	30,68	?	-55	17,5%
	2000	1.410.408	72,53%	30,04	32,10	2,06	99	21,2%
	2001	1.915.751	35,83%	26,30	28,40	2,10	107	22,2%
	2002	2.119.800	10,65%	20,10	24,10	4,00	117	22,1%
	2003	2.305.800	8,77%	17,30	22,40	5,10	147	22,3%
3G	2004	2.129.000	-7,67%	17,30	24,30	7,00	190	18,0%
	2005	2.353.200	10,53%	16,40	21,90	5,50	167	20,0%
	2006	2.601.900	10,57%	15,10	19,70	4,60	169	20,1%
	2007	2.893.500	11,21%	14,80	18,20	3,40	154	20,1%
	2008	3.191.600	10,30%	?	16,80	?	142	17,0%
	2009	3.432.573	7,55%	?	14,83	?	167	20,0%
	2010	3.604.098	5,00%	?	13,66	?	185	15,7%

Figure A.6: Information on Optimus

Technology	Year	ZON mobile					Phone-ix			
		ZON Subscribers	ZON Growth	Economic data Group		Market Share	Phone-ix Subscribers	Phone-ix Growth	Group	Market Share
				ARPU (€)	EBITDA (M€)				EBITDA (M€)	
1G	1989								?	
	1990								?	
	1991								?	
2G	1992								?	
	1993								?	
	1994								?	
	1995								?	
	1996								?	
	1997								?	
	1998			na	na				?	
	1999			?	?				?	
	2000			?	?				56	
	2001			?	?				44	
	2002			?	?				14	
	2003			?	?				59	
3G	2004			?	?				72	
	2005			27,60	?				58	
	2006			29,10	?		na	na	79	na
	2007	na	na	30,80	220	na	100.000	100,00%	100	0,74%
	2008	7.200	100,00%	32,00	242	0,05%	120.000	20,00%	118	0,80%
	2009	68.900	856,94%	33,80	262	0,43%	88.000	-26,67%	105	0,54%
	2010	107.900	56,60%	35,40	302	0,80%	65.895	-25,12%	?	0,40%

Figure A.7: Information on ZON mobile and Phone-ix

Appendix B

EU27 MTS Subscribers 1991-2009

Country Name	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	EU27
Austria	1,48	2,22	2,79	3,51	4,82	7,52	14,55	28,72	53,12	76,35	81,33	83,33	89,61	97,77	105,24	112,06	119,41	129,74	140,74	1
Belgium	0,51	0,61	0,67	1,27	2,32	4,71	9,57	17,21	31,16	54,91	74,82	78,41	82,94	87,63	91,66	93,36	101,06	110,38	115,03	2
Bulgaria	0,00	0,00	0,01	0,08	0,25	0,32	0,84	1,54	4,26	9,16	19,60	33,01	44,75	60,78	80,68	107,20	129,21	137,74	139,97	3
Cyprus	0,66	1,22	1,87	2,74	5,20	8,11	10,32	12,82	16,39	23,14	32,69	42,65	55,28	64,80	75,78	82,78	92,97	94,40	89,64	4
Czech Republic	0,01	0,05	0,14	0,29	0,47	1,94	5,11	9,38	18,91	42,30	67,95	84,37	95,11	105,55	115,05	120,81	128,01	132,19	135,96	5
Denmark	3,41	4,08	6,89	9,67	15,73	25,02	27,33	36,43	49,42	63,02	73,95	83,32	88,49	95,66	100,61	107,19	115,50	124,91	134,09	6
Estonia	0,04	0,16	0,48	0,94	2,12	4,91	10,30	17,82	28,13	40,67	47,74	64,84	77,59	93,09	107,37	123,46	147,71	188,30	202,98	7
Finland	6,36	7,66	9,66	13,28	20,34	29,31	42,07	55,23	63,37	72,03	80,49	86,85	91,06	95,41	100,46	107,67	114,96	128,54	144,23	8
France	0,64	0,74	0,97	1,49	2,19	4,13	9,71	18,63	35,51	47,81	60,45	62,59	67,18	71,23	76,33	81,44	86,73	90,32	92,25	9
Germany	0,67	1,21	2,19	3,06	4,56	6,73	10,08	16,96	28,56	58,63	68,17	71,66	78,51	86,43	96,12	103,98	116,98	128,51	128,20	10
Greece	0,00	0,00	0,46	1,45	2,57	4,97	8,70	18,89	35,87	54,34	72,73	84,77	81,06	84,29	92,40	98,49	109,85	122,80	117,84	11
Hungary	0,08	0,22	0,44	1,38	2,57	4,59	6,86	10,42	15,90	30,13	48,76	67,79	78,43	86,35	92,40	98,95	109,69	121,78	117,66	12
Ireland	0,91	1,24	1,71	2,46	4,38	7,93	14,83	25,48	44,66	64,68	76,82	76,30	87,58	94,83	102,65	110,09	114,09	114,06	109,24	13
Italy	1,00	1,38	2,12	3,94	6,90	11,29	20,63	36,00	53,22	74,18	89,94	94,83	98,55	107,86	122,00	136,44	151,24	150,99	150,54	14
Latvia	0,00	0,04	0,15	0,33	0,60	1,14	3,15	6,95	11,48	16,92	27,84	39,23	52,45	66,44	81,36	95,44	97,40	98,58	99,48	15
Lithuania	0,00	0,01	0,03	0,12	0,41	1,41	4,62	7,53	9,40	14,97	29,24	47,44	60,86	88,81	127,51	139,01	145,52	149,57	148,57	16
Luxembourg	0,29	0,29	1,28	3,20	6,57	10,86	16,02	30,73	48,60	69,51	92,65	106,01	119,35	102,60	109,64	150,86	142,61	144,68	144,44	17
Malta	0,63	0,95	1,43	2,01	2,85	3,29	4,62	5,85	9,68	29,34	60,92	69,92	72,76	76,27	80,23	85,33	90,09	93,61	102,13	18
Netherlands	0,76	1,09	1,41	2,09	3,49	6,55	11,00	21,35	42,68	67,53	76,03	74,93	81,35	90,90	97,02	105,81	117,72	125,43	128,14	19
Poland	0,00	0,01	0,04	0,10	0,19	0,56	2,10	4,99	10,23	17,55	26,16	36,35	45,55	60,49	76,42	96,34	108,57	115,21	116,78	20
Portugal	0,13	0,37	1,02	1,74	3,40	6,60	14,94	30,35	45,92	65,18	77,50	83,62	95,80	100,66	108,51	115,51	126,80	140,36	142,75	21
Romania	0,00	0,00	0,00	0,01	0,04	0,08	0,89	2,86	6,04	11,13	17,37	23,44	32,38	47,11	61,73	74,07	94,76	113,73	118,14	22
Slovak Republic	0,00	0,03	0,06	0,11	0,23	0,53	3,72	8,63	12,31	23,08	39,92	54,35	68,38	79,43	84,28	90,76	112,43	102,10	101,46	23
Slovenia	0,03	0,18	0,33	0,82	1,37	2,07	4,71	8,15	31,80	61,12	73,80	83,61	87,14	92,57	87,94	90,67	95,55	101,66	102,98	24
Spain	0,28	0,46	0,66	1,05	2,40	7,59	10,96	16,21	37,58	60,27	72,83	81,16	88,61	90,47	98,38	103,58	107,90	109,05	111,07	25
Sweden	6,59	7,57	8,88	15,73	22,74	28,18	35,81	46,42	57,87	71,85	80,71	89,07	98,27	97,70	100,89	105,80	111,25	118,14	122,88	26
United Kingdom	2,19	2,62	3,93	6,81	9,89	12,46	15,16	25,44	46,33	73,78	78,30	82,98	91,09	99,70	108,71	115,65	121,07	126,01	130,05	27
Average Values	0,99	1,27	1,84	2,95	4,76	7,51	11,80	19,30	31,42	47,91	61,06	69,88	78,15	86,10	95,61	105,66	115,15	122,70	125,45	

Figure B.1: EU27 MTS penetration between 1991 and 2009 [151]

Appendix C

ANACOM - Auction results

Lot	Frequency	Lot size	Lot price (€)	Winner
A1	450 MHz	2 x 1,25MHz	-	-
B1	800 MHz	2 x 5 MHz	45.000.000	TMN
B2	800 MHz	2 x 5 MHz	45.000.000	TMN
B3	800 MHz	2 x 5 MHz	45.000.000	VODAFONE
B4	800 MHz	2 x 5 MHz	45.000.000	VODAFONE
B5	800 MHz	2 x 5 MHz	45.000.000	OPTIMUS
B6	800 MHz	2 x 5 MHz	45.000.000	OPTIMUS
C1	900 MHz	2 x 5 MHz	-	-
C2	900 MHz	2 x 5 MHz	30.000.000	VODAFONE
D1	1800 MHz	2 x 5 MHz	4.000.000	TMN
D2	1800 MHz	2 x 5 MHz	4.000.000	TMN
D3	1800 MHz	2 x 5 MHz	4.000.000	VODAFONE
D4	1800 MHz	2 x 5 MHz	4.000.000	VODAFONE
D5	1800 MHz	2 x 5 MHz	4.000.000	OPTIMUS
D6	1800 MHz	2 x 5 MHz	4.000.000	OPTMUS
D7	1800 MHz	2 x 5 MHz	-	-
D8	1800 MHz	2 x 5 MHz	-	-
D9	1800 MHz	2 x 5 MHz	-	-
E1	1800 MHz	2 x 4 MHz	3.000.000	TMN
E2	1800 MHz	2 x 4 MHz	3.000.000	VODAFONE
E3	1800 MHz	2 x 4 MHz	3.000.000	OPTIMUS
F1	2,1 GHz	5 MHz	-	-
F2	2,1 GHz	5 MHz	-	-
G1	2,6 GHz	2 x 5 MHz	3.000.000	TMN
G2	2,6 GHz	2 x 5 MHz	3.000.000	TMN
G3	2,6 GHz	2 x 5 MHz	3.000.000	TMN
G4	2,6 GHz	2 x 5 MHz	3.000.000	TMN
G5	2,6 GHz	2 x 5 MHz	3.000.000	VODAFONE
G6	2,6 GHz	2 x 5 MHz	3.000.000	VODAFONE
G7	2,6 GHz	2 x 5 MHz	3.000.000	VODAFONE
G8	2,6 GHz	2 x 5 MHz	3.000.000	VODAFONE
G9	2,6 GHz	2 x 5 MHz	3.000.000	OPTIMUS
G10	2,6 GHz	2 x 5 MHz	3.000.000	OPTIMUS
G11	2,6 GHz	2 x 5 MHz	3.000.000	OPTIMUS
G12	2,6 GHz	2 x 5 MHz	3.000.000	OPTIMUS
G13	2,6 GHz	2 x 5 MHz	-	-
G14	2,6 GHz	2 x 5 MHz	-	-
H1	2,6 GHz	25 MHz	3.000.000	VODAFONE
I1	2,6 GHz	25 MHz	-	-

Figure C.1: Auction results.[6]