



**Richard Queirós
Soares**

Serviços OTT TV – Aspectos Técnico-Económicos

OTT TV services – Technical and Economic Aspects



**Richard Queirós
Soares**

Serviços OTT TV – Aspectos Técnico-Económicos

OTT TV services – Technical and Economic Aspects

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia de Electrónica e Telecomunicações, realizada sob a orientação científica do Dr. Diogo Nuno Pereira Gomes, Professor Auxiliar Convidado do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro e co-orientação do Dr. A. Manuel de Oliveira Duarte, Professor Catedrático do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro.

À Mes Cher Parents...

o júri

presidente

Professor Doutor João Nuno Pimentel da Silva Matos

Professor Associado da Universidade de Aveiro

vogal – arguente principal

Mestre Ricardo Jorge Moreira Ferreira

Gestor de Negócios na PT Inovação

vogal - orientador

Professor Doutor Diogo Nuno Pereira Gomes

Professor Auxiliar Convidado da Universidade de Aveiro

agradecimentos

Este espaço é dedicado a todos aqueles que contribuíram para que esta dissertação fosse realizada.

Ao Professor Diogo Gomes desejo expressar o meu profundo agradecimento pela partilha da sua visão e seus conhecimentos que me levaram a escolher este tema. Ao Professor Manuel Oliveira Duarte gostaria de deixar os meus irrestritos agradecimentos pelos seus conselhos, as condições de trabalho disponibilizadas, a partilha da sua profunda experiência e paixão pelas telecomunicações que foram determinantes para o desenvolvimento do meu trabalho e incentivo para a conclusão desta etapa e começo de uma carreira profissional. A ambos, agradeço a disponibilidade, sentido crítico e todos os *inputs* valiosos, dados ao presente documento.

Por fim, gostaria de expressar toda a gratidão, aos meus pais, por todo o carinho, apoio e incentivo que me ajudou a chegar a bom porto. À minha irmã, por dar sempre a palavra certa no momento oportuno.

Ao Carlos Campos, pelas horas infindáveis de apoio e auxílio nos momentos mais difíceis desta etapa académica. Aos meus amigos e colegas de carteira, em especial ao David Barroso, agradeço todos os momentos de camaradagem, boa disposição e partilha que ficarão gravados para a vida.

palavras-chave

Serviços Over The Top, Vídeo, Televisão, Operadores, Multiscreen, Streaming, Telecomunicações, Análise Técnico-Económica

resumo

A amplitude e variedade de conteúdos disponíveis *online* têm ajudado a promover uma experiência cada vez mais móvel da televisão, serviço que se tem revelado particularmente popular entre os mais jovens. Serviços *Over The Top* (OTT), sobretudo aqueles disponíveis através de plataformas de *video on-demand*, têm-se tornado cada vez mais atraentes para os consumidores, em comparação com os atuais pacotes de televisão.

Este documento descreve como funciona, do ponto de vista técnico, o ecossistema do vídeo sobre OTT. A descrição apresentada abrange ambas as extremidades da cadeia de distribuição: desde a forma como os sinais de vídeo são adquiridos e processados até ao modo como eles são entregues ao cliente, passando pelos problemas e consequências que tais serviços podem ter na rede.

O principal objectivo deste trabalho é contribuir para compreender se é possível criar em Portugal um novo operador onde o *core business* seja a distribuição de vídeo utilizando apenas serviços OTT.

keywords

Over The Top Services, Video, Television, Operators, Multiscreen, Streaming, Telecom, Techno-Economic Analysis

abstract

The breadth of availability and variety of online video contents has helped to encourage a far more mobile experience, which has proved particularly popular among younger generations. Over The Top (OTT) services, particularly those on-demand video platforms, became more and more attractive to consumers when compared with the current main TV packages.

This document describes how the video OTT Ecosystem works from a technical side. The description presented reaches both ends of the distribution chain: from how the video signals are acquired and processed, thru all the way to how they are delivered to the client, passing by the challenges and consequences that such services have on the network.

The main objective of this dissertation is to understand the possibility to create in Portugal a new operator where the core business is video delivery using only OTT services.

Index

	PAGE
Index	i
Figure Index	v
Table Index.....	ix
List of Acronyms	xi
1 Introduction	1
1.1 Over The Top (OTT)	2
1.2 Competitors and Stakeholders.....	2
2 OTT TV Ecosystem.....	5
2.1 Video Specifications.....	7
2.2 Streaming Technologies	10
2.2.1 Apple HTTP Live Streaming	10
2.2.2 Microsoft IIS Smooth Streaming.....	12
2.2.3 Real-Time Messaging Protocol (RTMP).....	13
2.2.4 MPEG – DASH	16
2.2.5 P2P/ BitTorrent Live.....	19
2.3 Streaming Servers	20
2.3.1 Darwin Streaming Server (DSS).....	20
2.3.2 Red5	20
2.3.3 Wowza Media Server.....	20
2.3.4 Flumotion Streaming Server.....	21
2.4 Adaptive Bit Rate (ABR) Streaming.....	22
2.5 Content Protection and Digital Right Management Systems.....	24
2.5.1 Microsoft PlayReady DRM Protection	24
2.5.2 HTTP Live Streaming DRM Protection.....	25
2.6 Authentication, Authorization, and Accounting	25
3 Telecommunication Networks.....	27
3.1 Network Structure	27
3.1.1 Core Network.....	28
3.1.2 Access Network	29
3.1.3 Customer Network.....	30
3.2 Access Network Technologies.....	31
3.2.1 Digital Subscriber Line (xDSL)	31
3.2.2 Fiber To The X (FTTx)	33
3.2.3 HFC.....	34

3.2.4	Mobile Networks	36
3.3	IPTV	41
3.3.1	IPTV Distribution over ADSL and FTTH Networks	42
3.3.2	IPTV vs. OTT	44
4	OTT Distribution Network, challenges and consequences	45
4.1	Quality of Service and Quality of Experience	45
4.1.1	Quality of Service	45
4.1.2	Quality of Experience	45
4.2	Content Delivery Networks	45
4.3	Network Neutrality	48
4.3.1	Arguments for network neutrality	49
4.3.2	Arguments against network neutrality	50
4.4	Service Level Agreements (SLA)	51
4.5	Transparent Caching	52
5	Client Platforms – Operating Systems and Devices	55
5.1	Computer Operating Systems	55
5.2	Mobile Operating Systems	56
5.2.1	Android	56
5.2.2	iOS	56
5.3	Other Multimedia Systems	57
5.3.1	XBMC	57
5.4	Set-Top BOX	58
5.4.1	Raspberry PI	58
5.4.2	Android PC or Google TV	59
6	Proof of Concept	61
6.1	Initial Concept	61
6.2	Server Solution	63
6.3	Content Preparation	65
6.3.1	XSplit Broadcaster	65
6.3.2	Handbrake (ffmpeg)	66
6.4	Prototype Platform	66
7	Economic Analysis of a possible implementation	73
7.1	Project Assumptions Summary	73
7.2	Target Market and Scenarios	74
7.2.1	Case Study Scenarios	76
7.2.2	Market Dynamics	76
7.3	Offer, Product and Pricing	78
7.4	Infrastructure Sizing	79
7.4.1	Scaling the Catalog	79

7.4.2	Data Center and Content Distribution Network	81
7.4.3	Costs and Other Assumptions	87
7.4.4	Stream and Cost Distribution.....	87
7.5	CAPEX – Capital Expenditure	96
7.5.1	Investments in Case 1	96
7.5.2	Investments in Case 2	97
7.5.3	Investments in Case 3	97
7.6	OPEX - Operational Expenditure	98
7.6.1	Main Expenses	98
7.6.2	Other Expenses	100
7.6.3	Wages and Salaries.....	101
7.6.4	Case 2 and 3 Costs Summary.....	102
7.7	Financial Balance and Cash Flow Results	103
7.7.1	Case 1	103
7.7.2	Case 2	105
7.7.3	Case 3	106
7.8	Conclusions of the Economic Analysis	107
8	Conclusions	109
8.1	Future Work	110
9	Appendix	111
9.1	Appendix 1 - TCP/IP and the OSI Reference Model	111
10	References & Bibliography.....	113

Figure Index

	Page
Figure 1 – OTT TV Technical Concept Overview	5
Figure 2 – High-level topology of end-to-end OTT Ecosystem	6
Figure 3 – OTT ecosystem Chapter 2 subject: Head End and Data Center	7
Figure 4 – Comparison of Video Resolution Standards [6]	9
Figure 5 – HTTP Live Streaming (HLS) overview [4]	11
Figure 6 – Microsoft IIS Smooth Streaming Overview [7]	12
Figure 7 – Handshake [8], [9]	14
Figure 8 – Create Connection [8], [9]	14
Figure 9 – Create Stream [8], [9]	15
Figure 10 – Play [8], [9]	15
Figure 11 – Typical HTTP Streaming architecture [10]	16
Figure 12 – Scope of the MPEG-DASH standard [11]	17
Figure 13 – Hierarchical data model of the Multimedia Presentation Description [11]	18
Figure 14 - OTT Broadcast Before and after Wowza [17]	21
Figure 15 – Adaptive Streaming Overview[20]	22
Figure 16 – OTT Ecosystem, Chapter 3 and 4 subject: Distribution Network	27
Figure 17 – Main Segments of the network Structure [25]	27
Figure 18 – Core Network: SDH Ring [26]	28
Figure 19 – xDSL Access Network [26]	31
Figure 20 – ADSL Frequency Spectrum [26]	31
Figure 21 – Transmission rate (Mbps) versus distance (Km) of the client to the DSLAM	32
Figure 22 – Transmission scheme of OTT content over ADSL	33
Figure 23 - Transmission scheme of OTT content over FTTH	34
Figure 24 – HFC Network Diagram [29]	35
Figure 25 – Hybrid Fiber Coax Network Overview	35
Figure 26 - Transmission scheme of OTT content over HFC	36
Figure 27 – Mobile Network Evolution from GSM to LTE [31]	38
Figure 28 - Transmission scheme of OTT content over LTE	39
Figure 29 – Fixed WiMAX deployment and usage models	40
Figure 30 – IPTV network [34]	41
Figure 31 – IPTV transmission scheme over ADSL Networks	43
Figure 32 - IPTV transmission scheme over FTTH Networks	43
Figure 33 – CDN basic concept [37]	46
Figure 34 – OTT video distribution without using a Content Delivery Network [38]	47

Figure 35 – OTT video distribution using a Content Delivery Network [38]	47
Figure 36 – Content Transmission without Transparent Caching [48].....	52
Figure 37 – Content Transmission With Transparent Caching [48]	53
Figure 38 – Transparent Caching Process [48].....	53
Figure 39 - OTT Ecosystem, Chapter 5 subject: Client Platforms	55
Figure 40 – Raspberry PI running XBMC	58
Figure 41 – Raspberry Pi representation and picture	58
Figure 42 – Android PC Overview	59
Figure 43 – Android PC	59
Figure 44 - The figure illustrates a possible example of an end to end ecosystem of the OTT television delivery system.....	62
Figure 45 – XSplit Broadcaster configuration page.....	65
Figure 46 – Handbrake Software	66
Figure 47 – Prototype layer architecture	67
Figure 48 – Website Layout on Tablet and PC/MAC	68
Figure 49 – Website Layout on a smartphone	68
Figure 50 – HLS stream playing in iOS native player from OTTPlay	70
Figure 51 – Video Page layout on Android.....	71
Figure 52 – Adaptive HLS stream playing on Android native player.....	71
Figure 53 – Example of .strm files on XBMC menu	72
Figure 54 – HLS stream playing on XBMC	72
Figure 55 - Market Penetration Rate (Logistic Curve).....	77
Figure 56 – Evolution of the number of assets in the catalog	80
Figure 57 - Optimal resolution for the sequence “Public Television” at various bit rates [60].....	80
Figure 58 – OTT Video Distribution Architecture.....	81
Figure 59 – Idealized location of The CDN Servers in Portugal mainland.....	84
Figure 60 – Sensitivity Analysis of the Concurrency Rate	86
Figure 61 – Stream Handling Distribution	87
Figure 62 – Total Streams to handle in Case 1	88
Figure 63 – Data Center Evolution in Case 1	89
Figure 64 – Edge cache server evolution in Case 1	90
Figure 65 – Evolution of the total number of servers in Case 1	90
Figure 66 – Bandwidth evolution of the distribution network in Case 1	90
Figure 67 – Total costs involved in the distribution network in case 1	91
Figure 68 - Total Streams to handle in Case 2.....	92
Figure 69 - Data Center Evolution in Case 2.....	93
Figure 70 - Bandwidth evolution of the distribution network in Case 2	93
Figure 71 - Total costs involved in the distribution network in case	93
Figure 72 - Total Streams to handle in Case 3.....	94
Figure 73 - Data Center Evolution in Case 3.....	95

Figure 74 - Bandwidth evolution of the distribution network in Case 3	95
Figure 75 - Total costs involved in the distribution network in case 3.....	95
Figure 76 – Investments in case 1	96
Figure 77 - Investments in case 2	97
Figure 78 - Investments in case 3	97
Figure 79 – Costs in supplies and external services in Case 1	98
Figure 80 – Call Center, number of required operators in Case 1	100
Figure 81 – Call Center yearly costs in Case 1	100
Figure 82 – possible Company's organizational chart	101
Figure 83 – OPEX Summary in Case 2	102
Figure 84 - OPEX Summary in Case 3	103
Figure 85 - Financial Balance Summary of Case 1.....	103
Figure 86 - Cash Flow Result in Case 1	104
Figure 87 - Financial Balance Summary of Case 2.....	105
Figure 88 - Cash Flow Result in Case 2	105
Figure 89 - Financial Balance Summary of Case 3.....	106
Figure 90 - Cash Flow Result in Case 3	107

Table Index

	Page
Table 1 - Competitors in the OTT market segmented by service type.....	3
Table 2 - Competitors in the OTT market segmented by company type	4
Table 3 – Common Video Containers	7
Table 4 – Common Video Codecs	8
Table 5 – Comparison of IPTV vs. OTT [36]	44
Table 6 – Android PC specifications	60
Table 7 – Streaming Server Comparison Table, Test Specification and Streaming Protocols comparison	64
Table 8 - Streaming Server Comparison Table, Video Formats and Codecs Comparison	64
Table 9 - Streaming Server Comparison Table, Audio Comparison.....	64
Table 10 – Live encoding configurations used in the Prototype	65
Table 11 – Technology vs. Browser vs. OS resume table	69
Table 12 – Used values in the calculation of the penetration rates	76
Table 13 - Penetration Rate Evolution (percentage).....	77
Table 14 - Penetration Rate Evolution (Number of Clients)	77
Table 15 – OTT Service Pricing table	78
Table 16 – Summary table of asset catalog projections	79
Table 17 – Live Stream service for Premium events description.....	81
Table 18 - Data Center Structure description.....	83
Table 19 – Maximum number of connections to handle in Case 1	88
Table 20 - Maximum number of connections to handle in Case 2.....	92
Table 21 - Maximum number of connections to handle in Case 3.....	94
Table 22 – Financial Results Summary in Case 1	104
Table 23 - Financial Results Summary in Case 2	106
Table 24 - Financial Results Summary in Case 3	107

List of Acronyms

3GPP	3rd Generation Partnership Project
AAC	Advanced Audio Coding
ABR	Adaptive Bit Rate
ADSL	Asynchronous Digital Subscriber Line
AES-128	Advanced Encryption Standard
AMR	Adaptive Multi-Rate
APs	Application Providers
ATM	Asynchronous Transfer Mode
AVC	Advanced Video Coding
AVI	Audio Video Interleaved
Bps	Bit Per Second
CATV	Cable Television
CDMA	Code Division Multiple Access
CDN	Content Distribution Network
CM	Cable Modem
CMTS	Cable Modem Termination System
CO	Central Office
CPE	Customer Equipment Premises
CR	Concurrency Rate
DASH	Dynamic Adaptive Streaming over HTTP
DNS	Domain Name System
DOCSIS	Data Over Cable Service Interface Specification
DRM	Digital Rights Management
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DSS	Darwin Streaming Server
DTT	Digital Terrestrial Television
DVB-S	Digital Video Broadcasting — Satellite
DVB-T	Digital Video Broadcasting - Terrestrial
EDGE	Enhanced Data rates for GSM Evolution)
E-UTRAN	Evolved UMTS Terrestrial Radio Network
FDD	Frequency-division duplexing
FLOPS	Floating-point Operations Per Second
FLV	Flash Video
FM	Frequency Modulation
FPS	Frames Per Second

FR	Frame Relay
FTTB	Fiber To The Building
FTTC	Fiber to The Curb
FTTCab	Fiber To The Cabinet
FTTH	Fiber To The Home
FTTN	Fiber To The Node
FTTP	Fiber To The Premises
FTTx	Fiber To The X
GEM	GPON Encapsulation Method
GERAN	GSM EDGE Radio Access Network
Gpixel	GigaPixel
GPRS	General Packet Radio Service
GRAN	GSM Radio Access Network
GSM	Global Systems for Mobile Communications
HD	High Definition
HDMI	High-Definition Multimedia Interface
HDS	Flash HTTP Dynamic Streaming
HDSL	High-bit-rate digital subscriber line
HFC	Hybrid Fiber-Coaxial
HLS	HTTP Live Streaming
HSDPA	High Speed Downlink Packet Access
HSPA	High-Speed Packet Access
HSUPA	High Speed Uplink Packet Access
HTTP	Hypertext Transfer Protocol
IDSL	ISDN Digital Subscriber Line
IEC	International Electrotechnical Commission
IIS	Internet Information Services
IMS	IP Multimedia Core Network Subsystem
IP	Internet Protocol
IPTV	Internet Protocol Television
ISO	International Organization for Standardization
ISP	Internet Service Provider
ITU	International Telecommunication Union
IU	Internet Users
Kbps	Kilobit Per Second
LAN	Local Area Network
LTE	Long-Term Evolution
MAC	Media Access Control Address
Mbps	Megabit Per Second
MIMO	Multiple-Input Multiple-Output

MPD	Media Presentation Description
MPEG	Moving Picture Experts Group
MPEG-TS	MPEG2 Transport Streams
MPLS	Multi-protocol Label Switching
MSN	Microsoft Network
NAT	Network Address Translation
NGN	Next-Generation Networks
NRZ	Non-Return-to-Zero
NSV	Nullsoft Streaming Video
OFDM	Orthogonal Frequency Division Multiplexing
OTT	Over The Top
P2P	Peer-2-Peer
PC	Personal Computer
POTS	Plain Old Telephone Network
PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
QPSK	Quadrature Phase-Shift Keying
RADSL	Rate-adaptive digital subscriber line
RF	Radio Frequency
RTMP	Real-Time Messaging Protocol
RTP	Real-time Transport Protocol
RTSP	Real Time Streaming Protocol
SD	Standard Definition
SDH	Synchronous Digital Hierarchy
SDSL	Symmetric digital subscriber line
SLA	Service Level Agreement
SMIL	Synchronized Multimedia Integration Language
SMS	Short Message Service
SNR	Signal to Noise Ratio
TCP	Transmission Control Protocol
TCS	Transparent Cache server
TS	MPEG transport stream
TV	Television
UDP	User Datagram Protocol
UI	User Interface
UMTS	Universal Mobile Telecommunications Systems
URI	Uniform Resource Identifier
URL	Uniform Resource Locator

USB	Universal Serial Bus
UTRAN	UMTS Radio Access Network
VDSL	Very-high-bit-rate digital subscriber line
VOD	Video On Demand
VoLTE	Voice Over LTE
WAMP	Windows Apache MySQL PHP server
W-CDMA	Wide-band Code-Division
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
xDSL	Digital Subscriber Line
XML	Extensible Markup Language

1 Introduction

The main scope of this dissertation is to gain a better understanding about the television ecosystem and contribute towards the development of more efficient and cost effective delivery solutions to the end user.

The initial motivation for this dissertation was the following question:

“Is it possible for a start-up to introduce a multiscreen Video on Demand service using only the network of others?”

Nowadays we are approached, on the media, by operators offering triple play services including internet, television and telephone. These services are offered claiming to be a good deal for the customer but that's not always the case. Typically the customer doesn't watch most of the channels that he is paying for, neither use all the internet bandwidth that is provided.

Currently there are two types of customers, those who are looking for services with only the essential and the lowest price possible and those who look for a quality value service, where they prefer to pay more and have a better service with extra features.

Due to the current economic crisis, the household budgets are shrinking day-by-day and on-demand video platforms are attracting consumers, leading them to “cut the cord” or unbundling their triple or quadruple play packages, with hundreds of channels, unlimited bandwidth, and a whole bunch of services and applications that are barely used by the common consumer. Instead consumers are keeping only their internet connections and they are watching television online through unlicensed websites.

Video on Demand services are attracting consumers and especially the young ones (or the YouTube generation) because of their simplicity and usability. The user simply chooses what to watch in the instant he wants to. From February's 2012 CMB [1] study, 16% of the American consumers inquired were highly likely to cut back on Pay TV in the same year.

The competition to retain subscribers has increased, mainly due to new video on demand services that represent cheaper alternatives by using the latest technologies and reaching a wider set of devices. Network websites and streaming content providers like Netflix, Amazon and Apple are providing more stream-lined subscription packages against the industry heavyweights such as Sky, Fox or HBO (USA) and Portugal Telecom or ZON in Portugal.

The challenge of this dissertation is to find a way to deliver a cost effective television service using only Over The Top (OTT) services in order to satisfy this kind of customers who are looking for cheaper and mobile experiences.

To use OTT protocols it is only necessary an internet connection to access a video stream and with the adaptive streaming capabilities it is possible to watch these type of contents on any network,

which means anywhere. With this new reality the consumers will start dictating the way in which they want their TV service rather than the other way around.

1.1 Over The Top (OTT)

Over The Top is also referred as a “value added” service. Everyone has already used OTT services without actually realizing it. To better understand the concept here is an example:

Almost everyone nowadays has a subscription with a mobile network operator that includes calls, SMS (Short Message Service) and data (3G/4G). The data traffic included in your subscription can be used with smartphone applications to do calls and exchange SMS without using the traditional mobile services. For example, Skype uses your data connection to do VoIP calls over the internet, with a cheaper cost than the one offered by the mobile operator.

The data service provider or the network operator whose network is being utilized for the OTT service has no control, no rights, no responsibilities and no claim on the latter. This is because the user should be free to make use of the Internet the way they want [2]. If the network is neutral the network operator only carries the IP packets from source to destination. The vision that Network Neutrality rules are fully applied and ISPs turn a blind eye or do not care about the content being delivered through their “pipes” can be easily shattered. Due to copyright infringements ISPs have to monitor their networks, but they are requesting the ability to do packet detection [3].

In the fields of broadcasting and content delivery, Over-The-Top content describes broadband delivery of video and audio without a network operator being involved in the control or distribution of the content itself. Simply put, OTT refers to a service that is delivered over the network of another service provider.

OTT TV can also refer to any video content that is not delivered through traditional linear television channels, although that definition may encompass even on-demand content provided as TV Everywhere by the pay TV operator [3]. Wikipedia's ever-morphing definition also notes that OTT delivery over broadband connections are outside of the "control" of the internet service provider (ISP) network it is delivered on.

Consumers can access OTT content through internet-connected devices such as desktop and laptop computers, tablets, smartphones, set-top boxes, smart TVs and gaming consoles. The consumer accesses the content through the apps developed for each different platform.

1.2 Competitors and Stakeholders

The stakeholders are all the operators present on the residential entertainment market and content owners.

Without the need of a managed network to transmit video over IP networks, it is possible that new players can appear on the market offering OTT television services on multiple platforms.

Residential Entertainment stakeholders are all the operators who deliver television services included in bundle packs, such as duple/triple or quadruple services. These television services can include hundreds of linear TV channels, paid on demand videos or live events, interactive applications related to specific programming or for general use, such as Weather or News Applications.

As example, a content owner can deliver the content directly to the user, without the need of selling it to a network or a telecom operator to reach the consumer. Using OTT services, from own deployment or external companies, the owner can sell the content directly to the consumer cutting the value-added chain. This vision can lead to a market where the content is king, meaning that who owns the content could also own the client and eventually cut down prices.

Video On Demand	Live Television
Netflix	Aereo TV (New York City Only)
Hulu	Nimble TV (USA only)
LoveFilms (Amazon)	VODAFONE MOBILE
Google Play Movies	Mobile TV (Deutsche Telekom)
HBO GO	TVI (Portugal)
Xfinity (Comcast)	
Swisscom TV air	
BBC iPlayer	
Meo Go! (Portugal Telecom)	
Oi Go! (Oi Brasil)	
ZON Online (ZON)	

Table 1 - Competitors in the OTT market segmented by service type

The OTT challenge has already been addressed in other circumstances. Some of the companies who already have their own products in the market are described in Table 1.

Netflix, ventured into online streaming, but its initial streaming service was limited to PCs and about 1,000 movies and television titles. Fast forward to the summer of 2010, and Netflix announced that it had inked a \$1 billion deal to add films from Paramount Pictures, Lions Gate, and MGM to its online subscription service. In November 2010 the company solidified its online position by introducing an unlimited streaming-only plan to its packages.

NimbleTV will give customers the ability to select channel packages based on personal preferences, though that'll depend heavily on the TV providers going along for the ride. This means that the client will be able to choose a cable or satellite package from any country and they will sign up the package for the client and stream it. They will provide alongside cloud based features, like unlimited recording and storage of any content.

Aereo's technology offers the ability to watch live HD TV online, access over 20 broadcast channels, 40 hours of remote DVR storage and usage on up to five devices. Aereo is launching with compatibility on web-enabled iOS devices including the iPhone, iPad, Roku, Apple TV and MacBook, with Android support coming soon.

Services like Aereo TV and NimbleTV are taking similar approaches, both plan to launch their subscription-based services allowing future users to stream cable content to unspecified devices at any time and from anywhere on the globe, all thanks to cloud-based and OTT software. Although they are selling these services to restricted areas, they are getting sued for digital rights infringements.

ZON Online is only available for PC and iOS Devices and offers a package of approximately 40 live channels available anywhere, pay-per-view video-on-demand and the ability to watch shows already broadcasted by the channels available in the package (Restart TV).

MEO GO!, developed by Portugal Telecom and sold as an extra of the residential offer, MEO, enables the client to access a package of approximately 70 live TV channels, Video On Demand and time-shift television functionalities. Almost all of these features are available in multiple platforms, such as PC/MAC, iOS, Android, Windows Phone, Connected TVs and Gaming Consoles. Oi Go! also developed by Portugal Telecom, is based on the same technology, but offers fewer services, only Live TV and Video On Demand.

It is possible to divide the competitors by their company type: Content Owners, OTT or Content Aggregators and Content Retailers.

Content Owners	Content Aggregators	Content Retailers
BBC iPlayer	Netflix	VODAFONE MOBILE
HBO GO	Hulu	Mobile TV (Deutsche Telekom)
TVI	LoveFilms	Xfinity
	Google Play Movies	Swisscom TV air
	Aereo TV	Meo Go!
	Nimble TV	Oi Go!
		ZON Online

Table 2 - Competitors in the OTT market segmented by company type

With OTT the competitors are changing, until then we only had Telecom Operators in the Pay TV business. Now content owners are starting to deliver their contents directly to the end user and new content aggregators are appearing delivering entertainment with lower prices. Telecom operators are offering OTT solutions as side companions to their residential packages.

2 OTT TV Ecosystem

The Over The Top (OTT) technology will be the enabler to stream and distribute video content through the open Internet or through unmanaged networks. Conceptually this end-to-end ecosystem can be summarized in four simple steps, illustrated in Figure 1:

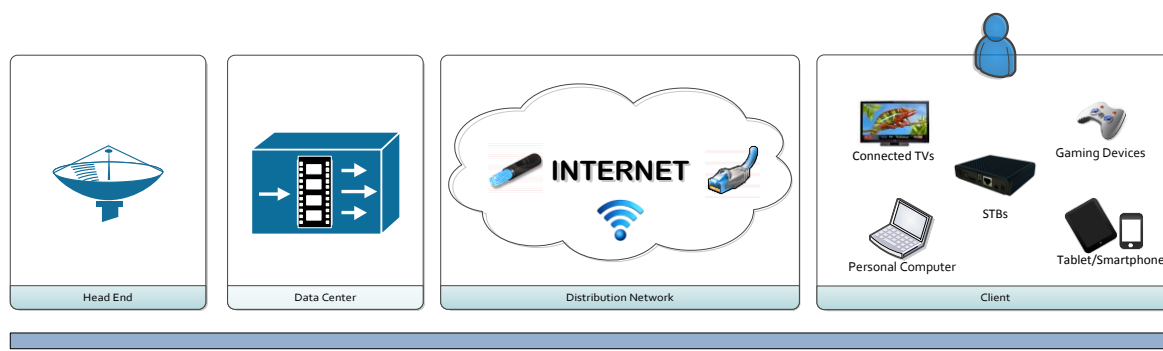


Figure 1 – OTT TV Technical Concept Overview

1. **Acquisition and Encoding:** takes place usually in a head-end, the content is acquired from different sources (satellite, IP, over the air broadcast, and others) and encoded according to specific requirements. The most used codec for stream encoding is H.264 AVC.
2. **“Packetization”:** the encoded streams are packetized and distributed over the Internet using standard web servers, mainly based on HTTP services. These servers are responsible for accepting client requests and delivering prepared media with associated resources to the client. For large-scale distribution, edge networks or other content delivery networks may be used.
3. **Distribution:** the video distribution is done using unmanaged networks, which means that the operator who is streaming the content has no rights or control over the network on which the content is being transported. Neither the owner of the network as any rights or control over the streamed content [4].
4. **Play:** From the data provided by the servers and according to the equipment hardware specifications, the client software will choose which is the more appropriate media to request. The player will then download those resources, and reassemble them so that the media can be presented to the user in a continuous stream [4].

The OTT Video ecosystem consists in multiple technologies that work together in order to distribute the video over any network, with the best quality of service possible and to largest number of connected devices.

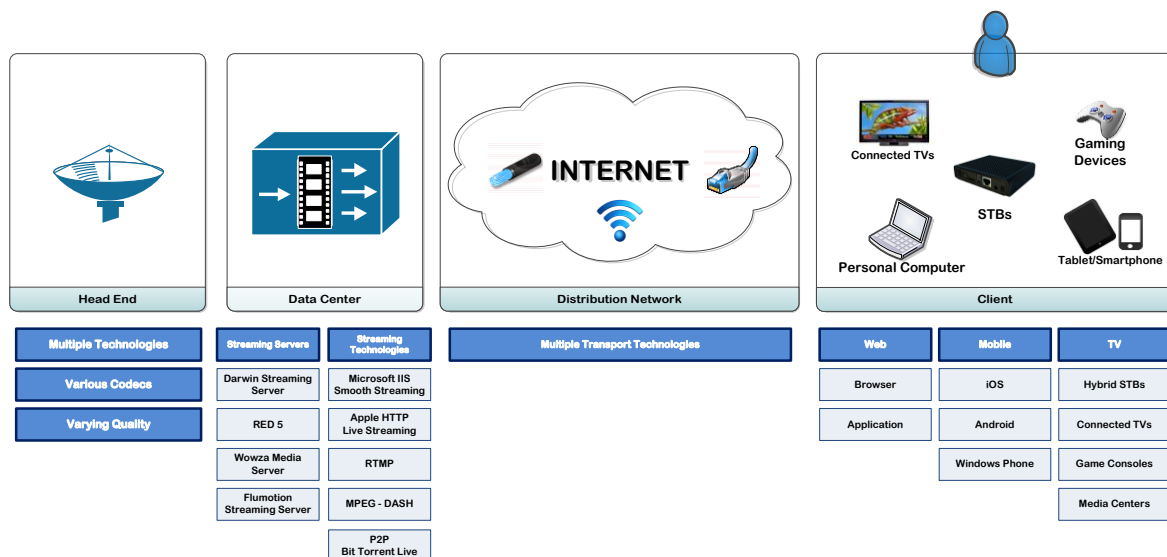


Figure 2 – High-level topology of end-to-end OTT Ecosystem

In Figure 2, most of the technologies used in the OTT TV are outlined:

- **Head End:** handles multiple acquisition technologies, streams with different codecs and encode this content with varying video qualities.
- **Data Center:** streaming servers will be responsible to packetize the streams using one or more streaming technologies.
- **Distribution Network:** Once the distribution is done mainly using HTTP protocols, the streams can be transported with any transport protocol. It is important to refer that in order to obtain a better quality of service it is mandatory that the stream can adapt to the available client's bandwidth that will be explained in the sub-chapter Adaptive Streaming.
- **Client:** the streams have to be compatible with the client's software. Because of the multiscreen it is why we need different at this end of the ecosystem, different Video Encodings and Streaming Protocols.

In this chapter we will focus on the technologies usually used in the Head End and in the Data Center. It will be described the technologies that enable the video distribution, the encoding and streaming technologies and the different streaming server software. To do so, we will start to understand some basic video specifications.

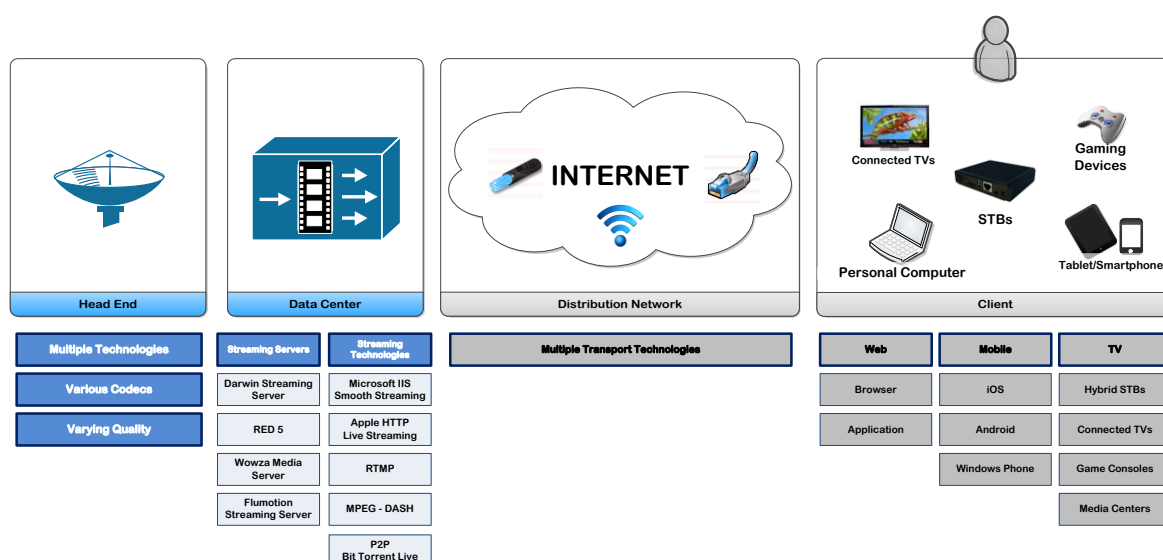


Figure 3 – OTT ecosystem Chapter 2 subject: Head End and Data Center

Open source and commercial server side software solutions were studied and tested with the aim of finding the best solution to use ahead in a practical case of this dissertation. Test results are described in Chapter 5.

Content Protection and Digital Right Management Systems are described ahead in order to understand how to better protect the transmitted content.

Last but not least, Authentication, Authorization, and Accounting theme will also be covered.

2.1 Video Specifications

Video Formats involve two distinct and very different technology concepts:

Containers: it is the structure of the file that contains the video data. It specifies where and how the different pieces are stored and interleaved, and which codecs are used. It is used to package video and other components such as audio and metadata. The most familiar file extensions are .AVI, .MP4 or .MOV.

Common Containers	
Name	Description
AVI	Windows standard multimedia container.
MOV	Apple QuickTime video container.
MPEG-4	Standard container of MPEG-4
OGG	Open source container
FLV	Flash video container. Used to deliver MPEG video through Flash Player.

Table 3 – Common Video Containers

Codecs: encodes the video into a stream of bytes. Encoding is the method used to encode the video and it's the chief determiner of quality. Then the encoded video is saved into a container.

Common Codecs	
Name	Description
MPEG-1	Oldest codec of Moving Pictures Expert Group, broadly supported and reasonably efficient.
MPEG-2	Similar with MPEG-1, with better compression and supports between other features, interlaced video.
MPEG-4	MPEG-4 is still a developing standard and absorbs many of the features of MPEG-1 and MPEG-2. Supports DRM.
H.264	H.264 video is broadly used, from low bit-rate Internet streaming applications to HDTV broadcast and Digital Cinema applications with nearly lossless coding. With the use of H.264, bit rate savings of 50% or more are reported. It's part of MPEG-4 codec.
Sorenson	Apple's proprietary codec, commonly used with MOV container.
Ogg theora	A relatively new open source codec from Xiph.org

Table 4 – Common Video Codecs

It is important to not confuse these two terms because, for example, a .MOV container can handle almost any kind of codec data in the other hand “MPEG-4” describes both a codec and a container. It is possible to have a video encoded with MPEG-4 codec inside an AVI container and have a video encoded with H.264 codec inside an MPEG-4 container [5].

Other video specifications have to be introduced and will be or have been mentioned in this document:

Digital Storage Space: depends on the video/audio quality and codification used.

Frames per second (fps): The standard is set to roughly 30 fps (29.97 fps), increasing the FPS allows for more images per second thus smoother image. Decreasing FPS will make the video a bit choppy and nearly as smooth [5].

Video Bitrate: it is a measurement of the number of bits that are transmitted over a set length of time. The overall bitrate of a video file will depend from the combination of the video stream, audio stream and metadata inside the file. Higher bit rate will provide better quality and bigger will be the dimension of the file [5].

Resolution: is defined by the number of pixels present in each image of the video. This determines whether the video is standard (SD – 640X480) or high definition (HD – 1280X720; FULL HD – 1920X1080). Higher the resolution, bigger the video file and clearer is the image.

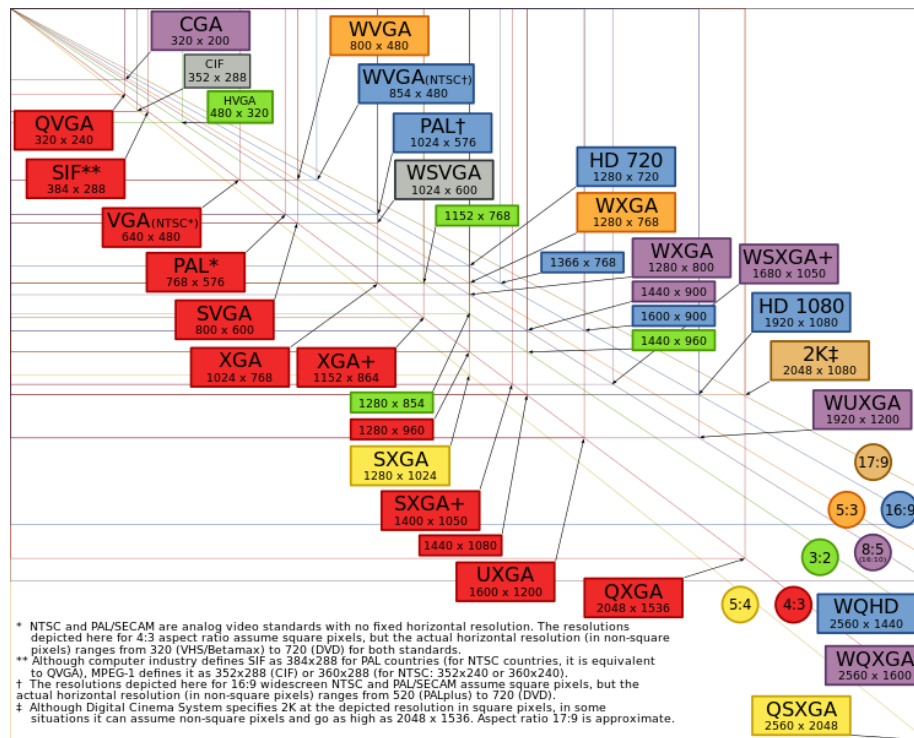


Figure 4 – Comparison of Video Resolution Standards [6]

2.2 Streaming Technologies

When attempting to stream video on a un-managed network we need to transport information through routers, firewalls and ports which we don't know if are opened or not. In a home network, there are personal firewalls, possible routers and security software scanning port activity. In a Wi-Fi hot spot, the port access can be extremely limited due to security concerns.

This is a well-known hurdle with network applications and is overcome through the use of the HTTP protocol for communication. HTTP uses port 80 for requests. Requests to this port are most likely to be allowed through any firewall or router as they are used for all web surfing. As HTTP uses a state-full TCP connection, any issues that can be incurred by NAT based networks are also overcome.

2.2.1 Apple HTTP Live Streaming

Apple introduced HTTP Live Streaming (HLS) in June 2009 with iOS 3.0. HLS is today the most widespread protocol used for OTT, as it is available on all Apple devices (iPhone, iPad, Apple TV, and others) as well on most of the software players and some set top boxes.

HLS works with segmented TS-based video streams of files. These files are contained in a MPEG transport stream (TS) this container is also used for satellite broadcasting and IPTV on managed networks. The codec used is MPEG H.264 for video and AAC for audio, which are also mainly used in other technologies.

The approach developed by Apple uses modified industry standards in order to fit with the requirements of an OTT solution. The way to achieve HLS streaming is to [4]:

1. Encode video in H.264/TS format (taken from a live feed or from a file), at different bitrates;
2. Use a stream segmenter to generate short “chunks” of content, typically 10 seconds each;
3. Generate a playlist file (m3u or m3u8) indicating where to download the chunks;
4. Distribute the playlist file through an HTTP server, and provide appropriate caching.

Index file is generated indicating different profiles (streaming qualities) available for one channel/content file; the receiving device (PC, mobile, STB) looks for the most suitable bitrate based on how long it takes to receive a chunk file.

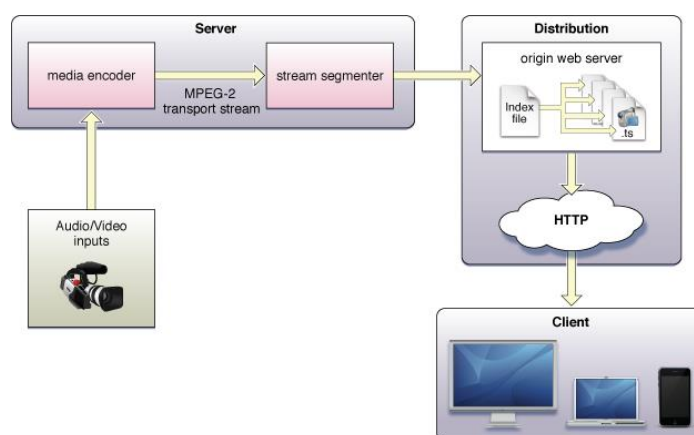


Figure 5 – HTTP Live Streaming (HLS) overview [4]

The server component is responsible for ingesting media streams and digitally encapsulates them in a format suitable for delivery, and prepares the encapsulated media for distribution.

In a typical configuration, HLS streaming can be accomplished through the following steps:

- A hardware encoder takes audio-video input, encodes it as H.264 video and AAC audio, and outputs it in an MPEG-2 Transport Stream.
- Stream segmenter software breaks the TS into a series of short media files. The segmenter also creates and maintains an index file containing a list of the media files.
- These files are placed on a web server.
- The URL of the index file is published on the web server.
- Client software reads the index, then requests the listed media files in order and displays them without any pauses or gaps between segments.

The stream segmenter is typically software that reads the Transport Stream from the local network and divides it into a series of small media files of equal duration. Even though each segment is in a separate file, video files are made from a continuous stream which can be reconstructed seamlessly.

The segmenter also creates an index file containing references to the individual media files. Each time the segmenter completes a new media file, the index file is updated. The index is used to track the availability and location of the media files. The segmenter may also encrypt each media segment and create a key file as part of the process [4].

Media segments are saved as .ts files (MPEG-2 transport stream files). Index files are saved as .M3U8 playlists.

An important feature of HLS is the ability to adapt the streaming bitrate intelligently. Unlike techniques that are used in RTP streaming, it is the end user device that decides the stream quality, according to the available bandwidth (and not the video server). This approach aims to ensure unbroken video streaming, thus creating a positive user experience through an unmanaged network.

2.2.2 Microsoft IIS Smooth Streaming

In October 2008, Microsoft announced that Internet Information Services (IIS) 7.0 would feature a new HTTP-based adaptive streaming extension: Smooth Streaming.

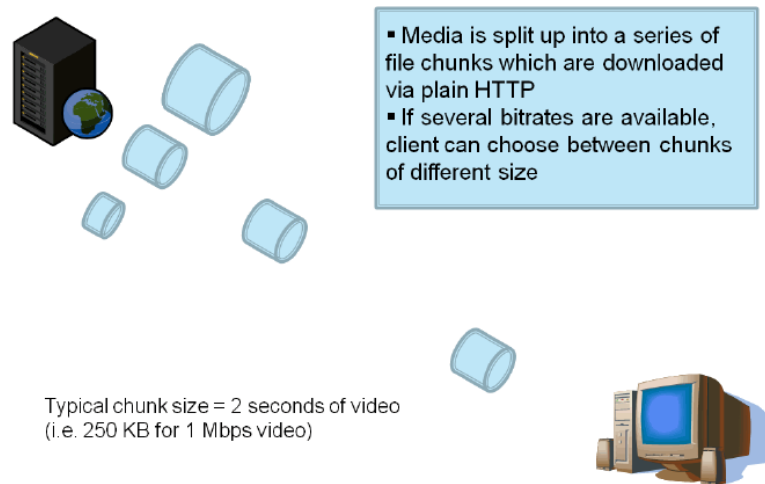


Figure 6 – Microsoft IIS Smooth Streaming Overview [7]

The Smooth Streaming technology dynamically detects local bandwidth, the device CPU conditions and seamlessly switches, in near real time, the video quality of a media file that a player receives. Users with high-bandwidth connections can experience high definition (HD) quality streaming while others with lower bandwidth speeds receive the appropriate stream for their connectivity, allowing consumers with different needs and specifications to enjoy uninterrupted streaming experiences.

IIS Smooth Streaming uses the MPEG-4 Part 14 (ISO/IEC 14496-12) file format. Specifically, the Smooth Streaming specification defines each chunk as an MPEG-4 Movie Fragment and stores it within a contiguous MP4 file for easy random access. One MP4 file is expected for each bit rate. When a client requests a specific source time segment from the IIS Web server, the server dynamically finds the appropriate Movie Fragment box within the contiguous MP4 file and sends it over the wire as a standalone file, thus ensuring full cacheability downstream [7].

Some reasons why MP4 was chosen [7]:

- MP4 is a lightweight container format.
- MP4 is easy to parse in managed (.NET) code.
- MP4 is based on a widely used standard, making 3rd party adoption and support more straightforward.
- MP4 is architected with H.264 video codec support in mind. H.264 is an industry leading video compression standard that has been adopted across a broad range of operating systems and devices.
- MP4 is designed to natively support payload fragmentation within the file.

Two parts compose the Smooth Streaming format: the wire format and the disk file format. The wire format defines the structure of the chunks that are sent by IIS to the client, whereas the file

format defines the structure of the contiguous file on disk, enabling better file management. Fortunately, the MP4 specification allows MP4 to be internally organized as a series of fragments, which means that in Smooth Streaming the wire format is a direct subset of the file format [7]. In other words, with Smooth Streaming, file chunks are created virtually upon client request, but the actual video is stored on disk as a single full-length file per encoded bit rate. This offers tremendous file-management benefits.

The Smooth Streaming Wire/File Format specification defines the manifest XML language as well as the MP4 box structure. Because the manifests are based on XML, they are highly extensible. The Smooth Streaming Manifest files supports diverse features such as: Multi-language audio tracks, alternate video and audio tracks (for example, multiple camera angles, director's commentary, etc.), multiple hardware profiles (for example, a bit rate targeted at different playback devices), captions, among others [7].

2.2.3 Real-Time Messaging Protocol (RTMP)

Real-Time Messaging Protocol (RTMP) refers to the proprietary protocol developed by Adobe Systems for streaming audio, video, and data over the Internet between a Flash player and a Flash Media Server.

RTMP belongs to the application-level protocol, and runs over TCP as transport-level protocol.

The basic unit of the RTMP to transmit information is Message. During transmission, for consideration of multiplexing and packetizing multimedia streams, each Message will be split into some Chunks.

In the process of playing a streaming media, the client can send Command Message such as “connect”, “createStream”, “play”, “pause” to control the playback of streaming media.

Message need to be split into a number of Chunks when it transmits data in the network. Chunk provides multiplexing and packetizing services for a higher-level multimedia stream protocol. RTMP Chunk Stream Protocol prescribes that the Payload of each Message is divided into fixed-size Chunks (except the last one).

Playing a RTMP-based streaming media, under normal circumstances, need to use the Flash application as client. User can use ready-made Flash web player to play streaming media.

2.2.3.1 Method of playing a RTMP Video

A RTMP-based video streaming need to go through the following steps: Handshake, Create Connection, Create Stream, and Play. Outlining the steps we have:

- The Handshake initiates the connection;
- Then the Create Connection step is used to establish the NetConnection between the client and server;
- The following stage is used to establish the NetStream between the client and server, called Create Stream;

- Play stage is used to transmit video and audio data.

2.2.3.1.1 Handshake

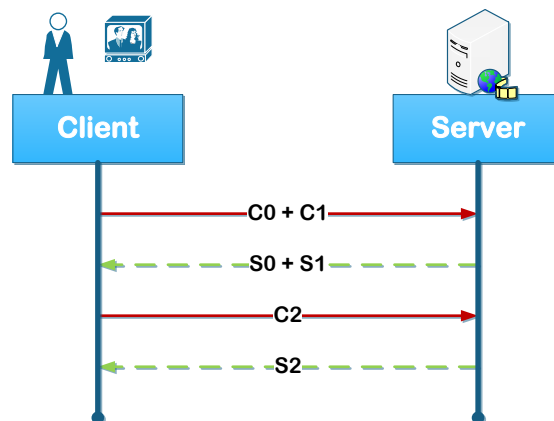


Figure 7 – Handshake [8], [9]

1. The client sends C0, C1 block. Server receives the C0 or C1 and then sends S0 and S1.
2. When receiving all the S0 and S1, the client starts sending C2. When receiving all the C0 and C1, the server starts sending S2.
3. When the client received S2 and the server received C2, the Handshake is complete.

2.2.3.1.2 Create Connection

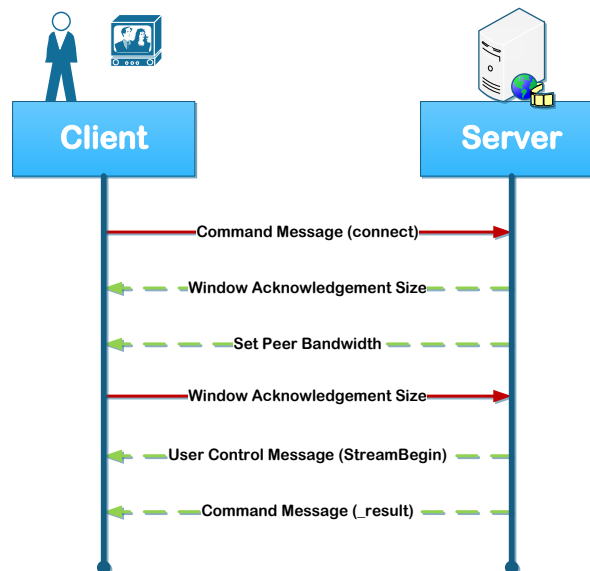


Figure 8 – Create Connection [8], [9]

1. The client sends a Command Message "connect" to the server to establish a NetConnection with a server application instance.
2. After receiving the "connect" Command Message, the server sends the Message "Window Acknowledgement Size" to the client, and connect to the application mentioned in the Command Message.

3. The server sends the Message “Set Peer Bandwidth” to the client to update the output bandwidth.
4. After dealing with the set bandwidth Message, the client sends the Message “Window Acknowledgement Size” to the server.
5. The server sends the User Control Message “Stream Begin” to the client.
6. The server sends Command Message “_result” to notify the client the result of the Command.

2.2.3.1.3 Create Stream

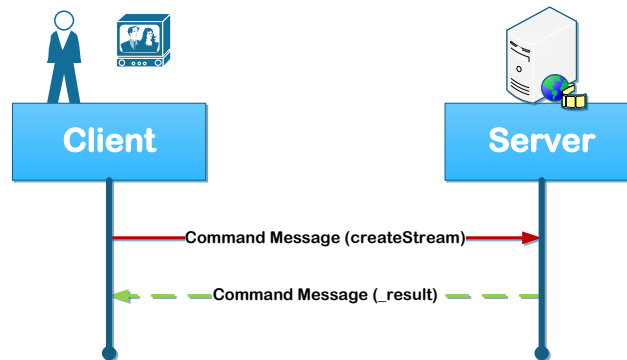


Figure 9 – Create Stream [8], [9]

1. The client sends a Command Message “createStream” to the server to request to establish a NetStream with a server application instance.
2. The server sends Command Message “_result” to notify the client the result of the Command.

2.2.3.1.4 Play

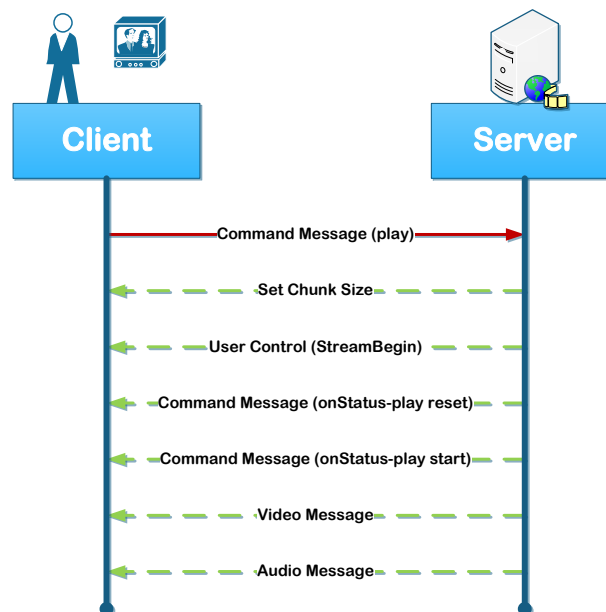


Figure 10 – Play [8], [9]

1. The client sends the Command Message “play” to the server.
2. On receiving the “play” Command Message, the server sends “Set Chunk Size” Message to notify the client the chunk size used in the stream.
3. The server sends User control Message “StreamBegin” to inform the client that the stream has become functional.
4. The server sends Command Message “NetStream.Play.Start” and “NetStream.Play.reset” to notify the client the “play” Command is successful.
5. After this, the server sends audio and video data, which the client plays.

2.2.4 MPEG – DASH

The new standard Dynamic Adaptive Streaming over HTTP (DASH), also known as MPEG-DASH, has been developed by MPEG and 3GPP to enable the interoperability in the industry.

Due to the heterogeneity of today’s telecom networks, “adaptivity” is a very important requirement for any streaming client. DASH has the potential to play a major role in networks with fluctuating bandwidth. For this reason, DASH is based on the underlying layer of HTTP, TCP that is notorious for its throughput variations.

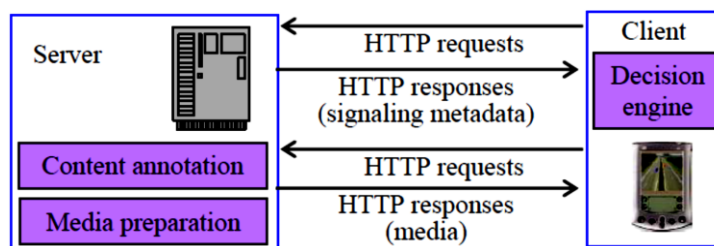


Figure 11 – Typical HTTP Streaming architecture [10]

Typically in HTTP streaming, the server has very little knowledge about the client or the network status, therefore the client has the power to decide how the content is delivered in order to provide the best quality of service possible.

For “adaptivity” matters, to clients or networks, multiple alternatives of each component (video or audio) have to be generated, and the signaling metadata have to contain the characteristics of each alternative (such as bitrate, resolution, etc.). These multiple versions of same media will be then “chopped” into segments that can be individually requested by the client through HTTP. This enables the client to switch between different qualities and/or resolutions during the same streaming session.

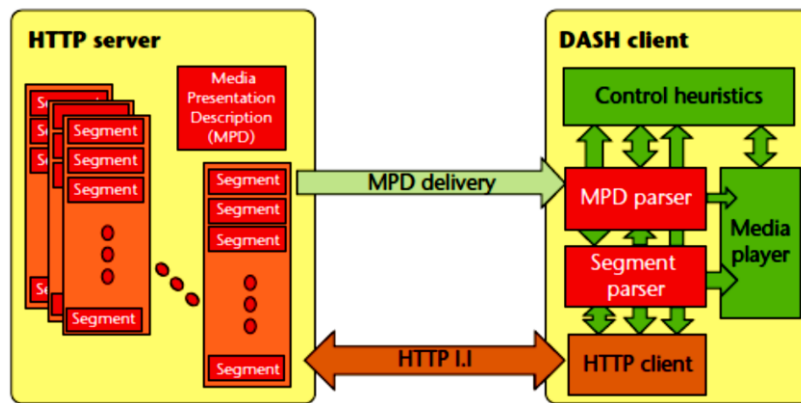


Figure 12 – Scope of the MPEG-DASH standard [11]

The content exists on the server in two parts:

1. **Media Presentation Description (MPD):** describes a manifest of the available content, containing the multiple profiles and respective URL addresses, among other characteristics;
2. **Segments**, which contain the actual multimedia bit streams in the chunk form, in single or multiple files.

To be able to play the content, the client has to obtain first the MPD file. By parsing it, the DASH client learns about the program timing, media content availability, media types, resolutions, minimum and maximum bandwidths and the existence of various encoded alternatives of multimedia components, accessibility features and required digital rights management (DRM), media component locations on the network, among other content characteristics. [11]

With this knowledge, the client can select the appropriate encoded alternative and starts streaming the content by fetching the segments using HTTP GET requests.

Appropriate buffering is done to allow network fluctuations and to control this, the client is always monitoring the network bandwidth. At the same time the client continues fetching the subsequent segments and depending on its measurements, the clients decides how to adapt to the available bandwidth by fetching segments with higher or lower bitrates in order to maintain an adequate buffer and playback.

2.2.4.1 *Multimedia Presentation Description*

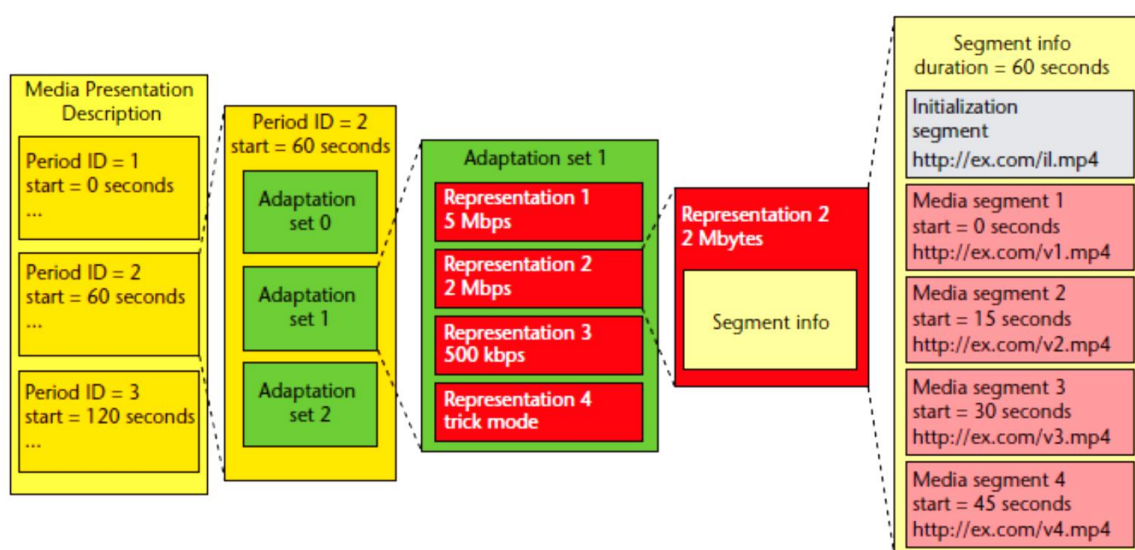


Figure 13 – Hierarchical data model of the Multimedia Presentation Description [11]

All the different characteristics required by a Dynamic HTTP stream, are described in the MPD file, which is an XML document.

The MPD contains one or multiple periods, where a period is a program interval along the temporal axis. Each period has a starting time and duration and consists of one or multiple adaptation sets. An adaptation set provides the information about one or multiple media components and its various encoded alternatives. For example, an adaptation set might contain the different bitrates of the video component of the same multimedia content. Each adaptation set usually includes multiple representations [11].

A representation is an encoded alternative of the same media component, varying from other representations by bitrate, resolution, number of channels, among other features.

Each representation consists of one or multiple segments. Segments are stream chunks in temporal sequence. Each segment has a URI, an addressable location on a server that can be downloaded using HTTP GET instruction[11].

When the client tries to play the content, it first downloads and then parses the MPD XML document. Then it selects the set of representations that will be used based on descriptive elements in the MPD, according to the client's capabilities and user's choices. The player then builds a timeline and starts playing the multimedia content by requesting appropriate media segments. Each representation's description includes information about its segments, which enables requests for each segment to be formulated in terms of the HTTP URL and byte range. For live presentations, the MPD also provides segment availability start time and end time, approximate media start time, and the fixed or variable duration of segments [11].

2.2.5 P2P/ BitTorrent Live

Recently, Peer-2-Peer (P2P) technology has attracted the focus from the broadcast industry because it is possible to deliver content from a single source to many receivers, without the support of the network layer (multicast). It's done using a large fraction of the total peer upload capacity. Applying this technology to streaming it is possible to use end-user capacities to support streaming and video delivery applications.

On an unmanaged network, multicast is still limited due to many practical issues. CDNs are also used to deliver content to the end-user, however when the number of client increases, extra equipment is needed and sometimes only for few hours a day. Large cost of CDNs can be not profitable. This is why P2P can be a future solution, because it is possible to achieve cheap and scalable video delivery systems.

Study shows that the video server load of the MSN website can be reduced by approx. 95% through the use of P2P systems.[12]

File sharing done using BitTorrent divides, for example, a video file into multiple chunks to distribute it, after that peers need to recover all the blocks to download the whole file. In the process, the peers exchange with each other a buffer-map, where it is shared the information about the data blocks they own and which they want to retrieve, organizing the P2P network in a transient mesh whose links are between peers depending on their availability and interest. To encourage sharing and allow fairness in the network, BitTorrent mechanism rests on reciprocal exchange of data between peers [13].

Video delivery based on P2P/BitTorrent can be achieved in two ways:

- Live streaming: live streams are normally consumed on-the-fly as they are received. Normally for a stream of this kind, blocks do not have the same importance given to their position in the flow, since they have to be consumed in real time. From the continuous nature of the transmission, there is a time restriction in the consumption order of the blocks. In concrete, block b in a flow must be consumed before block $b+1$ from the same flow to respect the playback time of each block, and to render the flow with good quality [14]. This can lead to lag problems between clients, since some clients are consuming blocks already received by others that can be still buffered or already consumed. In this case there's the advantage that users are watching the stream at around the same time, typically requesting data around a particular playback point [12].
- Video-on-Demand: in this case the only disadvantage is that nodes (clients) request videos at different times, and thus their playback points differ greatly. This can imply that the nodes may need to hold the entire movie, in order to share it for those who request it in a near/far future. Another implication is that playback deadlines of file pieces in VOD have a larger variance than those in live streaming [13].

There is some work done to adapt BitTorrent technology to streaming because a number of fundamental issues need to be addressed, it is why this technology is still in draft state.

This technology is mainly used in Asia and by some non-licensed broadcasters. There is still no commercial version of this technology.

2.3 Streaming Servers

2.3.1 Darwin Streaming Server (DSS)

The Darwin Streaming Server, launched on March 16, 1999, allows the transmission of video and audio in several formats, such as MP3, H.264/MPEG-4 AVC, MPEG-4 Part 2 and 3GP through RTSP and RTP protocols [15].

This software is an open source version of Apple's, QuickTime Streaming Server, which allows you to stream media contents over the Internet. An advantage of this software is that it allows you a higher level of customization and runs on multiple platforms including Windows, Mac OS X and several Linux distributions.

The first mobile versions of YouTube used DSS to stream video to mobile devices using the 3GP format encoded with the H.263/AMR codec.

2.3.2 Red5

Red5 is another open source streaming server solution, based on Java technology and is only supported by Linux.

This server supports [16]:

- Video and audio streaming in multiple formats, such as: FLV, MP3, F4V, MP4, AAC, M4A;
- Recording Client Streams (FLV only);
- Shared Objects;
- Live Stream Publishing (Sorenson, VP6, H.264, Nelly Moser, MP3, Speex, AAC, NSV);
- Remoting

All the applications have to be programmed or configured on top this server to run. All applications must be built according to the RED 5 and Adobe Flash documentation. This feature can be seen as an advantage because it is possible to customize applications on top of this streaming software. It is possible to use RED 5 for: streaming server, video recorder or for bandwidth measurements.

2.3.3 Wowza Media Server

Wowza Media Server software is useful to do simultaneous streaming to PCs, smartphones, tablets and IPTV set-top boxes. Wowza Media Server provides a large number of functionalities such as adaptive bitrate (ABR) streaming, time-shifted live playback, and digital rights management simple.

Wowza Media Server is compatible with a wide range of video player technologies, including Adobe Flash player, Microsoft Silverlight player, iOS and Android native player, QuickTime player, Connected TVs, and IPTV/OTT set-top boxes.

Besides it supports many streaming protocols, including[17]:

- Real-Time Messaging Protocol (RTMP);
- Flash HTTP Dynamic Streaming (HDS);
- Apple HTTP Live Streaming (HLS);
- Microsoft Smooth Streaming (IIS);
- Real-Time Streaming Protocol (RTSP)
- Real-time Transport Protocol (RTP)
- MPEG2 Transport Streams (MPEG-TS).

Conventionally, to deliver streams to different player client types, separate encoders and client-specific servers were used. This approach requires a bigger investment because we need to acquire multiple client-specific encoders and servers plus the management costs incurred with separate delivery workflows. In many cases it is simply unfeasible to maintain separate infrastructures, limiting the delivery choices.

The example below illustrates how multi-client delivery for live streaming is approached in a conventional segregated fashion (Figure 14 - a) and using the Wowza Media Server (Figure 14 - b).

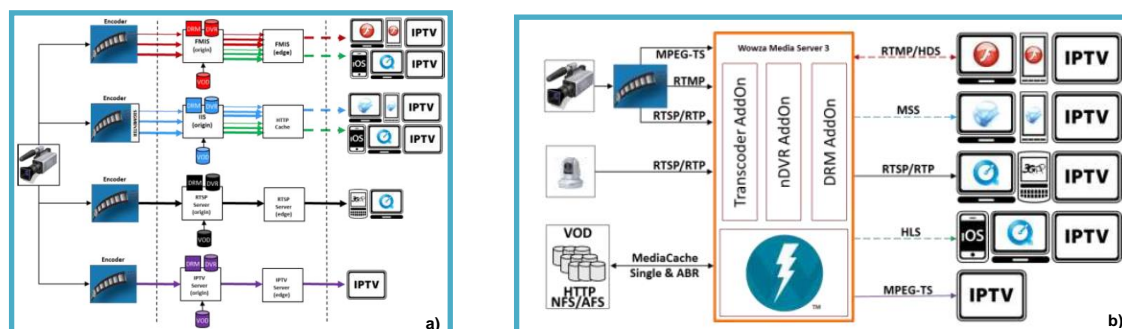


Figure 14 - OTT Broadcast Before and after Wowza [17]

This media server makes possible to stream from a single H.264 encoder (either live or on-demand) to all client types simultaneously eliminates the need to invest in client specific encoders and servers.

2.3.4 Flumotion Streaming Server

Flumotion Streaming Software is an open source media server solution that enables live and on demand streaming in some of the most used video formats from a single server. Flumotion platform helps to reduce the workflow and costs by covering the entire streaming value chain. This end-to-end yet modular solution includes signal acquisition, encoding, multi-format transcoding, streaming and state-of-the art interface design [18].

Thanks to its use of Linux, GStreamer and other open source software it supports a wide range of input hardware.

Flumotion allows processing to be distributed across multiple machines, this turns possible to scale and handle more viewers of more streams in more formats. Its open source architecture makes it more efficient and more flexible than competing systems, making better use of your hardware. This platform can capture directly from DVB-S or DVB-T inputs[19].

This platform treats Ogg and WebM as first class components and stream them using flash based technology.

2.4 Adaptive Bit Rate (ABR) Streaming

In order to better distribute video on unmanaged networks and provide a better quality of service, it is possible to make the stream “adapt” to the user access network.

First the video needs to be encoded in different video profiles, with different bitrates and width. Usually, a video is encoded in 4 different profiles:

- Mobile Definition Profile, approx. 500 Kbps and width=360p;
- Standard Definition Profile, approx. 1 Mbps and width=480p;
- High Definition (720p) Profile, approx. 3 Mbps and width=720p;
- Full High Definition (1080p) Profile: approx. 5 Mbps and width=1080p;

If it's a video file, this file will be encoded at least with these 4 different profiles, and then saved as 4 different files. If it is a live stream, the encoder will generate as many different streams as many profiles needed on the fly.

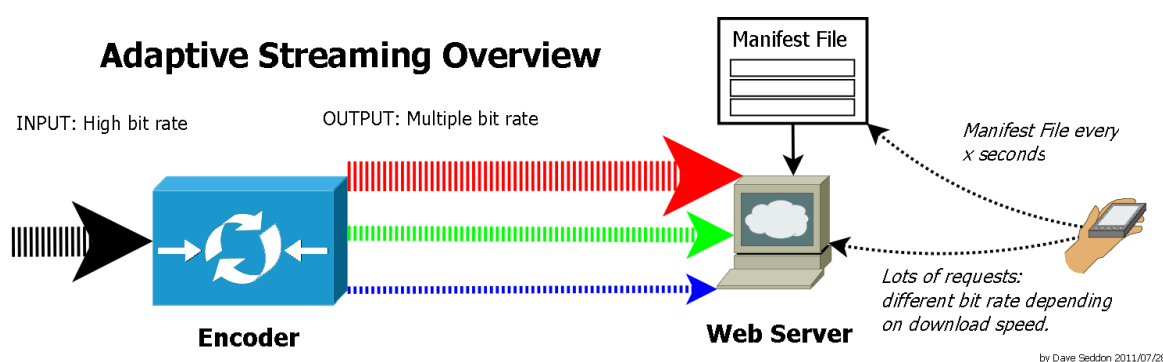


Figure 15 – Adaptive Streaming Overview[20]

Multimedia content is prepared and encoded in different bit rates and dimensions, these different video files are described in the Synchronized Multimedia Integration Language (SMIL) file (XML-based language that allows authors to write interactive multimedia presentations[21]). The server is going to read the SMIL file and generate the Manifest. In this SMIL file it is described the location and bitrate of each video profile, previously encoded.

Example of .smil file, used for tests:

```
<smil>
  <head>
  </head>
  <body>
    <switch>
      <video src="coldplay360.mp4" system-bitrate="526000"/>
      <video src="coldplay480.mp4" system-bitrate="907000"/>
      <video src="coldplay720.mp4" system-bitrate="1290000"/>
      <video src="coldplay10801.mp4" system-bitrate="1665000"/>
    </switch>
  </body>
</smil>
```

When the client software, asks the server for a stream, the server will reply with a Manifest file and the player will start downloading the video chunks. According to the bandwidth fluctuations the player will switch between the different streams or files. The different video profiles can also be hardcoded directly in the video player [22].

The Manifest file description that contains the number of segments, duration of each segment, number of profiles and the location of the different video chunks.

Example of a Manifest from a Smooth Streaming Stream:

```
<SmoothStreamingMedia MajorVersion="2" MinorVersion="1" Timescale="10000000"
Duration="2716714000">
  <StreamIndex Type="audio" Index="0" Chunks="135" QualityLevels="1" Timescale="10000000"
Url="QualityLevels({bitrate})/Fragments(audio={start
time})/WowzaSessions(265948014).isma">
  <QualityLevel Bitrate="149547" FourCC="AACL" SamplingRate="44100" Channels="2"
BitsPerSample="16" PacketSize="4" AudioTag="255"CodecPrivateData="1210"/>
  <c d="20201360"/>
  <c d="20201361"/>
  <c d="20201360"/>
  <c d="20201361"/>
  <c d="20201360"/>
  (...)
</StreamIndex>
  <StreamIndex Type="video" Chunks="50" QualityLevels="4" MaxWidth="1920" MaxHeight="1080"
DisplayWidth="1920" DisplayHeight="1080"
Timescale="10000000"Url="QualityLevels({bitrate})/Fragments(video={start
time})/WowzaSessions(265948014).ismv">
  <QualityLevel Index="0" Bitrate="907000" FourCC="H264" MaxWidth="848"
MaxHeight="480"CodecPrivateData="00000001674d401fec06a1edff81aa81a835010101400000fa40003
a9823c60c6580000000168efbc80"/>
  <QualityLevel Index="1" Bitrate="1290000" FourCC="H264" MaxWidth="1280"
MaxHeight="720"CodecPrivateData="00000001674d401fec02802dd80b5010101400000fa40003a9823c6
0c65800000000168efbc80"/>
  <QualityLevel Index="2" Bitrate="1665000" FourCC="H264" MaxWidth="1920"
MaxHeight="1080"CodecPrivateData="00000001674d4028eca03c0113f2e02d404040500000030010002bf
200f18319600000000168efbc80"/>
  <QualityLevel Index="3" Bitrate="526000" FourCC="H264" MaxWidth="640"
MaxHeight="352"CodecPrivateData="00000001674d401eeca05016dff803e804035010101400000fa40003
a9823c58b65800000000168efbc80"/>
  <c d="21021000"/>
  <c d="57390666"/>
  <c d="87420667"/>
  <c d="73406667"/>
  <c d="56723333"/>
  <c d="100100000"/>
  <c d="60060000"/>
  <c d="47047000"/>
  <c d="100100000"/>
  (...)
</StreamIndex>
</SmoothStreamingMedia>
```

Then the actual adaptive streaming session starts. The software agent continuously measures the bandwidth with each server using a round trip time evaluation of HTTP requests/responses. A

smoothed version of this bandwidth measurement is used by the software agent to decide from which representation to request the next segment [22].

The video profile requested from the server is proportional to the estimated bandwidth for the connection between the server and the client

2.5 Content Protection and Digital Right Management Systems

Distribution and monetization of video content requires a key component: Security.

Traditionally, telecom operators have maintained large private networks in which they control the whole transmission chain, from the head-end until the customer endpoint, to protect content. These networks can be seen as “walled gardens”, where typically they are highly optimized, pre-provisioned to ensure delivery performance, while relying on physical security and network access control, all that in order to protect content. As a consequence, consumer equipment for use in network A could not be used in network B or vice versa.

To deliver content directly to the user some operators or content providers will have to go out from these “walled gardens”, and transmit video in networks where they don’t have any control and in most cases over competitor networks. Some solutions were developed to solve this problem.

In order to distribute OTT video ensuring the content security, it is mandatory to use one of the different solutions already on the market:

- Adobe flash access
- Marlin DRM
- Microsoft PlayReady

2.5.1 Microsoft PlayReady DRM Protection

PlayReady is a Digital Rights Management (DRM) proprietary technology from Microsoft, developed for connected devices.

The deployment of content services across public and non-owned networks brings with it the need to ensure that the content is not widely distributed in unauthorized ways. That’s why it is mandatory to ensure content providers that their digital rights rules are enforced and their content is protected from being used in unauthorized ways [23].

Microsoft PlayReady protects content by encrypting data files, but the encryption itself may not be enough it is why file needs to be protected from copy, edition, or distribution without restriction.

In order to ensure content protection, when a player receives an encrypted content it goes through the following steps to decrypt it [23]:

1. The user will attempt to play a protected video stream using a player compatible with Play Ready technology. The client will make a request to the distribution server.

2. In this case, the client will download some of the content and the content header from the video distribution server.
3. The client reads the header where usually the URL for the license is described. The client application will make a request for a license in order to decrypt the content. If the license is not available in the local license store, the player will contact the License Server to obtain a license.
4. If the License Server approves the request, it issues a key that will help the client to decrypt the video stream. This process is seamless and transparent to the user.
5. The video is decrypted and the stream is played.

2.5.2 HTTP Live Streaming DRM Protection

There are several ways to protect Apple® HTTP Live Streaming (HLS) streaming using DRM encryption. One of the most used is AES-128, the entire chunk is encrypted using AES-128 encryption as described in the Apple HLS specification. This method is supported directly by the iOS and OS X players. Key rotation is supported.

Media files containing stream segments may be individually encrypted. When encryption is employed, references to the corresponding key files appear in the index file so that the client can retrieve the keys for decryption.

When a key file is listed in the index file, the key file contains a cipher key that must be used to decrypt subsequent media files listed in the index file. Currently HTTP Live Streaming uses AES-128 encryption with 16-octet keys. The format of the key file is a packed array of these 16 octets in binary format.

The encryption can be configured using 3 methods [24]:

1. It is possible to specify a path to an existing key file on disk. In this mode the segmenter inserts the URL of the existing key file in the index file. It encrypts all media files using this key.
2. The video segmenter can generate a random key file, save it in a specified location, and reference it in the index file. All media files are encrypted using this randomly generated key.
3. The segmenter can also generate a new random key file in every n media segments, save it in a specified location, and reference it in the index file. This method is referred to as key rotation. Each group of n files is encrypted using a different key.

The key files can be shared using either HTTP or HTTPS. It is also possible to choose to protect the delivery of the key files using session-based authentication schemes.

2.6 Authentication, Authorization, and Accounting

Authentication, Authorization, and Accounting (AAA) is the process of identifying a user, determining the permissions granted to that user, and keeping a record of that user's activity. Using

AAA, it is possible to identify users, determine their group memberships and attributes, and use that information to implement access control policies to effectively control who allowed to “live” in the network (while keeping a record of all transactions).

These server normally already exist in traditional operators, they are developed by the company inside their “walled gardens”.

Walled garden or closed ecosystem is a software system where the carrier or service provider has control over applications, content, and media and restricts convenient access to non-approved applications or content.

There are many solutions available on the market, but normally they are custom made in order to meet the needs of each operator.

3 Telecommunication Networks

Chapter 3 and 4 will focus about the network distribution. Since in OTT the video is distributed over unmanaged networks it is needed to understand the structure of the different telecom networks, and understand the problems and consequences of this distribution.

It is also important how an OTT stream flows over the different access networks, existing in Portugal.

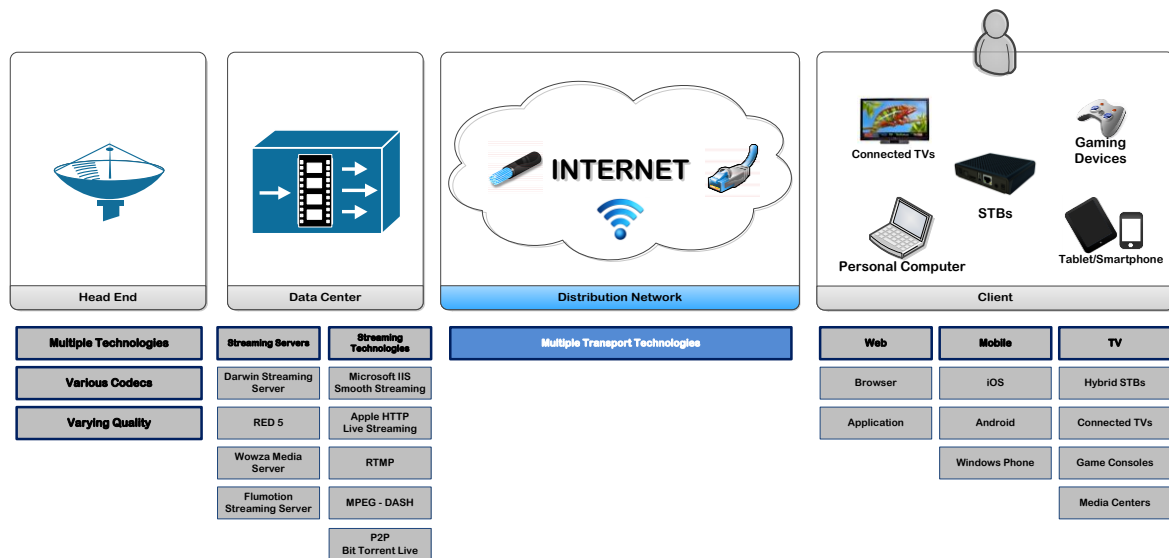


Figure 16 – OTT Ecosystem, Chapter 3 and 4 subject: Distribution Network

3.1 Network Structure

A basic network infrastructure can be split in three main segments: Core Network, Access Network and Customer Network. The following figure (Figure 17) represents a global telecommunications infrastructure model, it is possible to identify the different network segments.

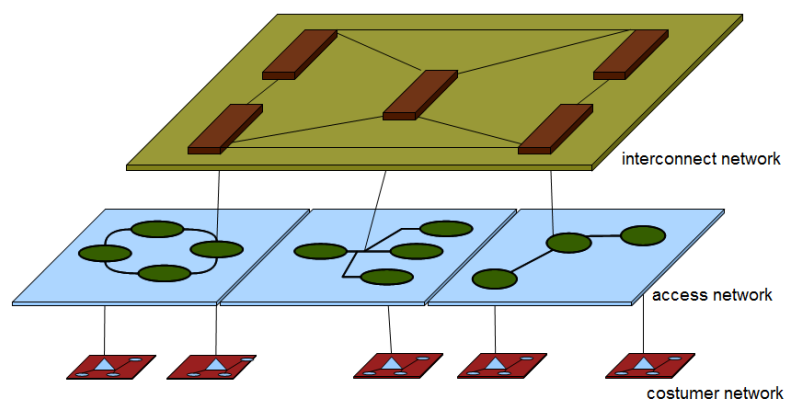


Figure 17 – Main Segments of the network Structure [25]

On each one of these segments, several telecommunication technologies are used for data transmission, commutation and routing. Multiple services are supported by these segments.

3.1.1 Core Network

The Core Network is the central part of a telecommunications network, this network provides the basic infrastructure to support the interconnection between the different access networks, it is responsible for the transport of huge amounts of aggregated traffic, in wide distances. It also supports various services to customers who are connected by the access network.

On this network segment, the most spread technology in use is the Synchronous Digital Hierarchy (SDH) technology. This is a standard technology for synchronous data transmission on electrical, optical and radio media. Management and maintenance mechanisms that act on a physical level assure transmission reliability and quality. The SDH networks (Figure 18) commonly have a double ring topology, where one ring is used to transmit in one direction and the other in the reverse direction, this type of topology enables great network flexibility and protection. The possibility of redundancy resultant of this topology confers to this technology robustness and auto recovery of possible errors and hardware failure.

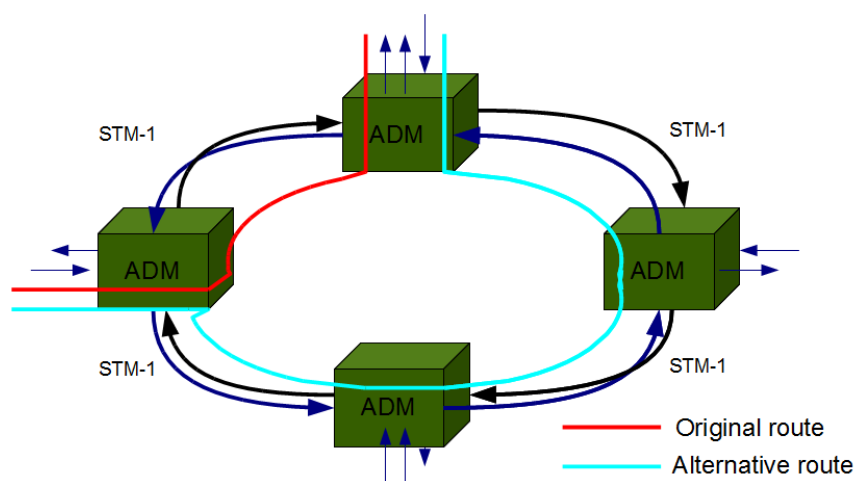


Figure 18 – Core Network: SDH Ring [26]

The SDH frame encapsulates frames belonging to other technologies and therefore inside SDH there are different types of traffic. There are other technologies such as Asynchronous Transfer Mode (ATM) and Frame Relay (FR) that are still used in core networks. These technologies are commonly encapsulated onto SDH frames and transmitted over SDH.

ATM is a dedicated-connection packet switching technology that re-arranges digital data into 53-byte cell units and transmits them over a physical medium using digital signal technology. This technology has some 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. Unlike X.25, frame relay is a fast packet technology, which means that the protocol does not attempt to correct any errors, when 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 comparing to analog networks.

Multi-protocol Label Switching (MPLS) is another technology used in core networks. This technology allows setting up a specific path for a given sequence of packets, these packets are identified by a label present in each packet, consequently saving the time needed for a router to look up the address to the next node to forward the packet to. It is called a multi-protocol technology because it works with the IP, ATM, and Frame Relay network protocols.

3.1.2 Access Network

The Access Network is the network segment that interconnects the Central Office (CO) and customer equipment's (CPE: Customer Equipment Premises).

These networks, initially developed for voice traffic, have been evolving for data traffic. The access network, which was completely analog, endures a process of digitization.

The first data transmission technologies in the access network had one big flaw; the user wasn't able to enjoy voice and data simultaneously: Dial-Up solutions. The xDSL (Digital Subscriber Line) allowed the simultaneous existence of multiple types of traffic.

Hybrid Fiber-Coaxial (HFC) is a very popular access network technology. Emerged with the aim of broadcasting television by cable, it quickly became an alternative to xDSL networks focused on monetizing copper "legacy" networks POTS (Plain Old Telephone Network). HFC technology currently allows voice and data traffic, besides the broadcast of television channels.

Recently, with the objective of increasing the bandwidth available to each customer, the optical fiber is implemented in this segment. It's where we see the appearance of FTTx (Fiber To The x) technologies that can be active or passive, allowing a wide range of services with a quality unattainable by copper.

There are several types of media used in access networks:

- Copper twisted wire pairs - being the most common, the twisted pair is commonly used in POTS and DSL networks.
- Copper coaxial wire - Initially used for CATV, it is now also used for data and voice transmission.
- Wireless:
 - Telecom: 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.
 - Media: Television and radio broadcast over Digital Terrestrial Television (DTT) networks using DVB-T technology and Frequency Modulation broadcasting (FM) for radio.
- Optical fiber - Initially used on core networks due to its high transmission rates, it has been increasingly being used in the access network.

The choice of technology, obviously, has to take into account bandwidth and distance requirements as well as the number of clients and respective services to be provided. For example, if one of the requirements includes mobility, wireless can be an attractive option.

3.1.3 Customer Network

The customer networks are usually small networks, installed inside buildings, homes or residential areas, which connect the end user to the access network. These networks are inside the premises of businesses or residential customers and they are their responsibility. In this network, the different services (TV, voice and data) are delivered through CPE's (Customer Premises Equipment's) and routed to their respective transport networks within the customer premises.

The IP is the dominant protocol that is then encapsulated into Ethernet frames, which communicates with the local area network (LAN: Local Area Network). This communication may be done using cable (LAN) or wireless technologies (WLAN: Wireless Local Area Network), according to the IEEE 802.11 standard.

The size of these networks is variable and depends on the size and type of customer.

3.2 Access Network Technologies

3.2.1 Digital Subscriber Line (xDSL)

xDSL networks appeared as an attempt to make the most of the existing infrastructure of copper telephone network (PSTN) through the development of modulation techniques and spectral compression. This technology establishes a permanent circuit between the user and the service provider, offering a higher transmission speed.

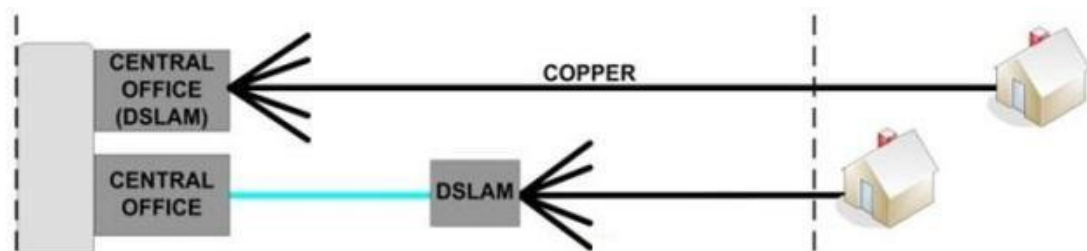


Figure 19 – xDSL Access Network [26]

The PSTN network has been optimized to transmit signals in the range between 300 Hz and 3400 Hz (voice signals). In order to transmit data along the voice signals, the filters that limited the bandwidth were removed to transmit at higher frequencies. Data communications require higher bandwidth than voice communications.

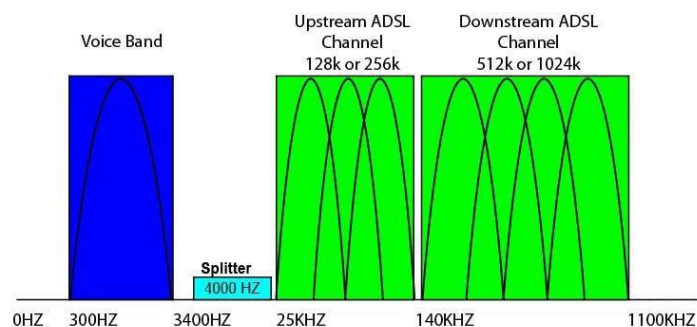


Figure 20 – ADSL Frequency Spectrum [26]

These two signals are then divided, in the homes of users and in the switching centers, and sent respectively to the DSL equipment and the PSTN equipment.

There are various DSL technologies that provide symmetrical or asymmetrical speeds, such as ADSL, SDSL, VDSL, HDSL, IDSL and RADSL.

Asynchronous Digital Subscriber Line (ADSL) appeared as a way for telephone companies to first deliver Internet over POTS networks and then compete with the upcoming CATV offer, by delivering both TV (over IP), Internet and telephone services over their installed copper network. The Asymmetric part of xDSL means that the download link has much more allocated bandwidth than the uplink.

The speed in this type of connections depend on the distance between the end user and the DSLAM (Digital Subscriber Line Access Multiplexer), so the commitment distance / transmission rate is one of the most important factors to take into account.

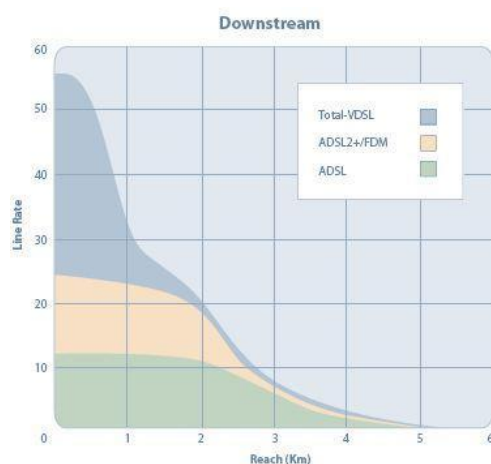


Figure 21 – Transmission rate (Mbps) versus distance (Km) of the client to the DSLAM

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 ISP. An advantage of this technology, 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 a certain area. This advantage becomes one of xDSL's stronger points against, for instance, cable and wireless technologies because wireless and cable subscribers can suffer from traffic congestion, once the allocated area bandwidth becomes overcrowded.

3.2.1.1 OTT over ADSL

In the Figure 22 – Transmission scheme of OTT content over ADSL, it's represented how an OTT stream based on HTTP protocols, e.g. HTTP Live Streaming, is transmitted through an ADSL Network.

The scheme represents the end-to-end transmission since the video server until the clients' device. This transmission can be done using the network of one or multiple operators, (Tier 2 operators) that will do the connection between the data center and the core network by (Tier 1 operators).

The OTT service is received by the end user through HTTP based streams. All the HTTP streams are received by the ADSL Router owned by the client and routed to the CPE where the client wants to use the service. This final step in the delivery can be done through Ethernet or Wi-Fi access network.

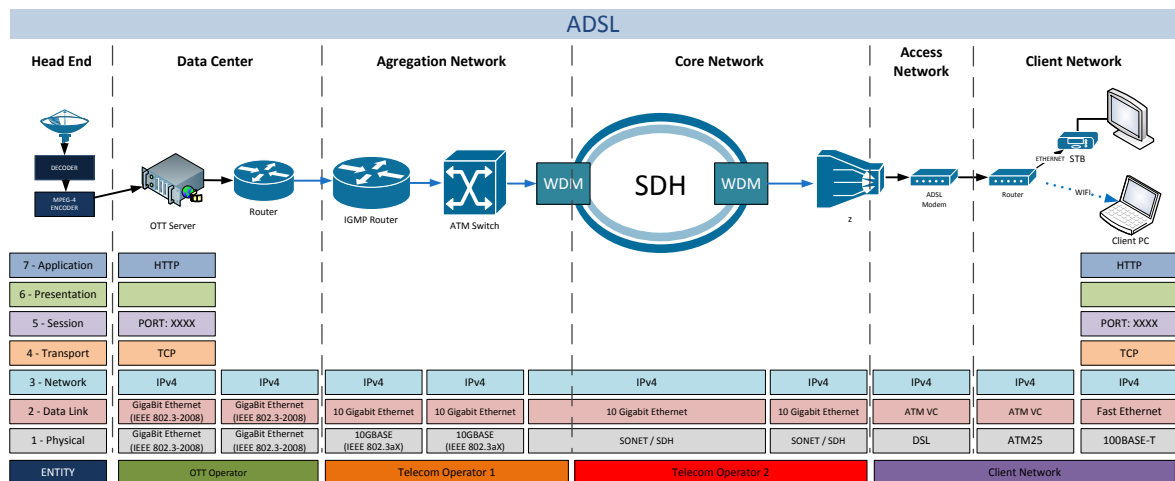


Figure 22 – Transmission scheme of OTT content over ADSL

3.2.2 Fiber To The X (FTTx)

Fiber To The X (FTTx) is a generic expression to describe different fiber optics based telecommunication networks. Depending on the termination point of the fiber optics, these architectures have various designations: FTTN (Fiber To The Node), FTTCab (Fiber To The Cabinet), FTTC (Fiber to The Curb), FTTP (Fiber To The Premises), FTTB (Fiber To The Building), and FTTH (Fiber To The Home).[27]

- Fiber to the node (FTTN) or Fiber to the Cabinet (FTTCab), refers to a network architecture in which fiber is extended to a street-side or on-pole cabinet. These points are at a distance of approximately between 300m and 1500m from the user. From that point forward, xDSL technology or Ethernet (over copper or wireless) are used to reach the user. These architectures are suitable for small dimensions areas and low population density.
- Fiber to the curb (FTTC) is a network architecture where the optical fiber goes until a street cabinet, serving very small areas (about 300m radius) and low population density. Users connect through the existing infrastructure of copper or coaxial cables. This architecture differs from the FTTx architectures, since the cabinet street is nearer to the residence of the customer, while the FTTN architectures or FTTCab, the street cabinet is far away from the customer residence.
- Fiber to the building (FTTB), in this architecture the optical fiber reaches up to the entrance of the building, but it doesn't arrive directly to the users home. The connection to the end user is not made using optical fiber, but using other transmission means such as copper or coax.
- Fiber to the home (FTTH) refers to an architecture where commonly the optical fiber connects directly the end user. By definition, the fiber optic communication path is terminated on or in the premise for the purpose of carrying communications to a single subscriber.

3.2.2.1 *OTT over FTTH*

The main difference from the previous example of the OTT stream distribution scheme is the Access Network technology used. On FTTH, the HTTP stream is transported over a fiber access network, it means that the data leaves the Core Network through an OLT, then the signal is splitted until it arrives to the client's home and is received by an ONT. The ONT converts the optical signal in an electrical signal that is then connected to a router over an Ethernet connection. The ONT and the router may be integrated into the same hardware by some vendors.

Over the Access Network, the transmission is based on NRZ technology in the Physical Layer and then on ATM/GEM in the Data Link.

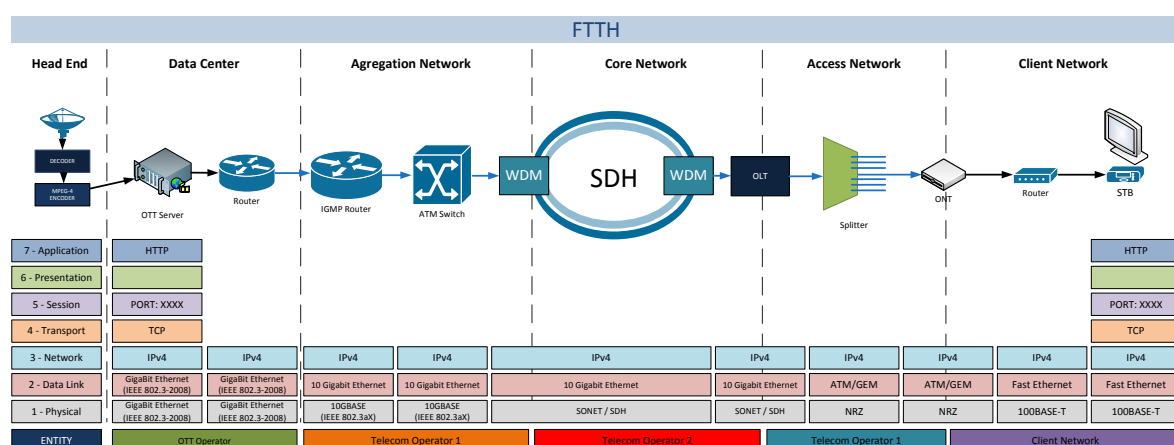


Figure 23 - Transmission scheme of OTT content over FTTH

3.2.3 HFC

HFC (Hybrid Fiber-Coax) networks appeared as an evolution of CATV networks. Cable networks or CATV networks were originally designed to broadcast video over coaxial cabling until the subscriber's residence. However these networks have evolved to a multi-service platform, offering not only TV broadcasts but a variety of telecom services, such as: FM radio programming, high-speed Internet, telephone, and others.

With this evolution the physical network had to evolve from a broadcast only model to a two way communication network, with separate user communication in order to ensure that user privacy is not compromised. This capacity has been achieved by the use of a new set of frequencies between 50 and 860MHz for downlink and between 5 and 65MHz on the uplink [28]. Each downstream/upstream data channel uses a 6MHz window.

The architecture of a hybrid fiber coaxial network uses fiber optic cables in the core network and coaxial cables in the distribution/access network, as seen in Figure 24.

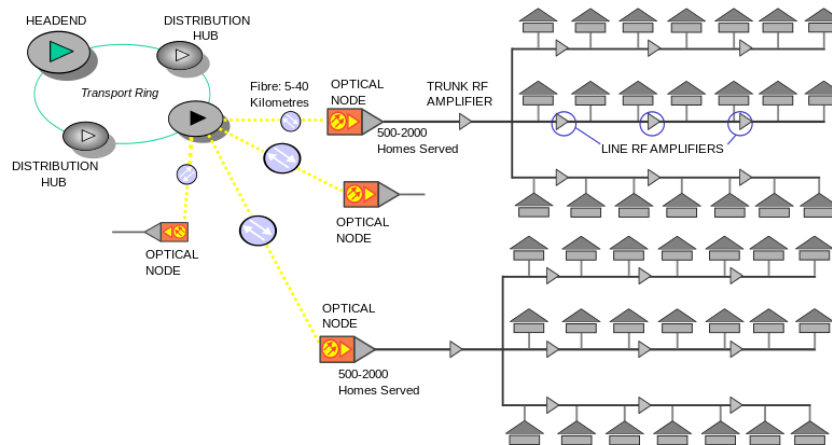


Figure 24 – HFC Network Diagram [29]

An advantage of these networks 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.

The signal is composed at the head-end, where the television signals are received, they are then encoded and finally injected into fiber optic cables. The broadcasted channels are received via satellite or DTT. The signal is transported via optical networks until the distribution centers, where the optical signal is converted in electrical and finally distributed via the coaxial network until the subscriber's home.

In order to adapt the HFC networks for interactive services and normalize supply, ITU-T adopted in 1998 the Data Over Cable Service Interface Specification (DOCSIS) as standard ITU-T J.112 that enables interoperability and access to data services.

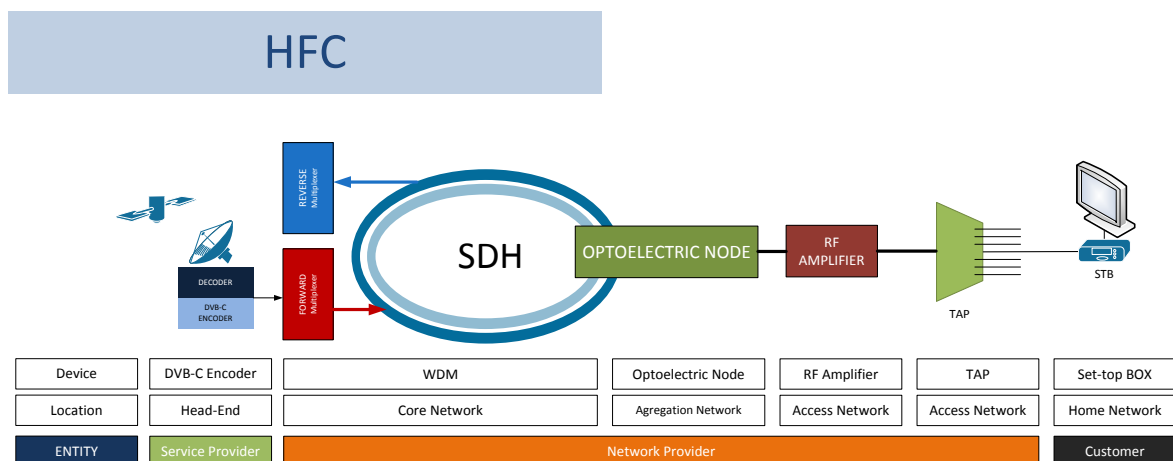


Figure 25 – Hybrid Fiber Coax Network Overview

DOCSIS specifies methods for transporting data over CATV networks using QAM and/or QPSK RF modulation techniques. A DOCSIS architecture 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.

According to ITU-T recommendation J.222.1, these networks are defined by:

- Symmetrical Transmission (upward and downward);
- The maximum distance between the cable modem termination system (CMTS) and the cable modem (CM) is 160km in each direction, although typical maximum separation is 15-24km.

3.2.3.1 OTT over HFC

In this case since the HFC network is based on DOCSIS, the OTT streams are distributed in the Access network over Ethernet technology, as can be seen in Figure 26.

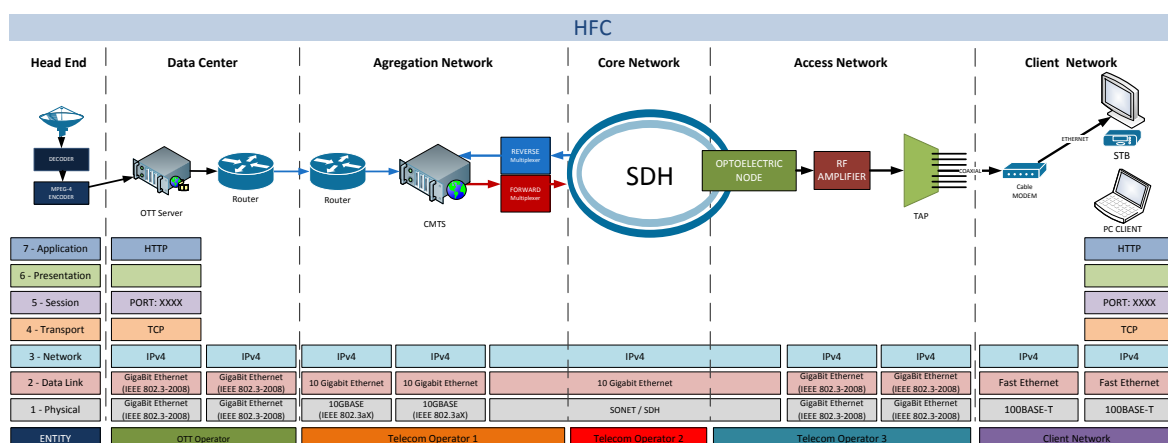


Figure 26 - Transmission scheme of OTT content over HFC

3.2.4 Mobile Networks

Nowadays there is increasingly more need to access different kind of services or data anywhere and anytime, only mobile networks provide this ability to the user. The importance of mobility led to the great development of mobile telephone networks and then mobile data networks.

3.2.4.1 GSM

The GSM (Global Systems for Mobile Communications) network is the most used mobile telephone network across Europe. This telecommunication system has the ability to transmit voice, data and message services among other supplementary services such as call forwarding or calls suspension. This network allows transmission rates up to 14.4 kbps. The GSM system made the transition from analog technology to digital technology, bringing improved security, robustness and reliability.

OTT video couldn't be transmitted over GSM networks because of its low transmission rates.

3.2.4.2 GPRS

GPRS (General Packet Radio Service) is an evolution of the GSM system, which introduced the transmission of data with packet switching. The GPRS network is implemented on the GSM infrastructure and keeps most of the network equipment and acts as a supplement to this network providing enhanced data services. Now there are two parallel networks: the GSM network responsible for voice traffic and the GPRS network responsible for the data traffic (packet switching). This system allows transmission rates up to 171 Kbps.

OTT video could be distributed over GPRS, but only the lowest profiles because of its limited transmission rates.

3.2.4.3 UMTS

The UMTS (Universal Mobile Telecommunications Systems) network is one of the third generation's mobile access technologies. It was designed in order to continue the success of GSM and then GPRS technology, providing higher access speed to data services. The UMTS data service supports from 144 Kbit/s (for mobile access) up to 2 Mbps (for a fixed wireless access)[30]. W-CDMA (Wide-band Code-Division) and CDMA2000 (Code Division Multiple Access) are modulations used in UMTS[27]. This technology enables easy interconnection with other telecommunications systems, such as the PSTN or other data networks, allowing the user to move between different environments.

A UMTS system can be based on already existing mobile communication system and have radio equipment capable of accommodating systems such as GSM, GPRS, EDGE (Enhanced Data rates for GSM Evolution) and UMTS, in order to ease the transition from GSM to UMTS. [30]

3.2.4.4 HSPA

High-Speed Packet Access (HSPA) is a set of technologies that defines the migration path for 3G/WCDMA operators worldwide. This technology was standardized by the 3GPP, it 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 UMTS, HSPA provides very efficient voice services in combination with mobile broadband data, consequently 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.

This technology was developed to cover a flaw existing in UMTS networks, i.e. to make the link between 3G mobile network and Internet services, allowing to overlay various protocols that enable high-speed data communications to several users served by same cell.

3.2.4.5 *LTE*

Long Term Evolution (LTE) is a 4G wireless broadband technology developed by the 3GPP and it represents an evolution of the mobile access technology from GSM, a 2G standard, to UMTS, the 3G technologies based upon GSM. This technology is also known as Evolved UMTS Terrestrial Radio Network (E-UTRAN).

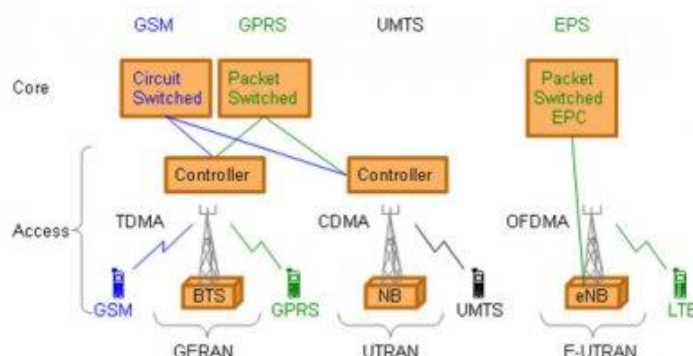


Figure 27 – Mobile Network Evolution from GSM to LTE [31]

The capacity of each sector is substantially increased improving the bit rate and mobility of each end use, leading to a lower latency in the network. With the rise of the IP protocol as a transport protocol carrying all types of traffic, LTE upper layers are based upon TCP/IP which results in an all-IP network with point-to-point QoS. LTE supports mixed data, voice, video and messaging traffic, they all run over IP, for example the voice service will be supported by VoLTE (Voice Over LTE).

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.

It is expected that this technology can achieve peak data rates of around 100 Mbit/s upward and 50Mbit/s downward, these maximum values for optimal conditions that can hardly be achieved in commercial wireless networks today.

3.2.4.5.1 *OTT over LTE*

LTE is the most recent wireless access technology and the broadband available is the ideal to access OTT multimedia content. Today LTE offers a broadband downlink of approximately 100 Mbps.

In Figure 28, it is illustrated the transmission of an HTTP video stream over a LTE access network. The last hop of the stream goes through an all IP network, based on IPv4 and Ethernet over a RF link.

In LTE when data flow of information leaves the core network, enters the E-UTRAN Networks and is routed by a Radio Network Controller (RNC), then the information is transmission over the air through an RF link by an eNodeB.

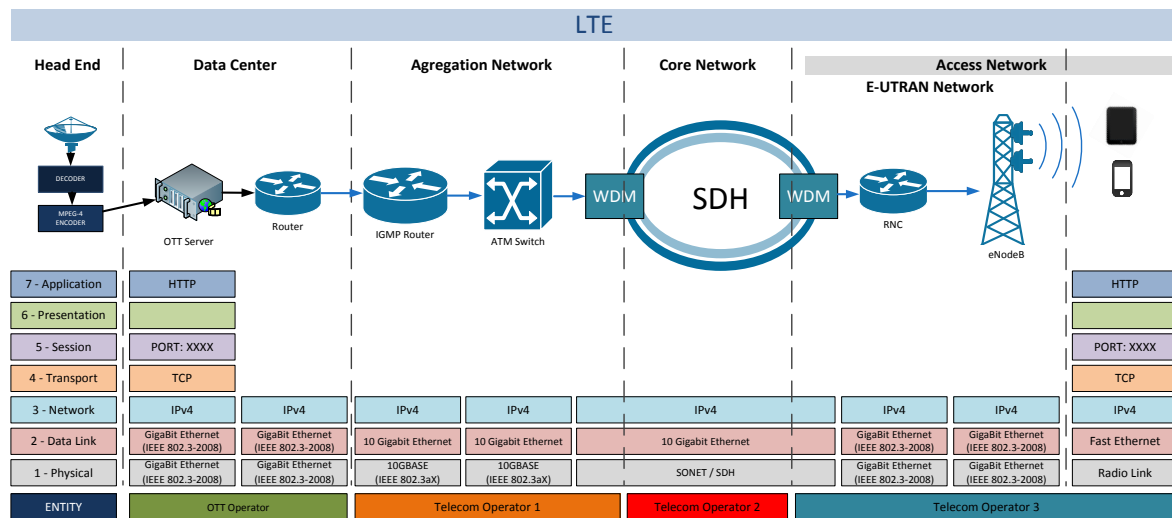


Figure 28 - Transmission scheme of OTT content over LTE

We can have multiple telecom networks involved in the transmission of OTT streams. We can have a first Telecom Operator that the OTT service provider contracted to connect him to the Internet. Telecom operator 1 can be connected to a Tier 1 operator (Telecom Operator 2) to transmit information to the access telecom operator (Telecom Operator 3) where the client is connected. It means that the stream flow can go through multiple operators in the whole end to end connection. In some cases the whole transmission can also be done by only one operator.

Typically Tier 1 operators are operators who transmit high quantities of data between telecom operators.

This multiple telecom operator end-to-end concept also applies to the other access networks already described, where an OTT video can be streamed.

3.2.4.6 WiMAX

WiMAX (Worldwide Interoperability for Microwave Access) is a wireless technology and it's defined according to the IEEE 802.16 standard. This access network technology is intended as an alternative to xDSL or cable in the last mile access.

This technology has a much greater range than Wi-Fi (IEEE 802.11), providing wireless broadband access coverage up to 50 km for fixed stations and 5-10 km for mobile stations with the same performance of Wi-Fi but with the same coverage and quality of service as a traditional cellular network. It works in the 2 to 66 GHz range and enables connectivity without a direct line-of-sight to a base station, providing data rates up to 70Mbps.

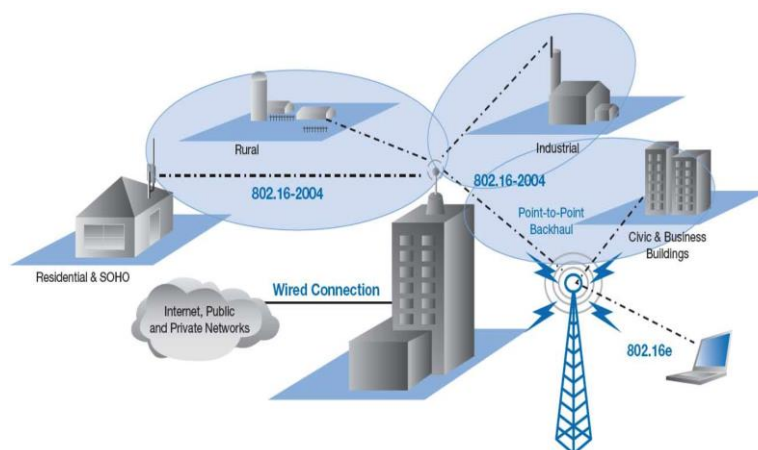


Figure 29 – Fixed WiMAX deployment and usage models

However, the available bandwidth is also shared by all the users that are connected to the network simultaneously, so greater the number of users, smaller the bandwidth available for each.

Wireless networks offer some advantages over wired ones because they can be helpful to connect remote areas, where wired networks are not yet installed or are too expensive to deploy. We can see this happen in some developing countries, where WiMAX is being adopted in areas that had no previous broadband infrastructures.

3.2.4.7 Wi-Fi

The Wi-Fi technology was developed to provide wireless short range, giving users greater convenience in their daily lives. This technology is generally used for distances of 30 meters indoors and 90 meters outdoors. Transmission rates evolved over the years with many amendments introduced into the original standard and today we can achieve connection speeds up to 300 Mbps (using IEEE 802.11n, the fastest standard in optimal conditions [32]). However, under “normal use” it operates at lower speeds, probably around 130Mbps or less. These speeds are, mainly influenced by the number of users on the network (shared medium, shared timeslots) and on the number of different Wi-Fi networks on the same physical space (radio signal interference).

This technology is viewed as a complement and an essential part of the Home Network and is wide spread and well established over the world.

3.3 IPTV

IPTV – Internet Protocol Television - is a technology that uses Internet Protocols (IP) to deliver television services through packet switched networks, instead of other traditional networks such as terrestrial broadcast, satellite signal, and cable television formats. The official definition approved by the group focused on IPTV of the International Telecommunication Union (ITU-T FG IPTV) is:

"IPTV is defined as multimedia services such as television/video/audio/text/graphics/data delivered over IP based networks managed to provide the required level of quality of service and experience, security, interactivity and reliability." [33]

Nowadays IPTV services aren't used to deliver only television channels, but they deliver also a large amount of other contents, such as applications, games, information content, radio streams, among others. This service being usually part of Triple Play bundles, including also voice and data services it becomes a challenge for telecom operators, where they have to provide these services through their already existing networks with high standards of quality of service (QoS).

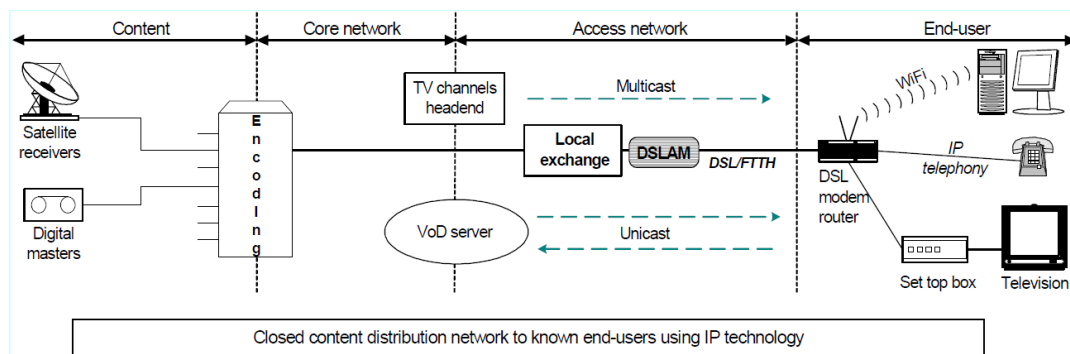


Figure 30 – IPTV network [34]

The main features of this technology are:

- Support for interactive television - the ability to transmit information in both directions, server/client and client/server, allows IPTV service providers to offer a larger quantity of interactive television applications such as video on demand
- Customization - an IPTV system, through its bi-directional communication allows users to personalize their television content in order to see what they want and when they want to see, according to their interest programming this can be achieved with on demand content.
- Optimized bandwidth management - instead of sending all channels available to all users, the IPTV technology allows service providers to send only the channel requested by the user. This allows network operators to save a lot of bandwidth on their networks.

In order to take advantage of the already existing copper networks, the operators have improved the efficiency of these to be able to quickly provide the contents to the end user without errors. One of the reasons for the increasing need of more bandwidth is due to the size of the content that is distributed. Video data requires large storage space, so if we want to transmit this data in the shortest time possible we need a higher rate of transmission and consequently more bandwidth.

The IPTV architecture evolution can be summarized through the following steps:

1. IPTV architecture not based on next-generation networks - the first generation of IPTV architecture consisted in one IPTV headend and middleware platforms for distribution services. This is the solution that is currently implemented in the IPTV market. You can interact with this architecture subsystems NGN (Next-Generation Networks) but generally the service control is done separately and is used a new application layer.
2. IPTV architecture for next generation networks not based on IMS - allows interaction at specific points between IPTV functions (such as control functions) and some existing elements of next generation networks (such as control elements of transport). In this step, a dedicated IPTV subsystem is used to provide all the IPTV functionality (IPTV control and user management) to integrate IPTV components in NGN architectures.
3. IMS-based IPTV architecture - specifies IPTV functions based on subsystem IMS (IP Multimedia Subsystem), and allows reuse of IMS functionalities, initiation of services and control mechanisms based on SIP (Session Initiation Protocol).

3.3.1 IPTV Distribution over ADSL and FTTH Networks

The distribution of IPTV over ADSL or FTTH networks can be summarized in in Figure 31 and Figure 32, and described by:

- IPTV uses RTP (application layer) over UDP (transport layer);
- The signal goes normally through 3 different Networks:
 - Service Provider network: usually inside the data center or between the head-end and the data center. This network is used to acquire, encode and broadcast the content.
 - Network Provider: since we're talking about a service where it's mandatory to own a managed network to guarantee quality of service. The network has to be owned practically end-to-end by the IPTV operator.
 - Customer or Home Network: owned by the client inside its premises and usually installed by the network and/or service provider.

The main difference between the distribution of IPTV over ADSL or FTTH lies on the access network:

- Because the ADSL (Figure 31) is based on the old POTS technology it offers slower speeds in the access network, this can restrict the access to channels with HD quality. In order to maintain quality IPTV reserves a content bandwidth to deliver the TV channels, usually 4 Mbps for SD channels, this normally interferes with the customer internet signal since they are sharing the same network. So if we have 2 SD signals over an ADSL network with a top speed of 16 Mbps, we are consuming with the IPTV service half of the bandwidth (8Mbps).

- FTTH is fiber based (Figure 32), and offers higher access speeds. Nowadays the access speed is set to 100 Mbps, more than 4 times the offered by ADSL. With this technology we've got no constraints offering multiple HD and SD signals.

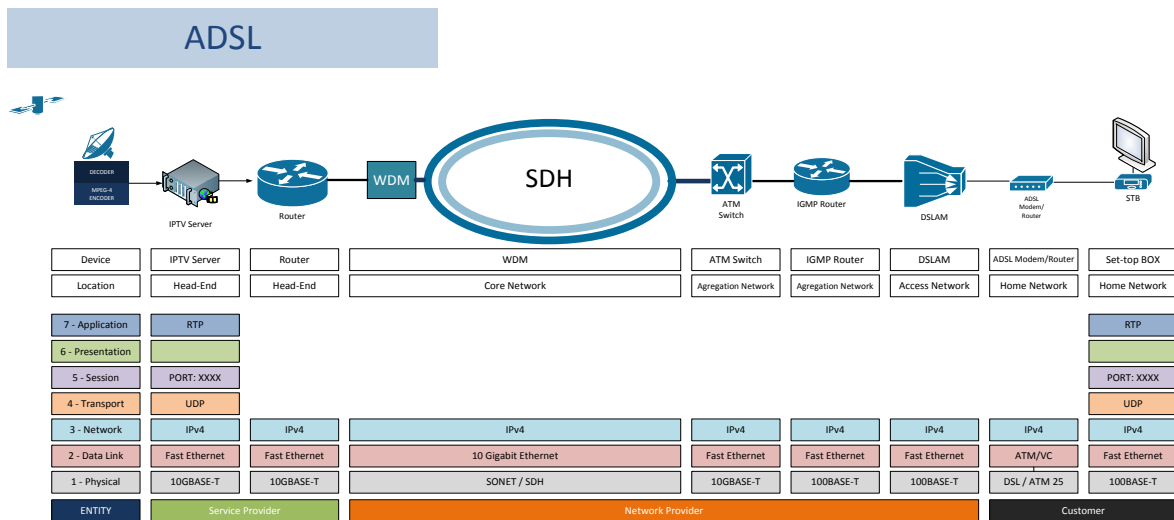


Figure 31 – IPTV transmission scheme over ADSL Networks

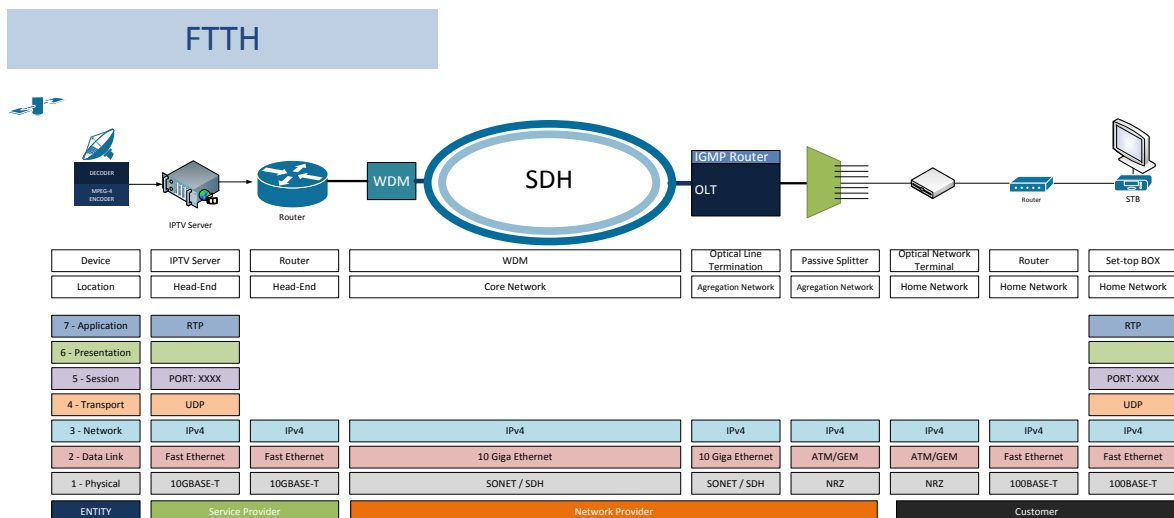


Figure 32 - IPTV transmission scheme over FTTH Networks

3.3.2 IPTV vs. OTT

IPTV and OTT are two technology mediums to distribute television and video over IP networks. However the main difference between them is that IPTV was designed to be used over a managed network, the service provider has to own the infrastructure in order to provide the service; and OTT was intended to deliver video over unmanaged networks.

IPTV had formerly the advantage of quality control over the video delivery since it was running over a managed network, but nowadays QoS over OTT can be controlled with content management systems and advanced CDN solutions [35].

The main advantage of OTT over IPTV is that it was designed to reach any connected device, giving a key competitive advantage in terms of customer and device reach [35].

Other differences between these two technologies are resumed in Table 5 below.

	IPTV	OTT
Type of network	Managed ("walled gardens")	Un-managed (open internet)
Network ownership	Service Provider has to own the network	Service provider may or not own the network
Quality of Service	Guaranteed (control over quality can be easily achieved)	Guaranteed if some delivery techniques are used such as Adaptive Streaming and CDNs.
Protocols	Transport Streams (TS) over UDP	Mainly based on HTTP over TCP
Routing Topology	Multicast	Unicast

Table 5 – Comparison of IPTV vs. OTT [36]

4 OTT Distribution Network, challenges and consequences

4.1 Quality of Service and Quality of Experience

4.1.1 Quality of Service

Quality of Service (QoS) is a set of methods to guarantee a bandwidth relationship between individual applications or protocols. The main goal of QoS is to prioritize traffic and improve some aspects of communication as dedicated bandwidth, jitter or latency control. It is also important to ensure that prioritizing the delivery of one or more streams do not lead to the failure of other.

Quality of service is widely used in video streaming technologies due to the fact that service quality has a direct impact on quality of experience.

It is important to retain that "best effort" network is a common name given to a network that does not use QoS mechanisms.

4.1.2 Quality of Experience

The Quality of Experience (QoE) determines how well a particular system or application meets the user's expectations focusing on the perceivable effects that the network may have to the user, such as degradation of the quality of audio (voice) or video.

It can be stated that QoE is directly related to QoS, but the challenge for a service provider is to have the right tools and operations processes to control QoS in their network and by extension the user's quality of experience.

4.2 Content Delivery Networks

Content delivery networks (CDNs) are an important part of Internet infrastructure that are frequently used in the distribution of OTT video services.

To simply understand how CDNs works, we can take the simple example of a web browser requesting for a resource, the first step is to always make a DNS request. A DNS request is a lot like looking up a phone number in a phone book: the browser gives the domain name and expects to receive an IP address back. With the IP address, the browser can then contact the web server directly for subsequent requests. For a simple web site, a domain name may have only a single IP address; for large web applications, a single domain name may have multiple IP addresses[37].

It is commonly accepted that attempting to access a server in China or in the U.S. from a computer in Portugal will take longer than trying to access a Portuguese server. To improve user experience (latency and connection speed), lower transmission costs and server load, large companies set up

servers with copies of data in strategic geographic or closest to their users. This network is called a CDN, the server who are part of this network are usually denominated as edge-servers.

When the browser makes a DNS request for a domain name that is handled by a CDN, there is a slightly different process than with one-IP websites. The server handling DNS requests for the domain name looks at the incoming request to determine the best set of servers to handle it. The DNS server roots the request according to:

- A geographic lookup based on the DNS resolver's IP address and then returns an IP address for an edge server that is physically closest to that area;
- Server load lookup, where the IP address returned routes to a less loaded edge server;
- Or simply to a server that is cheaper to run.

Most of the new CDN smartly return the best possible IP address to handle the request.

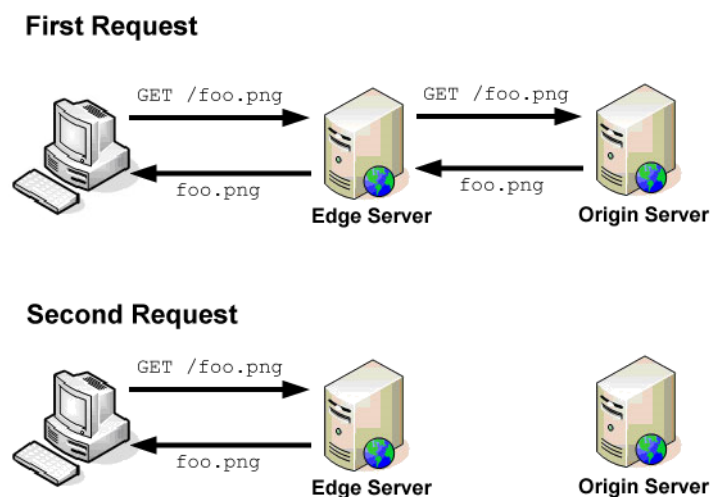


Figure 33 – CDN basic concept [37]

To access content, the request comes into an edge server, it first checks the cache to see if the content is present. If the content is not in the cache or the cache entry has expired, then the edge server makes a request to the origin server to retrieve the information. The origin server is always the source content and is capable of serving all of the content that is available on the CDN. When the edge server receives the response from the origin server, it stores the content in cache based on the HTTP headers of the response [37].

As said before OTT video is distributed recurring to unicast HTTP streams, each client is a new stream and thousands of clients will generate thousands of streams and will be really hard to handle such amount of outgoing bandwidth. It's why we need to cache our content in server as closest as possible to the client.

Unfortunately in Portugal we don't have such service available from any company, a company who would like to deploy this video distribution technology will need to implement a custom made solution.

In matter of best QoS possible, the edge cache should be the closest to the client. We could use global solutions such as Amazon or Akamai but if they didn't deploy closest server to the client, for example in the north of Portugal quality couldn't be assured. The only existing servers from this delivery network companies in Portugal are centered in Lisbon.

To demonstrate the importance of a CDN in the distribution of OTT video we can see that without a CDN each client asks for a stream. However OTT streams are unicast streams this means that each stream bandwidth will be added and total can be higher than the available bandwidth in the network. This can lead to network congestion problems. These problems are showed in Figure 34.

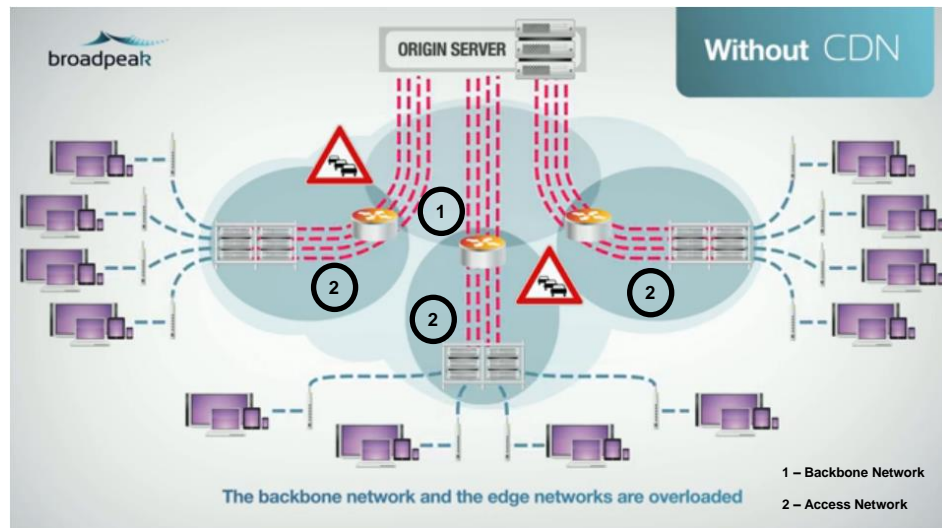


Figure 34 – OTT video distribution without using a Content Delivery Network [38]

With a CDN network (Figure 35), we are alleviating the load on the backbone network (Figure 35 - 1), and we are caching the content closest to the client. But unfortunately we are still congesting the access network, this is one of the reasons why it is important to install the edge caches the closest to our clients and rationalized according to the number of potential clients in each regional area.

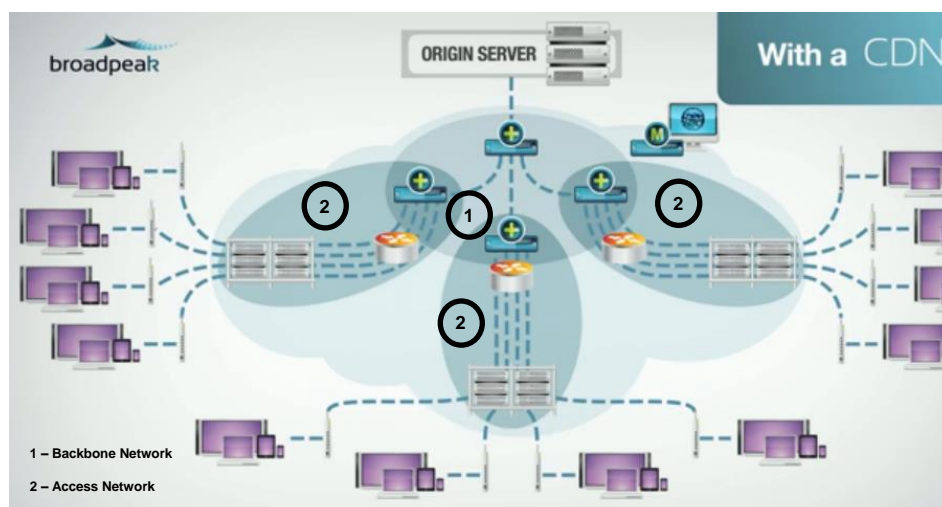


Figure 35 – OTT video distribution using a Content Delivery Network [38]

To better understand the traffic congestion generated by OTT TV services, if we have 1000 connections and 100 assets to deliver with an average bitrate of 1.8 Mbps we would need approximately 1.8 Gbps of upload in the data center.

To alleviate the traffic we could take the most popular contents, usually only 5% of the assets are generating 60% of the traffic, and using a CDN we would replicate the data of the 5% most viewed assets onto the edge servers, alleviating 60% of the traffic from the data center. From this point the most popular assets would be delivered directly from the edge-servers.

For example if we have 3 edge servers we could distribute the load equally among them or upon the load of geographical areas.

4.3 Network Neutrality

Network neutrality is the principle that defines that all data generated by a particular user is not discriminated against the traffic or data of any other user of the network. Neither the data of different users can be charged differentially. All users should be able to freely have access and control the content and applications they wish.

It is possible to guarantee different QoS based on, for example, destination/sender address, or the port that user is using (generally related to a given protocol, commonly TCP/IP).

Accordingly to the network neutrality principle, network operators shouldn't be allowed to filter data based on their own criterions in the same way that telecom companies are not allowed to tell consumers with whom they can talk on the phone or what they are allowed say, ISPs should not be allowed to use their power to control the user activity online.

The legal issues of network neutrality are discussed around the world, including the United States of America (USA). Network neutrality is seen in its stricter conception as a "best effort service" and ISPs are not allowed to introduce any discrimination in traffic. But this concept can be interpreted in countless ways.

The issue of network neutrality and the complexity of its definition reflect a conflict of interests between application providers (APs), Internet users (IU), and ISP providers. Groups of APs and IUs support network neutrality in its most strict concept, believing that differentiation for any service should be prohibited and that all Internet traffic should be treated as 'best effort service'. They argue that the current network has sufficient capacity to support all traffic necessary with all due guarantees. In most cases this is true, because network resources are often oversized, so we have to be aware of the tremendous progress in telecommunications in recent years, especially in investment in new access networks such as FTTx in Portugal.

The number of new applications and services are growing rapidly and increasing day to day the number of Internet users.

One of the fathers of the Internet, Lawrence Roberts, predicts that over the next ten years, the vast majority of world's population will be online. One of the consequences of this may be that the

capacity of the network link is no longer enough to carry all traffic with a QoS appropriate. This is one of the main arguments raised by ISPs to enable service differentiation and introducing traffic priorities [39].

They claim that data transmission networks without QoS mechanisms can become unacceptable from the point of view of the user in the future. ISPs are also concerned that providing network neutrality would discourage investment and development of new services and applications.

Supporters of network neutrality agree on service differentiation, but without being additionally charged. They fear that some applications might be blocked or certain services would be discriminated, lowering the connection speed, if extra fees aren't paid to the ISP. For example, ISPs could discriminate OTT service users which are subscribers of a competitor OTT service, by simply reducing the bandwidth available to the service making the video visualization deteriorate.

There are also some other proposals to deal with this issue. The debate over how to ensure adequate quality of traffic transmitted in IP networks has been a subject widely discussed over the last 15 years. It is possible that some of the proposed solutions might not be scalable, not work as expected, or even allow bad behaviors from the user.

Some entities suggests a new network architecture that enables implicit traffic differentiation and prioritization without user or ISP intervention, ensuring network neutrality only based on QoS parameters.

Proponents of net neutrality include consumer advocates, online companies and some technology companies, such as Yahoo!, Ebay, Amazon, among others. Microsoft, along with many other companies also adopted a posture to support neutrality regulation.

For example, some supporters of network neutrality accuse ISPs of wanting to be "gatekeepers" of the Internet, where they have the power to decide who can access faster, slower or simply not access [40]. According to them, these companies could discriminate others in favor of their own services (search engines, phone services, streaming video, etc.).

Neutrality opponents are hardware companies and members of the cable and telecommunications industry, including ISPs like AT&T.

4.3.1 Arguments for network neutrality

4.3.1.1 Control of Information

Proponents of net neutrality want to legally ensure that cable companies provide ISPs access to their network, called a common carriage agreement. They also want to prevent that operators interrupt or filter content without court order [41].

4.3.1.2 Competition and innovation

Those in favor of neutrality argue that allowing preferential treatment of Internet traffic could put in disadvantage new companies and the respective development of new online applications and services [42].

Without net neutrality, the Internet would start to look like cable TV. A handful of large companies would control access and distribution of content, deciding who has access and the access value.

Most of the major innovations in the Internet history began in garages with large ideas and little capital. This was not an accident, network neutrality allowed to maximize today's competition and allow "outsiders" to innovate in a free market [39].

4.3.1.3 Prevention against pseudo services

Some argue that any violation of net neutrality could lead to unnecessary payments and dubious services. Some believe that new investments in the network could be made only to benefit some content providers [43].

4.3.1.4 End-to-End Principle

According to this principle, a neutral network is a "dumb network", which only passes packets regardless of the applications they support [44].

4.3.2 Arguments against network neutrality

4.3.2.1 Property rights

Some opponents of network neutrality argue that net neutrality is a violation of the property rights of Internet service providers, because they build and paid for their own Internet access network.

4.3.2.2 Innovation and Investment

Opponents also argue that the bandwidth prioritization is necessary for future innovations [45]. Some operators argue that service providers should have the ability to provide preferential treatment to customers willing to pay for better reliability and speed transporting their data. The additional revenue of these services may allow investments in the access networks. They say that without charging these extra fees, they would not be able to cover their investments on the network bringing adverse consequences on innovation and competition in the market [46].

4.3.2.3 Counterweight in server side

Those in favor of "non-neutral" Internet access argue that the Internet is no longer on equal terms to all its players: large companies achieve better performance over its competitors of smaller dimensions, using replication servers and buying large capacity broadband services.

If for example the access prices were according to protocols or levels of access, each individual or company could take advantage of the network only according to their needs, thus providing greater network neutrality.

4.3.2.4 Bandwidth Availability

In reaction to companies like YouTube, offering video content, using substantial amounts of bandwidth, at least one ISP provider, SBC Communications (now AT&T), suggested that they should have the right to charge these companies for making their content available in their access networks [47]. For example, YouTube streams generated in three months more than 75 petabytes of information.

4.3.2.5 Poor Legislation

Due to rapid technological development, it remains difficult to legislation follow the constant changes and makes difficult for adjustment purposes.

Misconceived legislation could hamper service providers to legally perform certain necessary tasks and generally useful to fight piracy, spam filtering, and prevent the spread of viruses. These necessary tasks are against network neutrality.

4.4 Service Level Agreements (SLA)

A service level agreement is a negotiated agreement between two parties: the customer and the service provider.

This agreement may be legally bounded or informal (between company departments). Contracts between service providers and third parties are often incorrectly called SLAs; this is due to the fact that the level of service has been set by the (main) customer, there can be no "agreement" between third parties. Operational level agreements or OLAs can be used to support SLAs.

The SLA records a common understanding about services, priorities, responsibilities and guarantees. In this agreement should be described the level of service of each area such as levels of availability, performance or function.

Targets can also specify the "level of service" or the minimum level, so the client can get an idea of the minimum and average service he can expect. In some contracts, penalties may be agreed in the case of non-compliance with the SLA. It is important to note that these agreements relate to the services that the customer receives, and not how the service provider offers the service.

SLAs often include parameters such as: service definition, performance measurement, problem management, customer's rights, guarantees, recovery in case of disaster, and termination of contract.

In our case, the distribution of video via OTT can lead to changes in the traditional SLAs between a Content Aggregator or OTT Operator and an ISP provider. For example, costs associated with content distribution are no longer represented as bit rate (speed) or byte volume (quantity).

The content providers may have to change their SLA agreements based on the perceived video quality, and in the other side ISPs also will have to agree to deliver the content to meet the specified constraints in the video quality agreed.

These restrictions on service quality could be parameterized using equipment that allows the automatic measurement of quality or use some reference introduced in the video, which could, in case of dispute, be compared with human observers, to determine whether the conditions of SLA hadn't been fulfilled.

These types of SLAs lead to problems, if we have only one network 'best effort service' distribution service video cannot be guaranteed 100%. However if you use QoS services, the ISP may be at risk of not respecting net neutrality, but it ensures the distribution agreed with the provider of the content.

4.5 Transparent Caching

Video streaming delivery services over the Internet are spreading rapidly, but further traffic growth may degrade the quality of streaming services due to congestion and packet loss events. This will lead to degrading quality of video playback and a longer waiting time to playback.

Transparent caching may have a decisive role in the distribution of OTT video services. It can help to deliver more efficient OTT streaming services, or be a problem to the content delivery service provider.

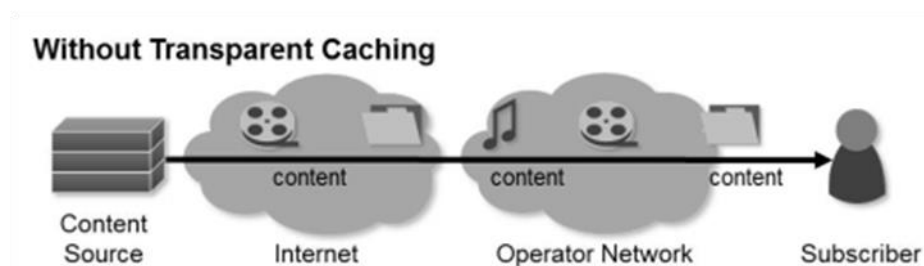


Figure 36 – Content Transmission without Transparent Caching [48]

To understand what happens in transparent caching it is important to know what happens to IP packets at the Ethernet level. An Ethernet IP packet contains four addresses [49]:

- **Destination MAC address:** when a packet is transmitted, all Ethernet devices on the network check the destination MAC address value. If the device MAC address matches the destination MAC address of the packet, the network will pass the packet to the operating system, which will then deal with the contents of the packet.
- **Source MAC address:** fixed by the sending Ethernet device.
- **Destination IP address:** set by the application sending the packet.

- **Source "IP" address:** fixed by the source host. This value is not changed through the transmission, routers re-forward the contents of the packet intact, they only change the destination MAC address.

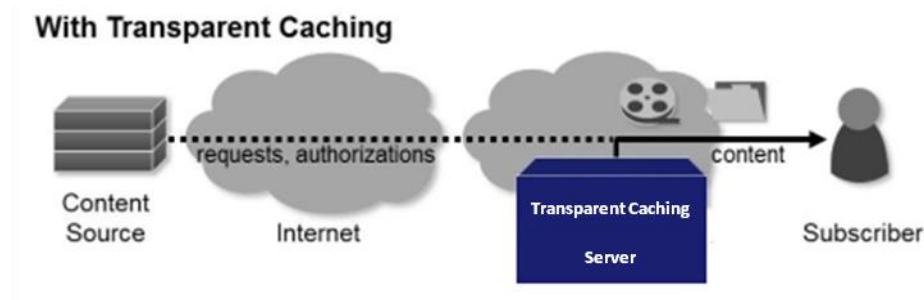


Figure 37 – Content Transmission With Transparent Caching [48]

A transparent cache essentially tracks packets in the network searching for TCP connections destined for port 80. These servers intercept these packets and convert them to a standard TCP "stream". When the Transparent Cache server (TCS) sends the reply data to the client, the Operating System "fakes" the source address of the packets, so that the client believes it is connected to the server that it originally sent the request to.

It is possible to simply plug a transparent cache into the network and get it to transparently cache any Webpages or streams. The cache server needs to be in a position where it can fake the reply packets, usually between the server and the client.

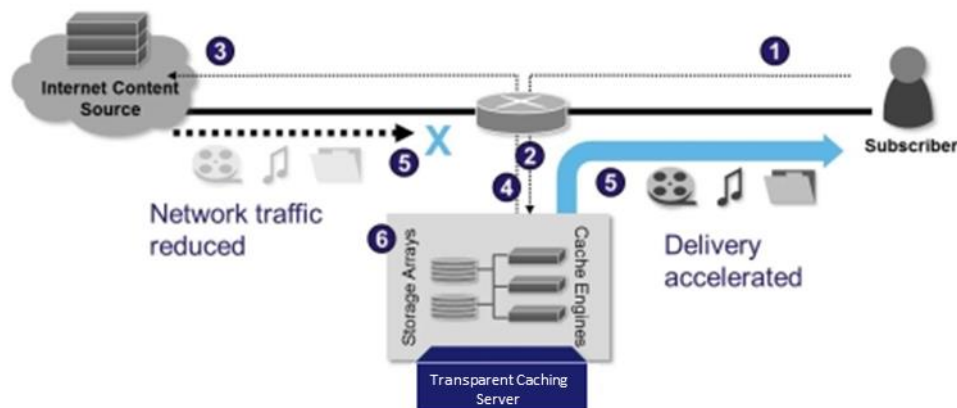


Figure 38 – Transparent Caching Process [48]

Figure 38 represents a possible transparent cache server setup [48]:

1. The client requests an object. The connection is established between the source and the client.
2. The Transparent Cache Server (TCS) inspects the request and passes it to the content source.
3. Source executes content delivery logic (authorization, content adaptation, reporting, etc.) and starts delivering requested object.
4. The TCS inspects the source response header and payload. Then:

- If object is in cache, it instructs the source to stop serving and serves it from cache in same session.
- If object is not in cache, it continues to deliver it from source, while storing a copy for future use.

Dealing with Transparent Caching can be helpful and at the same time a constraint for a content distribution service [50]:

- **Helpful:** video streaming and rich media downloads continue to flood operator networks, with no end in sight, if an SLA is made with these operators, transparent caching can help to reduce the traffic and consequently reduce network infrastructure and bandwidth costs. Therefore it also helps to differentiate their consumer broadband service and deliver better user performance. By eliminating any potential delays associated with the Internet or even the content origin, caching allows the operator to highlight their investment being made in the access network and deliver more content at top speeds.
- **Constraint:** this control usually is embedded inside the carriers network and provides the operator control over what to cache, when to cache, and how fast to accelerate the delivery. This can lead to a diversity of problems such as: insufficient delivery bandwidth, discrimination in the traffic prioritization and cause unsatisfactory quality of experience to the end user.

5 Client Platforms – Operating Systems and Devices

Client platforms are the last step in the OTT video ecosystem: the streams will be played in these devices and that is why it is important to analyze their operating systems compatibilities.

From the result of this analysis we will be able to choose which streaming technologies are more suitable to use in an OTT ecosystem, in order to be compatible with the widest number of users and the most popular platforms available.

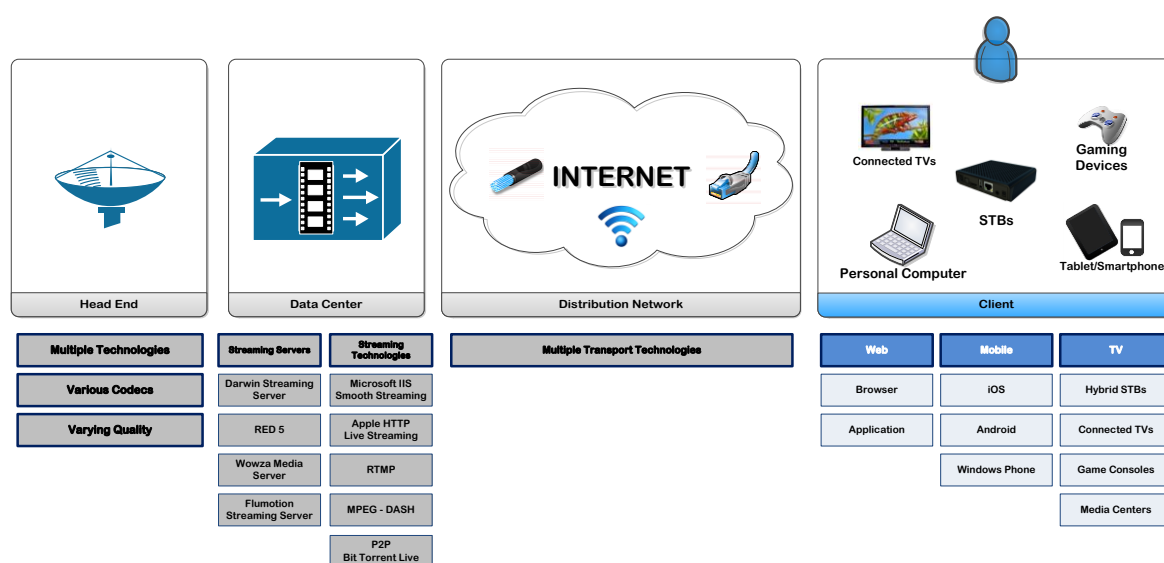


Figure 39 - OTT Ecosystem, Chapter 5 subject: Client Platforms

5.1 Computer Operating Systems

Computers are the most important and popular platform that clients will use to view OTT content. There are 3 major computer Operating Systems in the market and it is also important to identify the most popular browsers and which streaming technology they are compatible with.

Windows is still the most used operating system with over 90% of the market share, this almost universal platform is nowadays dominated with Flash technology, and all major video websites use almost exclusively this technology to deliver video. Likewise, all of the browsers running over this operating system are compatible with Flash. For this reason it was agreed that flash technology and the RTMP protocol should be used to deliver video to Windows Users.

Mac OS is restricted to Apple computers but the user base is growing year after year and Apple users are generally more aware and interested in consuming multimedia content in their equipment's. Since these computers are equipped with Intel processors, they are also compatible with flash technology. This technology is mainly used in Chrome and Firefox. Safari which is the native browser of this operating system is also compatible with the HLS technology.

Linux operating systems are mainly compatible with flash technology and the RTMP protocol.

5.2 Mobile Operating Systems

With the constant growth of the mobile market and the appearance of smartphones and LTE connection, multimedia services are being consumed everywhere. This is the main reason why studying these devices along with the personal computer scenario is important for the OTT system analyses. On the next sub-sections we analyze the main mobile operating systems available.

5.2.1 Android

Android's share of the global smartphone market was 64% in March 2013 [51]. In July 2013 there were 11,868 different models of Android device. Since September 3, 2013, there have been 1 billion Android devices activated and every day more than 1 million new Android devices are activated worldwide [52].

Android runs on millions of mobile devices in more than 190 countries around the world. It's the largest installed base of any mobile platform. It's mainly used for apps, games, and other digital content [53].

Android applications with a single binary can easily be optimized for phones, tablets, TV's and other devices, it is a major platform to reach with video services.

Android supports HTTP Live Streaming but only in some distributions and with some limitations [54]:

- **Android 2.3 (Gingerbread):** has no support, despite being the most popular version of Android;
- **Android 3.0 (Honeycomb):** some streams may cause some instability problems in tablet devices.
- **Android 4.0 (Ice Cream Sandwich):** there are still some known issues like, VOD streams have seek problems; aspect ratios are not detected and cause image deformation; fullscreen causes videos to restart from the beginning;
- **Android 4.1+ (Jelly Bean):** likewise there are also some known issues, video seek is still unavailable; chrome does not understand HLS leading to broken mimetype detection; taking video fullscreen causes devices to throw an error and stop.

5.2.2 iOS

iOS is a mobile operating system developed and distributed by Apple Inc. and it is restricted to Apple's own hardware (iPhone and iPad).

This operating system has 21% share of the smartphone mobile operating system units shipped in the fourth quarter of 2012, only behind Android [55].

It's important to note that in June 2012, iOS accounted for 65% of mobile web data consumption (including use on both the iPod Touch and the iPad) this is an evidence that devices equipped with this platform are truly “connected and mobile” [56].

iOS is natively compatible with HLS [4].

5.3 Other Multimedia Systems

5.3.1 XBMC

XBMC is a free and open source media player application developed by the XBMC Foundation, a non-profit technology consortium. This platform is available for multiple operating-systems and hardware platforms allowing users to play and view most videos, music, podcasts, and other digital media files from local and network storage media and the internet [57].

Through its plugin system, which is based on the Python programming language, XBMC is expandable via add-ons that include features such as television program guides (EPG), some streaming services such as YouTube, Hulu, Netflix, Veoh. XBMC also as some others interactive functions such as a gaming allowing users to play mini-games developed for the XBMC platform.

The XBMC is distributed as open source under GPL (GNU General Public License) and it is sponsored via the tax-exempt registered non-profit organization, XBMC Foundation. It is maintained and developed by a global community of volunteers that support free software [57].

Raspbmc and Xbian are XBMC and Linux-based OS distributions for Raspberry Pi. These distributions are custom designed to run over the open source platform.

5.4 Set-Top BOX

5.4.1 Raspberry PI

The Raspberry Pi is a credit card sized single-board computer developed in the UK by the Raspberry Pi Foundation with the intention of stimulating the teaching of basic computer science in schools.



Figure 40 – Raspberry PI running XBMC

This computer has 512MB of RAM and a 700MHz ARM-11 processor. The Model B, used in this work has two USB ports, one HDMI output and a 10/100 Mbps Ethernet port. For your audio needs, it's equipped with a 3.5mm audio jack and the HDMI output also supports audio transmission. The Raspberry Pi's GPU boasts 1 Gpixel/s, 1.5 Gtexel/s or 24 GFLOPs of general purpose compute power and is OpenGL 2.0 Compliant [58].

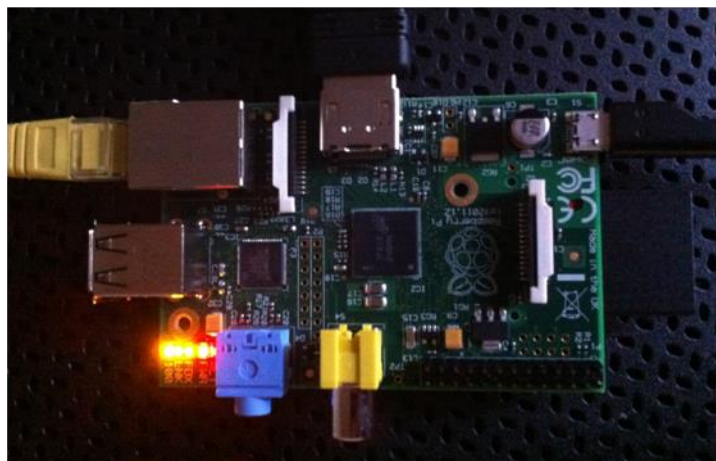
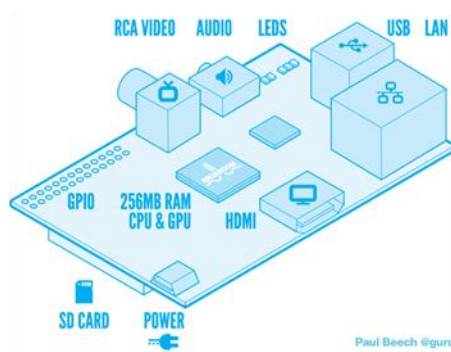


Figure 41 – Raspberry Pi representation and picture

This device has an excellent form factor and enough power to handle media playback, making it an ideal candidate for a low cost, OTT set top box, since it delivers the same XBMC experience that can be enjoyed on much more costly platforms. At the present time, some minimal Linux distribution based on Debian are being developed to bring XBMC to the Raspberry Pi, such as Raspbmc and Xbian.

This platform (Raspberry PI) combined with a custom release of Raspbmc or Xbian, could lead to the development of a great low cost set top box. Giving the users access to an open source platform that could be used not only to access an OTT service but also to enjoy other multimedia content.

For commercial use, it will be needed to develop an add-on on top of XBMC so that customers can receive the OTT service.

5.4.2 Android PC or Google TV

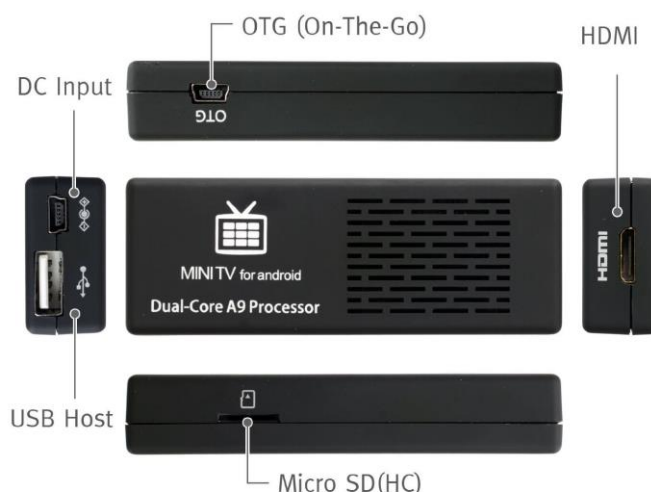


Figure 42 – Android PC Overview

Android PC it is a mini PC with approximately the same dimensions that a common flash drive pen. This device has low power consumption and can be powered-up only with the 5V USB port available on the television set. This device can be easily connected to any television or monitor with and HDMI input.

This mini PC allows any user to transform any TV set in a Connected TV, this will convert the “dummy” TV to a device that is connected to the Internet, has access to applications, browser and has a native player that is compatible with HTTP Live Streaming.



Figure 43 – Android PC

This device as the following specifications:

CPU	Rockchip RK 3066, CORTEX-A9
OS	Android 4.1 Jelly Bean
Display	HDMI OUTPUT (TV)
RAM	1GB DDR3
Flash	8GB Nand Flash
WIFI	802.11B/G/N
2.4G	Support 2.4Ghz wireless remote keyboard and mouse
Hard Disk	SUPPORT SD Card: 1GB-32GB ; Hard Disk: 1GB ~ 5TB

Table 6 – Android PC specifications

Due to its specifications, this device could also be a candidate to connect any TV set to an Over The Top Service. The user could access the service through a custom made android application, designed exclusively for TV use.

Since android has a native web browser application, the service could be distributed through a website that could adapt to any screen resolution (Smartphone to TV).

6 Proof of Concept

6.1 Initial Concept

In order to have a deeper understanding of the whole technique and technologies behind an Over The Top service, one of the goals of this dissertation was to build a prototype as proof of concept.

This proof of concept aim to demonstrate that is possible to implement a multiscreen video distribution system recurring to everyday use tools. Using a personal computer configured with internet access, streaming and encoding software we could turn this machine into a dedicated streaming/web server able to distribute both live channels and on-demand videos to multiple devices, such as computers, smartphones, tablets and set top box.

This prototype could be used for home sharing of personal videos, small corporate television or school television.

This system should use and demonstrate some of the technologies studied in the previous chapters and during the development of the prototype the following steps were accomplished:

- A unified platform should be developed for multiscreen access;
- Integration should use the minimum platforms possible and ideally open source software;
- Test and choose one of the streaming software studied in chapter 2.3;
- Adaptive to different network access and platform environments;
- Study which streaming technologies are more suitable to deliver video to the maximum devices;
- The website and player has to detect which device is being used and adapt both video and UI to it;
- Encode both live and offline video;
- Deliver video live and on-demand;

The idea behind this proof of concept or prototype was that with one server we could provide an OTT video service able to deliver to the following operative systems or platforms:

- PC (Windows or Linux)
- MAC OS
- Android
- iOS
- XBMC

In order to achieve cross platform compatibility we've concluded that we would need to use more than one streaming technology and create a website with a User Interface (UI) capable to adapt to different screen resolutions.

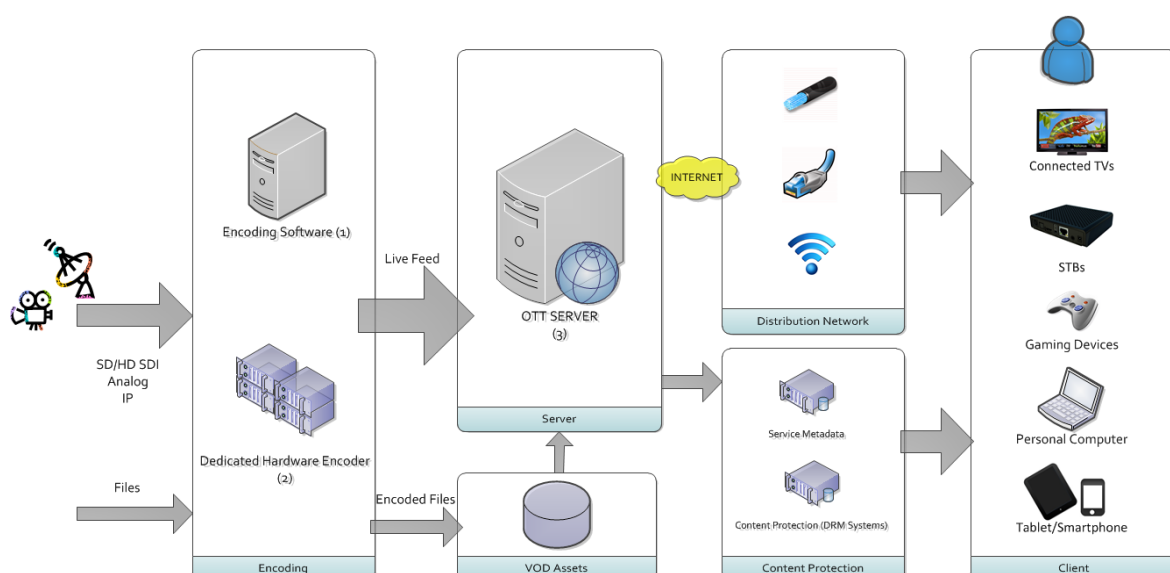


Figure 44 - The figure illustrates a possible example of an end to end ecosystem of the OTT television delivery system

Figure 44 illustrates the normal flow of an OTT video distribution architecture. Live video and on demand video go through different steps. Live Video flows through the following steps:

1. Live feed is acquired from an Over The Air (OTA) or Satellite source;
2. This live feed is encoded in multiple profiles by a dedicated hardware encoder or a machine running an encoding software;
3. This live feed is then ingested by a streaming software (dedicated server) that will prepare the content to the client requests. This software will add DRM and metadata to the video. And in some cases re-package and transcode the stream in order to adapt to the client needs.
4. Upon client request, the stream is sent to the client through different access technologies. In this request the client asks the server for a stream suitable for his device.

Video on demand has a similar flow, but with some differences:

1. The video files are encoded in multiple video profiles and DRM encrypted in the video encoders.
2. These files are stored in a data server.
3. Upon client request, the video files stored in the data server are sent to the streaming server and packetized according to the specifications of the client's device.
4. The stream that is delivered to the client goes through different access network technologies.

6.2 Server Solution

The following server solutions were tested, previously studied in Chapter 2:

- Darwin Streaming Server
- Flumotion Streaming Server
- Red 5
- Wowza Media Server

The first option to do this project was to choose an Open Source software solution, because it was preferable to choose free and open source software over a paid and closed solution.

From the results of the tests resumed in the Table 7, Table 8 and Table 9 it is possible to conclude:

- **Darwin Streaming Server:** it's the oldest server tested, it is restricted to RTP/RTSP protocols and the playback depends of the usage of Quick Time Player.
- **Flumotion Streaming Server:** this open source server, works only under Linux operating systems. Works perfectly for streaming video files using HTTP. For live streaming it's more restrictive because it doesn't support live feeds from other encoders than the one built in the server software. This drawback makes it not the perfect candidate because having the live encoding running in the same machine as the streaming distributor will overload the machine requiring machines with higher processing capacity and this issue will become not bearable in scale.
- **RED 5:** The biggest drawback of this Linux based and open source software, it's that it is only based on flash technology, RTMP protocol. This feature makes it not compatible with iOS platforms because they don't support the RTMP protocol natively.
- **Wowza Media Server (version used 3.5):** Although the fact that this is a paid and closed solution this was the more suitable for this project. The possibility to stream the video upon request that means that according to the construction of the URL, the server responds with a stream according to the requested, thus using different protocols or technologies. With this possibility it is possible to stream to multiple platforms or clients with the same server, the stream request is done in the client side making it possible to request a stream better suited to the OS or platform in question. The server makes the re-packaging of the video or live feed and adapts it to the protocol or technology requested by the device. This feature was the main reason why this platform was chosen.

Name	Version	Date	First Release	From	Version Type	Tested	Tested on OS	Other OS Compatible	Machine ID	Protocols in Description							Protocols TESTED						
										RTSP	RTP	Apple HTTP Live Streaming	MPEG-TS	HTTP	Flash HTTP Streaming	RTMP	RTSP	RTP	Apple HTTP Live Streaming	MPEG-TS	HTTP	Flash HTTP Streaming	RTMP
Darwin Streaming Server	6.0.3	10 May 2007	March 16, 1999	Apple	open-source	yes	Ubuntu 11.04	Linux; Mac OS; Windows	Acer	yes	yes	no	no	yes (audio only)	no	no	yes	yes	-	-	yes (audio only)	-	-
Flumotion Streaming Server	0.8.1	2010?	2004??	Fluendo	open-source	yes	Ubuntu 11.04	Linux	Acer	no	no	no	no	yes	no	no	-	-	-	-	yes	-	-
Wowza Media Server	2.2.3	2010?		Wowza	proprietary	yes	Mac OS X 10.6.8 Windows 7	Linux; Mac OS; Windows	MacBook Toshiba	yes	yes	yes	yes	n/a	yes	yes	yes	yes	yes	yes	-	yes	yes
red 5	0.9.1	21 Feb 2010	2009	Red5	open-source	yes	Ubuntu 10.04	Linux	Toshiba	no	no	no	no	no	??	yes	-	-	-	-	-	??	yes

Table 7 – Streaming Server Comparison Table, Test Specification and Streaming Protocols comparison

Name	Video Formats in Description								Video Formats TESTED								Video Codecs in Description								Video Codecs TESTED							
	MOV	FLV	F4V	M4A	MP4	WebM	OGG	3gp	MOV	FLV	F4V	M4A	MP4	WebM	OGG	3gp	Theora	Dirac	Screen Shared Codec	SorensonSpark	MPEG-4	H.264	vp8	VP6	Theora	Dirac	Screen Shared Codec	SorensonSpark	MPEG-4	H.264	vp8	VP6
Darwin Streaming Server	yes	no	no	no	yes	no	no	yes	no	-	-	-	yes	-	-	yes	no	no	no	no	yes	yes	no	no	-	-	-	-	yes	yes	-	-
Flumotion Streaming Server	no	no	no	no	no	yes	yes	no	-	-	-	-	-	no	yes	-	yes	yes	no	no	no	no	yes	no	yes	no	-	-	-	-	no	-
Wowza Media Server	yes	-	-	-	yes	-	-	-	yes	-	-	-	yes	-	-	-	-	-	yes	yes	yes	yes	-	yes	-	-	-	-	yes	yes	-	yes
red 5	no	yes	yes	yes	yes	no	no	no	-	yes	yes	no	yes	-	-	-	no	no	no	yes	no	yes	no	yes	-	-	-	no	-	yes	-	no

Table 8 - Streaming Server Comparison Table, Video Formats and Codecs Comparison

Name	Audio in Description					Audio TESTED				
	MP3	NellyMoser ASAO	AAC	Vorbis	Speex	MP3	NellyMoser ASAO	AAC	Vorbis	Speex
Darwin Streaming Server	yes	no	no	no	no	yes	-	-	-	-
Flumotion Streaming Server	no	no	no	yes	yes	-	-	-	yes	no
Wowza Media Server	yes	yes	yes	-	yes	-	-	-	-	-
red 5	yes	yes	yes	no	yes	yes	no	yes	-	no

Table 9 - Streaming Server Comparison Table, Audio Comparison

6.3 Content Preparation

6.3.1 XSplit Broadcaster

In order to simulate the broadcast of a live feed using OTT technology, a simple PC with a capture card was used. For this test, the encoding software was running in the same machine as the video server.

This windows based desktop application was designed for multimedia broadcasting and recording. The software allows users to broadcast professional live content through Internet.

Using a PCI video capture card, any PC can capture a live feed coming from a digital camera or in this case an analog feed issued from a DTT tuner. This program captures the analog signal and encodes it to the network.

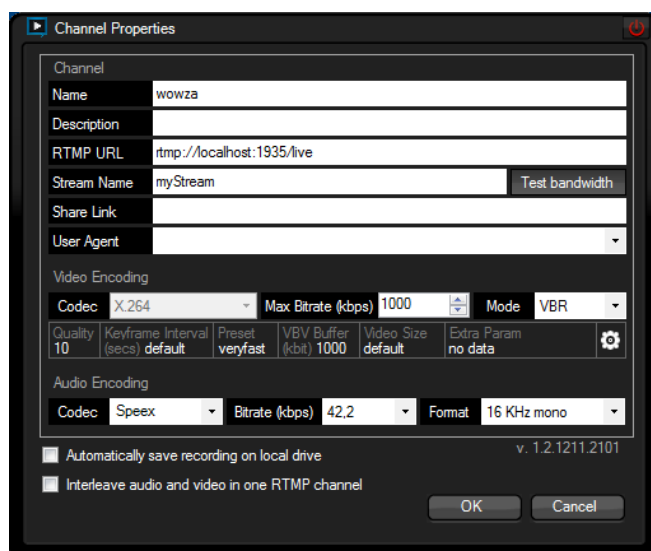


Figure 45 – XSplit Broadcaster configuration page

For the live feed tests, a video and audio was captured using a PCI video capture card, with a dimension of 768x576 to keep DV PAL 4:3 ratio of the original DTT European channels, and the video was transmitted to the Wowza Media Server with the configurations described in Table 10.

Streaming protocol		RTMP video stream (rtmp://localhost:1935/live) with the name myStream.
Video Encoding	Codec	Mpeg-4 X.264
	Max. Bitrate	1000 kbps
Audio Encoding	Codec	Speex
	Max. Bitrate	42.2 kbps

Table 10 – Live encoding configurations used in the Prototype

6.3.2 Handbrake (ffmpeg)

Handbrake is an open-source, GPL-licensed, multiplatform, multithreaded video transcoder.

This software can process most common multimedia files and any DVD or Blu-ray sources that do not contain any kind of DRM protection. It outputs video and audio encoded in:

- File Containers: MP4(M4V) and MKV
- Video Encoders: H.264(x264), MPEG-4 and MPEG-2 (libav), or Theora(libtheora)
- Audio Encoders: AAC, CoreAudio AAC/HE-AAC (OS X Only), MP3, Flac, AC3, or Vorbis.
- Audio Passthru: AC-3, DTS, DTS-HD, AAC and MP3 tracks

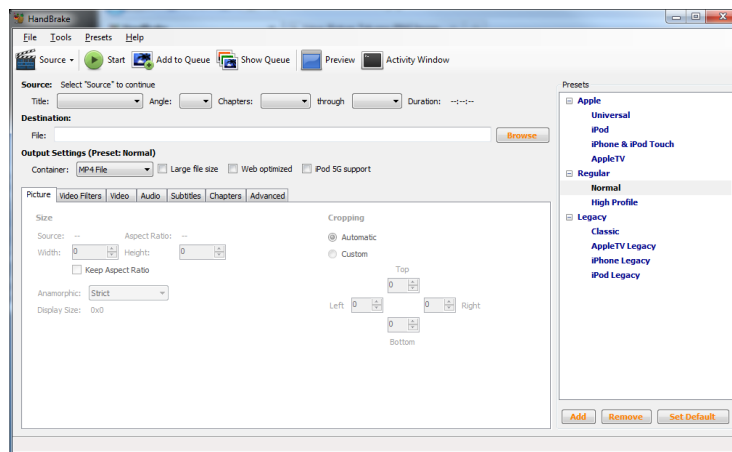


Figure 46 – Handbrake Software

As seen before in the Wowza Media Server specifications, the video input files must be in MP4 or MOV format. Since we are using this streaming software, all the video files used in this prototype will have to be compliant with these specifications: H.264 (x264) codec, with the same variable frame rate as the source, audio encoded using the AAC codec. All video aspect ratios were maintained.

6.4 Prototype Platform

For better understanding the platform design was segmented in 4 layers:

- **Client Platform:** represents all the different operating systems running in the client's hardware. They don't support all the same formats and/or technologies.
- **Application:** layer that makes possible the communication between the server and client platform. This layer will be in charge to identify the clients' platform type and ask the server for the right stream for it.
- **Server:** this layer will packetize and prepare the OTT streams.
- **Head End:** responsible to prepare the content for OTT streaming.

This concept is illustrated in Figure 47. The prototype was named OTTPlay.

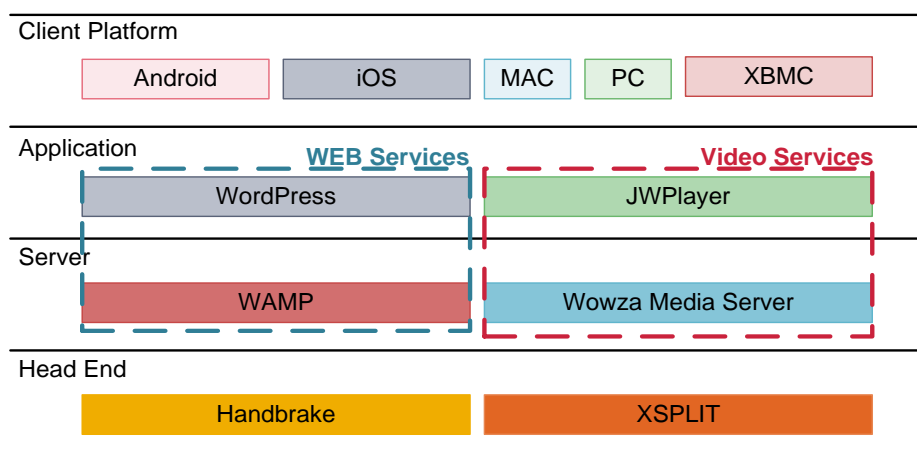


Figure 47 – Prototype layer architecture

In this experiment the software represented in the Application, Server and Head End layers were running all the same machine.

As said before Handbrake and XSplit are encoding software, for offline and live encoding respectively. These two programs were used to simulate the content preparation done in the Head End. Handbrake was used to encode videos in different video profiles, in order to prepare content for Adaptive Streaming. Using a PCI capture card and XSplit software we've achieved to prepare a live stream with a unique profile of 1 Mbps.

A prototype website was developed in order to have an idea of how this service could be provided to the clients. The machine where the prototype was running was accessible through a university private lan address: <http://193.136.82.48>.

To handle these Web Services, WAMP was installed in the machine. WAMP is Windows based web development platform that manages Apache2, PHP and MySQL services.

On top of that we needed a content management system (CMS) based on PHP and MySQL such as WordPress to build the website. WordPress has many features including a plug-in architecture and a template system that as the ability to adapt to different screen resolutions, making it very useful if we want to make it compatible and usable to different operating systems and screen sizes.

We can see in Figure 48 and Figure 49 how the website layout automatically adapted to the screen resolution where it was been accessed.

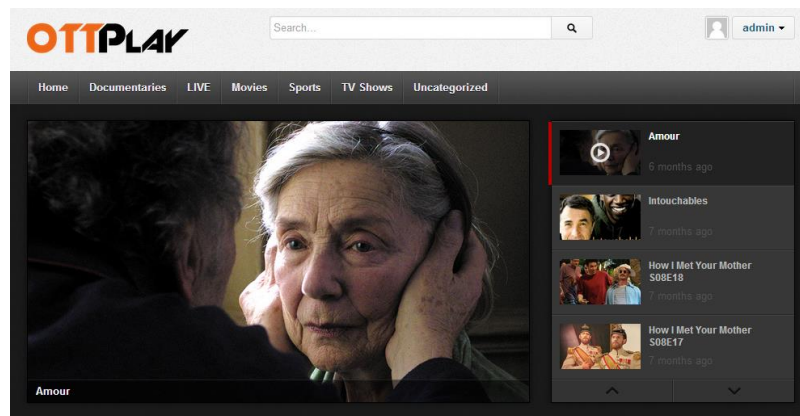


Figure 48 – Website Layout on Tablet and PC/MAC

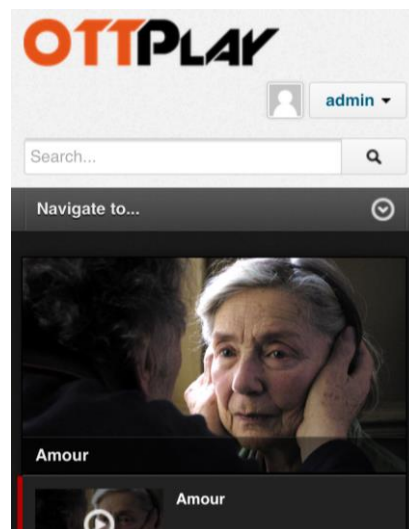


Figure 49 – Website Layout on a smartphone

This quite trivial website based on WordPress, was configured to work with only one player, JWPlayer 5, that was compliant with two different technologies:

- Flash Player: using RTMP streaming protocol.
- HTML5: using HLS streaming protocol.

The video player detects which technology is most suitable for the device where the website is being viewed. If the player detects that the browser's device supports Flash, the player will request an RTMP stream to the Wowza Media Server. Otherwise if the player detects that the browser isn't compatible with Flash technology and if it is HTML5 enabled, the player will request an HLS stream from the video server.

From the code below we can see that the player will first try to play the RTMP stream (green) using a flash player and then try to play the HLS stream (blue) if flash technology is not present in the device browser. This code individually configured each player.

The code below is an example of the players HTML script:

```
<script type='text/javascript' src='jwplayer.js'></script>
<div id='mediaplayer'></div>
<script type="text/javascript">
  jwplayer('mediaplayer').setup({
    'id': 'playerID',
    'width': '480',
    'height': '270',
    'provider': 'rtmp',
    'streamer': 'rtmp://193.136.82.48:1935/vod',
    'file': 'coldplay.mp4',
    'modes': [
      {type: 'flash', src: 'player.swf'},
      {
        type: 'html5',
        config: {
          'file': 'http://193.136.82.48:1935/vod/coldplay.mp4/playlist.m3u8',
          'provider': 'http'
        }
      }
    ]
  });
</script>
```

When the player tries to play a content, first it detects which is the streaming technology more suitable for the device where it will play and then it requests the stream to the Wowza Media Server through port 1935.

This feature makes the server video services “playable” in different operating systems and in most consumers platforms, in Table 11 is resumed all tests done in different operating systems, browsers, and platforms and demonstrates which technology’s the player used to play streamed video.

Operating System	Browser	Technology	Hardware
iOS (iOS 6)	Safari	HLS	iPad
	Chrome		iPhone
Android (4.1)	Android System Browser (Chrome)	HLS	Android PC
Windows (Windows 7)	Internet Explorer	RTMP	PC
	Chrome		
Linux (Ubuntu 10.04)	Firefox	RTMP	PC
	Chrome		
Mac OS X (Mountain Lion)	Safari	HLS	MacBook
	Chrome	RTMP	

Table 11 – Technology vs. Browser vs. OS resume table

Another player was tested, Silverlight Player, using proprietary technology Silverlight and the streaming video protocol, Smooth Streaming. Below there is an example of the configuration of this player:

```
<form id="form1" runat="server" style="height:100%">
<div id="silverlightControlHost">
<object data="data:application/x-silverlight-2," type="application/x-silverlight-2"
width="50%" height="50%">
<param name="source" value="SmoothStreamingPlayer.xap"/>
<param name="minRuntimeVersion" value="4.0.50401.0"/>
<param name="autoUpgrade" value="true"/>
<param name="InitParams" value="mediaurl=
http://richard.myftp.biz:1935/vod/coldplay.mp4/Manifest"/>
</object>
</div>
</form>
```

The Silverlight Player when requesting for a video stream to the Wowza Media Server it requests access to the manifest file of the video using HTTP protocols. Using this file, the player will know all the information about the video that he will play, such as first chunk, duration, and next chunk.

Smooth Streaming wasn't used in the OTTPlay platform because it depends on the Silverlight plugin. It must be present in clients' device. This technology is less widespread than flash in computers and isn't compatible in most of the mobile world (Android and iOS). Incompatibility and inflexibility were the main reasons why this player wasn't chosen. Comparing to JWPlayer it has a huge disadvantage because it is restricted to Microsoft technology.

Resulting from the adaptability of both video and web services, it is possible to access to OTTPlay from both Android and iOS devices. In Figure 49 we can see the website layout in an iPhone, and in Figure 50 it's showed an HLS adaptive stream playing from OTTPlay in the iOS native player.

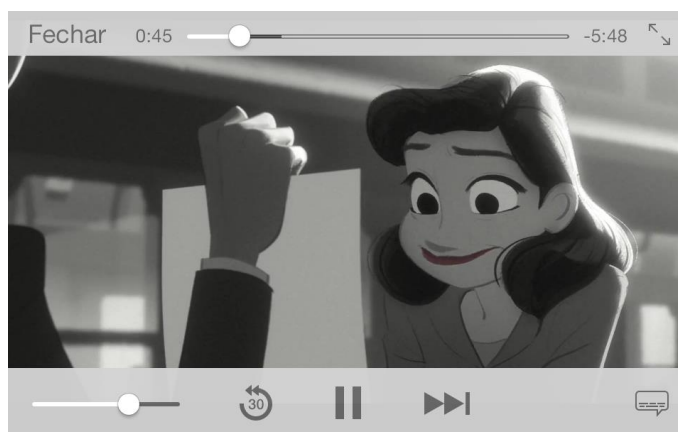


Figure 50 – HLS stream playing in iOS native player from OTTPlay

The same thing was tested on an Android PC. On OTTPlay website each video as its own page were it figures the player and some metadata about the video. This page appearance on Android is shown on Figure 51. On Figure 52 we can see the appearance of the Android native player playing an HLS adaptive stream.

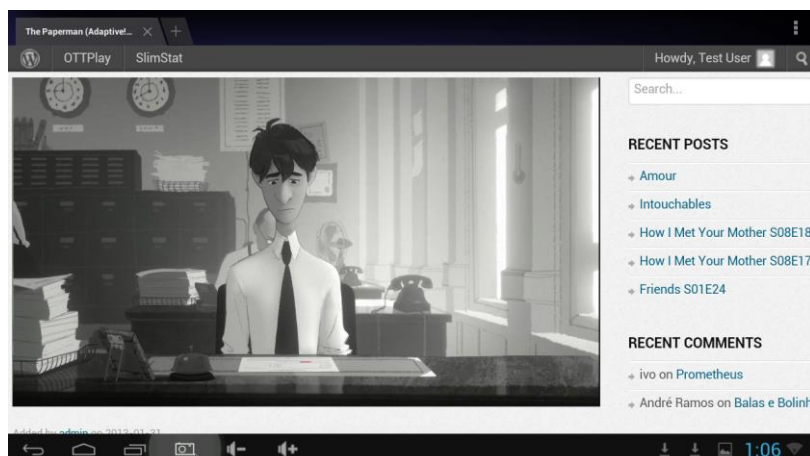


Figure 51 – Video Page layout on Android

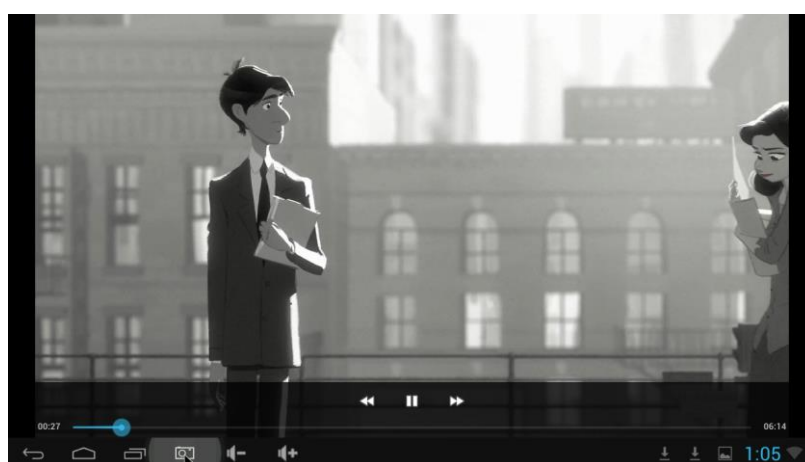


Figure 52 – Adaptive HLS stream playing on Android native player

Using the Raspberry PI combined with XBMC software we obtain an excellent set-top box candidate, using only open source platforms. It's possible to use a modified distribution of the XBMC or only deploy a customized Add-On, on the XBMC Add-on network, that satisfies our requirements.

Since the XBMC has no browser access, to play video streams on XBMC, it's only required to create a different ".strm" file to each different stream. This file should only include the link of the stream that we want to play, e.g., http://193.136.82.48/vod/<file_name>.mp4/playlist.m3u8. Figure 53 shows an example of a .strm files list on XBMC menu and one of this stream files playing is showed on Figure 54

For example, an Add-on could be created to link the XBMC with a database where is available the information of different TV channels or videos, with corresponding stream URL and additional information such as synopsis or EPG (Electronic Program Guide).

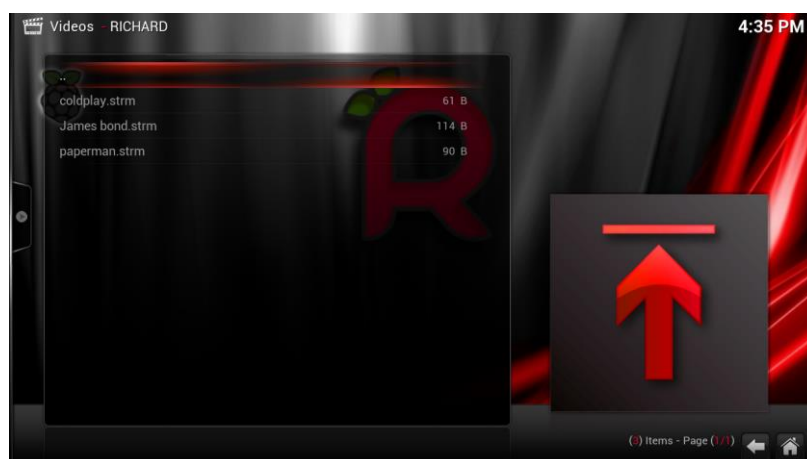


Figure 53 – Example of .strm files on XBMC menu



Figure 54 – HLS stream playing on XBMC

7 Economic Analysis of a possible implementation

In order to provide a high quality and personalized experience to each subscriber, operators need to leverage technology innovations and deploy solutions that are flexible and scalable for today's television delivery market. An OTT based video infrastructure can meet these requirements while maximizing efficiency and lowering costs.

The central issue of this economic analysis is:

- Is it economically viable to implement a video on demand service in Portugal?
- Is there enough scale and space in the Portuguese market to do so?

These issues are the subject of the present chapter.

7.1 Project Assumptions Summary

The whole economic analysis of this project was based in the following assumptions:

1. Television Service:

- Unlimited Movies and TV Shows, price:
 - i. Unsubscribed user, monthly fee of 20 euro.
 - ii. Subscribed user (12 month subscription), monthly fee 18 euro.

These prices were assumed in order to be both attractive to the client and profitable for the company. It is more expensive than other competitors but it is the lowest price possible in order to be profitable in the market chosen for this study.

- Premium Event price: 5 euro per event. This value was based on the price used by UEFA for live pay per view football games.
- Client Premises Equipment (set top box), price: 45 euro. Retail price estimated in order to have profit over the production price of approximately 15 euros per unit.

All the assumptions made for pricing and offer are explained with more detail in section 7.3 - Offer, Product and Pricing.

2. Catalog:

- Total number of assets: 2800 Videos
 - i. 40 different TV shows with each 20 episodes. Total 800 assets.
 - ii. 1500 SD Movies
 - iii. 500 HD Movies

The number of assets in the catalog was estimated according to the catalog dimensions of similar services, like Meo Go!.

- The catalog grows 4% per annum. The titles available in the catalog will be renewed each year, and the number of titles will be increased along the years.
- Live premium events: Maximum 10 live channels. If we are transmitting a football event (UEFA Champions League) we can have up to 8 games at the same time.

All these assumptions are explained in 7.4.1 - Scaling the Catalog.

3. Video Profiles:

- High Definition (HD) Profile: 3 Mbps [60].
- Standard (SD) and Medium Profile: 1.8 Mbps [60].
- Low Profile: 600 Kbps [60].

These profiles were chosen according to standard industry profiles. Further information is available in 7.4.1 - Scaling the Catalog.

4. Concurrency Rates:

Concurrency Rates refers to maximum of simultaneous requests that one network entity can handle in the same instant.

- Video Services: 6%.
- Web Services: 2%.

These rates are explained in 7.4.2.1 - Concurrency Rate for Video Services and 7.4.2.2 - Concurrency Rate for Web Services.

7.2 Target Market and Scenarios

In order to create a business model for this case study it is necessary to identify the foreseeable set of customers who might be willing to subscribe the service. For this purpose the universe of Portuguese users that pay a monthly subscription television services was considered.

The main goal of the new proposed service is to make the product usage and subscription simple, inexpensive and convince a larger number of customers.

The motto of this company is to reach the customer wherever he is connected, whenever he has time and the real possibility to watch what he wants. Being this service distributed over the internet, it can be globally expanded. However content may have to be restricted to residents in certain geographical area in order to manage acquired DRM rights. It means that we may have rights to broadcast content in some areas and not in others. All content rights are usually negotiated with content owners for certain areas and device type.

The client can access this service anywhere where an access network compatible with this kind of service is available, any area that is covered with a network with at least 1Mbps of download bandwidth.

Our customers are the end users that have entertainment equipment, such as Tablets, Smartphones, Connected TVs or Gaming devices. These devices are connected and active on the network. Nowadays customers prefer to buy low cost products or join smart deal subscriptions where they pay only for what they have. This product would be directly sold to the end user.

Thanks to the OTT distribution technology, it is possible to distribute audio-visual content without resorting to intermediates if the streaming is done through neutral networks.

7.2.1 Case Study Scenarios

All Scenarios are based on the same data and assumptions, only the market evolution will be different in each case:

- **Case 1 (Optimist):** The main goal for this case is to obtain profit and breakthrough the investment as soon as possible. Obtain 20% of the market share by Year 4.
- **Case 2 (Median):** Obtain between 19% and 20% of market share. Achieve cash flow breakthrough until the end of the project.
- **Case 3 (Pessimist):** In this scenario we consider that we can achieve 15% of the market share by Year 5.

7.2.2 Market Dynamics

The size of our market is equal to the number of subscriptions of pay TV in Portugal, approximately 3.1 million people by the end of 2012 [59] .

The market penetration model of the service is based on the logistics curve equation. This equation can be described by:

$$Penetration Rate_{Year} = Initial Penetration + \frac{(Final Penetration - Initial Penetration)}{1 + e^{\alpha + \beta^{Year}}}$$

In this formula α and β represent respectively the delay and the growth speed of the logistics curve.

For this dissertation three different market penetration evolution cases were designed based on logistics curve: optimist, median and pessimist.

	Case 1 (optimist)	Case 2 (median)	Case 3 (pessimist)
Initial Penetration	0.1 %	0.1 %	0.1 %
Final Penetration	20 %	20 %	20 %
α	500	2000	3000
β	- 2	- 1.85	- 1.5

Table 12 – Used values in the calculation of the penetration rates

The values described in the Table 12 above were designed in order that the initial penetration is 0.1% and the final penetration is 20% of the total number of subscribers in Portugal.

The initial penetration value was set to this very small value because in the first year will be dedicated to setup the service and the only few clients who will have access to the service will be selected users and beta testers.

In other hand, the final penetration was set to one fifth of the total number of Pay TV subscribers in Portugal. This value isn't higher value because the objective of gaining 20% of the market share for this kind of service is already highly ambitious.

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Case 1	0%	2%	9%	17%	20%	20%
Case 2	0%	0%	2%	9%	17%	19%
Case 3	0%	0%	1%	2%	8%	15%

Table 13 - Penetration Rate Evolution (percentage)

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Case 1	11979	63276	276152	526761	601026	612727
Case 2	5011	15195	72763	278225	516003	596659
Case 3	3985	7140	20888	75561	233035	449368

Table 14 - Penetration Rate Evolution (Number of Clients)

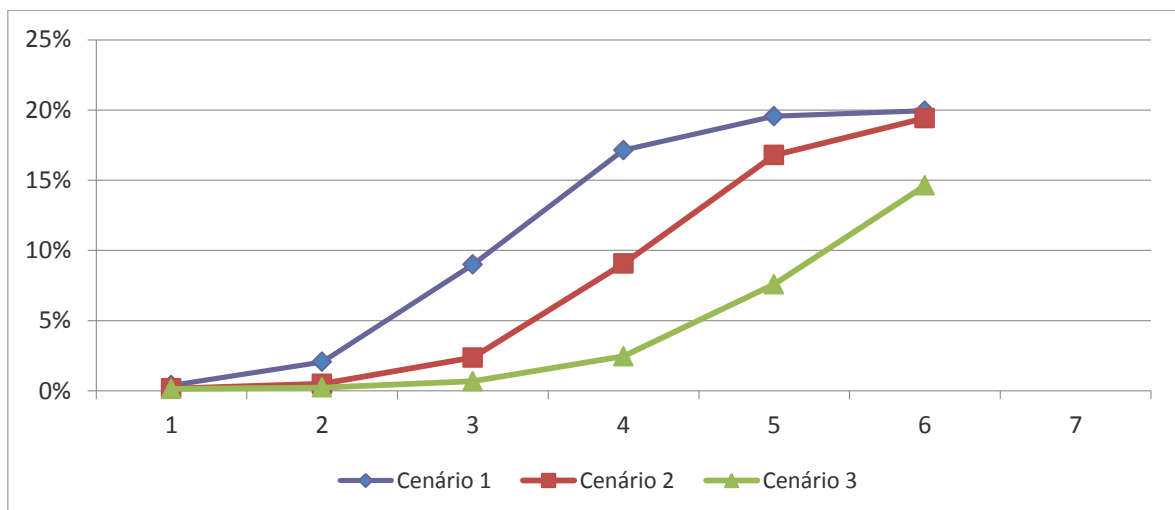


Figure 55 - Market Penetration Rate (Logistic Curve)

In Table 13 and Table 14, it is quantified the penetration rate forecast for the first six years of the project. This evolution is represented in Figure 55.

7.3 Offer, Product and Pricing

The idea of a new and innovative TV product in the Portuguese market would be to offer clients the possibility to optimize the time spent watching TV, by offering them the possibility to watch their favorite content whenever and wherever they want.

In order to deliver the service at the lowest price we need to keep the costs down and we need to cut any costs that are not vital. The price has to be one of the main factors to attract clients to turn down traditional Pay TV operators and move to this service. The other main factor is the anywhere anytime key.

With this platform the client will have total control of costs and will pay only for the content he wants. The client will be able to enjoy the content where he wants and on the consumer equipment he already has.

The product will offer clients the ability to access a catalog of approximately 2800 videos. The service is unlimited because the users will be able to watch the VODs as many times they intend to, on any device and whenever they happen to be.

Service	Price
Unlimited Movies and TV Shows NOT subscribed	20,00 €
Unlimited Movies and TV Shows subscribed	18,00 €
Premium Live Events	5 €
Set Top BOX	45,00 €

Table 15 – OTT Service Pricing table

On Table 15, it is described the assumed pricing table for this service.

Pricing will benefit the clients who will subscribe the service for a minimum period of 12 months, for them we will offer a 2 euro discount per month. For those who are subscribed a bigger discount could be applied if the client would be interested to pay 3 months or more in advance.

The decision to benefit users who are subscribed for a longer period over those who only pay one month without any minimum period of retention, is related with the fact that those users do not guarantee their permanence in the service.

As said in previous chapters, there are many available options to provide the client with a compatible set-top-box. With this equipment the user will be able to use our service in any television. This box will be available for the price of 45 euro and will be completely compatible with our service and will offer exclusive services like the possibility to rent pay-per-view premium events.

This Box will provide the customer the ability to have greater interactivity in its television set, because in addition to access our content, the client will be able to access other services such as games, social networks, web browser, among others.

Premium pay-per-view events will provide the client access to: sport events, like football games (international and national competitions), Formula 1, Boxing Events, or other special events like

concerts. All these could be available to the client upon the payment of a onetime fee per event, which will be priced around 5 Euros.

To quantify the number of customers who will use this service we assumed that only 30%, of our customers who already subscribed our main package, will buy at least one event per year.

7.4 Infrastructure Sizing

7.4.1 Scaling the Catalog

First we need to define the dimension of our catalog offer: we want to offer an unlimited streaming service of Movies and TV shows within a restricted catalog of approximately 2800 videos (assets) where the titles will be each year renewed and added, making the catalog grow at 4% per year. The catalog projection can be resumed in the Table 16 below:

VOD	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Nº TV Shows	40	42	43	45	47	49
Nº TV Shows Assets	800	832	865	900	936	973
Episodes per series	20					
Size of each episode (Gb)	1					
Nº SD Movies	1500	1560	1622	1687	1755	1825
Size of each SD movie (Gb)	3,5					
Nº HD Movies	500	520	541	562	585	608
Size of each HD movie (Gb)	7,5					
Average Catalog Bitrate (Mbps)	1,8					
TOTAL Nº Assets	2800	2912	3028	3150	3276	3407
TOTAL space needed (Tb)	9,57	9,95	10,35	10,77	11,20	11,64

Table 16 – Summary table of asset catalog projections

All the assets were oversized in this estimation.

In order to have a wider offer it was estimated that the catalog should include:

- 40 different TV Shows with each approximately 20 episodes and in average each episode will use 1 Gb of storage. It means that each TV show will represent 20 different assets and occupy approximately 20 Gb. If the average time for each TV episode is 40 minutes, and we encode them at our highest profile 3Mbps, from Equation 1 we get that each file will be 900 Mb.

$$\text{Video Bitrate (bits/sec)} * \text{Asset Duration (sec)} = \text{Total file size (bits)}$$

Equation 1 – Video file size equation

- 1500 Standard Definition Movies, which each asset will use an average of 3.5 Gb of storage. From Equation 1 we've calculated that encoding the file at a SD bitrate of 1.8 Mbps and estimating that each movie will be 4 hours long, the file will be 3.24 Gb.

- And 500 High Definition Movies, which each asset will use an average of 7.5 Gb of storage. With the same equation we've estimated that an HD movie encoded at 3 Mbps and an average duration of 5 hours will occupy approximately 6.75 Gb.

To encode these assets it has been assigned 4 video encoders, which will cost around 10.000€ each. To store all these videos it is going to be necessary approximately 10 Tb of storage in Year 0 and 12 Tb in Year 5. If we need redundancy to not lose any information we will need at least 24 TB of information storage, in Year 5. The investment needed to this storage server should be around 6.000 €.

Catalog evolution through the years:

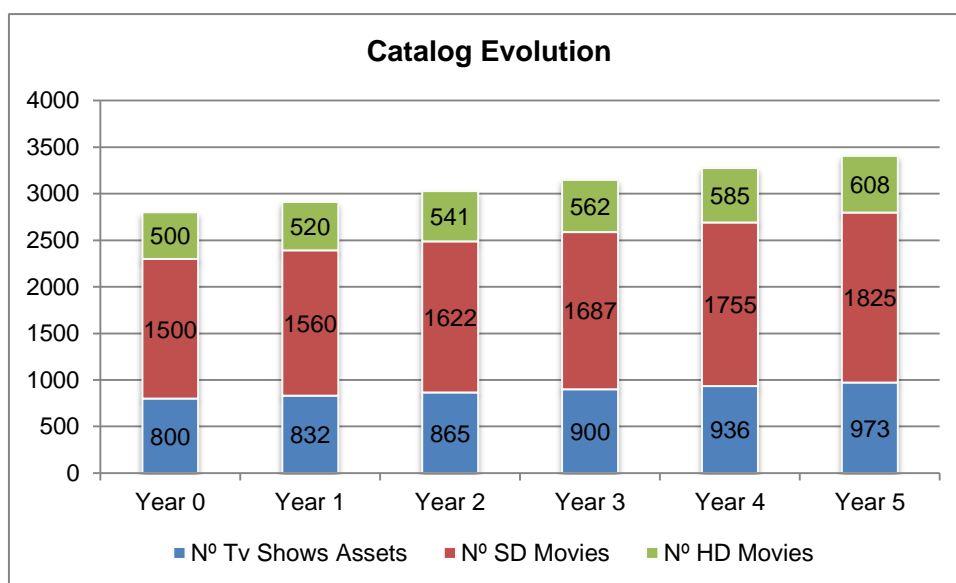


Figure 56 – Evolution of the number of assets in the catalog

It was defined that using an MP4 H.264 codification that the average bit rate of all the assets in the catalog will be 1.8 Mbps.

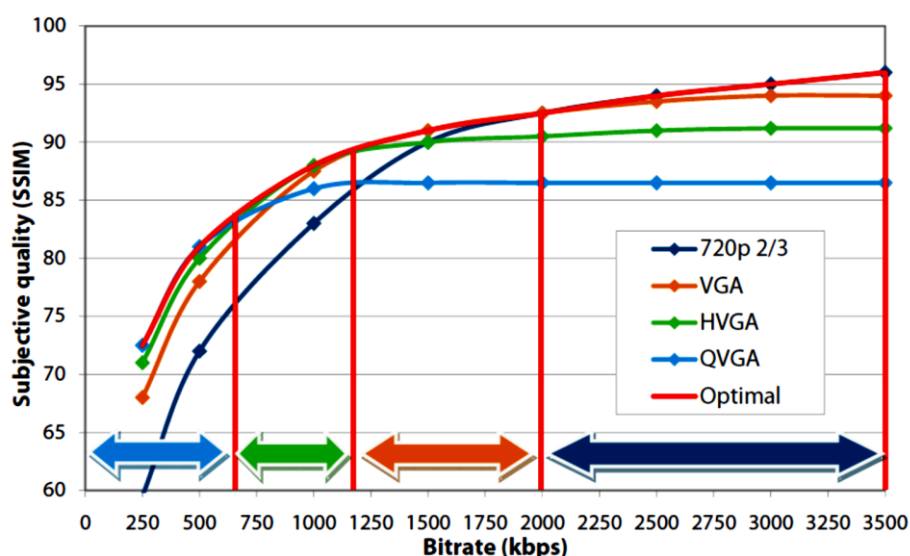


Figure 57 - Optimal resolution for the sequence “Public Television” at various bit rates [60]

Based on Figure 57 we've set three different bitrates for our video assets:

- For 720p HD video we've chosen 3 Mbps.
- For SD quality or VGA: 1.8 Mbps
- And for mobile quality we've chosen the profile between HVGA and QVGA, 600 kbps.

For premium events we will need to provide a live stream service. This service is described in the table below:

Nº Max de streams	10
Average Bitrate (Mbps)	1,8
Number of Encoders	4
Encoder Price (unit)	10.000,00 €

Table 17 – Live Stream service for Premium events description

Assuming that we will never have more than 10 simultaneous live events, it was designed that we will only need to encode and stream 10 live inputs with an average of 1.8 Mbps per stream. The chosen encoder has 4 live inputs and costs approximately 10.000 €. We will need 4 of them because we will need 3 extra inputs for SOS cases.

7.4.2 Data Center and Content Distribution Network

In order to properly achieve the transmission of live and on demand video, using Over The Top technology we will need the following network architecture:

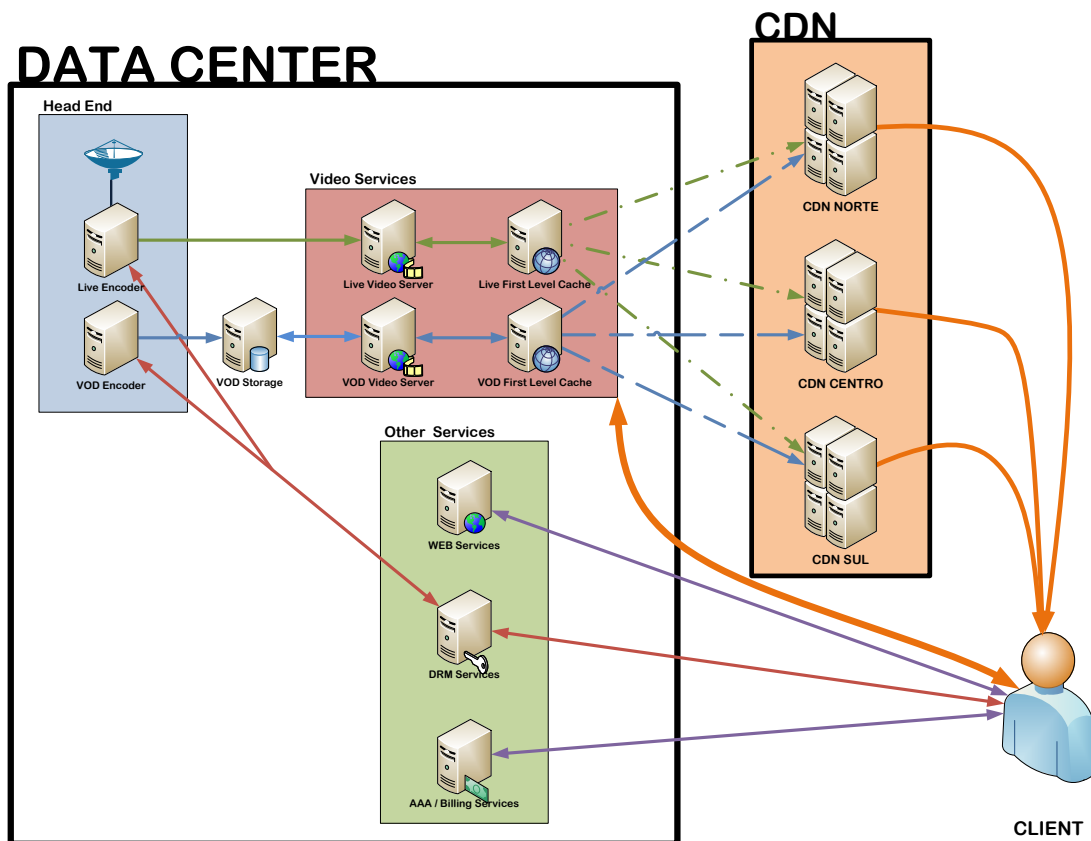


Figure 58 – OTT Video Distribution Architecture

This network architecture design, illustrated in Figure 58, was the result of learning and understanding the common practices in the area and some conclusions from this dissertation proof of concept.

First the live video feed is acquired in the data center's head end and then encoded by a hardware dedicated encoder. The video files are also ingested by another encoder, this one is dedicated to encode only files. All the encoded files are stored in a Data server, called VOD Storage. Both Live and VOD Encoder are connected with the DRM server, in order to include content protection to the assets.

The encoded live feeds are sent to the Live Video Server, that transcodes to video into live OTT streams, these streams are then cached by a First Level Cache who stores the content and distributes the stream upon client's request. If the live feed is one of the most popular, the live stream is replicated and cached into the CDN servers, and then when the client requests a stream it is usually redirected to the closest server to its location.

The same happens with VOD streams, the only difference it is when the clients makes the request to the VOD Video server, it will read the file saved in the VOD Storage Server.

If the streams are encrypted, before the player starts to play the stream it requests the DRM server for the decryption key, in order to decrypt the stream.

All the videos are supported by a website and web based applications. All the web data is stored and accessed via the Web Services server.

The user and billing management is done through AAA servers.

In this case study, AAA/billing servers, Web Services servers and DRM servers are all recorded and counted as Web Servers. And all video and CDN servers are considered as Video Servers.

Data Center Structure description:

All calculations were designed according to the following distribution network architecture assumptions:

Head End		
Server Function Name	Nº	Description
Live Encoder	4	Envivio encoders were chosen for this simulation. Any model in specific was selected, but it has main characteristic 4 Live Inputs. Once we want to stream up to 10 live channels, 4 encoders are needed making 12 Live Inputs. Two live Inputs for SOS.
VOD Encoder	4	Once we are talking of file encoding instead of Live inputs, it was assumed that 4 Envivio Offline encoders were needed to encode the whole catalog and successive updates.
Video Services (For this category applies Concurrency Rate for Video Services)		
VOD Storage	1	To avoid errors or loss of data we need data redundancy, we need to at least double the space needed. Initially, it is estimated that the catalog will occupy approximately 12 Tb and require a server with the capacity to store 24 Tb of data.
Live Video Server	2	These servers will receive the live feeds from the encoders, and prepare the streams for the different streaming technologies.
VOD Video Server	2	They will get the VODs from the VOD Storage Server and stream the content.
Live Cache Server	2	These First Level Cache Servers (FLCs) will be used as a first cache step in the distribution route in order to not overload the streaming servers. They will have the important task to do the content distribution or connection between the Data Center and the Content Distribution Network.
VOD Cache Server	2	
Other Services (For this category applies Concurrency Rate for Web Services)		
Web Services Server	6	These servers will handle all the web services necessary to keep the client's platform running: <ul style="list-style-type: none">• Application Web Services• Web Site Hosting• Image Server• Database Server
DRM Services Server	2	Needed to handle all the DRM key requests from both encoders and clients.
AAA/Billing Services Server	2	Handle all the login, user registration and billing of the platform.

Table 18 - Data Center Structure description

It is important to retain that with the initial configuration we've got 10 servers who will provide streams to the client, 4 cache servers and 6 edge cache servers in total. Each server is connected to a 1 Gbps link, making a total of 10 Gbps of upload. To estimate how many clients we could support with this data center structure we imagined 3 different scenarios:

- Scenario 1: All the clients would receive our lowest profile (600 Kbps), so will have capacity for approximately 1600 clients.

$$\# \text{ clients} = \frac{10 \text{ Gbps}}{600 \text{ Kbps}} \cong 16 \text{ k clients}$$

- Scenario 2: in this case 80% of our clients are receiving our standard profile of 1.8 Mbps. Under these circumstances we could handle about 4400 clients. The other 20% of bandwidth would be used to provide the clients with other profiles.

$$\# \text{ clients} = \frac{10 \text{ Gbps}}{1.8 \text{ Mbps}} \cong 4.4 \text{ k clients}$$

- Scenario 3: if we had 80% of our streams served with our highest profile, we could only handle approximately 2600 clients.

$$\# \text{ clients} = \frac{10 \text{ Gbps}}{3 \text{ Mbps}} \cong 2.6 \text{ k clients}$$

In order to have a reliable distribution we've established that our structure could handle a maximum of 2500 simultaneous streams.

Idealized Content Distribution Network Structure:

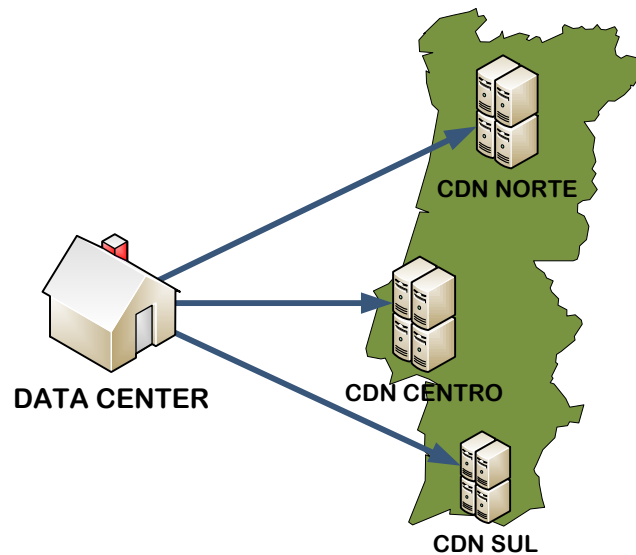


Figure 59 – Idealized location of The CDN Servers in Portugal mainland

To better serve the end user we needed to deploy servers closest to them. It is why for this case study, it was included a Content Delivery Network with 3 edge server bases. Each is initially equipped with 2 servers for redundancy matters.

The distribution of edge server base was made according to the demographics of the country:

- **“CDN NORTE”**: will handle the population of the north of Portugal, somewhere between 3.6 and 3.7 million people;
- **“CDN CENTRO”**: will handle the population of center of Portugal, approximately 2.3 million people;
- **“CDN SUL”**: will handle the populations of the Lisbon, Alentejo and Algarve area with a total of about 4 million people [61].

These Servers will be needed to cache the most requested contents closest to the client, it will decrease the load of the data center and will reduce the access time to the most requested video services. They will be served and connected to the Data Center through the FLC servers.

All the CDN servers are hosted in colocation within other operators' data center. Thereby we save space rental costs and electricity costs since this are included in the colocation rents.

For this study only video services will benefit from content caching because they are the main subject. Web services could also benefit from some levels of caching either in the CDN network or in the data center, but such subject wasn't studied.

In order to design and scale a data center and an infrastructure capable of delivering the best Quality of Service to the end user it was imperative to know one key value: how many streams the servers needed to handle simultaneously.

Assuming that this value will be the maximum streams our infrastructure will handle at its busiest hours, this value will be calculated from the rate of simultaneous clients accessing to the service at the same time, or concurrency rate.

For this case two concurrency rates were set: one for Video Services and another for Web Services.

To make the study more accurate and adjust the concurrency rate through the years, a slack of the concurrency rate was set. Thereby it is possible to make a fine adjustment of the concurrency rate over the years of the project.

7.4.2.1 Concurrency Rate for Video Services

The Concurrency Rate (CR) represents the maximum number of users who can access the service at the same time. It is a percentage of the total number of users in each year. Because video services need more server time, and consume high quantities of bandwidth the Concurrency Rate for Video Services is the key value of this study. Higher the concurrency rate more servers and more bandwidth will be needed to serve more clients at the same time. This value will directly influence the company's cash flow.

One of the first conclusions of this analysis is that the concurrency rate had a direct effect on the Cash Flow of the company. It means that if the concurrency rate is higher it will be required to handle more clients, consequently a bigger infrastructure will be needed and it will be necessary more investment.

In order to set this value in 6%, a "fine tuning" was done to find this value. Once this value as a direct influence in the Cash Flow and we wanted to breakthrough in case 2 around Year 5, we did a sensitivity analysis of the concurrency rate with the influence it has over the Cash Flow.

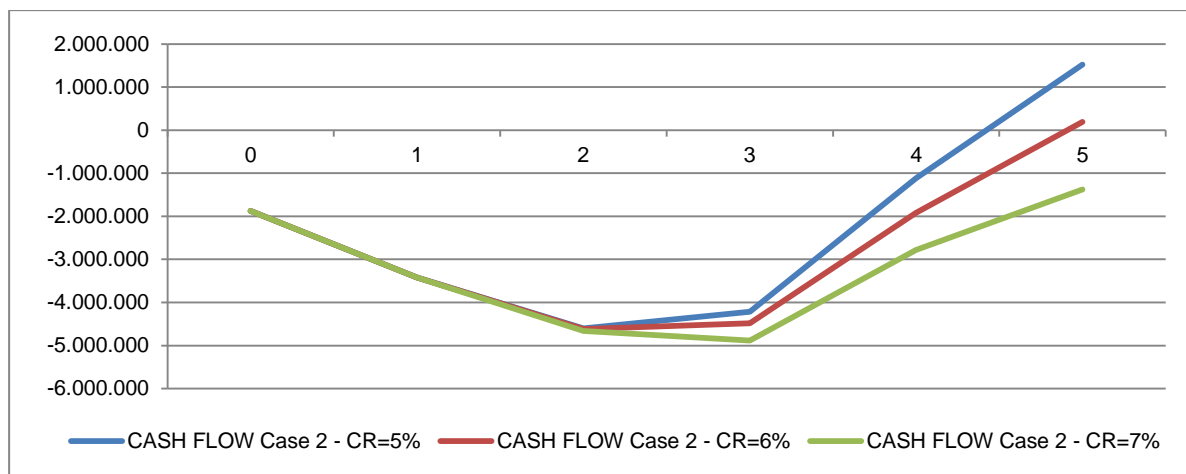


Figure 60 – Sensitivity Analysis of the Concurrency Rate

Since the goal was to breakthrough in Case 2 around the fifth year, we've concluded that the best concurrency rate suitable was 6%.

7.4.2.2 Concurrency Rate for Web Services

This rate was set to 2% of the total number of clients subscribed. This percentage of clients was set to a lower value than the rate for Video Services because the access to these services, even though it is done more frequently, it is faster and for short time periods allowing the system to handle more connections.

7.4.3 Costs and Other Assumptions

After extensive research the following cost assumptions were made:

Name	Cost	Description
Server Price Unit	7500 €	Price equivalent to HP or DELL Blade Servers
Wowza Media Server Licensing Cost per server	800 €	Licensing Cost per server. Used in all Video, FLC, and CDN servers.
Power Price (Kw/h)	0,10 €	Medium rate for power found Bibliography
Rent Cost per Server Rack per Year	12000€	Cost per year to rent a Rack Space in another's operator data center, including power cost.
Cost per 1 Gb/s Bandwidth Link per year	72000€	Yearly cost per gigabit link rented from a network operator, to connect the data center to the Internet.

Other assumptions:

- Each rack has 16 servers;
- Each rack consumes 22 Kw/h
- Every 3 years the Server Park is changed. Due to the evolution of the technology, continuous improvement of the processing capacity of the machines and their decreasing price. It was considered a re-investment every 3 years of 45% of the initial investment, to maintain and replace some of the machines.
- All the initial number of servers described in the architecture above, were calculated assuming that they could handle approximately 2500 streams.

7.4.4 Stream and Cost Distribution

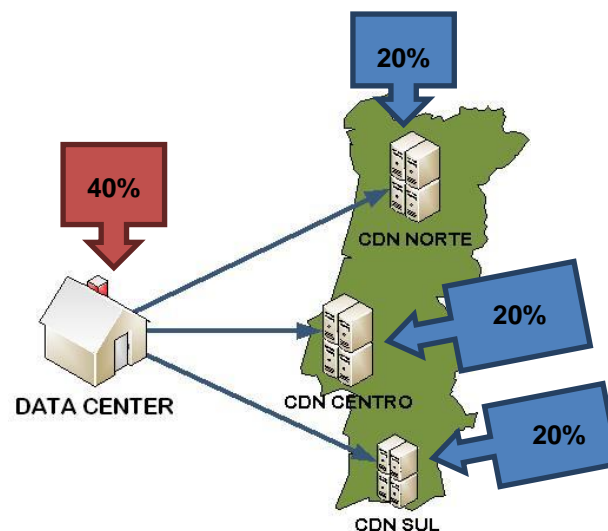


Figure 61 – Stream Handling Distribution

As represented in Figure 61, the following stream or server load was set:

- 40% of the whole video traffic would be handled by the Data center

- And each CDN edge cache would handle 20% of the video streams, making in total of 60% the traffic handled by the content distribution network.

In overload case of any CDN edge cache, the requests would be handled by the Data Center.

7.4.4.1 Case 1

Since the number of streams is directly proportional to the number of clients of each case scenario, we need to estimate how many streams and web requests we will need to handle recurring with the previously set concurrency rate for video and web services. These calculations were made recurring to Equation 2 are outlined in Table 19.

$$MaxStream = MaxRq = (NumClients \times ConcurrencyRate) \pm Slack$$

Equation 2 – Maximum Stream

	CR	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Number of Clients		11979	63276	276152	526761	601026	612727
Slack		1%	-2%	-5%	10%	-2%	3%
Maximum Number of Streams (MaxStreams) for Video Services	6 %	726	3721	15741	34766	35340	37867
Maximum Number of Requests (MaxRq) for Web Services	2 %	242	1240	5247	11589	11780	12622

Table 19 – Maximum number of connections to handle in Case 1

According to the previous assumptions the distribution the number of maximum number of connections to handle by the data center and each node of the CDN is resumed in the graphic below:

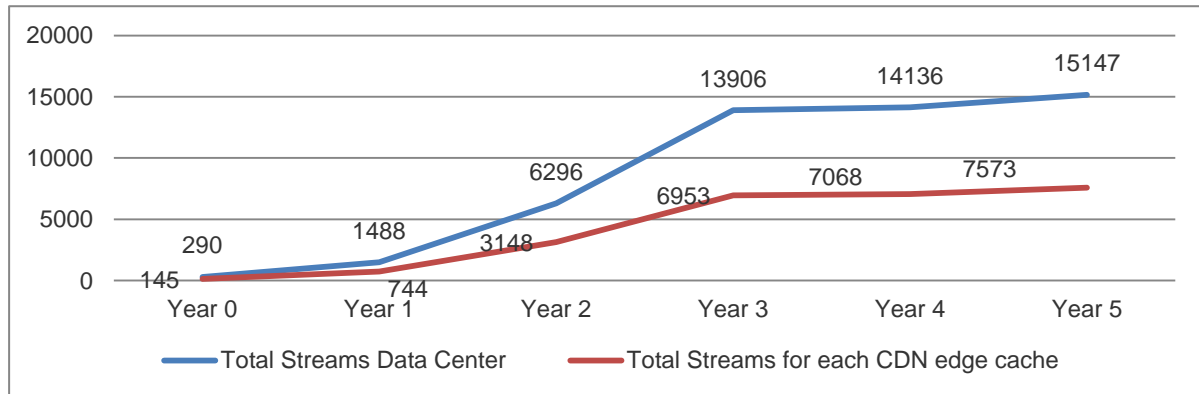


Figure 62 – Total Streams to handle in Case 1

To calculate the number of servers needed for each type or service and for each entity, the following:

$$NServers = ROUNDUP\left(\frac{ANS \times TMS}{AMS}\right)$$

Equation 3 – Server number estimation

Equation 3 is applicable to estimate the number of servers for both Data Center and CDN, and the number of each variable will depend directly from the values of each year. The variables description is:

- NServers: Number of servers needed to handle the number of streams required.
- TMS (Total Max. Streams): Number of streams required to be handled at the same time by the specific distribution instance it can be done by a cache server or edge cache server.
- ANS (Assumed Needed Servers): this number was previously assumed in the initial data center structure projection.
- AMS (Assumed Max. Streams): number of streams estimated to be handled by the initial data center structure.

Using this equation we can estimate and project the number of servers needed by each instance in the data center structure according to the years of the project. This evolution is based on the growth of the number of clients of the project.

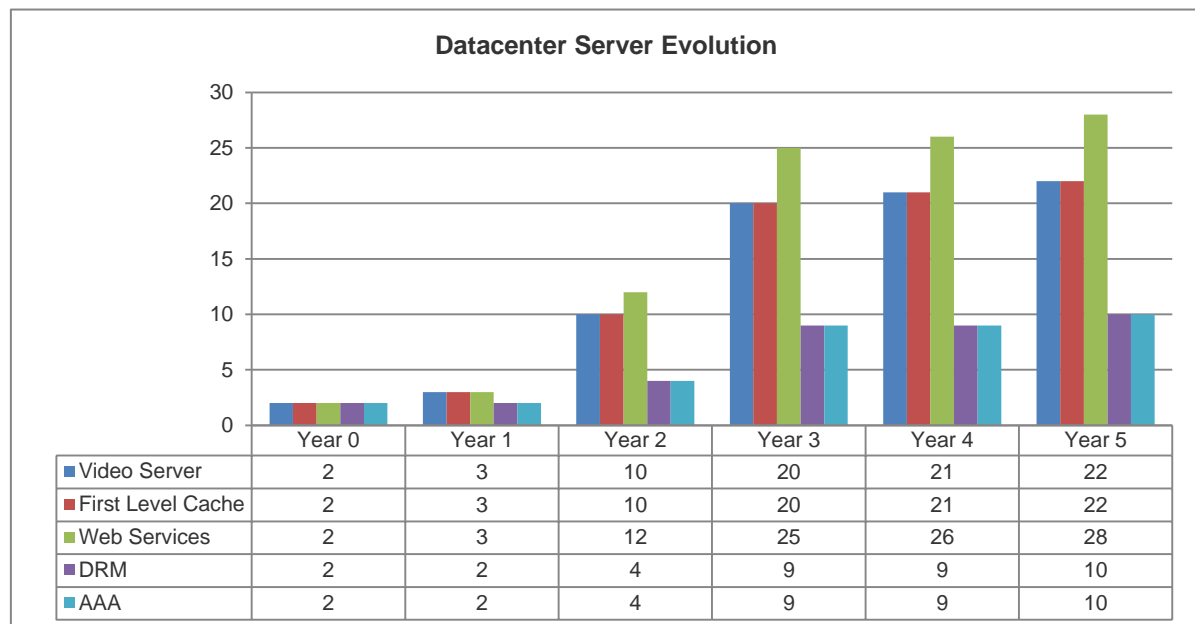


Figure 63 – Data Center Evolution in Case 1

We can see that due to increasing number of clients through the years, we will need to increase the number of servers. The most requested servers and those which the number will be increased each year are: Video Servers, First Level Caches and Web Services servers.

The same evolution can be seen in the each edge cache base of our CDN:

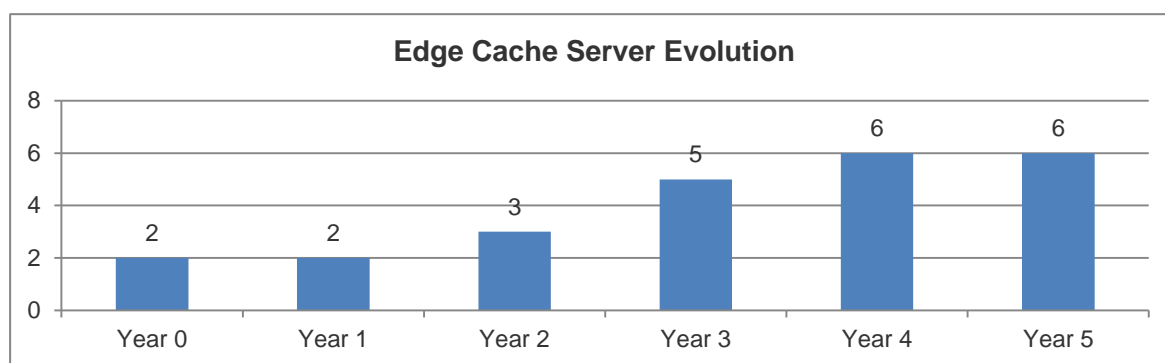


Figure 64 – Edge cache server evolution in Case 1

The evolution of each edge cache is the same once they are handling each the same percentage of streams (20% each).

The overall number of servers needed in this scenario is resumed in graph below:

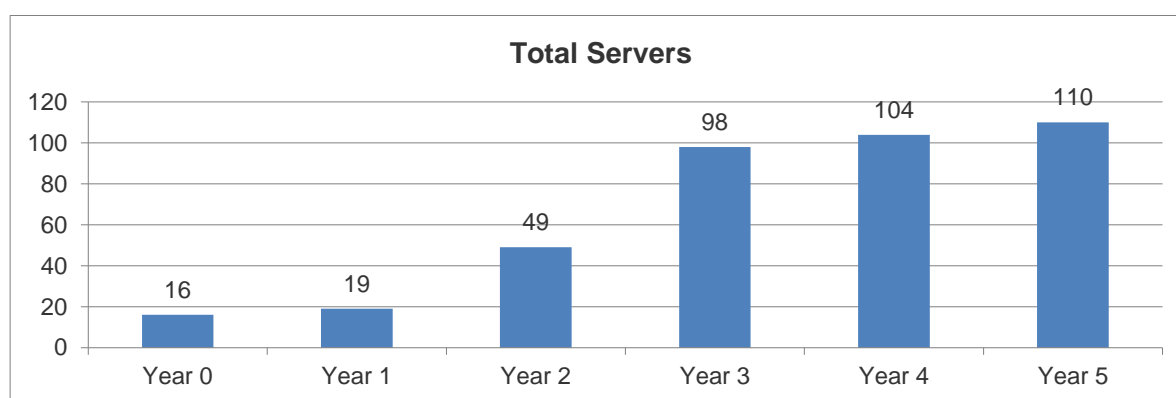


Figure 65 – Evolution of the total number of servers in Case 1

Using the assumption that the average bitrate of each stream is 1.8 Mbps and multiplying by the number of streams handled by each entity in the Infrastructure, it is possible to simulate the average output bandwidth evolution needed for the service.

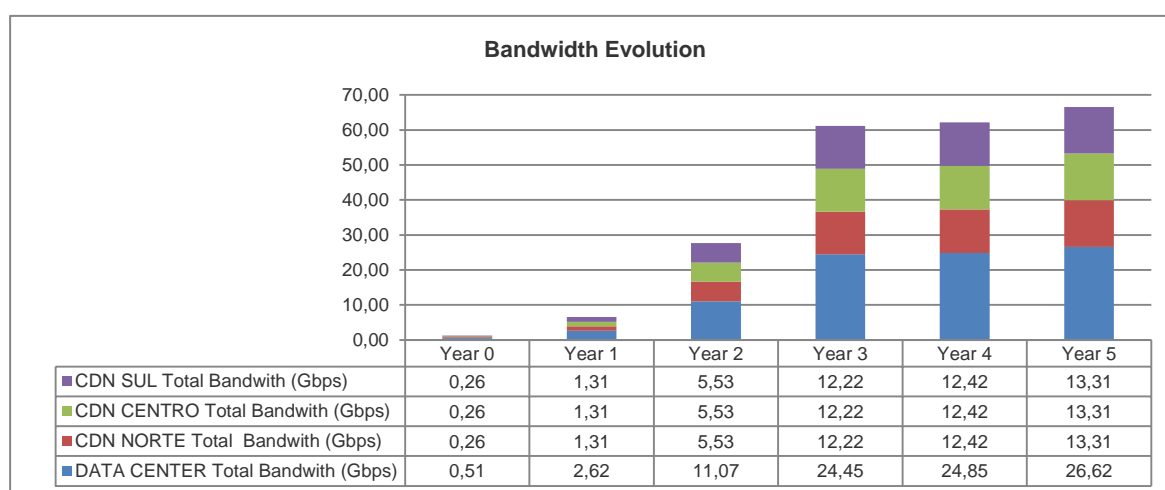


Figure 66 – Bandwidth evolution of the distribution network in Case 1

All these data involves costs, server units, bandwidth allocation, colocation rent, power consumption and licensing costs for server software. The Infrastructure costs are resumed below:

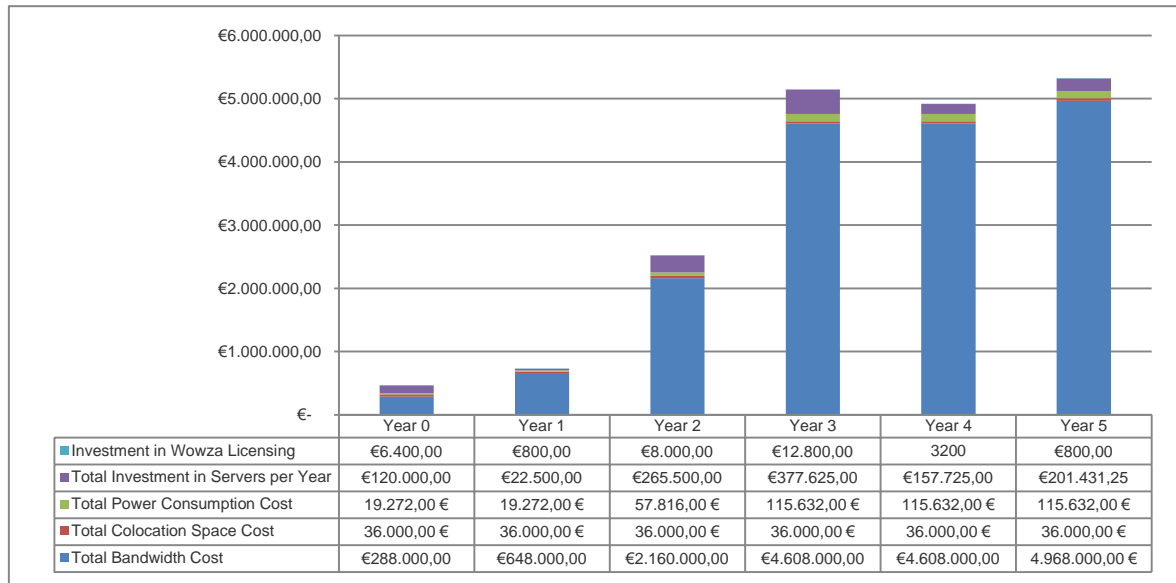


Figure 67 – Total costs involved in the distribution network in case 1

From the data above we can conclude that the largest part of our costs come from the cost of bandwidth usage.

7.4.4.2 Case 2

This case scenario is based on the same assumptions than Case 1, but it depends on the number of clients from Case 2.

For this scenario and using Equation 2 we've estimated the number of maximum streams to be handled in Table 20.

	CR	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Number of Clients		5011	15195	72763	278225	516003	596659
Slack		1%	-2%	-5%	10%	-2%	3%
Maximum Number of Streams (MaxStreams) for Video Services	6 %	304	893	4148	18363	30341	36874
Maximum Number of Requests (MaxRq) for Web Services	2 %	101	298	1383	6121	10114	12291

Table 20 - Maximum number of connections to handle in Case 2

The maximum number of streams to be handled from the data center and CDN network in this case scenario is showed in Figure 68.

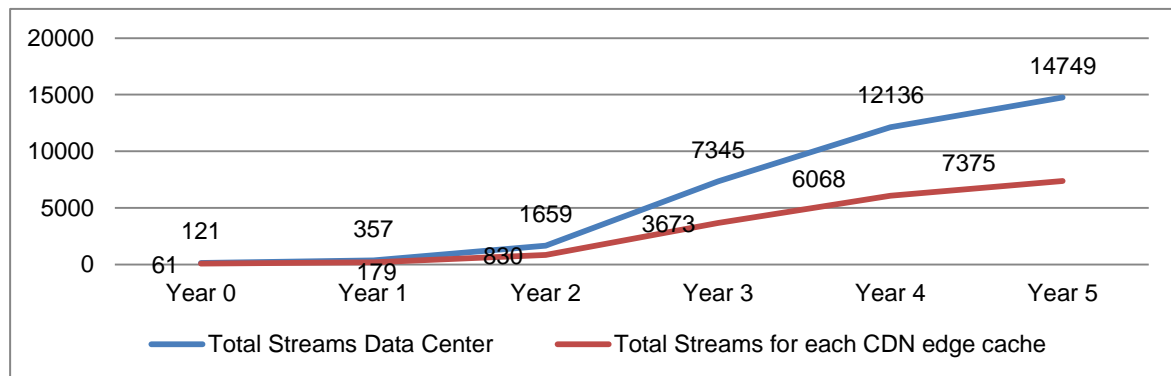


Figure 68 - Total Streams to handle in Case 2

Having a different number of clients in this case we will get different evolutions in the number of servers and amount of bandwidth needed in the distribution network. These evolutions numbers are summarized in Figure 69 and Figure 70. The total costs involved in the distribution network of Case 2 are showed in Figure 71.

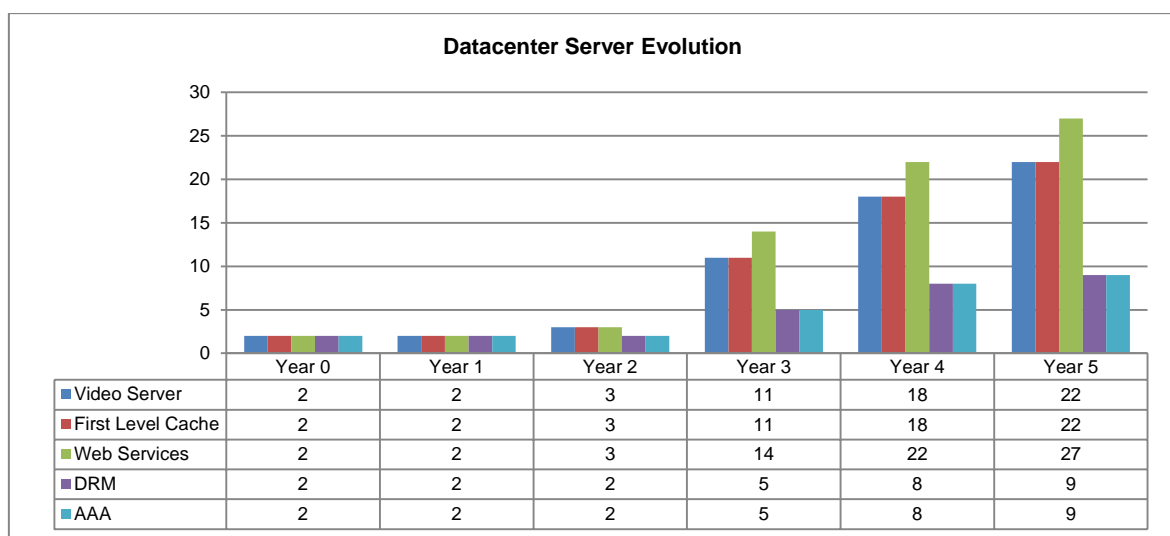


Figure 69 - Data Center Evolution in Case 2

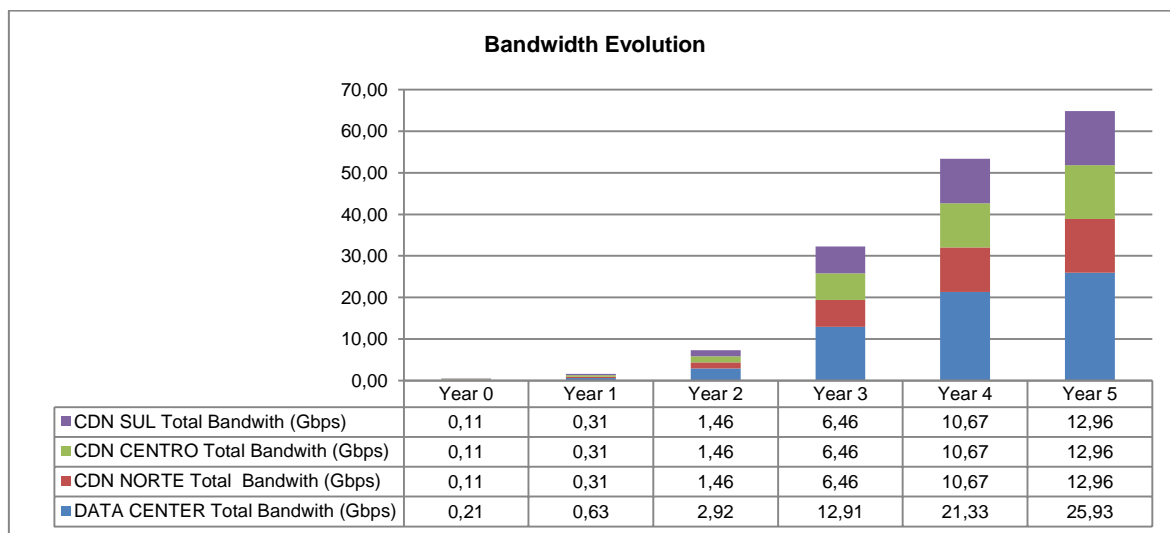


Figure 70 - Bandwidth evolution of the distribution network in Case 2

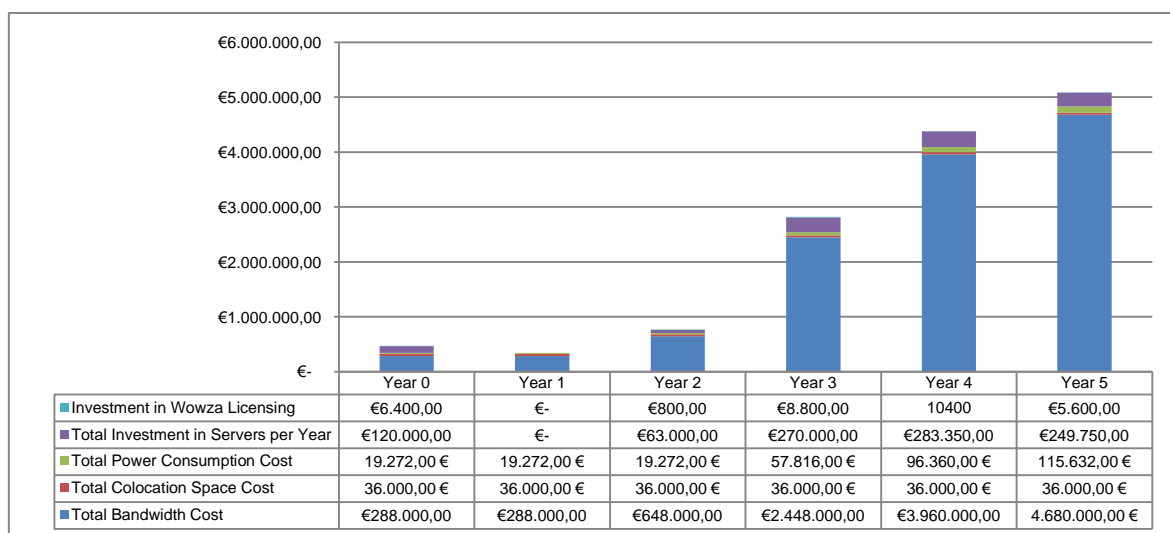


Figure 71 - Total costs involved in the distribution network in case

7.4.4.3 Case 3

Case 3 is based on the same assumptions than case 1 and 2 but has a different penetration rate in the market than other cases.

Using Equation 2 we've estimated the number of maximum streams to be handled in Table 21.

	CR	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Number of Clients		3985	7140	20888	75561	233035	449368
Slack		1%	-2%	-5%	10%	-2%	3%
Maximum Number of Streams (MaxStreams) for Video Services	6 %	242	420	1191	4987	13702	27771
Maximum Number of Requests (MaxRq) for Web Services	2 %	81	140	397	1662	4567	9257

Table 21 - Maximum number of connections to handle in Case 3

In Figure 72 it's represented the maximum number of streams that has to be handled from the data center and the distribution network.

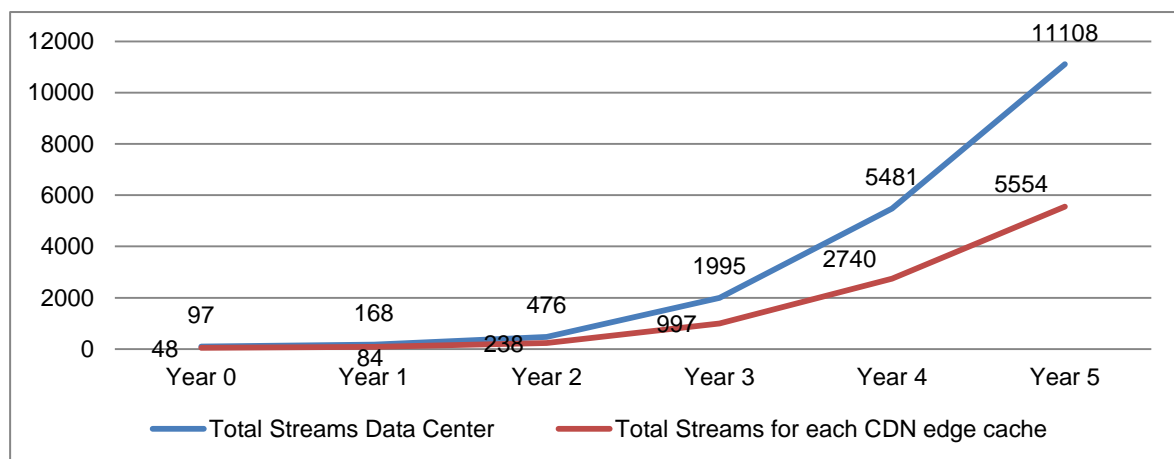


Figure 72 - Total Streams to handle in Case 3

The evolution of the infrastructure and the bandwidth needed in this case is summarized in Figure 73 and Figure 74. The costs involved are showed in Figure 75.

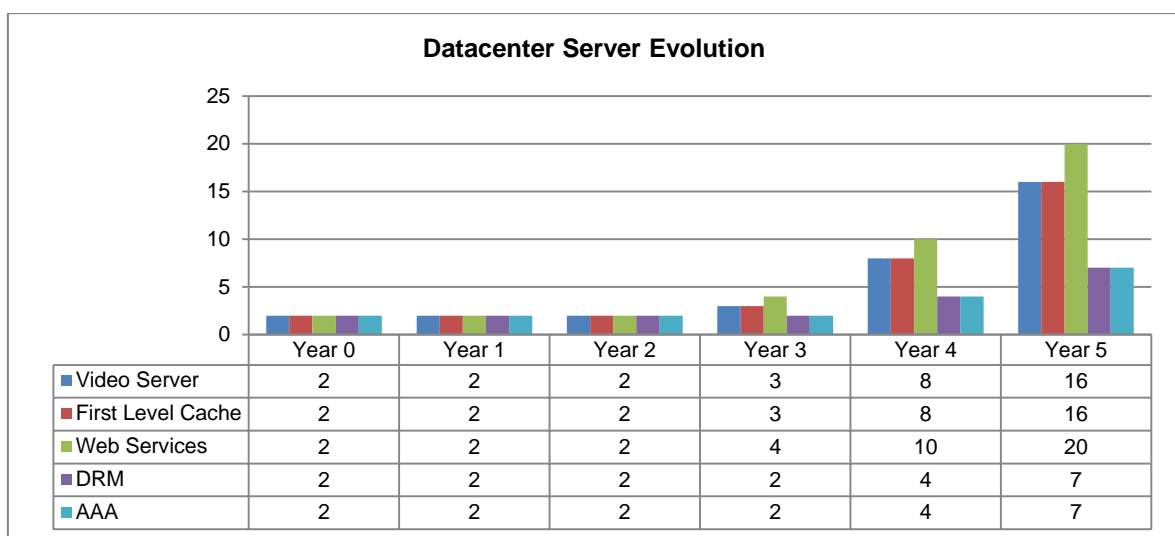


Figure 73 - Data Center Evolution in Case 3

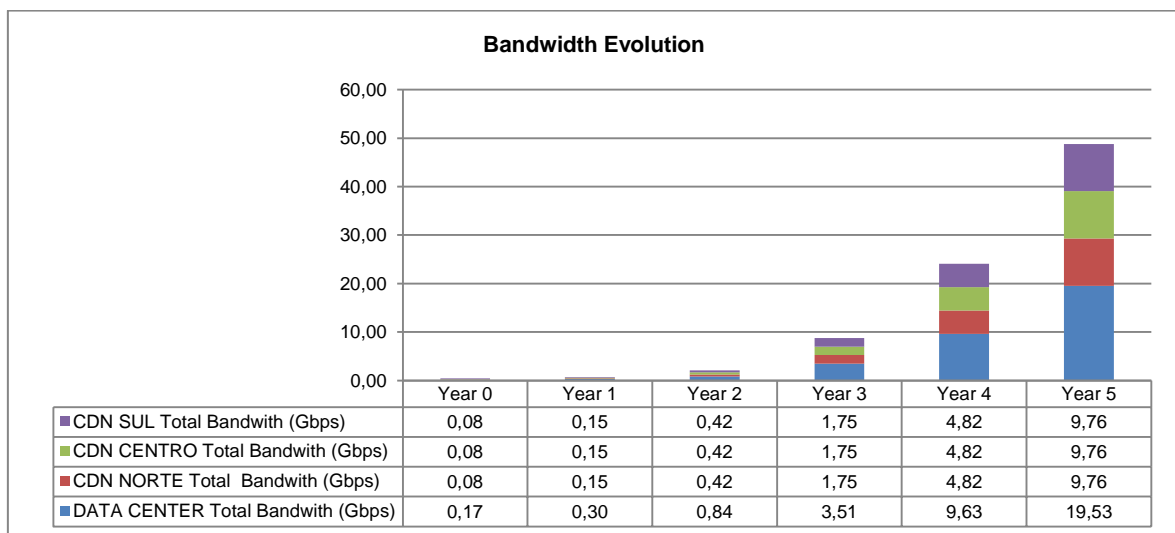


Figure 74 - Bandwidth evolution of the distribution network in Case 3

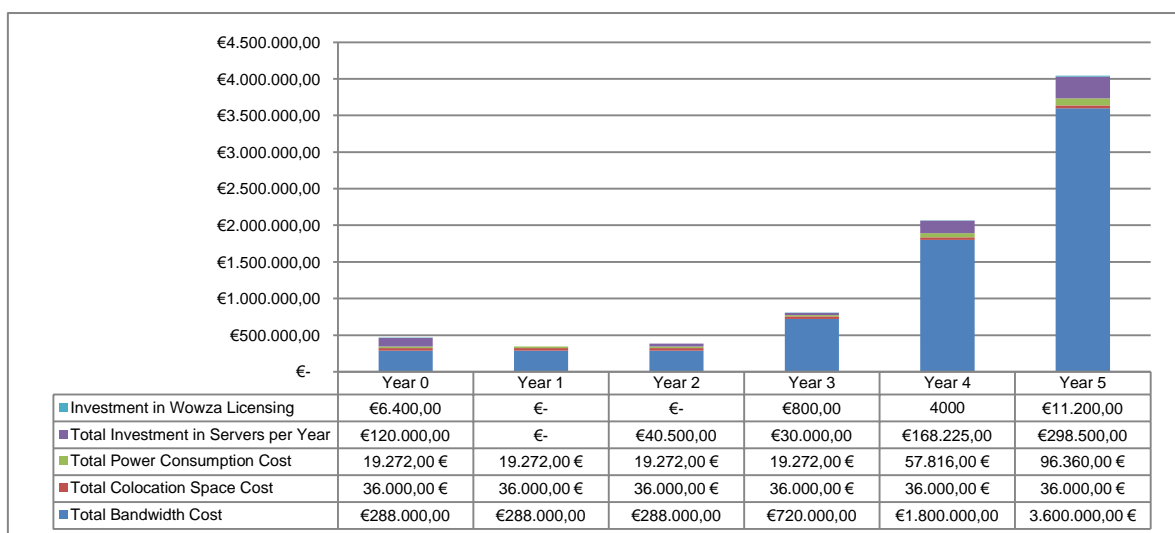


Figure 75 - Total costs involved in the distribution network in case 3

7.5 CAPEX – Capital Expenditure

7.5.1 Investments in Case 1

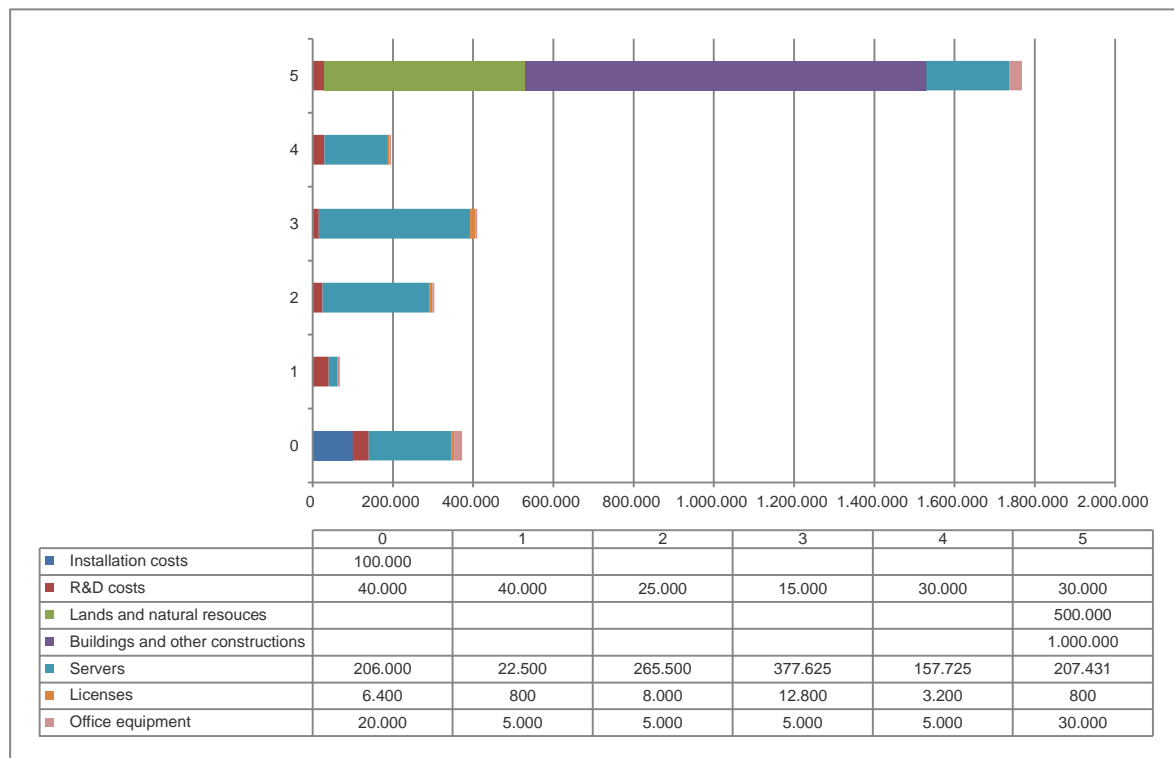


Figure 76 – Investments in case 1

The main company's investments are composed by:

- **Installation Costs** in order to start our company and take care of all the costs associated in that process, 100.000 € will be invested.
- **R&D costs**, in this field it's crucial to always be updated and keep up with technology advances. It is why a total of 180.000€ will be invested in Research & Development projects associated with Universities and Research Institutions, over the 6 years.
- **Servers and Licenses**, the investment values calculated in the previous subchapter - Infrastructure Sizing - were considered here.
- **Office equipment**, this investment includes essentially office equipment and supplies. However in the beginning of the company it is mandatory a larger investment, especially to purchase furniture and electronic equipment.
- **Lands and natural resources and Buildings and other constructions**, in the fifth year, the company became profitable and as a last step 1.500.000€ will be invested to build new headquarters.

7.5.2 Investments in Case 2

The Figure 77 refers to the investments costs in case 2.

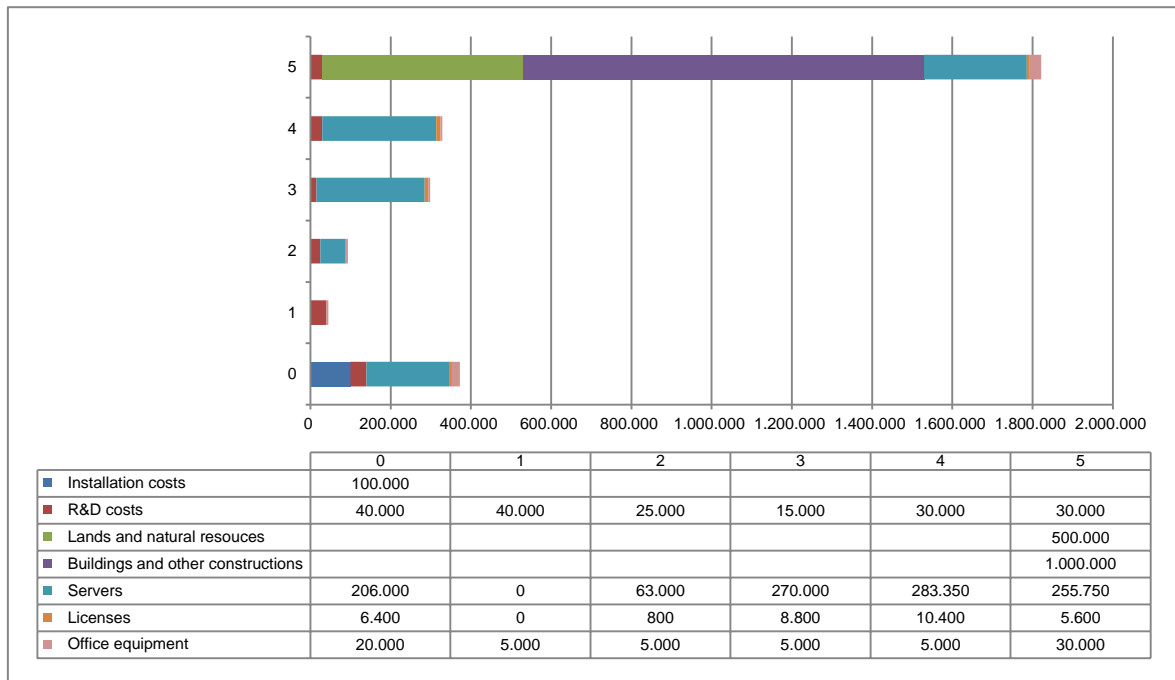


Figure 77 - Investments in case 2

7.5.3 Investments in Case 3

Case 3 has the same kind of investments than the other cases, but we've obtained different values of investment for Servers and Licenses, because these values depend directly from the infrastructure sizing of each case. These values are summarized in Figure 78.

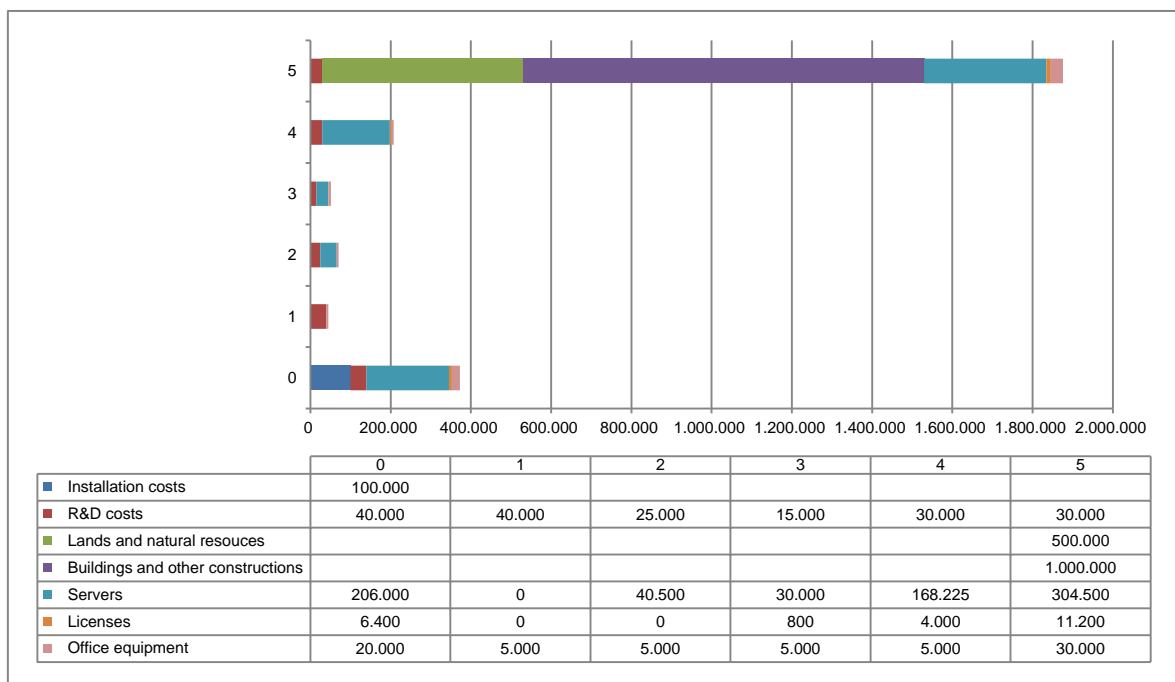


Figure 78 - Investments in case 3

7.6 OPEX - Operational Expenditure

7.6.1 Main Expenses

For Case 1 we've obtained the following graphic:

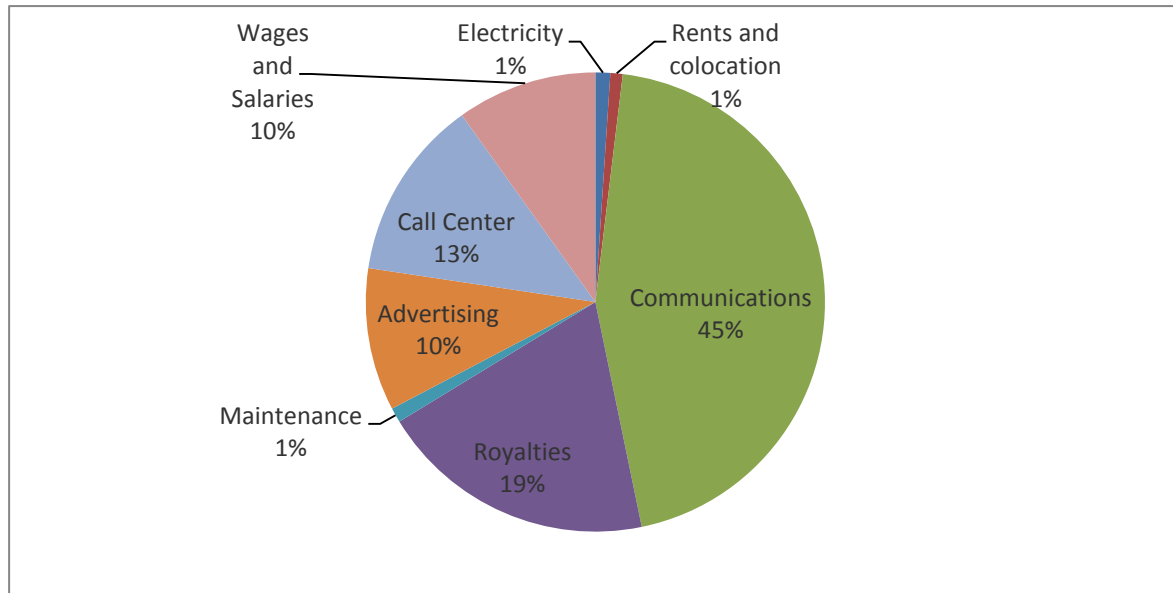


Figure 79 – Costs in supplies and external services in Case 1

7.6.1.1 Electricity

The service provided by this startup is based on an infrastructure of many servers/machines. These consume high power and are continuously working, which need to be in highly ventilated places with air coolers that have high energy consumption. The power consumption of the infrastructure was estimated in the previous sub-chapter.

The expenses with power consumption represent approximately 1% of our total expenses, in Case 1.

7.6.1.2 Rents and Colocation

Rent and colocation expenses include the previously calculated value of colocation space cost and the rent for the data center space.

Colocation is seen as a way to save money because the power costs are included in the monthly fee, and we save money renting a new space. Monthly fee is around 1000€ per rack. Making a total of 12000€ per year/rack.

Space must be rented to accommodate our data center, the amount of € 5,000 was expected for this purpose.

These expenses represent approximately 1% of our total expenses in external services.

7.6.1.3 Communications

Buying bandwidth allocation to external operators represents the largest portion of our costs, more than 50%, in Case 1.

This company directly depends from bandwidth allocation services this can become a major issue because:

- If operators do not provide their service according to the SLA's agreed, our service will be hampered.
- If operators fear the competition they can also cut our service or increase their price not allowing the company's sustainability.

7.6.1.4 Royalties

In order to ensure compliance with copyright and trademarks of content providers, it was estimated from Netflix Annual Reports, that 15% of provided services revenues would revert to content holders. This expense represents about 22% of our total costs, in Case 1.

7.6.1.5 Maintenance

In order to ensure maintenance of our equipment in the CDN and the data center, it was estimated that 10% of our investment in servers would be spent to their maintenance.

7.6.1.6 Advertising

Once this company has a low cost philosophy and the contact with the customer is made only through telephone and Internet it is why advertising has a very important role for the success of this company.

A share of 11% of our total costs (Case 1) will be invested in social media and happenings:

- Social Media, most of our costs will be invested on "Clicks" from ads on Google and Facebook; they are the main players in this market, beyond the fact that they are the platforms with the largest number of users in our geographic target area.
- Happenings, i.e., creative and social based events, with low investment and focused on the characteristics and interests of our clients with the goal of making social buzz.

7.6.1.7 Call Center

To the call center service, we need to ensure that we have the capacity to serve our customers when technical problems arise.

Thus, given an operator who works 7 hours per day (8 hours with lunch break), 5 days per week and 50 weeks per year, will work 105,000 minutes per year.

Considering that each call will have an average duration of 10 minutes (3 minutes with the client back office + 7 minutes), and that each customer will do three call per year, in Year 0 we will need

to handle 359358 minutes. Dividing this figure by the number of minutes that each employee works, this result will give the number of employees needed in the Call Center.

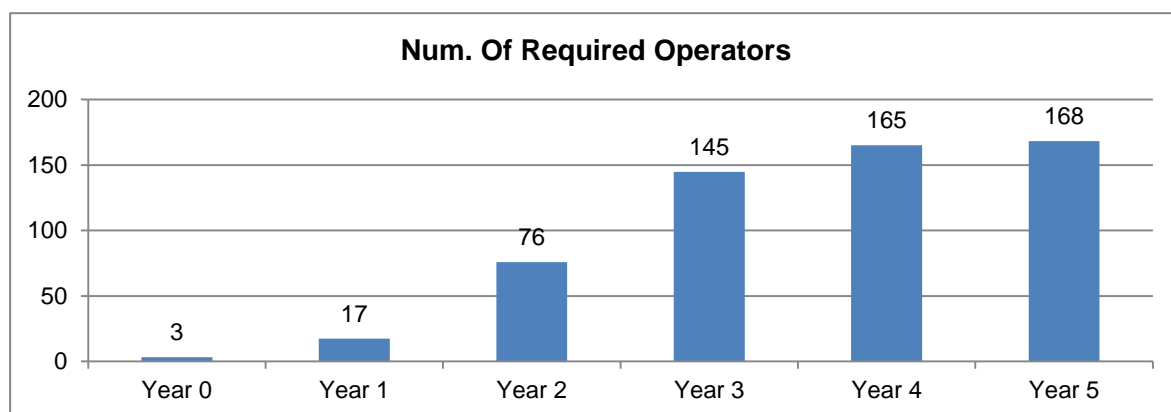


Figure 80 – Call Center, number of required operators in Case 1

That said, the number of required employees to run our data center is resumed in the Figure 80. Considering an average monthly payment of € 600 per employee, we have the human resources cost of running this call center. The Figure 81 resumes the costs of the data center per year:

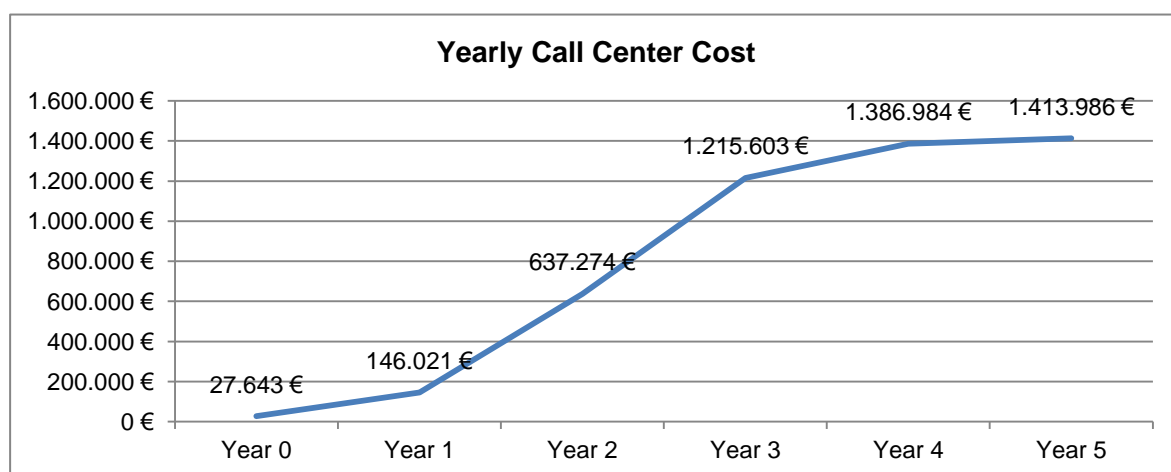


Figure 81 – Call Center yearly costs in Case 1

7.6.2 Other Expenses

Though less significant, other costs are considered in this study:

- **Work related travel Expenses:** to allow the company to promote the product, attract new investors and negotiate new contracts inside and outside our borders, it was estimated a budget of 5,000€ per month to cover travel expenses.
- **Insurance:** Due to continuous investment in new technology, it becomes very important that the entire property is insured. To prevent from theft, fire or any other type of event that could damage the company in significant amounts, an amount of 500€ per month will be spent to ensure company's property.

- **Merchandise Transport:** since the box bought and made in china will be shipped to our country through sea and then shipped to our client via national mail carriers, 6,000€ per month were set aside for this purpose.
- **Legal Expenses:** for legal and judicial issues, these services will be outsourced to law firms and service providers in these areas, so we assume an expense of € 200 monthly to cover these charges.
- **Cleaning and Security:** For basic cleaning services 200€ per month will be spent. Security and surveillance is an important factor for this kind of companies, the high value of owned and installed electronic equipment can be an attractive target for thieves. In addition it is necessary to guard the equipment from possible sabotage attempts. For this purpose an average of 2,000€ per month will be spent in security and surveillance installations. This figure includes the salaries of three security guards, who take turns so that the facilities are never empty, and a video surveillance system.

7.6.3 Wages and Salaries

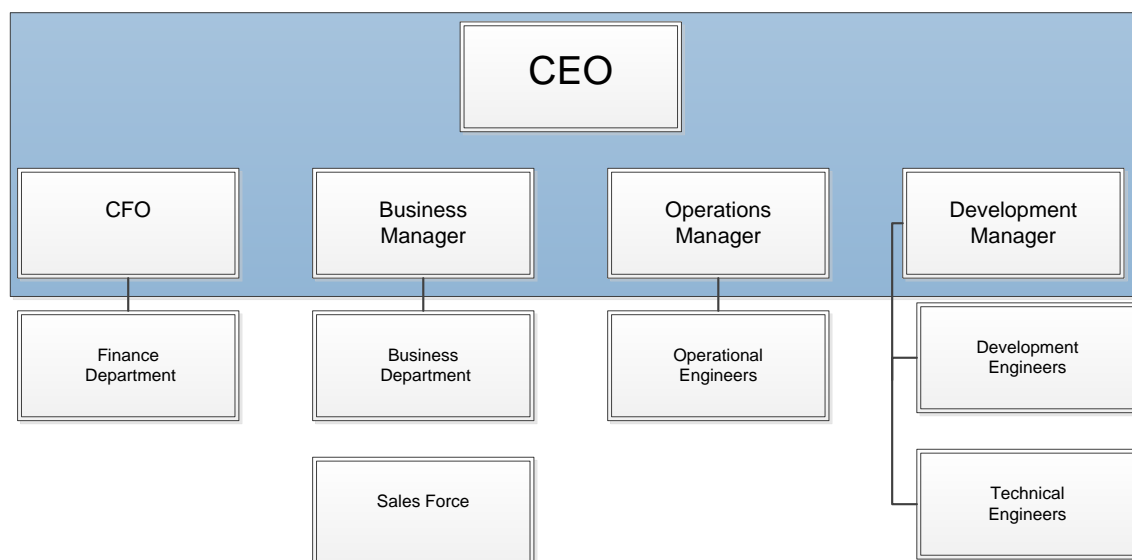


Figure 82 – possible Company's organizational chart

Our company will be initially formed by administration board, technical, operational, business and financial staff.

The administration board will be composed by:

- Chief Executive Officer (CEO)
- Chief Financial Officer (CFO)
- Business Manager
- Operations Manager
- Development Manager

Each member of this board will earn a monthly income of 1,500 € gross.

The staff will be composed by:

- **Technical Engineers** (Number of employees: 4) in charge of planning, integrate and test the platform;
- **Operational Engineers** (Number of employees 6) will be responsible to oversee and monitor the platform operation;
- **Development Engineers** (Number of employees: 15), they will develop the server side platform , the set-top box platform and the different client applications for the multiple CPEs most popular in the market;
- **Business and Finance** (Number of employees: 8), responsible of financial accounting and business management of the company.

All the above employees will earn 1,000 € per month.

It is also necessary commercial and sales force, to make contacts and attract new customers to our services. Thus, it was planned a team of 5 persons in year 0, value that will grow in subsequent years in accordance to the turnover of the company. Thus, we consider an increase of the sales members to 15 vendors in year 1 and 20 sellers from year 2.

7.6.4 Case 2 and 3 Costs Summary

In Case 2 and 3 they were considered the same costs than in Case 1 but since they directly proportional to the penetration rate in the market, we've obtained different results. Those results are summarized in Figure 83 and Figure 84 respectively.

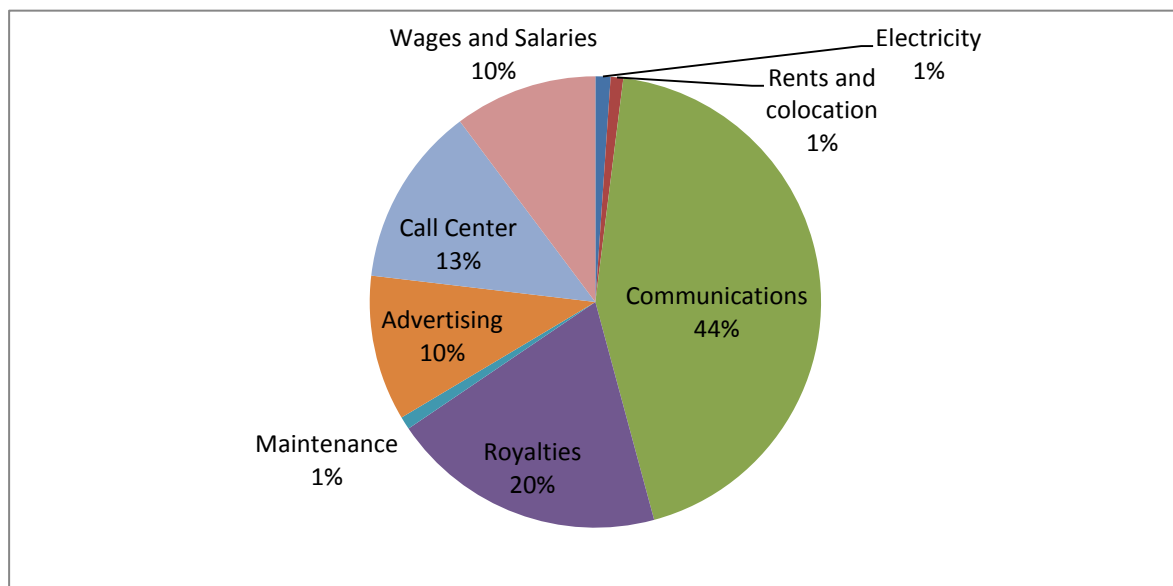


Figure 83 – OPEX Summary in Case 2

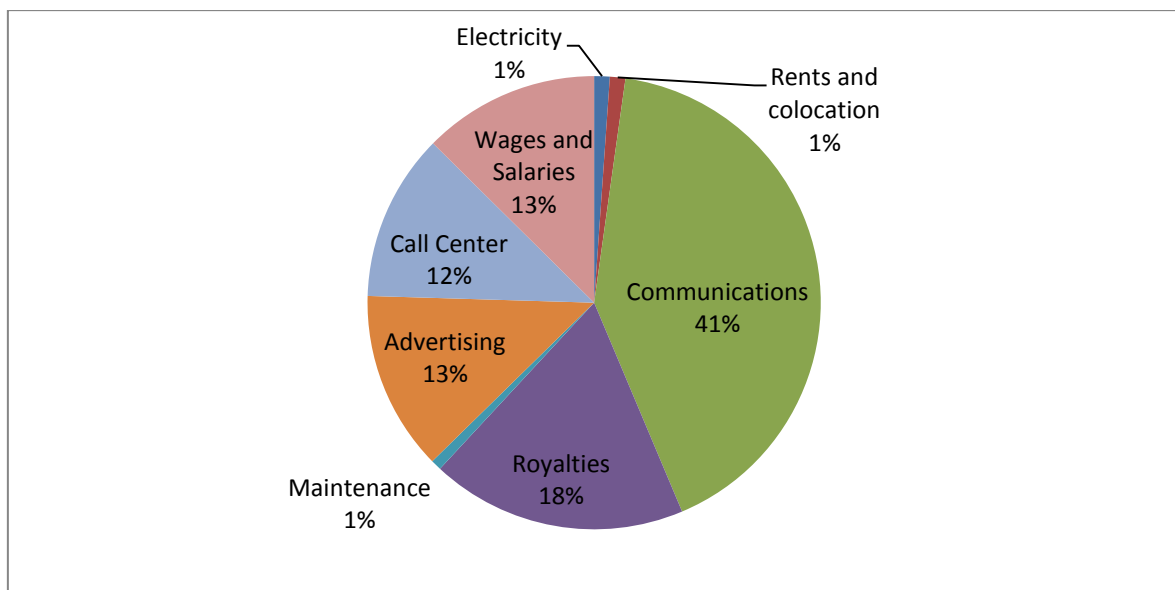


Figure 84 - OPEX Summary in Case 3

7.7 Financial Balance and Cash Flow Results

7.7.1 Case 1

Since this is a technology based startup in the Pay TV business, it will need a large initial investment to get started.

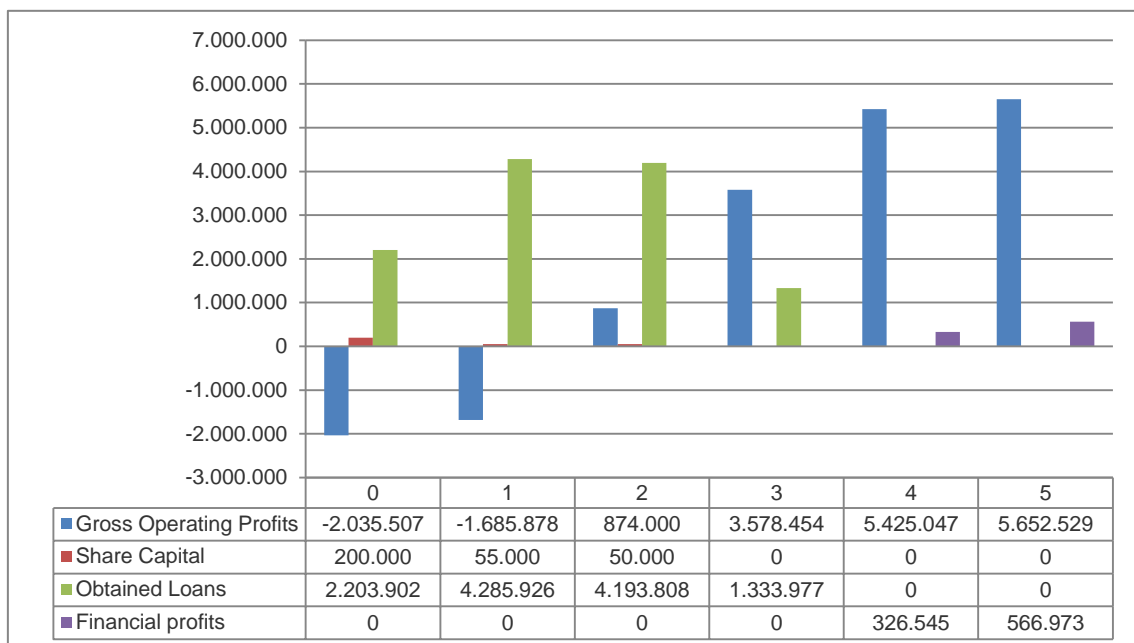


Figure 85 - Financial Balance Summary of Case 1

To start the company it will be necessary to obtain loans from financial institutions in order to invest in the needed infrastructure, import the set-top box, and cover all expenses associated to this initial process of the structure. In the first four years of activity it will be needed a loan which amounts a

total of 12.017.613 €. From Year 4 ahead it won't be necessary any more loans to operate the company.

The Share Capital will start with 200.000€ and be increased in the next two years with, 55.000€ and 50.000€ respectively.

From Figure 86, we verify that one of the objectives of this case has been achieved the cash flow breakthrough is done by Year 3.

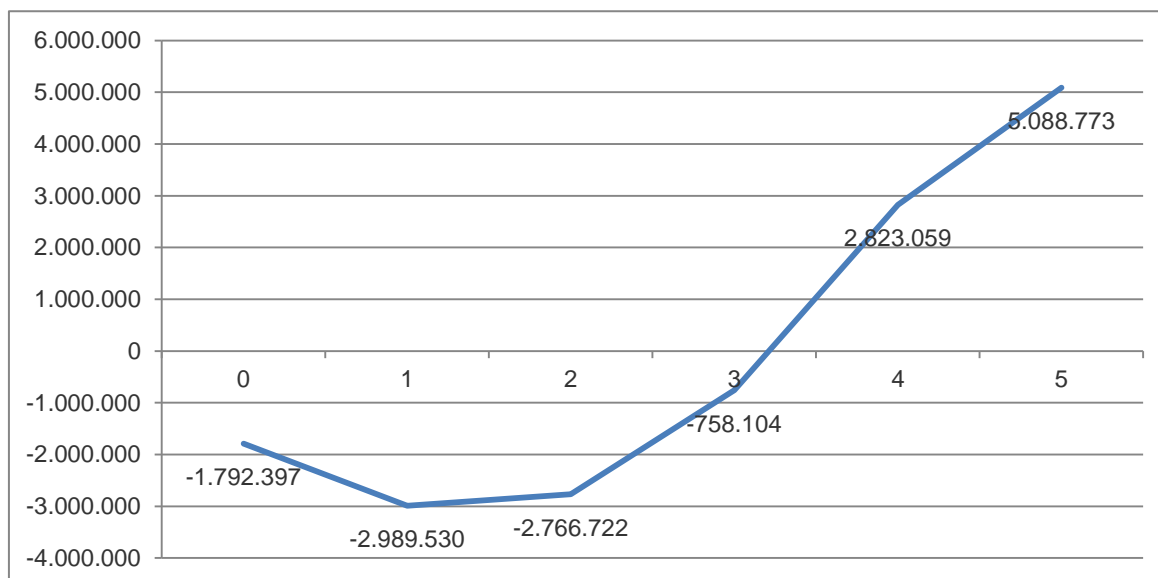


Figure 86 - Cash Flow Result in Case 1

It is possible to conclude from the graph above that the cash flow for this scenario will turn positive during year 3.

At the end of Year 5 we've obtained four important values from this analysis worth to mention, those are summarized in Table 22.

Cash Balance	12.381.550 €
NPV	3.936.669 €
IRR	22,24 %
Payback period	5 years

Table 22 – Financial Results Summary in Case 1

In this first case, the cash balance by the end of the project will be around 12 million Euros, the net present value (NPV) will be approximately of 4 million Euros. The internal rate of return is approximately 22 % and the expected payback period of the project is around 5 years, it means that by Year 4 all the initial loans were paid.

7.7.2 Case 2

In Case 2, through “fine tuning” of the concurrency rate for video services we’ve obtained cash flow breakthrough in the last year of the project (Figure 88).

Gross operating profits are only positive by Year 3, and with the same Share Capital in the company, we will need to obtain loans in each year of the project (Figure 87).

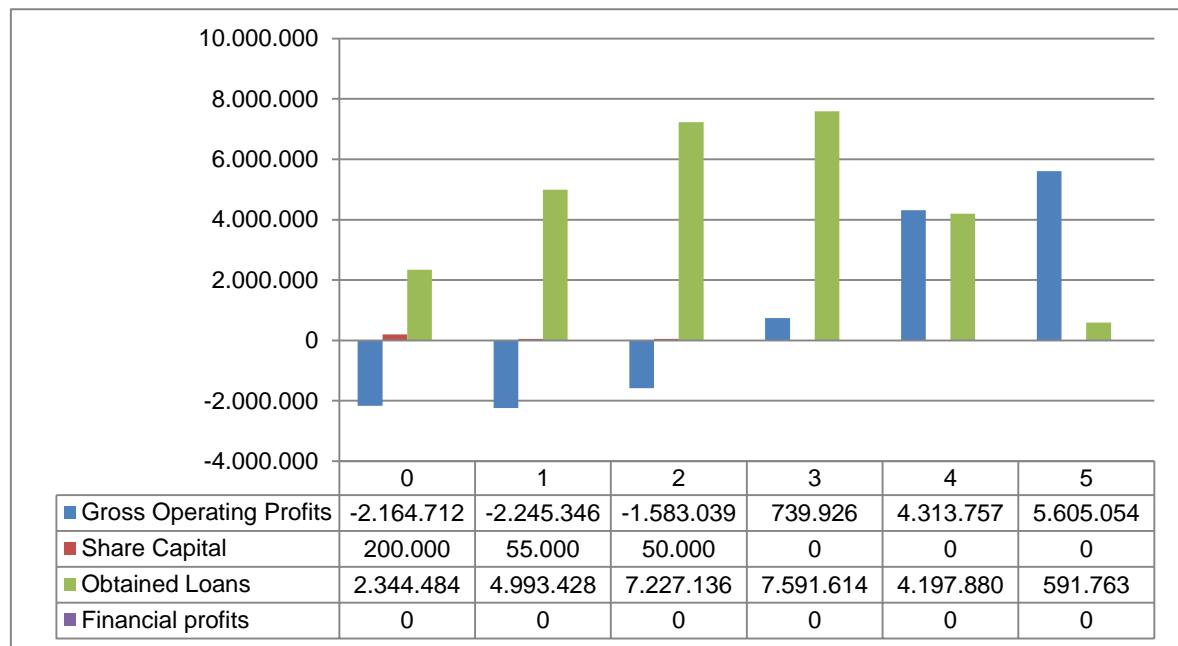


Figure 87 - Financial Balance Summary of Case 2

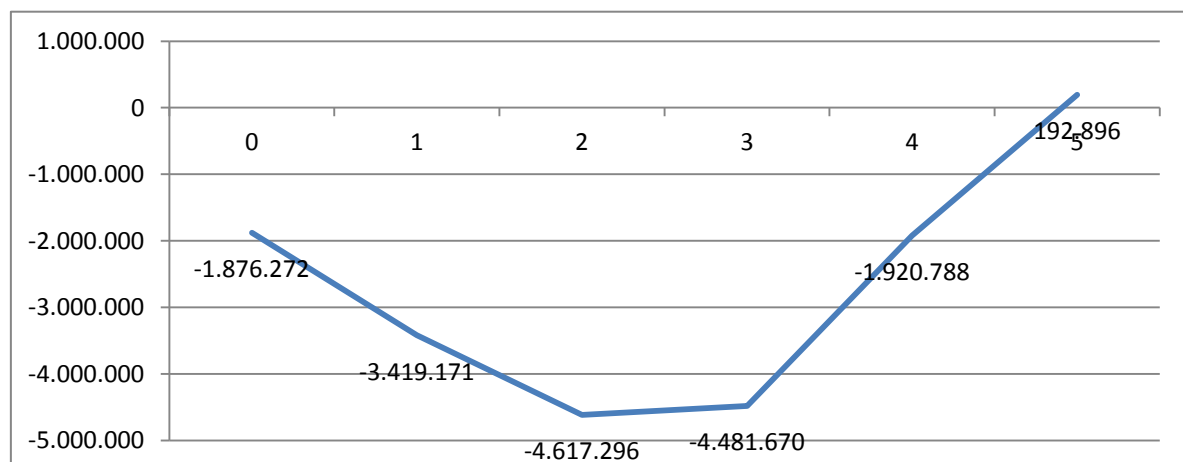


Figure 88 - Cash Flow Result in Case 2

For Case 2, Cash balance will be approximately 11.6 million Euros, and the NPV will be around 1 million Euros, in Year 5. By the end of the project the IRR will be 5.69%.

The payback will not be possible under the established duration of the project.

Cash Balance	11.686.345 €
NPV	1.148.118 €
IRR	5,69 %
Payback period	> 6 years

Table 23 - Financial Results Summary in Case 2

7.7.3 Case 3

In this case where the company only achieves 15 % of the market share, the gross operating profits are only positive in Year 4. To ensure project activity, loans are needed in every year.

As represented in Figure 90, the cash flow is negative in the whole duration of the project. There is a light rebound in year 4 and 5 because of the positive gross operating profits in those years.

Cash balance in Year 5 is positive but the net present value is around 4 million euros negative giving a payback period bigger than 6 years.

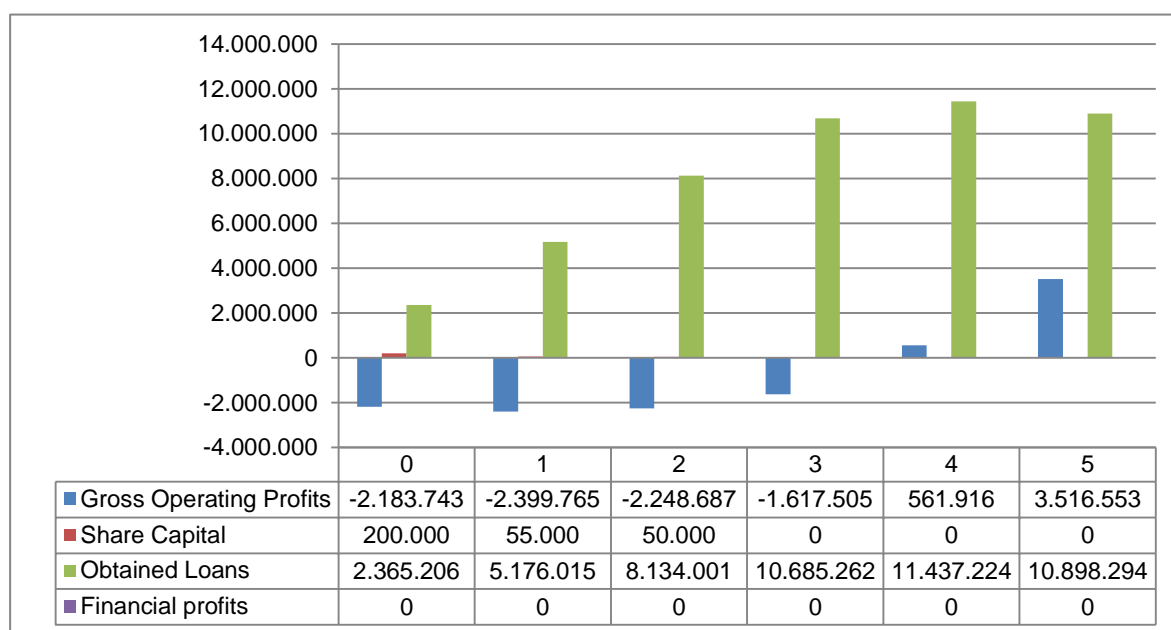


Figure 89 - Financial Balance Summary of Case 3

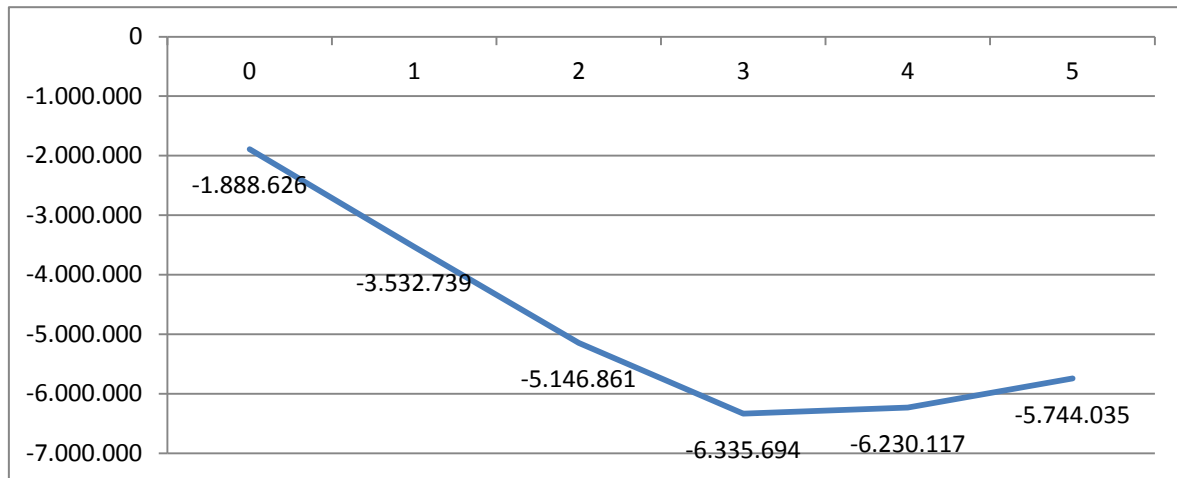


Figure 90 - Cash Flow Result in Case 3

Cash Balance	2.644.486 €
NPV	-3.957.010 €
IRR	0 %
Payback period	> 6 years

Table 24 - Financial Results Summary in Case 3

7.8 Conclusions of the Economic Analysis

From this case study we can draw the following conclusions:

- The size of the infrastructure is directly proportional to the concurrency rate, and has a direct repercussion over the costs of the company.
- If the penetration rate in the market is quicker, we will cover sooner the investment and the soonest we will obtain benefit (Case 1).
- If the penetration rate is slower, more difficult will be to breakthrough and more time will be needed (Case 2).
- If we don't achieve a certain percentage of the market share, and we have a slower penetration in the market, it will be even harder to breakthrough. It means that if we have to invest in an infrastructure that is not fully used, with fewer clients, we will have fewer incomes to repay the investment done. In case3, we have the same concurrency rate, the same operating costs and expenses but we have a slower and lower penetration rate in the market, and we verified that it will take more years than the one considered for this study to breakthrough.

- With this analysis we have concluded that the concurrency rate and market penetration rate are the main factors to consider in this kind of business.

8 Conclusions

The first conclusion from this dissertation is that it is technically possible for a start-up to introduce in the market a multiscreen Video on Demand service using only the network owned by others. Unfortunately if this new company isn't supported by a strong economical group, it will certainly be difficult to raise funds for the required initial investment. It would also be possible, if a startup were backed up by a player in the multimedia or telecom business, such as a content owner, a media company or a telecom operator; the delivery of video OTT services could be very interesting for this kind of players.

For example in Portugal, if a telecom operator without a residential network or a limited one, case of Vodafone or Cabovisão, offering OTT services over the existing networks of competitors could be a way to gain market share in the Pay TV business, without the need of investing in the deployment of new network infrastructures.

Major telecom operators could also take advantage of the “cut the cord” effect and introduce in the market low cost OTT television services bundled with internet connection for both residential and mobile devices.

For content owners, such as UEFA or FIFA, the deployment of an OTT service where these institutions could sell directly the football games to the subscriber could cut the chain of costs and leverage more profit for the content owner. Selling directly the content to the subscriber they will cut the cost of other players in the distribution chain.

The proof of concept demonstrates that the technology implementation is possible using minimal resources, which could lead to low implementation costs.

Although it is possible, from a technical point of view, to deliver video over other operator networks the price to access the network represents a significant portion of the operational costs. This decisive factor will determine the success or failure of the project. If an operator has already a network, this technology could be an important enabler on the market.

There will remain some unsolved answers from the economic analysis:

- Would 15% of the provided services revenues be enough to pay the rights from the content to the owners? Would they accept such a deal? This means would they accept a percentage of the revenues in exchange of the rights of their content?
- How such a service would be accepted in the Portuguese market once the monthly fee was assumed around 20 euros, and a basic residential internet service costs also around 20 euro making a total of 40 euro; and we have triple play services from other competitors starting at 25 euro? Would the content anywhere anytime be the key for success? Are the Portuguese customers changing their habits?

Only the market deployment could answer such questions.

From the economic analysis we can also conclude that in order to be profitable and reduce the price of the service to the lowest possible it is mandatory that the operating costs remain focused on the essential steps of the OTT business: Prepare, Sell, Provide and Monitor. The first step is to acquire and prepare the content in order to be streamed over unmanaged networks; then we need to sell the service to the customers using our sales force; then we need to distribute our service over unmanaged networks where our subscribers are connected; finally we need to monitor the OTT distribution operations.

Because OTT distribution is web based and Multiscreen oriented it could be used in many more cases than the one described over this dissertation, the coming of more and more connected devices and the internet of things could bring television to many other screens. In the future television will be in your car, your mirror, your glasses or even over thin air.

Television will be anywhere you look at.

8.1 Future Work

The aim of this dissertation was to gain a deeper understanding of the OTT ecosystem, in two points of views: Technical and Economic. This work described both views as an introduction to the theme.

From this document, further work could be developed in multiple topics:

- In the OTT server side, developments could be made in order to bring automation and monitoring in the management of this kind of services.
- MPEG-DASH is a promising OTT technology that is still in under development.
- In client side there is still a lot to be done, mainly in the development of platforms to bring this service to main screen, Television. Applications designed exclusively to bring OTT to televisions could be developed based on open source platforms like XBMC and Android.
- A lot can be done over the economic analysis of this dissertation: mathematic formulas and theorems could be developed to simulate the influence of the market penetration rate and the concurrency rate of video services over the cash flow.
- This work could bring inputs to simulations that would predict when and in which circumstances operators will migrate their IPTV services to OTT.

9 Appendix

9.1 Appendix 1 - TCP/IP and the OSI Reference Model

The TCP/IP model consists of four layers, each of which can have several sub layers. These layers correlate roughly to layers in the OSI reference model and define similar functions as we can see in the table below [62]:

OSI	Description	TCP/IP	Description
Application	<ul style="list-style-type: none"> Final application, that requires communication 	Application	<ul style="list-style-type: none"> Refer to communications services to applications and the interface between the network and the application. It is responsible for presentation and controlling communication sessions. Examples include: HTTP, POP3, and SNMP.
Presentation	<ul style="list-style-type: none"> Encoding and security 		
Session	<ul style="list-style-type: none"> Establishes the concept of a session, i.e., shared number of connections by a same application 		
Transport	<ul style="list-style-type: none"> Provides a link between two network points; 	Transport	<ul style="list-style-type: none"> Defines several functions, including the choice of protocols, error recovery and flow control. Reordering of the incoming data stream when packets arrive out of order is included. It correlates with the Transport Layer of the OSI reference model. Examples include: TCP and UDP, which are called Transport Layer, or Layer 4, protocols.
Network	<ul style="list-style-type: none"> Identifies different machines in distinct logical domains; Interconnects multiple networks; Set paths for interconnection between networks; Forward packets between networks; 	Internetwork	<ul style="list-style-type: none"> Defines end-to-end delivery of packets and defines logical addressing to accomplish this. It also defines how routing works and how routes are learned; and how to fragment a packet into smaller packets to accommodate media with smaller maximum transmission unit sizes. Correlates with the Network Layer of the OSI reference model. Examples include: IP and ICMP.
Logic	<ul style="list-style-type: none"> Responsible for: <ul style="list-style-type: none"> Machine Identification (address); Directing the information to the machines; Interface with the network layer; It's generally divided in: <ul style="list-style-type: none"> LLC (Logical Link Control); MAC (Media Access Control); 	Network Interface	<ul style="list-style-type: none"> Is concerned with the physical characteristics of the transmission medium as well as getting data across one particular link or medium. This layer defines delivery across an individual link as well as the physical layer specifications. It spans the Data Link Layer and Physical Layer of the OSI reference model. Examples include: Ethernet and Frame Relay.

Physical	<ul style="list-style-type: none">• Converts bits in signal (electric, optical or radio);• Receives and transmits bits;• Synchronizes information;• Defines size and connectors form• Establishes physical limits	
-----------------	---	--

10 References & Bibliography

- [1] CMB Consumer Pulse, “The New Age of Television,” pp. 1–11, 2012.
- [2] N. Unuth, “What is OTT and How is it Affecting Communication?” [Online]. Available: <http://voip.about.com/od/markettrends/a/What-Is-Ott.htm>.
- [3] T. Siglin, “The State of OTT Content Delivery 2013 - Streaming Media Magazine.” [Online]. Available: <http://www.streamingmedia.com/Articles/Editorial/Featured-Articles/The-State-of-OTT-Content-Delivery-2013-88178.aspx>.
- [4] Apple Developer, *HTTP Live Streaming Overview*. 2013.
- [5] “Video Formats - A Guide to Understanding Video Containers & Codecs .” [Online]. Available: <http://library.rice.edu/services/dmc/guides/video/VideoFormatsGuide.pdf>.
- [6] “File:Vector Video Standards2.svg - Wikimedia Commons.” [Online]. Available: http://commons.wikimedia.org/wiki/File:Vector_Video_Standards2.svg#metadata.
- [7] A. Zambelli, “IIS Smooth Streaming Technical Overview,” no. March, 2009.
- [8] Adobe Systems Inc., “RTMP Specification License,” no. April, 2009.
- [9] Adobe Systems Inc., “RTMP Commands Messages,” 2009.
- [10] T. C. Thang, Q. Ho, J. W. Kang, A. T. Pham, and S. Member, “Adaptive Streaming of Audiovisual Content using MPEG DASH,” vol. 58, no. 1, pp. 78–85, 2012.
- [11] A. Vetro and I. Sodagar, “Industry and Standards The MPEG-DASH Standard for Multimedia Streaming Over the Internet,” pp. 62–67, 2011.
- [12] C. Huang, J. Li, and K. W. Ross, “Can internet video-on-demand be profitable?,” *ACM SIGCOMM Comput. Commun. Rev.*, vol. 37, no. 4, p. 133, 2007.
- [13] Y. Yang, A. L. H. Chow, L. Golubchik, and D. Bragg, “Improving QoS in BitTorrent-like VoD Systems,” *2010 Proc. IEEE INFOCOM*, pp. 1–9, Mar. 2010.
- [14] T. Silverston, O. Fourmaux, and J. Crowcroft, “Towards an Incentive Mechanism for Peer-to-Peer Multimedia Live Streaming Systems,” *2008 Eighth Int. Conf. Peer-to-Peer Comput.*, pp. 125–128, Sep. 2008.
- [15] “Darwin Streaming Server.” [Online]. Available: <http://dss.macosforge.org/>.
- [16] “Red5 Media Server.” [Online]. Available: <http://www.red5.org/>.
- [17] W. M. Systems, “Wowza Media Server ® 3 - Overview,” no. December, 2011.
- [18] “About Flumotion.” [Online]. Available: <http://www.flumotion.net/about/>.
- [19] M. Cumming, F. D. Team, T. Vander Stichele, and F. Documentation, “Flumotion manual Flumotion manual.”

- [20] "Adaptive streaming overview." [Online]. Available: http://en.wikipedia.org/wiki/File:Adaptive_streaming_overview_daseddon_2011_07_28.png.
- [21] T. Michel, "About SMIL 3.0," W3C. [Online]. Available: <http://www.w3.org/TR/2006/WD-SMIL3-20061220/smil-introduction.html>.
- [22] "DISTRIBUTED & ADAPTIVE HTTP STREAMING Stéphane Gouache , Guillaume Bichot , Amine Bsila and Christopher Howson Technicolor," pp. 2–7, 2011.
- [23] M. Corporation, "Microsoft PlayReady Content Access Technology White Paper," no. July, 2008.
- [24] "HTTP Live Streaming Overview: Using HTTP Live Streaming." [Online]. Available: <https://developer.apple.com/library/ios/documentation/networkinginternet/conceptual/streamingmediaguide/UsingHTTPLiveStreaming/UsingHTTPLiveStreaming.html>.
- [25] A. M. de O. Duarte, "Rede e Serviços de Telecomunicações: Conceitos, Modelos e Estruturas Fundamentais das Redes de Telecomunicações." 2009.
- [26] A. M. de O. Duarte, "Rede e Serviços de Telecomunicações: Conceitos, Modelos e Estruturas Fundamentais das Redes de Telecomunicações." 2009.
- [27] A. M. de O. Duarte, S. Coelho, D. C. Carrilho, R. C. Madureira, J. M. Silva, and H. Félix, "Custos Associados às Infraestruturas de Telecomunicações à Escala Local," Aveiro, 2011.
- [28] P. J. Conlan, *Cisco Network Professional's Advanced Internetworking Guide*. John Wiley and Sons Publishing Ltd., 2009.
- [29] "HFC Network Diagram," *Wikimedia Found. Inc.*
- [30] A. M. de O. Duarte and S. Coelho, "Fibra Óptica na Rede de Acesso: Tecnologias e Soluções," 2010.
- [31] 3GPP, "LTE Overview." .
- [32] L. A. N. Man, S. Committee, and I. Computer, *Part 11 : Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, vol. 2012, no. March. 2012.
- [33] ITU-T Newslog, "IPTV Standardization on Track Say Industry Experts," 2006.
- [34] ITU, "IPTV – MARKET , REGULATORY TRENDS AND POLICY OPTIONS IN EUROPE," no. October, 2006.
- [35] Huawei, "IPTV survival in the OTT age - Huawei Solutions." [Online]. Available: http://www.huawei.com/ilink/en/solutions/broader-smarter/morematerial-b/HW_204158#.Upz_mMTIaQA.
- [36] N. Narang, "Concept Series : What is the Difference between OTT and IPTV," *Res. TV Technol.*
- [37] N. C. Zakas, "How content delivery networks (CDNs) work | NCZOnline." [Online]. Available: <http://www.nczonline.net/blog/2011/11/29/how-content-delivery-networks-cdns-work/>.
- [38] "nanoCDN." [Online]. Available: <http://www.broadpeak.tv/en/technologies/nanocdn-25.php>.

-
- [39] Lawrence Lessig and Robert W. McChesney and L. L. and R. W. McChesney, "No Tolls on The Internet," *Columns*, 2006.
 - [40] SaveTheInternet.com, *Frequently Asked Questions*. SaveTheInternet.com.
 - [41] P. Phillips, *Censored 2007*. Seven Stories Press, 2006.
 - [42] *What Is Net Neutrality? 10 Aug 2010*. .
 - [43] *Against Fee-Based and other Pernicious Net Prejudice: An Explanation and Examination of the Net Neutrality Debate*. Scribd.com, 2007.
 - [44] Isenberg, David and D. Isenberg, *The Rise of the Stupid Network*. 1996.
 - [45] J. D. Hart, *Internet Law*. BNA Books, 2007.
 - [46] P. E. Meza, *Coming Attractions?* Stanford University Press, 2007.
 - [47] T. L. Banks, *Corporate Legal Compliance Handbook*. Aspen Publishers Online, 2002.
 - [48] "What is Transparent Caching?" [Online]. Available: <http://www.peerapp.com/products/transparentcaching.aspx>.
 - [49] "Transparent Caching Proxy - Squid User Guide." [Online]. Available: <http://www.deckle.co.uk/squid-users-guide/transparent-caching-proxy.html>.
 - [50] "An Overview Of Transparent Caching and Its Role In The CDN Market - Dan Rayburn - StreamingMediaBlog.com." [Online]. Available: <http://blog.streamingmedia.com/2010/10/an-overview-of-transparent-caching.html>.
 - [51] Ingrid Lunden and I. Lunden, "Android, Led By Samsung, Continues To Storm The Smartphone Market, Pushing A Global 70% Market Share," *TechCrunch*, 2013.
 - [52] *Vic Gundotra - Google+ - Just back from a whirlwind trip to Asia visiting our....* Plus.google.com.
 - [53] "Dashboards," *Android Dev.*, 2013.
 - [54] "The Pain of Live Streaming on Android | JW Player." [Online]. Available: <http://www.jwplayer.com/blog/the-pain-of-live-streaming-on-android/>.
 - [55] *Android and iOS Combine for 91.1% of the Worldwide Smartphone OS Market in 4Q12 and 87.6% for the Year, According to IDC*. IDC, 2013.
 - [56] *Mobile/Tablet Operating System Market Share June 2012*. Net Applications, 2012.
 - [57] "XBMC." [Online]. Available: <http://xbmc.org/about/>.
 - [58] "So you got a Raspberry Pi: now what?" [Online]. Available: <http://www.engadget.com/2012/09/04/raspberry-pi-getting-started-guide-how-to/>.
 - [59] ANACOM, "Serviço de Televisão por subscrição - INFORMAÇÃO ESTATÍSTICA - 4º Trimestre de 2012," 2012.
 - [60] Envio, "Multi-Screen Media Delivery • On-Net , Off-Net and OTT," no. April, 2011.
-

- [61] I. N. de Estatística, Ed., *Censos2011*. 2011.
- [62] “Learn Network Administration.” [Online]. Available:
<http://learnnetworkadmin.blogspot.pt/2011/02/tcpip-and-osi-reference-model.html>.