Methodological and Statistical Background on The World's Technological Capacity to Store, Communicate and Compute Information 2012

Priscila López[1] and Martin Hilbert[2]

[1] Open University of Catalonia (UOC);
[2] University of Southern California (USC), Annenberg School of Communication; United Nations ECLAC

ABSTRACT SUPPORTING APPENDIX

We used more than 1,100 sources to estimate the world's technological capacity to store, communicate and compute information. In this Supporting Appendix we outline our underlying methodological assumptions. We place large emphasis on transparency in outlining our reasoning and sources, and hope that this will facilitate replicability and future improvements to the challenging undertaking of quantifying the world's technological information processing power. We measure storage and communication capacities in optimally compressed bits (or bits per second), which requires three kinds of sources: (a) the quantity of installed devices, (b) the hardware capacity of those devices, and (c) the level of compression of the respective content. This last variable enables us to transform hardware capacity into optimally compressed bits (which approaches the entropy of the source). We measure computational capacity in MIPS, which requires (a) the quantity of installed devices, (b) the hardware capacity of those devices. Given the nature and availability of the statistics, we measure the effective capacity in the case of communication (only those bits that are effectively transmitted), which requires statistics on effective media usage, and the installed capacity in the cases of storage and computation (maximum installed capacity). We start by presenting some general decisions that we took while working with these statistics in Section A, and then go into the details of the sources and assumptions employed to create those data. Sources and assumptions about compression rates for storage and communication are presented in Section B; Section C covers the case of storage, Section D communication, and Section E computation.

Please cite as: López, P., & Hilbert, M. (2012). *Methodological and Statistical Background on The World's Technological Capacity to Store, Communicate, and Compute Information 2012* (online document). Retrieved from http://www.martinhilbert.net/WorldInfoCapacity.html

Table of Contents

A Statistical Lessons Learned

Quantifying the amount of technologically mediated information processes is not only a methodological, but also a statistical challenge. In the following we discuss some of the lessons learned while gathering and harmonizing statistics.

This first lesson learnt is that any statistical and methodological appendix of such exercises has to be viewed as a “living document” (Lyman and Varian, 2003; p. 14). During the second half of 2011, we updated parts of our work (i.e. on storage and telecommunication and extended our estimates of the installed telecommunication capacity from 2007 to 2010. This is introduces slight changes in comparisons to our estimates for the year 2007 published in López and Hilbert (2011) (see Sections C and D). With this dynamic in mind, our first priority was to stay transparent and enable replicability, which is the reason why the Appendix to this article counts almost 300 pages.

A.1 Accumulation of infrastructure

Statistics about the quantity of technological deceives or subscriptions basically come in two types: (i) one type of sources present the amount of technology installed at a given moment in time (e.g. ITU, 2011); (ii) another one report the amount produced, sold, or shipped during a given period (e.g. Porter, 2005; Morgan Stanley, 2006; Faostat, 2010). In order to harmonize both of them, it has to be remembered that not all of the installed devices of a given year have been produced at the same year. This is important since the average performance of a certain technology can change decisively from year to year. Knowing about the year of production allows estimating the likely performance of a certain device. Considering that the same device, with the same performance, is used for a certain numbers of years (utility shelf-life), an accumulation effect of devices from different years leads to the total capacity of all installed devices in a given year. Therefore, assumptions about the utility shelf-life of a certain device enable to convert statistics of type (ii) into type (i) and the other way around.

This process has to consider that shelf-life could change over the years. For example, in the case of analog VHS video cassettes, we suppose an average lifetime of 8 years for the entire period of our exercise. This number can be seen a weighted average, for example 20% of the cassettes are kept for 15 years, 40 % for 10 years, 30 % for 3 years and 10 % for less than a year (0.2*15 + 0.4*10 + 0.3*3 + 0.1*1 = 8). However, for the case of PCs, we come to the conclusion that the average life-time was 10 years for the period 1976-1986, 7 years during the years 1987-1989, and merely 5 years since 1990 (after Microsoft Windows and the worldwide Web started to take off). We reached this conclusion after comparing various sources, some that report the number of installed, others the number of shipped devices. It is important to compare different sources in this regard, since assumptions about shelf-life can sensitively affect estimates (especially for digital technologies where performance changes quickly from year to year).

A.3 Blanks in time-series

There are very valuable time-series sources out there, including ITU, 2010; Porter; 2005; Coughlin; 2007; IFPI, 2005; JRIA, 2007; Faostat, 2010; UPU, 2007; TOP500, 2009; Longbottom, 2006; McCallum, 2002; among others. However, they are not always complete, and it is necessary to fill in the blanks with either linear estimates (e.g. Xi = [Xi-1 + Xi+1] / 2), or constant growth rates (e.g. Xi = Xi-1 * [Xi+1/Xi-1](1/2)). This choice depends on the nature of the overall growth process in question. In cases where the beginning of the time series was missing, one can identify the date of first commercialization of the technology, and then interpolate according to the linear or constant growth method. It is also important to revise estimates for specific countries in light of information from other sources. Filling in these gaps and revising details adds up can lead to notable differences. For example, ITU (2010) reports some 4,000,000 fixed Internet subscriptions in 1993. Filling in their own blanks (i.e. missing years for specific countries) and revising inconsistencies (e.g. unlikely up- downturns, which are most probably the result of changing methodologies on the country level) results in almost 5,000,000 subscriptions, which is a difference of 25 %. For 2000 this difference results in ITU: 176,000,000 versus ours: 209,000,000, equal to almost 20 %. By 2007, the ITU data are more complete, which results in a difference of mere 8 % (ITU: 580,000,000; ours: 625,000,000).

A.3 Blanks in geographical coverage

Many of the How-Much-Information inventories focus on a global scale (Lyman and Varian, 2000; 2003; Lesk, 1997; Gantz, et al., 2008; Hilbert and López, 2011). The problem is that most reliable statistics are only available for a handful of highly developed nations (i.e. United States, Europe and Japan). While important advancements have been made in recent years in the promotion and collection of globally harmonized ICT statistics (see Partnership, 2008; Olaya, 2007), most of the developing world is often still a statistical black box.

One rather simple solution is to extrapolate from highly developed countries to the rest of the world in a one-to-one relationship (e.g. Lyman and Varian; 2003; Bounie, 2003). Another way is to try to find sporadic statistics for some developing countries and then estimate the remaining countries on basis of neighboring countries in their world region, or, what we often did, at least distinguish between developed countries, i.e. member countries of the OECD (Organisation for Economic Co-operation and Development) and developing countries (all others). While this approach neglects that there are differences between countries, it recognizes the difference between developing and developed countries. This can already have a decisive impact on the final estimation.

For example, for the estimation of global telephone traffic, Lyman and Varian (2003) follow the lead of Bounie (2003) in taking the number of minutes per line of France as a representation for the entire world (resulting in some 9.5 minutes per line per day). We take ITU's data (2010) and differentiate between the member countries of the OECD (weighted average of some 21 minutes per line per day) (heavily influenced by the United States with 36 minutes) and a sample of non-OECD countries (some 7 minutes per line per day). This gives us a global weighted average of some 18 minutes per installed line in the world. This is almost twice as much as the average of France. In many other cases, statistics from the United States are taken as the global benchmark (Lyman and Varian, 2000; 2003). Doing this in this case would severely overestimate the global capacity by supposing twice its actual size. The introduction of a globally more balanced perspective can make a significant difference in the final results.

A.4 Future improvements

There is ample room future refinement of all kinds of statistics used. Among the ones we see most potential for improvement are:

(1) The quantity of installed devices. For example, our estimation of the quantity of paper-based information is based on statistics of the global paper production in tons, which is quite complete but not very fine-tuned.

(2) The performance of devices. For example, our estimations of the information contained in newspapers are based on the sampling of the New York Times only.

(3) The lifetime of the products, and therefore to the process of accumulation, which affects the installed capacity in a given moment in time through the adjustment of the number and performance of devices.

(4) The distribution of information content (text, images, audio, video). For example, we assume that the content on hard disks behaves according to the average of web and P2P Internet traffic.

(5) The most commonly used compression rates. This was the main reason why we merely estimate the years 1986, 1993, 2000, and 2007 as the main anchors of our estimations. One can assume significant changes during a period of seven years, while year-to-year changes would require better statistics.

Improving those estimates would require more time and resources. While we are quite confident that our estimates are in the right ballpark, we hope that future exercises will contribute in identifying better sources and to improve our working assumptions.

A.5 References

Bounie, D. (2003). The International Production and Dissemination of Information. Special Project on The Economics of Knowledge Autorità per le Garanzie nelle Comunicazioni. Paris: École Nationale Supérieure des Télécommunications (ENST). Retrieved from http://ses.telecom-paristech.fr/bounie/documents/Recherche/Annex.pdf

Coughlin, T. (2007). Digital storage technology newsletters. Coughlin Associates. Retrieved from http://www.tomcoughlin.com/

Faostat. (2010). ForesSTAT. Food and Agriculture Organization of the United Nations. Retrieved from http://faostat.fao.org/

Gantz, J., Chute, C., Manfrediz, A., Minton, S., Reinsel, D., Schlichting, W., & Toncheva, A. (2008). The Diverse and Exploding Digital Universe: An Updated Forecast of Worldwide Information Growth Through 2011. Framingham: IDC (International Data Corporation) sponsored by EMC. Retrieved from http://www.emc.com/leadership/digital-universe/expanding-digital-universe.htm

Hilbert, M., & López, P. (2011). The World's Technological Capacity to Store, Communicate, and Compute Information. Science, 332(6025), 60 -65. doi:10.1126/science.1200970

IFPI. (2007). The Recording Industry World Sales 1995-2004. International Federation of the Phonographic Industry. Retrieved from http://www.ifpi.org/content/section_statistics/index.html

ITU (International Telecommunication Union). (2011). World Telecommunication/ICT Indicators Database. Geneva: International Telecommunication Union. Retrieved from http://www.itu.int/ITU-D/ict/statistics/

JRIA. (2007). Press Releases. Japanese Recording-Media Industries Association.

Lesk, M. (1997). How Much Information Is There In the World? lesk.com. Retrieved from http://www.lesk.com/mlesk/ksg97/ksg.html

Longbottom, R. (2006). Computer Speed Claims 1980 to 1996. Roy Longbottom's PC Benchmark collection. Retrieved from http://www.roylongbottom.org.uk/mips.htm

Lyman, P., Varian, H. R., Dunn, J., Strygin, A., & Swearingen, K. (2000). How much information 2000. University of California, at Berkeley. Retrieved from http://www2.sims.berkeley.edu/research/projects/how-much-info/

Lyman, P., Varian, H., Swearingen, K., Charles, P., Good, N., Jordan, L., & Pal, J. (2003). How much information? 2003. University of California, at Berkeley. Retrieved from http://www2.sims.berkeley.edu/research/projects/how-much-info-2003/

McCallum, J. (2002). Price-Performance of Computer Technology. In V. G. Oklobdzija (Ed.), The computer engineering handbook (pp. 136 – 153). CRC Press.

Morgan Stanley. (2006). Technology Q1 2006 Global Technology Data Book. Global Technology Team. Retrieved from http://www.morganstanley.com/institutional/techresearch/pdfs/global_techdatabook0306.pdf

Olaya, D. (2007). Compendium of Practices on the implementation of ICT questions in household and business surveys in Latin America and the Caribbean. Santiago: United Nations ECLAC Observatory for the Information Society in Latin America and the Caribbean. Retrieved from http://www.cepal.org/ddpe/publicaciones/xml/4/32164/W169_Ingles.pdf

Partnership, U. N. (2008). The Global Information Society: a Statistical View. Geneva: ITU, OECD, UNCTAD, UNESCO Institute for Statistics, UN Regional Commissions (UNECLAC, UNESCWA, UNESCAP, UNECA), World Bank, EUROSTAT. Retrieved from http://www.unctad.org/en/docs/LCW190_en.pdf

Porter, J. (2005). Disk/Trend Reports 1977-1999. California. Retrieved from http://www.disktrend.com/

TOP500. (2009). TOP500 List Releases. TOP500 Supercomputer sites. Retrieved from http://www.top500.org/lists

UPU. (2007). Postal statistics. Universal Postal Union. Retrieved from http://www.upu.int/en/resources/postal-statistics/

B Compression rates

In order to compare the informational capacity of different storage devices and communication technologies, it is necessary to normalize the used compression level on one selected compression level of reference. A symbol (for example a binary digit of 1 or 0) may represent different quantities of information (bits in Shannon's sense (1948)). The amount of information depends on the probability distribution of the source and therefore, the redundancy in the message (see also Cover & Thomas, 2006), while the amount of data depends on how efficient this information is coded. In practice, messages are stored and sent with different levels of compression, which makes it difficult to compare just how much information is being contained in the message. The idea is to translate the different messages into one single level of compression. We have chosen to normalize on what we call the "optimal compression level", which represents what in 2007 was understood to be the "entropic" level of compression: the maximum level of compression available in 2007.

In order to be able to do this, we must consider two characteristics: (1) the compression rates vary significantly between different types of sources. The largest distinction consists between sources of different content types: text, still images in black and white, still images in color, audio, music, voice, and moving images (video). Therefore, we will require an estimation of the type of content. (2) Achievable compression levels have changed considerably over time, as they are subject to technological progress in the software algorithms used to compress and decompress information. In order to make a valid estimate, we will need the compression algorithms used for each content type in each year. These statistics are very scarce. For that reason, we have decided to focus only on the years 1986, 1993, 2000 and 2007. We consider that in 1986, compression algorithms were not yet used (with a few exceptions, such as text in UNIX systems). The most fundamental leap in the progress of compression algorithms was made in 1993 with the introduction of "turbo codes". During the years 2000 and 2007, compression algorithms evolved rapidly. For some types of contents, the most widely used algorithms in 2007 are also the best ones known to date (for example MPEG-4 for video), while for others, the "optimal compression rate" is determined by algorithms that exist, but are not commonly used (for example, to compress text, usually ZIP or RAR software are used –or similar ones that make part of a word processing software— even though they are inferior to other more efficient algorithms to compress text).

Normalization on compression rates is particularly important when comparing analog and digital information. For example, digitalizing an analog radio transmission using Nyquist's theory (2002) results in a transmission rate of 705.6 [kbps]. Digital radio of medium to high quality is usually transmitted with 128 [kbps]. Judging from these two hardware performance measures, one might conclude that digital radio transmits more information than digital radio, which obviously is not the case: digital radio has higher quality. We can see this when we normalize for compression. The most efficient compression for these types of transmissions in 2007 is MPEG-4 HE-AAC, which compresses with a ratio of 1:20. If we compressed analog radio with this same ratio, we would obtain a rate of 35.5 [kbps] (705.6/20). The 128 [kbps] of digital radio of medium/high quality is already compressed with MPEG-2 @128, which achieves compression with a ratio of 1:11. Therefore, we first "uncompress" digital radio, and then normalize it with the most efficient compression rate available (MPEG-4 HE-AAC). This results in a transmission rate of 70.4 [kbps] (128*11/20). We can see now that the information that analog radio contains is equal to 35.5 [kbps], and that of digital radio almost double, with 70.4 [kbps]. Given that we are now speaking of the quantity of information (bits that reduce uncertainty in Shannon's 1948 sense), this increase represents an improvement in quality (effectively more information, not mere data). In general, we can observe that with every new technological progress in compression algorithms (consisting of exploiting the underlying structure of information from a certain kind of source, focusing on detecting the redundancy in a message), we are able store more information (bits) with less symbols (binary digits, or "data").

B.1 The "optimal level" of compression

The majority of all information sources are redundant, which is to say, they contain a lot of information that is predictable, and therefore does not represent "information", in the sense that they reduce uncertainty (Shannon, 1948). *A clssic exmpl is the rdndancy of the ltters in our wrttn lngage*. Even without having all of the letters, it is possible to reconstruct the phrase, because it follows certain probabilities, which are defined in the use of our words and phrases. In short: these letters are redundant (especially vowels). This is also the reason why some old languages (like Arabic) have lost them over the centuries (shortcuts used in mobile phone text messaging apply the same information theoretic insight). The purpose of efficient codification is to remove this redundancy, so as to transmit/store the minimum number of symbols with which the original message can be reconstructed. From the point of view of data compression, the most important result from information theory is Shannon's first fundamental theorem (1948), also known as the noiseless channel coding theorem, which establishes the minimum average code length per symbol that can be achieved theoretically. This provides the highest obtainable level of lossless compression.

Redundancy in information can appear in diverse forms. In an image, neighboring pixels are highly correlated spatially amongst each other, which is to say, the values of the pixels are similar in the soft non-border regions. In the case of moving images, consecutive frames can be almost the same with or without a slight shift, if the movement is slow. For example: in a video, a blue sky might stay the same for at least a few seconds without changing. After the first image with the blue sky, the next will be “redundant”. Instead of encoding and sending more blue pixels, the receiver simply goes with what is to be expected: the sky stays blue until told otherwise. The composition of words or sentences in a text follows some model of context based on the grammar that is being used. Similarly, the record in a typical numeric database may have some kind of relation between the entities that contain the base itself. There are rhythms and pauses in regular intervals in any voice or audio signal. These redundancies in the representation of data can be reduced to achieve potential compression.

Normally, the representation of data corresponds to a combination of information (entropy) and redundancy. The first is that part of data which must be conserved permanently in its original to correctly interpret the meaning or purpose of the message; while the second part corresponds to that, which can be removed when not needed, or rather reinserted to interpret the data when it is required. Generally this is done to regenerate the data in its original form (Acharya & Ray, 2005).

To explain efficient source coding, Shannon (1951) liked to use the following analogy: a pair of twins is located separately as the transmitter and receiver of a message. The transmitter is asked to predict which will be the next character in a particular text. If he guesses correctly, he is told so and writes the character down; if not, he is told which was the correct character, or is asked to keep trying until he hits upon it. For his part, the twin who is at the receiver commits exactly the same mistakes as its transmitting twin (at the end they are twins and have the same knowledge about the world). To send a message, the twin at the transmitter must guess; if he is correct, his counterpart at the receiver will be as well. For this reason, information only need be sent to the receiver when the twin at the transmitter is wrong, this being sufficient information for both to be able to write the correct character. Following this logic it is possible to transmit only very little data, while transmitting lots of information (reducing lots of uncertainty).

Information Theory (Cover & Thomas, 2006) permits the calculation of the theoretically possible compression level when the probable distribution of the source (which could be text, image, sound, etc.) is known. Unfortunately in many cases this distribution is not known (e.g. what is the probability of a blue pixel appearing in a video?). Coding theory aims to reach this theoretical level in practice. Lamentably, there exists no systematic method. In general, progress consists of engineering processes of “trial and error”, and in some cases it is not even understood why some specific algorithms have reached a performance as close to the theoretical limit. It is a continual process and significant advances have been achieved over the last 20 years in getting closer to the optimal level of compression (which is to say, in removing the largest amount of redundancy). Here we assume that the most efficient level of compression achieved in 2007 represents the "entropic" level and refer to it as "optimal level of compression". We normalize on this level of compression. It might well be that that future algorithms discover ways to compress a certain kind of content even further. Only the future will tell if this will be the case. If this is the case, it might be useful to renormalize on the newly found “entropic level” of compression.

B.2 Classification of Compression Algorithms

In an abstract sense, the compression of data may be described as a method that takes data from input *D* and generates a shorter representation of data *c(D)* with a lower number of binary digits in comparison with *D*, since redundancy has been removed. The inverse process, called decompression, takes the compressed data *c(D)* and generates or reconstructs data *D’* (see Figure B-1).

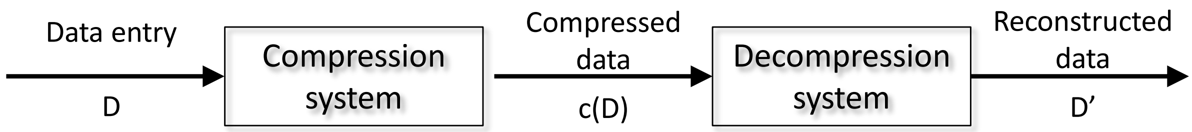


Figure B-1: CODEC (Encoder/Decoder).

There are two ways to compress data: without losses (lossless) and with losses (lossy). These terms make reference to the fact that reconstructed data (*D’*) may be identical or an approximation of the originals, respectively; depending on the requirements of the user. In the case of lossless compression, compression is totally reversible.

Regarding lossy compression, the step of the transformation of data usually removes the non-perceptible information for the given user (information which many times is irrelevant to human senses) that appears in the known structure of the data sequence. Depending on how much compression is applied to the original file, it is possible to achieve that no deterioration is caused whatsoever. In terms of how much compression is achieved, lossy algorithms are much more efficient than lossless, given that the latter are limited only in removing the present redundancy. For example, lossless algorithms for still images are based on the idea that neighboring pixels tend to have similar values; on the other hand, lossy algorithms, in addition to that stated above, take in consideration that the eye is not very sensitive to high frequencies (blue colors) and is more sensitive to color changes than to changes in brightness, for which they are able to eliminate much more information without necessarily damaging the quality of the finished product. So, we may say that lossy methods are generally utilized in audio, voice, still image, and video files.

Text files or those which contain scientific data are not usually coded with lossy algorithms, since the slightest error in reconstruction could cause its significance to change completely (for example, compressing the message

“You should no*t* delete this file” with losses of only one letter, could upon decompression show up as “You should no*w* delete this file”). Lossy compression techniques are applicable where no absolute fidelity of the reconstruction of data is required (Acharya & Ray, 2005). For our purposes, we assume that quality compression is applied with "very good" or "excellent" results, which enables some, but ensures no significant loss of information (i.e. losses that are not noticeable for human senses).

The following explains the operating principles of the most efficient algorithms, which occasionally are also the most popular ones, and presents the achieved compression rates. We also report the most commonly used algorithms (“dominant design”) in 1986, 1993, 2000 and 2007, which are necessary to estimate at which level of compression a certain type of content can be found at which point in time.

B.3 Text

Although many specific algorithms exist for the compression of text (e.g. Salomon, 2007; Cleary and Witten, 1984; Sayood, 2006), the most popular compression programs used in computers are the RAR and ZIP formats. Both are widely used principally in the compression of text, but can also be used for the storage/transmission of several coded files of diverse contents (for example, all the songs contained on a disk or a photo album from some special occasion can both be compressed into one ZIP file). We also use the compression levels of RAR and ZIP algorithms as an approximation for the compression algorithms used by Microsoft in its Word processor program (in “.doc” and “.docx” files, both of which achieve rates very similar to those of RAR and ZIP).

B.3.1 RAR

RAR is a proprietary format, an acronym for *Roshal Archive (or RoshalARchiver)*, with its names owing to its creator Eugene Roshal, who developed this method as his doctoral thesis. Its implementations in software have the particular characteristic of permitting the user to specify the amount of redundancy (as a percentage of the original size of the data to be processed), in this way allowing the data to be more or less robust against file corruption depending on the amount of redundancy left (Salomon, 2007).

RAR has two compression modes: general and special. The first of the two utilizes an algorithm based on LZSS, very similar to ZIP’s *deflate*. Starting with version 3.0, RAR also uses a special compression mode to improve the compression of like-text data. This mode is based on the PPMD mode (also known as PPMII).

In Table B-1 we present the results of the compression of text in this format (other types of content besides text are not considered, because it known that RAR is not as efficient as other methods when it comes to other types of content).

Table B-1: Results of the benchmark for optimal compression algorithms.

Algorithm	Data to be compressed [bytes]	Compressed data [bytes]	Compression factor[1]
PPMD (WinRAR 3.6)	1,000,000,000	198,454,545	5.04
	100,000,000	22,713,569	4.40
LZSS (WinRAR 2.01)*	3,393,000	782,050	4.34

Source: (Mahoney, 2009a; Nieminen, 2004)

B.3.2 ZIP

The compressed file format ZIP is very simple. It permits a reduction in size of a group of files (each in an independent manner), and is widely used. Applications such as WinZip, Gzip, etc. utilize a method called *deflate*[2]. This is a very popular method and is used by other applications such as HTTP protocol, the protocol of compression control PPP, PDF (*Portable Document File*) and the graphic file formats PNG and MNG (*Multi-Image Network Graphics*), among others (Salomon, 2007).

Developed by Philip Katz in 1989, the *deflate* method and the ZIP file format are part of the public domain, which is why there exists a grand number of applications which utilize them in different computing platforms. In order to identify an average compression factor for ZIP (regardless of the application being used), we consider a simple average of the compression factors reported in Table B-2, which results in 4.61.

Table B-2: Results of the benchmark for optimal compression algorithms.

Algorithm	Data to be compressed [bytes]	Compressed data [bytes]	Compression factor
7-Zip	3,393,000	650,610	5.22
Bzip2	3,393,000	678,030	5.00
advZip	3,393,000	808,720	4.20
Gzip	3,393,000	841,490	4.03

Source: (Nieminen, 2004)

[1] The presented figure corresponds to the quotient between the original size of the file and its compressed size.
[2] The ZIP format utilizes several methods for compression (all based on the dictionary, such ash LZW, LZ77, based on sliding window, etc.); however, *deflate* is the one most commonly used.

B.3.3 Text Compression Rates over time

1986

Around 1986, the LZW algorithm (an improvement on LZ77), developed by Abraham Lempel, Jacob Ziv, and Terry Welch in 1984, was implemented in the program *compress*, and was the standard in UNIX systems ("Lempel-Ziv-Welch", 2010). This algorithm is referred to as the standard. The compression rate achieved by LZW is variable and depends on the type of data (text) that is being compressed. Based on what is reported in (Welch, 1984), we have formed a simple average of each of the rates, obtaining a result of 2.2:1.

1993

The assumptions for this year are that in comparison with the period before 1993, the distribution of compressed data formats did not vary in 1993; and that there is a direct proportional relation between what is transferred and what is stored (it is known that this is not always the case, but given the lack of information, it is considered valid).

Table B-3 presents the percentages which represent each of the formats and their respective compression rates. With respect to the percentages, that is to say, the distribution of use of LZW, ZIP, and others, they were calculated starting with the number of archives most commonly transferred by FTP (*File Transfer Protocol*) (Ewing et al., 1992), and not the number of bits that such file transfers involve, this being because said number would better indicate the preferences of the users regarding the use of the different formats. We may suppose that the assigned compression rate with other formats (different than LZW and ZIP, among which include the files .arj, .uu, .dms, .lzh, etc.) is the same achieved by LZW (on this subject, no other statistic is known).

Table B-3: Distribution of formats of file compression and their respective compression rates.

Algorithm	Percentage [%]	Compression factor
LZW	45%	2.2
Zip (deflate)	31%	4.6
Others	24%	2.2
Sum and weighted averaged		
Total text	100%	2.9

Source: Authors' own elaboration, based on various sources (see text).

2000

It is supposed that the ZIP format is the most used in compression of text files in this period. While it is so that the RAR format had already been introduced in 1996, for the fact of being a proprietary software, it still was not able to get a significant percentage of use (apart from that, both formats present a very similar performance: 4.6:1 versus 4.7:1). On the other hand, LZW fell out of use owing to technical problems and difficulties with the patent in 1987 ("Lempel-Ziv-Welch", 2010), so it is assumed that its percentage of use is negligible.

2007

For this year we suppose the most common use of RAR in combination with ZIP for the compression of text. The difference is marginal, given that both formats present a very similar performance (4.6: 1 versus 4.7: 1). It is important to note that new algorithms have been developed for the compression of text (PPM, CM, etc) that achieve a higher performance; however, their use still is not very wide, mostly owing to problems with the applications which implement them (for example, they require certain hardware characteristics to be able to function correctly) or to a lack of market interest or publicity.

Optimal

There exists a large amount of literature on the different types of text compression algorithms, which has generated a series of contradictory results. For our studies, we have decided to use the Mahoney report (2009b), which is used in the selection of the winner of the Hutter Prize[3]. It evaluates the performance of 120 different programs, each of them implementing one or a combination of the following text compression alogorithms: based on dictionary, LZ77 (Lempel-Ziv-1977), LZW (Lempel-Ziv-Welch), ROLZ (Reduced Offset Lempel-Ziv), LZP (Lempel-ZivPredictive), PPM (PredictionbyPartial Match), SR (Symbol Ranking), BWT (Burrows-WheelerTransform), DMC (DynamicMarkovCoding) and CM (ContextMixing). The programs are utilized to compress the first 10^8 (considered for the Hutter prize) and 10^9 bytes of the English version of Wikipedia on March 3, 2006.

The program with the best performance was DURILCA, a compressor based on the PPMD algorithm with compression filters for different types of files (text, executable .exe and data with fixed length registers), developed by the Russian Dmitry Shkarin in 2006. 8 versions of the program were evaluated (with 27 distinct configurations in all), each of them serving different sizes in byte of compressed archives. The next table shows the average performance of this program calculated as a simple average of the sizes of compressed files (for results with more detail, see (Mahoney, 2009c).

Table B-4: Results of the benchmark for the optimal compression algorithm.

[3] The aim of the Hutter Prize is to promote research in the field of artificial intelligence, specifically in the area of text compression; http://prize.hutter1.net/.

Algorithm	Data to be compressed [bytes]	Compressed data [bytes]	Compression Factors
PPM (durilca)	1,000,000,000	136,578,536	7.32
	100,000,000	17,023,623	5.87

Source: (Mahoney, 2009c)

Given the difference in the observed compression rates caused by the difference between the texts to be compressed, we have opted to utilize an average compression ratio of both –equal to 6.6:1 (original: compressed). This way it is taken into consideration that the algorithm in effect presents a performance, which is not always constant. This would imply that on average, every character, which at first is coded with 8 bits (UTF-8), would need only 1.21 bits to be represented, which is within the proposed limits by Claude E. Shannon (1951) in his publication *"Prediction and Entropy of Printed English"*: between 0.6 – 1.3 bits per character.

B.4 Still Images

A continuous image (non-digital or "analog") is the spatial distribution of irradiance[4] on a plane. In laymen terms, what the scanning process does is divide that image into small areas and then calculate the average irradiance for each one to create a two dimensional array (of *m* rows and *n* columns), in which the value of each of its components –called pixels or pel (*picture element*)- corresponds to the average irradiance. Pixels are fundamental in the digitization and the resolutions[5] already equal to *mxn* of the image depending on their size. In Figure B-2, the same image with different numbers of pixels (different resolutions) is shown (Jänhe, 2002).

[4] The irradiance is the quantity used to describe the power per unit area for all kinds of electronic radiation, corresponding to the visible spectrum.
[5] The term resolution is sometimes used to indicate the number of pixels per unit length in the image. Examples of this are the units ppi or pdi.

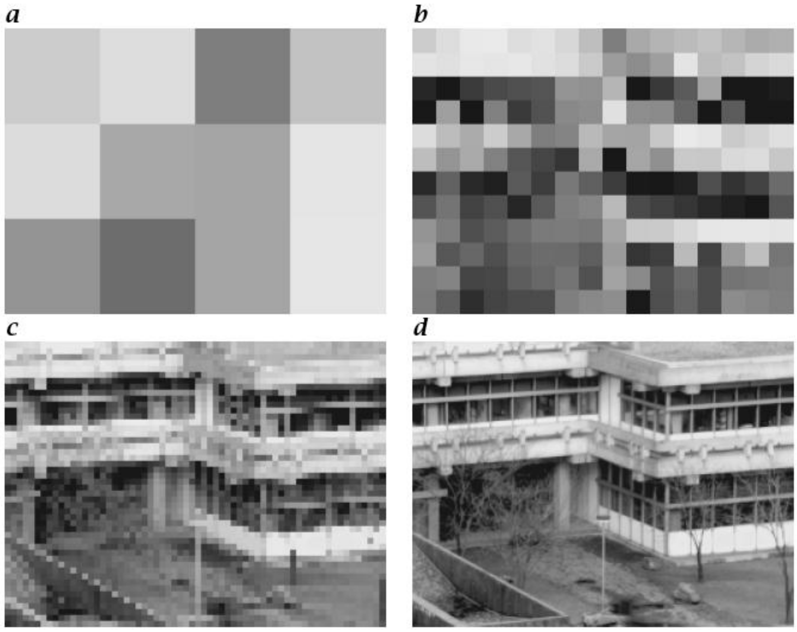


Figure B-2: Dependence of resolution on the number of pixels. Image with different resolution. (pixel count): (a)3x4, (b) 12x16, (c) 48x64 y (d) 192x256 (Jänhe, 2002).

The first step in the digitization of a continuous image corresponds to sampling, a process in which a continuous space is converted into a discrete one. Following the sampling of an image, it becomes necessary to quantify the sample values: to measure the irradiance of each pixel in a two-dimensional image, they should be mapped out on a limited number of discrete values (quantization levels) in gray or in color. Figure B-3 shows monochromatic images quantified with 2 to 256 levels of grey. It can be easily observed that with fewer levels, it becomes more difficult to recognize objects that show a slow spatial variation of grey values. With two levels (1 [bit/pixel]), the image produced is in black and white. Generally, the image data of these types are quantified in 256 levels of gray. So, each pixel is represented by 8 bits (2^8) (Jänhe, 2002). Also, each component of a color image is quantized with 24 bits, yielding a total of more than 16 million different colors. This is known as "true color" (Russ, 2007).

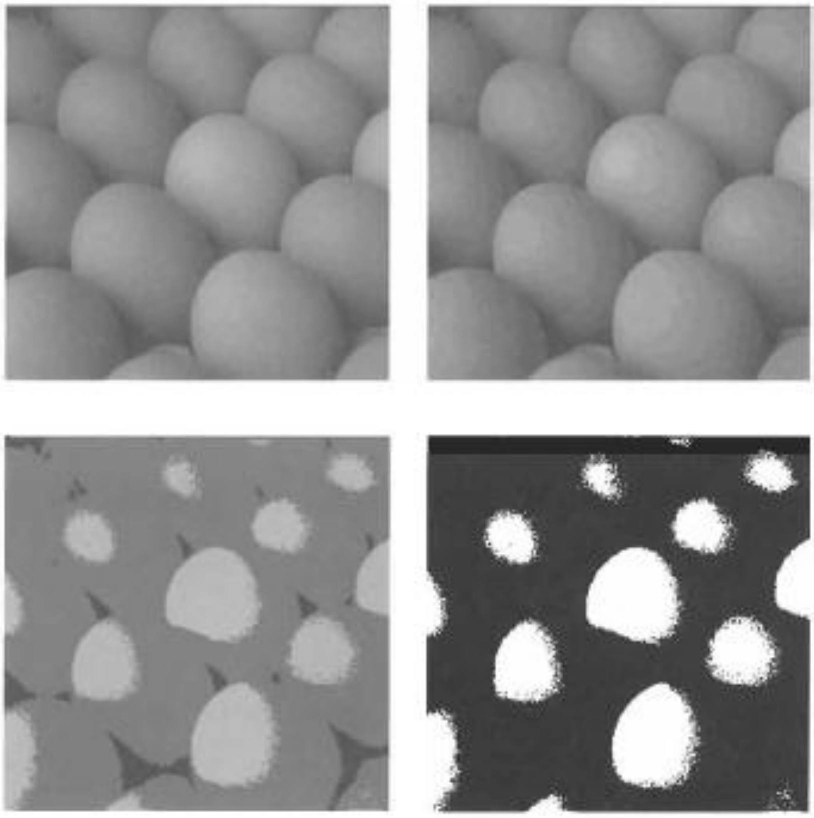


Figure B-3: Effect of quantization levels on the quality of the image: (a) 8 [bit/pixel], (b) 4 [bit/pixel], (c) 2 [bit/pixel] y (d) 1 [bit/pixel] (Bovik, 2000).

Digital images tend to use a lot of space on the storage hardware. For example, a 512x512 pixel resolution in true color (24 [bit/pixel]) uses 786 432 bytes, while one of 1024x1024 requires 3 145 728 bytes for its storage purposes. With this in mind, image compression algorithms have become essential. Lossy compression aims at discarding some of the features that are not visible to the naked eye, without losing the quality of the compressed image. The idea is the corner stone of lossy compression algorithms, which in addition to classic reduction or elimination of redundant content used in lossless algorithms, also uses the additional concept of removing irrelevant content (information that is not noticeable to the human senses).

When coming up against the challenge of cutting out the redundancy of an image, the art of image compression consists in exploiting the correlation between pixels. If two pixels are perfectly correlated, then all that needs to be done is store the first ones: the second is predictable in relation to the first, and therefore it does not transmit any additional information. One of the problems with images is that there exists no clearly established alphabet and dictionary of shapes and colors, as there does for letters and words. This makes it somewhat difficult to calculate the probabilities of each pixel in the image. For example, if a pixel has the color blue, what are the chances that the pixel to the left is green? This depends on a lot of things and varies for different types of images.

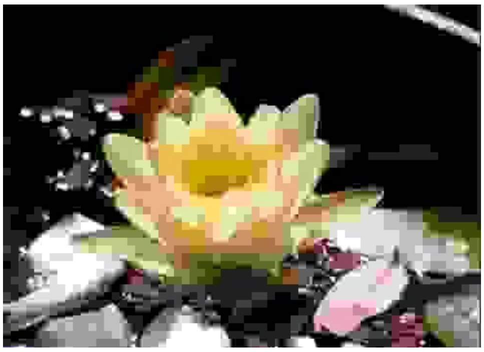
That said, there are many algorithms to compress images, each with its own advantages and disadvantages. For this study, we look at the three most-used which as well show good performance at the time of compression. The selected techniques are JPEG, PNG and GIF. According to (Acharya & Tsai, 2005), more than 90% of users utilize JPEG and following several sources, among them (Miano, 1999; King, 2000; Sayood, 2006), GIF and PNG are the most-used format on the Web.

B.4.1 JPEG

JPEG (Joint Photographic Expert Group) is a compression technique with and without losses for images in color or in gray scale, standardized by the joint group CCITT/ISO in 1991. In 2000, the successor to the lossy JPEG was standardized: JPEG2000, which gives better results in terms of trade-off quality/compression than did its predecessor (Levien, 2000; Purandare, 2008). The better performance of JPEG2000 in highly compressed images is due to the fact that it does not present pixelization (notable pixels in the image), but something more like a “blur” (see Figure B-4). However, it is clear that these high rates (greater than 100:1) greatly affect the image quality.

JPEG (21:1 – high quality)

1.1.1.1.1 JPEG2000 (21:1 – high quality)



1.1.1.1.2 JPEG (217:1 – Poor quality)

1.1.1.1.3 JPEG2000 (217:1 – Poor quality)

Figure B-4: Comparision JPEG vs JPEG2000 (Purandare, 2008).

One key feature that has allowed the all-around success of JPEG is that it lets the user configure many parameters, including the amount of losses permitted and the compression ratio, which in the end enables the user to determine the quality and the desired compression

The sequential lossless mode is based upon predictive coding principles, a simple method which predicts the value of a pixel by the value of previously encoded pixels, given the correlation between them. The typical ratio achieved is 2:1 for moderately complicated color images (Acharya & Ray, 2005; Wallace, 1992, Salomon, 2007). This can be understood as follows: each pixel in the image is represented by 16 binary digits, so after compression, on average, it would then be represented by only 8 binary digits. This compression level is not very effective and still ends up being a fairly large image. The DCT based sequential mode (Baseline JPEG) is a lossy image compression and is the most-used (following Acharya & Tsai, 2005). JPEG *Baseline* meets the standards of *criteria of fidelity* defined by Shannon, which say that an accurate representation of the original message is not necessarily needed because of the limitations of the human perceptual system (i.e. vision) (Pierce, 1980). In this case, it takes advantage of the fact that the human eye is less sensitive to color changes than to changes in the brightness of an image. In color images, the majority of spatial information is found in their "brightness", while the color components remain largely redundant (King, 2000; Wallace 1992; Salomon, 2007; Bovik, 2000; Acharya & Ray, 2005).

(Wallace, 1992) proposes a guideline on the quality and quantity of bits (binary digits) per pixel for a color image with moderately complex scenes. These can vary significantly depending on the characteristics of the image source and on the content of the scene, but they do give a good base for making estimations on the amount of information (Table B-5).

Table B-5: Relationship between the number of bits per pixel and the quality of the resulting image.

[bits/pixel]	Characteristics
0.25 – 0.5	Moderate to good quality, sufficient for some applications
0.5 – 0.75	Good to very good quality, sufficient for most applications
0.75 – 1.5	Excellent quality, sufficient for almost all applications
1.5 – 2.0	Usually indistinguishable from the original, sufficient for most demanding applications

Source: (Wallace, 1992).

B.4.2 GIF

The GIF format, (Graphic Interchange Format) was developed in 1987 by Compuserve Information Services as a format for efficiently compressed graphic files (Miano, 1999). Due to its superior compression ratio and greater color depth, JPEG has replaced GIF in the storage of photographic images during the last years, even though GIF is still used for other applications, mainly in Web browsers (because it compresses at a smaller size). The main features of a GIF image are that they can have up to 256 colors (using from 1 up to 8 bits per pixel) (Salomon, 2007). GIF scans images row by row and finds out the correlation between the pixels in them but not the correlation between the different rows. This shows that GIFs inefficiency lays in the singular dimensional work of the GIF encoder, where the images are two dimensional. It could be that a certain image has a large region of constant values which can be taken advantage of when considering two dimensional areas. Recently, a new standard called PNG has arrived which utilizes the fact that the surroundings of a pixel present a variation of its values, generally in a small sub-area of a coded image. PNG (Portable Network Graphics) utilizes the differences in neighboring pixels, and therefore can achieve between 10% - 40% more storage than GIF (Miano, 1999). Another factor to be considered is the fact that GIF does not introduce losses of information because it does not eliminate what is irrelevant and preserves each original pixel.

B.4.3 Image compression rates over time

The following summarizes the compression ratios achieved by different compression methods for still images. Regarding JPEG, we arrived at our estimation based on the data presented in Table B-6 and considered that a pixel has 24 bits in the case of a color image or 8 bits in gray scale. For the rest, we verified the information by other sources taken from (King, 2000). It should be mentioned that the column on the ratio of black and white compression is only an estimation (there is no specific information on the respect) based on the number of bits per pixel in the case of JPEG, which is achieved once the compression is the same as for colors. This assumption is justifiable since much of the information is contained in the glossy (reflecting exactly a grayscale image) while the information provided by the color components are practically redundancies. From this we may conclude that the amount of byte/pixel must be very similar in both cases.

Table B-6: Compression rates for the algorithms considered[6].

Format	Typical compression rate (color)	Typical compression rate (B&W)	Description
GIF	4:1 – 10:1 [7:1]	4:1 – 10:1 [7:1]	Lossless compression for images with a palette of 256 colors
JPEG (high quality)	12:1 – 16:1 [14:1]	4:1 – 5.3:1 [4.7:1]	High quality. Little or no loss in image quality with continuous original tones
JPEG (moderate to high quality)	16:1 – 32:1 [24:1]	5.3:1 – 10.7:1 [8:1]	
JPEG (moderate quality)	32:1 – 48:1 [40:1]	10.7:1 – 16:1[13.4:1]	Moderate quality. Usually the best choice for use on the Web
JPEG (poor quality)	48:1 – 96:1 [72:1]	16:1 – 32:1 [24:1]	Poor quality. Ok for simple images (thumbnails). The pixelation is obvious
PNG	10 – 30% smaller than GIF	10 – 30% smaller than GIFs	It behaves in a similar way to GIF but with higher quality

Source: (Wallace, 1992; King, 2000)

[6] In (King, 2000) the conjoining of JPEG is slightly different. It reports that for high quality, they vary between 10:1 – 20:1, for medium quality –without separation between upper-middle and lower-middle between 30:1 – 50:1 and for low quality, between 60:1 – 100:1, which is consistent with reports by (Wallace, 1992).

Since there is no information available on the percentages of color or black and white images, we will follow the same distribution of photographic negatives (for more in depth details see Table E-19 in storage). Different from text compression, the factors are not the same for each type of storage device and for transmission technologies for certain years because it is considered that they store or transmit images with different qualities.

1986

Although the history of the digital image dates back to 1957 (Kirsch et al., 1957), in 1986 the commercial compression methods were still in the experimental stage. That is why we may assume that the compression factor is equal to 1: 1 (that is to say, no image is compressed) for all storage devices and all transmission technologies.

1993

Since JPEG was established in 1992 (Ewing, 1992), it may be assumed that is 1993 its use was still minimal, so we will assume that all digital images were compressed in GIF format with a compression ratio of 7:1 (average compression is chosen with the aim ensuring that the image has good quality). As support for this assumption we have (Mogul, 1995), which indicates that 99.8% of server image requests were in GIF format in 1994 (for black and white and color images).

2000

Wolman (1999) reports that 77.5% of image files in 1999 were stored in GIF format, while 22.5% corresponds to JPEG. This ratio is considered for 2000, furthermore assuming that the distribution is valid for any storage device or transmission. Since it is assumed that the images are stored/transmitted with different qualities, the compression factor will vary in accordance with the technology. Below we look over the details.

JPEG moderate-low quality

Compressed images of moderate to low quality are mainly used on the Web, producing slight but noticeable distortions. They do not support extensions (whether done by the zoom of some photo editor or in print) without affecting the quality negatively. It is assumed that technologies that store JPEG with low-medium quality are for WWW, FTP and e-mail traffic. On the other hand, with the exception of newspapers, we can suppose that the distribution between color and black and white images is the same as those of photographic films for this year (97.5% and 2.5%, respectively), so that if we calculate a weighted average it would yield a compression factor equal to 14.28.

Table B-7: Compression Factors.

	Compression factors		Percentage [%]
	Color	B&N	
GIF	7.0	7.0	77.5
JPEG	40.0	13.4	22.5
Average factors	14.43	8.44	-
Percentage	97.5	2.5	
Weighted average	14.28		

Source: Authors' own elaboration, based on various sources (see text).

JPEG medium-high quality

Within this category, we have considered images stored on mobile phones (which only store color JPEG color, not the GIF combination), floppy disks, digital data magnetic tapes and video-game console data storage devices. Compression factors are shown in the next table. Considering the combination of JPEG and GIF, the resulting weighted average of the image in color and in black and white is equal to 10.74.

Table B-8: Compression Factors.

	Compression factors		Percentage [%]
	Color	B&N	
GIF	7.0	7.0	77.5
JPEG	24.0	8.0	22.5
Average factors	10.83	7.23	-
Percentage	97.5	2.5	
Weighted average	10.74		

Source: Authors' own elaboration, based on various sources (see text).

JPEG High quality

In this case, we will suppose that USB, PDA and hard disks store high quality JPEG, and that furthermore, only digital cameras and CD/DVD use JPEG exclusively. For images stored in "analog" (paper and film photographs; radiographies, etc.), only JPEG is used at this quality; this is because this level of compression does not produce additional losses in quality. It is important to keep in mind that the low level of quality of printed images has already been considered during the process of digitization, and therefore, any further reduction through compression would result in an impoverishment that would not fit with reality.

Table B-9: Compression factors.

	Compression Factors		Percentage [%]
	Color	B&N	
GIF	7.0	7.0	77.5
JPEG	14.0	4.7	22.5

Average factors	8.58	6.48	-
Percentage	97.5	2.5	
Weighted average	8.53		

Source: Authors' own elaboration, based on various sources (see text).

2007

Andersen (2006) reports that in 2005, 63.7% of the compressed images on servers that contained all Danish web pages were stored were in JPEG format and the remaining 36.3% in GIF. Supposing that the portions were kept constant with the passage of time and are valid for the entire world, we consider the resulting weighted compression rates.

JPEG medium-low quality

Table B-10: Compression factors.

	Compression factors		Percentage [%]
	Color	B&N	
GIF	7.0	7.0	36.3
JPEG	40.0	13.4	63.7
Average factors	28.02	11.08	-
Percentage	97.5	2.5	
Weighted average	27.60		

Source: Authors' own elaboration, based on various sources (see text).

JPEG medium-high quality

Table B-11: Compression factors

	Compression factors		Percentage [%]
	Color	B&N	
GIF	7.0	7.0	36.3
JPEG	24.0	8.0	63.7
Average factors	17.83	7.64	-
Percentage	97.5	2.5	
Weighted average	17.57		

Source: Authors' own elaboration, based on various sources (see text).

JPEG High quality

The corresponding compression ratios are shown in the following table. We must mention that the PNG image format, since its standardization in 2003, has grown in popularity and according to (Marshall, 2008) has started to replace the dominating GIF standard on the Internet and in the storage of digital images, because it achieves between 10% - 40% better compression. Nevertheless, due to the lack of information about percentage of use, this format is not included in the estimate.

Table A-B-12: Compression factors.

	Compression Factors		Percentage [%]
	Color	B&N	
GIF	7.0	7.0	36.3
JPEG	14.0	4.7	63.7
Average factors	11.46	5.53	-
Percentage	97.5	2.5	
Weighted average	11.31		

Source: Authors' own elaboration, based on various sources (see text).

Optimal

For this case, we will assume the maximum level of JPEG compression rates for each of the categories seen.

Table B-13: Optimum compression factors for still images.

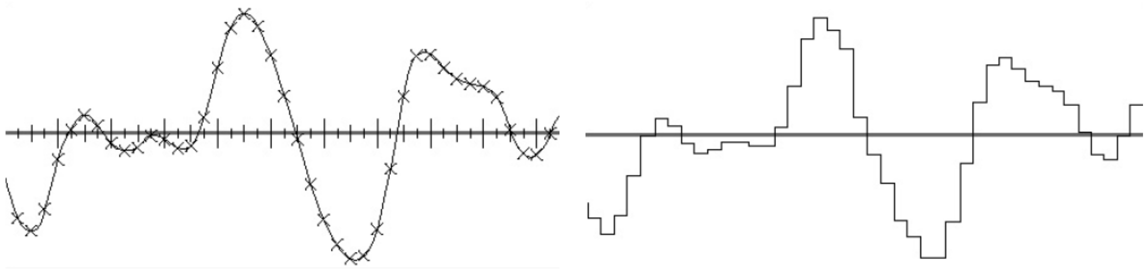
Quality	High	Medium-High	Medium-Low
Color compression factors	16	32	48
Black and white	6.0	10	16

Source: Authors' own elaboration, based on various sources (see text).

B.5 Sound

The compression of sound information is grouped into two categories: voice and audio. In each case, the algorithms take advantage of the very characteristics of each type of information, and furthermore of the functioning of the human auditory system, to eliminate the greatest amount of redundancy and, in the case of lossy compression, any irrelevant information. The logic of digitization is common to both. In the first stage –sampling- the continuous wave that represents sound is transformed into a sequence of simple values which are taken in certain regular intervals of time. In practice, these take a rate 10% - 12% greater than that obtained with the application of the Sampling Theorem (Ibrahim, 2007; Salomon, 2007). When sound is digitized at high fidelity, a sample rate of 44.1 [kHz] is utilized, which is only slightly greater than the maximum audible frequency. Any lesser rate would lead to distortions (which become more noticeable the lesser they are), while higher sample rates do not produce notable improvements in the reconstruction (reproduction) of sound. Many low fidelity applications sample sound at a rate of 11 [kHz] and the telephone system, originally designed for conversations and not for digital communication, samples at 8 [kHz]. In this last case, any frequency larger than 4 [kHz] is distorted and it is because of this that, during a call, it is difficult to distinguish between the sounds of an "f" and an "s", or of a "p" and a "b" or "d", reason why it is customary to use reference words when spelling over the phone ("a as in apple", etc).

In the second stage of the process –quantization- the number of predefined discrete values is determined by the quantity of binary digits with which each sample is codified. In general, 8 to 16 bits are assigned by sample: if the first is utilized, a higher compression of the file is achived; but a poorer reconstruction of the audio would be the result than when using 16 binary digits, since the sound would only present 256 distinct amplitudes (2^8), instead of 65,536 (2^{16}). In Figure B-5, we present a comparison between an original sound wave (sampled at 8 [kHz] and coded with 8 bits per sample) and a reconstruction. Using a little imagination, it is possible to see that if quantization considers a smaller number of bits per sample, which implies that the range between maximum and minimum signal amplitudes is divided in less intervals (for example, if 4 bits per sample are used, this range would be divided in only 16 (2^4) intervals versus the 256 intervals achieved with 8 bits per sample), the reconstructed signal would present longer vertical "steps" and the wave would present even greater distortions than what is presented in the figure. The contrary situation would occur if more bits per sample were used.



Original signal (the x's show the location of the samples) **1.1.1.1.4 Analog signal reconstructed from digital**

Figure B-5: Comparison between an original audio signal and an analog reconstruction from digital[7] (Nelson &Gailly, 1995).

B.5.1 Voice

Among audio encoders, there exist a few that are designed specifically for the compression of voice signals, owing to the nature of the human voice, which has certain properties that allow for the achievement of more efficient signals (Benesty et al., 2008). The basis of voice compression techniques is the strong correlation that exists between adjacent samples in a digitized audio signal, including in samples that are separated by 20 [ms] (Salomon, 2007). Rarely some kind of perceptual modeling is utilized (such as the kind used in MPEG-4 for other types of audio), since the perception of the voice is quite different from other non-voice sounds (experiments have indicated a

[7] While at first sight it would seem that the two are radically different (the "soft" form of the original wave is replaced with another with well-defined "steps"); mathematically, the abrupt jumps that occur when moving from one sample to another represent the high frequency components of the signal. These are usually eliminated with a filter (high-pass), which is located at the exit of the digital/analog converter and amplifier before its reproduction. This causes the wave to regain, to a certain point, its softness (Nelson & Gailly, 1995).

specialization in the brain, where one part is in charge only of processing voice information (Chu, 2003)).

The basic techniques of voice compression come from the time of the invention of the telephone by A. Graham Bell and the possibility to represent the form of a voice wave as an electric analog signal by Homer Dudley (Linggard, 1990). There are three principle types of voice encoders:

- Waveform: attempts to reproduce the original waveform signal, producing good to excellent quality voice after compression and decompression, but generate high bit rates (10 - 64 [kbps]). They do not predict the form in which the sound is generated, but base it on a simple digitization of the sound (improving results with the application of *companding*, ex. G.711). In voiced sound samples, they are correlated (ex. ADPCM) or transform the audio samples to frequency domain, taking advantage of the difference in sensitivity of the ear to different frequencies (ex. SBC y ATC);
- Vocoders: use a predictive mathematical model for the calculation of certain parameters that describe the production of voice, generating voice with low to acceptable quality and compressing at very low rates (up to 2 [kbps]);
- Hybrids: combine the previous two to produce voice with quality ranging from acceptable to good, with bit rates of between 2 and 16 [kbps].

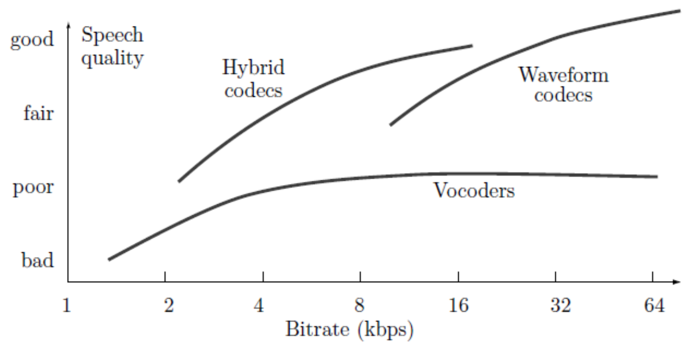


Figure B-6: Comparison of different kinds of voice encoders in terms of quality achieved (Salomon, 2007).

For example, a telephone voice signal requires 64 [kbps] to be transmitted without a great loss in quality, but modern compression techniques permit the bit rate to be reduced from 13 to 8 [kbps] with algorithms based on a paradigm called “analysis-by-synthesis”[8] (RTP-LPE o

---

[8] The term “analysis-by-synthesis” refers to the active analytic process that can be applied to signals that are produced by a generator whose properties are known. The nucleus of a system that implements this technique is a generator of signals able to synthesis all the analyzed signals. The signals analyzed by the generator are compared with the signals to be analyzed, and a measure of error is calculated. Different signals are generated until it finds one that causes an error to reach some small value, the

CELP, for example) –the base of hybrid encoders and the principle responsible for those achievements-, with very little additional degradation (Chen & Thyssen, 2008). On the other hand, the appearance of new applications, like video-conference services and the third generation of mobile phones (3G), has let to the development of new encoders to provide higher fidelity voice than that of classic telephony which limits the signal frequencies up to 4 [kHZ], extending the aforementioned range up to 8 o 16 [kHz] (Wakefield, McNally, Bowler&Mayne, 2007). From this we may infer that by increasing the bandwidth, the quantity of contained redundancy in the digitized signal is raised to improve the robustness of the message.

Within the *Speech Profile* of MPEG-4, specialized tools are integrated for the codification of voice, which operate in the range of 2 to 24 [kbps]. They are CELP (CodeExcited Linear Prediction) and HVXC (Harmonic Vector eXcitationCoding), which was selected to cover the range from 2 to 4 [kbps] (Edler. 1998; Goldberg & Riek, 2000; Chu, 2003). Both are part of the hybrid encoder family. It is important to note that the value of optimal compression is approximated using predictive analysis, which eliminates the greatest amount of redundancy possible in the signal.

B.1.1.1 Voice compression rates over time

Regarding digital fixed-line phones, from 1972 up to today the standard is G.711, with compression factors equal to 1.63 and 1.75 for the United States, Japan, and Australia, and for Europe and the rest of the world, respectively;. Those have remained constant up to current times (see Ojala et al., 1998). The case of mobile telephones and VoIP is different and is presented in the following.

1986

Only the analog mobile phone existed by this time, for which no compression scheme is used.

1993

The only digital mobile technology commercially available was GSM (since 1992), which utilized the GSM.FR algorithm, based on RPE-LPC, achieving a compression factor equal to 8.

2000

---

moment in which the analyzer indicates the properties of the internally generated signal (Chen & Thyssen, 2008).

In the year 2000, there already existed GSM (including 2.5G GPRS y EDGE), PDC, TDMA, iDEN and cdmaOne technologies. To calculate the average compression factor, we consider that the percentages of each of them represent the total subscribers of digital technologies and their respective compression factors, in this way obtaining a weighted average of 13 (Table B-14).

Table B-14: Compression factors for technologies in use in 2000.

	GSM	cdmaOne	PDC	TDMA	iDEN
% subscribers	68.1	12.4	7.8	10.4	1.3
Compression factor	15.1	4.9	15.5	8.0	8.0
Average factor			13.0		

Source: Authors' own elaboration, based on various sources (see text).

VoIP had already been functioning for five years in 2000 (in 1995, a small company called VocalTech released the first software with support for VoIP (Malik, 2004), right after the appearance of the Intelx486 which could manage the coding/decoding of voice in real time). VoIP supports a large amount of compression algorithms, and the one that is eventually utilized is "negotiated" between the participants in agreement with those used by each party and with the nature of the web traffic at this moment. Table B-15 shows the most common encoders, together with their compression rates. Given that there is no *a priori* knowledge on which percentages represent each one or which is the most popular, we have opted to utilize a simple average of the representative compression factor, equal to 7.9: 1.

Table B-15: Most-used compression algorithms by VoIP before 2000 and their respective compression rates.

Codec	Year	[kbps]	Sample Rate[kHz]	Bits/Sample	Compression Factor
G.711	1988	64	8	13 or 14	1.7
G.729	1996	8	8	13	13.0
G.723.1	1996	6.3	8	13	16.5
G.723.1	1996	5.3	8	13	19.6
G.726	1990	32	8	13	3.3
G.726	1990	24	8	13	4.3
G.722	1988	48	16	14	4.7
G.722	1988	56	16	14	4.0
G.722	1988	64	16	16	4.0
GSM	1986	13	8	13	8.0
			Average compression factor		7.91

Source: (Cisco, 2006; "Comparison…", 2010; Unuth, 2010)

2007

To the previous technologies, we add those of the third generation: (UMTS), cdma2000 1x y cdma2000 1xEV-DO. The procedure for obtaining the average compression factor is the same as described above.

Table B-16: Compression factors for technologies in use in 2007.

	GSM	cdmaOne	PDC	TDMA	iDEN	CDMA2000 1x	WCDMA	CDMA2000 1xEV-DO
% subscribers	81.0	0.4	0.5	0.2	0.9	9.0	5.6	2.5
Compression factor	15.1	4.9	15.5	8.0	26.0	15.0	16.8	20.2
Average factor					15.4			

Source: Authors' own elaboration, based on various sources (see text).

Given that there is no further information regarding VoIP, we have opted to use a simple average of the compression factors reported in Table B-15 and Table B-17, which is equal to 8.28.

Table B-17: Most-used compression algorithms by VoIP and their respective compression rates.

Codec	Year	[kbps]	Sample rate [kHz]	Bits/Sample	Compression Factor
iLBC	2002	15.2	8	16	8.4
Speex	2003	2.15 – 24.6	8	16	9.6
Speex	2003	4.0 – 44.2	16	16	10.6
Average compression factor (considering Table B-15)					8.28

Source: (Cisco, 2006; "Comparison…", 2010; Unuth, 2010)

Optimal

We have considered the subjective results of the quality evaluations of encoded narrowband voice (Edler, 1998; Ojala et al., 1998). These are expressed in MOS (*Mean Opinion Score*) values, which provide a numerical index of the perceived quality of sound received after compression and/or transmission. Just as the name indicates, this index is subjective, and is based on the perceived quality by the persons that participate in the sample. The relevant question follows a scale of 1-5, with 5 points being excellent quality, and 1 point poor quality. Table B-18 shows the equivalence between the value of this measure and the quality.

Table B-18: Description of MOS rating system

MOS	5	4	3	2	1
Quality	Excellent	Good	Acceptable	Poor	Very Poor
Distortion	Imperceptible	Perceptible, but not annoying	Slightly annoying	Annoying	Very annoying

Source: (ITU, 1996)

Measurements have been made on how many bits are needed to encode different telephone calls with CELP-MPE/HVXC. It has been found that for acceptable quality (close to 3 on the MOS scale, see Table B-19) some 4kbps are required to digitize all of the information contained in a call with CELP-MPE/HVXC, while for good quality (close to 4 MOS points), 12 kbps would be required. It has been discovered that MOS for digital land line telephony (G.711 codification) is in the MOS range of [3.6 - 4.1] (Liu & Du, 2007; Cisco, 2006). For our purposes we have therefore considered the highest average MOS rate from the tests, that of 12 [kbps] with CELP-MPE, for the calculation of the compression rate. Similarly, in the case of analog transmission, where an acceptable quality has been supposed, a rate of 8.3 [kbps] will be used, which is also achieved with CELP-MPE (see Table B-19).

Table B-19: Results of subjective quality tests on coding of narrowband voice in SpeechProfile MPEG-4.

	HVXC	HVXC	CELP-MPE	CELP-MPE	AMR-WB	EVR-C
Bit rate [kbps]	2	4	8.3	12	12.65	8.55
MOS	2.53	2.92	3.25	3.69	3.78	3.82

Source: (Ojala et al.,1998; Ramo &Toukomaa, 2005; Gibson, 2005).

Regarding mobile telefony, as a compression technique, RPE-LPC utilized for GSM has an MOS that varies from between 2.91 and 3.16 (Rämö & Toukomaa, 2005). Following the logic of selecting the transmission rate achieved with the codification in accordance with quality, it can be said that a rate of 4 [kbps] is appropriate, given that the perception of quality is comparable. On the other hand, in agreement with (Rosenberg and Kemp, 2003), the typical MOS for a call in AMPS is 2.3, a rate of 2 [kbps] is considered the most suitable for analog telefony.

The following table presents the compression factors for consideration. They were calculated in the following fashion: in digital telephony it is supposed that, in accordance with the MOS, its compression rate can be optimally compressed at 12 [kbps]. This implies that it achieves a compression rate of 9.0, which is equal to the ratio between the simple average of the digitized rates (112 y 104 [kbps]) and the compressed rates (12 [kbps]). As for analog telephony, we may follow the same logic, supposing however that the optimally compressed rate is 8.33 [kbps] and the average rate of digitized voice is 100 [kbps], which would indicate a compression factor of 12.

Table B-20: Compression rates for the transmission of voice via telephone

	Fixed-line analog	Fixed-line Digital	Analog Mobile	Digital Mobile	
				2G/2.5G	3G
Compression factor	12.0	9.0	32.0	16.0	22.9

Source: Authors' own elaboration based on (Ojala et al., 1998; Rämo & Toukomaa, 2005).

For 2G/2.5G mobile telephony, compression factors achieved with HVXC are used for bit rates of 2 to 4 [kbps], which is to say, 32 and 16 respectively. For 3G, we consider a weighted average –in accordance with the percentage of users- of the compression factors with Wideband AMR-WB and CELP WB algorithms. It is important to mention that in spite of these algorithms achieving higher compression (lower rates than those considered for the calculation on capacity), a potential compromise forces us to chose the rates that assure to maintain the same level of quality. In the case of VoIP, there is no typical measurement, as the MOS varies depending on the encoder used, the conditions of the web, etc. The maximum is obtained with the use of G.711 (MOS = 4.4) (Tamo Soft, 2010), and various sources report that a fall below 3.5 would serve as an indication of problems (Network

Instruments, 2007). It is for this reason that we consider the compression of 2007 and not that which would be obtained in Table B-19, since this one is less than the achieved compression of 2007.

B.5.2 Audio: MPEG

Audio compression methods, like image compression, may or may not allow losses of irrelevant information. Any loss does normally not result in a large damage of the quality of the reconstructed archive. Lossless algorithms take advantage of the fact that adjacent signal samples are highly correlated (it is not difficult to imagine if you consider that generally, in the digitization of an audio signal, more than 40 thousand samples are taken in a single second) (Salomon, 2008). Audio signals may be generated using a great number of different mechanisms. For this reason, the compression algorithms for lossy audio are focused on a model of sound perception, in other words, they utilize a psychoacoustic (ear+brain) model of human hearing, unlike voice compressors which are based on a model of the information source (in the output of the voice) to be able to identify the structures in the voice signal that can be used for their compression (Sayood, 2006; Salomon, 2007; Ibrahim, 2007). With the identification of what can and can not be heard, the schemes achieve a high level of compression by removing what can not be perceived.

There exist a large quantity of file formats and compression algorithms, both with losses and without, but the method of lossless compression most widely used is MPEG (*Moving Pictures Experts Group*) ("Data compression", 2010; Brandenburg & Popp, 2000). The original objective of MPEG was to create a standard for the codification of both audio and video in digital media storage. However, the part associated with the codification of audio began to be developed separately thanks to diverse studies and experiments. These trials proved that it was possible to compress a lossy audio signal without damaging its quality (Salomon, 2007). With this, MPEG audio began to be utilized for several applications; such as the transmission of digital audio (with Eureka-147 DAB,WorldSpace, ARIB, DRM), the storage of archives in broadcasting, the sound in digital television (DVB, Video CD, ARIB), streaming Internet, portable audio devices and for the storage and interchange of music files in computers.

The standard codification of MPEG-1 audio (1992) contains three different layers known as I, II, and III. MPEG-2 (1994) inherits and incorporates a new characteristic for improving the efficiency of codificiation, which in 1997 became the MPEG-2 AAC (*Advanced Audio Coding*) standard, a second generation audio compression scheme for the generic codification of stereo and multichannel signals (Watkinson, 2004; Salomon, 2007; Brandenburg & Popp, 2000; Sayood, 2006; Ibrahim, 2007; Herre & Dietz, 2008). One famous standard is the MPEG Audio Layer-3, better known as MP3. The difference between the different layers is that their complexity and performance increase progressively.

For its part, MPEG-4 is different than the two standards that came before. It puts more emphasis on the development of new features than on the efficiency of the codification. This standard aims to facilitate the growing interaction and overlap between the worlds of telecommunications, computation and massive electronic devices (TV and radio). As far as audio is concerned, MPEG-4 has a family of compression algorithms that range from voice compressors (at rates as low as 2 [kbps]) to high quality audio encoders for low bit rates (64 [kbps] per channel). It must be noted that for medium and high bit rates, MPEG-4 does not implement any improvement over MPEG-2 AAC.

MPEG does not work at a fixed compression rate. The resulting bit rate depends on the desired quality of the person who is using the encoder. For example, MP3s may have rates that vary from 8 to 320 [kbps], with which the compression ratio shifts between 4:1 and 176:1. What matters here is that the larger the bit rate or the less the compression rate, the better the quality, as the audio compression meets the general rule that says that the higher the bit rate, the better the quality of the audio played, since more original information is included in the compressed file. In addition to this, the audio quality depends as much on the quality of the encoder as on the nature of the signal to be encoded.

Based on various studies that have tested diverse encoders and digital audio formats in a subjective manner (i.e., a group of listeners listen to different sound archives and then grade them), we present the bit rates and their respective qualities (see Table B-21). It is certain that there exist qualities lower than this, but given the consequences of the use of lower rates (noticeable noise, unnatural sound, poorly defined bass/treble, "elimination" of instruments, etc.), such types have not been included in this study. In other words, this is equivalent to saying that at the time of compressing audio files, users prefer to have a backup of acceptable quality, although it would use more space in their storage devices.

Table B-21: Bit rates vs. Quality for different audio compression methods.

Quality	MPEG-1/2 Layer 1	MPEG-1/2 Layer 2	MPEG-1/2 Layer 3	MPEG-2 AAC[9]
Excellent (indistinguishable from CD)	384 – 448 [kbps]	256 – 384 [kbps]	224 – 320 [kbps]	160 – 256 [kbps]
Very good (very similar to CD, small loss of quality)		224 – 256 [kbps]	192 – 224 [kbps]	128 – 160 [kbps]
Good (sound different than CD, noise perceptible, but not annoying)		192 – 224 [kbps]	128 – 192 [kbps]	96 – 128 [kbps]

Sources: (Bouvigne, 2003; Meares, 1998; Lin, 2005; Mares, 2005; Wittle, 2001; Amorim, 2006; Costello, 2006, "MP3", 2010)

[9] The equivalences between bit rates and quality between the MPEG-2 AAC and MP3 formats are like those of the following (respectively): 96 is like 128 [kbps], 128 is like 192 [kbps], 160 is like 256 [kbps], 192 is like 256 [kbps], and 256 is like 320 [kbps].

Because, perhaps, the main use of audio encoders is by common people who "rip" their CDs so that they may store them digitally on computers or other digital devices, we consider that MPEG-1/-2 signals are digitized in accordance with the audio CD format. In other words: 44 100 samples per second, per channel (i.e., 88 200 samples per second if it is seen immediately that two stored stereo sound channels are sampled), each coded with 16 bits (Zölzer, 1999), which results in a rate of 1 411.2 [kbps]. In the case of MPEG-4, the digitization of the signal is generally sampled with 48 [kHz] per channel (96 thousand samples per second if it is stereo sound), coded with 16 bits per samples, showing a rate of 1 536 [kbps]. In Table B-22, we present the percentages of compression, derived from the quotient between the resulting bit rates after compression and the digitized rates.

Table B-22: Compression Factors

Quality	MPEG-1/2 Layer 1	MPEG-1/2 Layer 2	MPEG-1/2 Layer 3	MPEG-2 AAC
Excellent (indistinguishable from CD)	3.15 – 3.68	3.68 – 5.51	4.41 – 6.30	6.00 – 9.60
Very good (very similar to CD, small loss of quality)		5.51 – 6.30	6.30 – 7.35	9.60 – 12.00
Good (sound different than CD, noise perceptible, but not disturbing)		6.30 – 7.35	7.35 – 11.03	12.00 - 16.00

Source: Authors' own elaboration, based on various sources (see text).

B.5.3 Audio compression rates over time

Audio compression is applied in three main fields: storage, broadcasting, and streaming.

1986

The compression of digital audio was still being developed, and had not yet been standardized.

1993

An algorithm existed that was used only for Digital compact Cassettes, PASC (*PrecisionAdaptive Sub-Band Coding*) and was based on MPEG-1, achieving a compression ratio of 3.68:1 ("Digital compact cassette", 2010). However, given the sporadic use of this method, we do not consider compression for this year. Sound stored on film (movies) is a special case. Since 1991, Dolby Digital codification has remained the most utilized format (DeBoer, 2005). We assume that the typical sample rate is 44.1 [kHz], each sample coded with 16 bits and the sound with 6 channels (DellaSala, 2004). This results in a rate of 705.6 [kbps] per channel and a total of 4 233.6 [kbps]. Given that the compressed bit rate is commonly found at 384 [kbps], a compression factor equal to 11.025 is obtained.

2000

Storage

MPEG Audio Layer-3 or MP3 (from 1996) rapidly became the most popular format for the compression of digital audio (Brown, 2000), which can be assumed to be used starting from the appearance of the first completely functional MP3 reproduction software in 1997-1998 –the well-known Winamp (Bellis, 2009). Storage devices are divided into two categories: those that utilize MP3 with excellent quality, and those with good quality, with average compression factors equal to 5.36 and 6.83, respectively (calculated with the simple average or the corresponding range in Table B-22). A compression of very good quality compares to the quality of digital audio without compression (CD). This sacrifice of storage capacity is due to the lower compression that is achieved at higher quality.

In the case of film used for shooting movies, the audio is encoded with Dolby Digital, a format which achieves an average compression rate of 12:1, this being the factor used to make comparable the analog sound stored in the film.

Radio Broadcasting

It must be considered that the transmission of digital radio and the sale of devices able to reproduce this information began only recently in 1999, with the standardization of DAB, also known as Eureka 147. In those times, MPEG-2 Layer II (MUSICAM) was used as the compression algorithm, with a stereo transmission rate of 128 [Kbps] (according to ("Digital audio broadcasting", 2010), the quality with which the signal was reproduced was quite poor), which would imply a compression ratio of 11.025 : 1.

TV Audio Broadcasting

The transmission of digital TV began in 1998 in the United Kingdom, the same algorithm (implementing DVB, ATSC and ISDB) was used, except in this case with a rate of 128 [Kbps] and a total transmission rate equal to 256 [Kbps] (Benoit, 2002). Considering this, the compression ratio for television is 5.51 : 1.

Streaming audio

For the streaming of audio, at least three systems existed in 2000: IceCast, Darwin Streaming Server and SHOUTcast, which were used as MP3 compression algorithms. *Internet Radio* was used to encode music (mono) with rates that vary between 28 and 56 [Kbps], so it could be transmitted over dial-up connections in which we saw the predominant numbers (Austerberry, 2005). Given what has been stated before, the corresponding average compression rate is 16.8 : 1. This quality is not very good, but corresponds to the quality of streamed music.

2007

Storage

At the start of 2002, with the introduction of other compressed audio formats such as *Windows Media Audio* and *Ogg Vorbis* which have a better quality/bit rate than MP3, it was expected that the latter would become obsolete. Notwithstanding MP3 today continues to be the most used standard. We therefore consider the same compression rate in storage systems as in 2000. It is important to mention however, that the "new generation" of MPEG coding (AAC, HE-AAC, etc.) is winning ground. While this technology was designed mainly for streaming, iTunes 9 and many mobile telephones convert MP3 files to one of the aforementioned formats to be stored. For films we also keep the previous compression rate.

Radio Broadcasting

For audio broadcasting, MPEG-4 HE-AAC is the new standard in digital radio systems DAB+ (World DMB, 2007). It allows for more redundancy and is less extreme in its lossy compression, which brings it up to a compression factor of 7.35.

TV audio Broadcasting

For digital TV, MPEG-4 has also been adopted by the new standard DVB (DVB-T2/-S2/-C2); however in 2007 this was not yet used. Since there is no evidence in the change of audio encoding, the same compression rate is considered (6: 1).

Streaming audio

It is known that the mobile environment MPEG-4 AAC and AACv2 have been widely adopted (note that streaming came with the introduction of 3G technologies in 2001). With rates that vary between 48 and 64 [kbps] were able to play music with very good quality (Meltzer & Mozer, 2006). This results in a compression rate of 27.42: 1.

In the field of wired audio streaming, although MPEG-4 counts with advantages, the majority of content providers do not yet support it (MPEG Industry Forum, 2007). While many streaming systems already support at least AAC encoding, according to ("MP3", 2009), MP3 continues to dominate the scene. However, not anymore with the bit rates used in 2000. Following (Barlow, 2007) currently the rates vary from between 96 and 192 [Kbps] (in most cases the user can choose the rate which works best with the bandwidth which is available) with stereo sound. Considering the average bit rate between the two, we end up with a compression rate equal to 10: 1.

It could seem strange that the compression rate in broadcasting and streaming does not decrease when compared with the performance in 2000 and 2007. This is due to increasing the bit rate available to users allowed to transmit higher quality audio (monaural sound versus stereo 60 [kbps] versus one which varies between 128 and192 [kbps]). In the case of broadcasting, the use of spectrum has been optimized. In short, this tendency does not say that the performance of the encoders has worsened (as far as the compression rate is concerned), but that content providers have preferred to increase the quality of signals transmitted given the evolution in the transmission of files.

Optimum

Storage

MPEG-4 is currently the optimal way to encode audio and from the ranges shown in Table B-22, we select one that represents the maximum compression for each one of the grades shown. Following the assumption made above and considering MPEG-4 AAC (designed for storage), for analog devices (Excellent quality) corresponds with a factor of 9.6 and for the rest (very good quality), one of 12.

Broadcasting (Radio and TV)

MPEG-4 HE-AAC (v1 and v2) is the encoding profile of MPEG-4. It has been developed for applications which need good quality at a lower bit rate, like streaming and broadcasting (Meltzer & Mozer, 2006). In the case of radio transmission, DAB+ is the technology that implements this encoder and in accordance with (Alphonso, 2007) has the following characteristics: for quality better than FM: 56 – 96 [kbps]; for quality similar to FM: 40 – 64 [kbps]; for quality poorer than FM: 24 – 48 [kbps]. According to tests reported by (World DBM, 2008[a], 2008b; DigitalRadioTech, 2010), at 64 [kbps] an excellent quality is achieved for radio broadcasting, which is why we choose the average rate “superior quality FM” (76 [kbps]) as the best rate for use. This implies a compression factors equal to 20. In the case of audio transmission by TV, we assume that the same rate is applicable.

Streaming audio

In the mobile field, (Autti & Bitström, 2004) indicates that a rate of 48 [kbps] is the minimum for very good quality, which is supported by sources like (Frerichs, 2003; Wolters et al., 2003). With this the compression rate is equal to 32: 1. For the wiring stage, we have selected a rate of 64 [kbps], backed up by (Apple, 2010), which provides recommendations so the service may work properly. Thus the compression factor is 24.

B.6 Video

The compression of video enabled this type of content to go beyond the world of broadcast and enter the world of telecommunication (videoconferences, the streaming of video on Internet, etc.) and the storage of the same with high quality in magnetic or optical devices (Ghanbari, 2003). We review the principles of the encoding codec used, which is also MPEG, i.e. MPEG-2 to MPEG-4. Both are the leading standards.

B.6.1 MPEG-2

At the beginning of the 90s, the Motion Picture Experts Group (MPEG) had already begun their investigation into the development of coding techniques for video storage, for example CD-ROMs. With this, the first MPEG generation was born, called MPEG-1, which was capable of exceeding the previous rate of no more than 1.2 – 1.5 [Mbps]. However, this standard was not very well received on the part of the broadcasters (the image obtained with analog cameras had a higher quality than that achieved after compression with MPEG-1, besides that fact that it was designed to encode video “progressive” and not “embedded” like the one used on TV). Years later, the situation took a turn with the appearance of the MPEG-2, standard which allowed the embedded video coding with a rate which varied between 2 and 9 [Mbps]. Currently MPEG-2 is the most popular of the video codecs that exist, being used in a wide range of application, among which are noteworthy formats like digital terrestrial TV, satellite and by cable, the HDV format of the video recorders and storage in DVDs (Jacklin, 2002)

The standard MPEG-2 introduces the concept of profiles and levels. Of all existing profiles the one considered for this study is the one called Main (MP), being the one which is most general consumer oriented (Watkinson, 2004; Long, 1999; Ciciora et al., 2004). We continue with reviewing the bit rate used to store video and audio in a device. MP@ML (Main profile at the Main level) has a maximum rate of 15 [Mbps] and is relevant to the distribution of SDTV (*Standard-Definition Television*) and the storage in DVD at a rate between 2 and 6 [Mbps], having a maximum rate of 9.8 [Mbps]. For PAL systems (720 x 576 con 25 [fps]), the rates vary between 4 and 6 [Mbps]; for NTSC (720 x 480 con 30 [fps]), the rates vary between 2 and 3 [Mbps]. For its part, MP@HL (at high level) is relevant for the distribution of HDTV (High-Definition Television), with a rate that varies from 12 to los 20 [Mbps] (Wooton, 2005; Rairhurst, 2001). MP@LL (at low-level) is employed in the storage of video in CD (SVCD) with a maximum rate of 2756 [kbps].

Table B-23: Bit rates resulting from digitization with different sub-sampling of color components (SDTV).

Sampling structure		4:4:4	4:2:2	4:2:0
Number of pixels per line (Y)		720	720	720
Number of pixels per line (C_R)		720	360	360
Number of pixels per line (C_B)		720	360	360
Number of lines per frame	NTSC	480	480	240
	PAL	576	576	288
Number of frames per second	NTSC	30	30	30
	PAL	25	25	25
Transmission rate [bps]	TNTSC	248 832 000	165 888 000	124 416 000
	PAL	248 832 000	165 888 000	124 416 000

Source: Authors' own elaboration, based on various sources (see text).

For quality video, MPEG-2 uses the recommendation 601 of the CCIR (now called ITU Rec. B.601) which defines that each line in a frame must be sampled with 720 pixels (both NTSC and PAL/SECAM), besides supporting the sub-sampling of color 4:2:0 for the transmission of TV and the storage in DVDs, and 4:2:2 for the storage of videos mainly in magnetic tapes (see Table B-23 bit rate results) (Arnold et al., 2007; Tudor, 1995) (Table B-24). We consider the average of the rates mentioned in the previous paragraph for each category and then calculate the compression rates with the ratio between the previous value and the bit rate of the signal, considering in the sub-sampling scheme 4:2:0 y 4:2:2 where appropriate.

Table B-24: Compression factors for MPEG-2 typical rate.

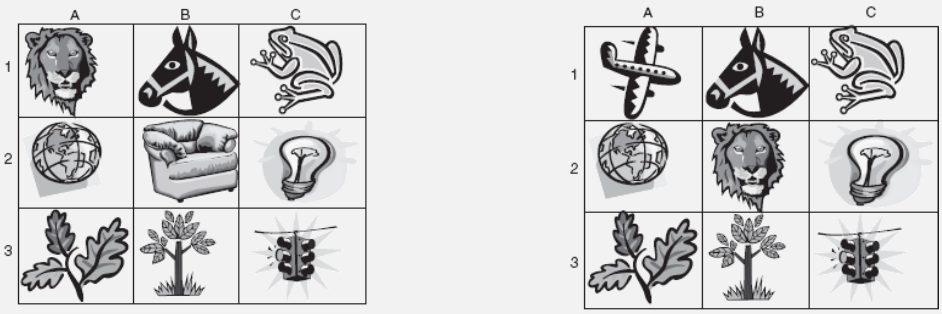
Application		Compression factor	Application	Compression factor
Television SD	NTSC	49.78	DVD	41.47
	PAL	24.88	Video Tape	27.03

Source: Authors' own elaboration, based on various sources (see text).

Box 1: Video coding MPEG-2

The encoding process consists of three main stages: data preparation, spatial and temporal compression and quantization. The purpose of the first is to to ensure that the frame samples are organized in a way which is appropriate for compression. The video information enters the codifier in form of coded samples of lumination components *Y* and chrominance (C_R y C_B). These samples are regrouped into blocks of 8 x 8 pixels, which become utilized in the removal of spatial redundancy (like in the encoding of JPEG still images). This process aims at removing those parts of the image that are the same, for example parts of a blue sky. Instead of coding "pixel1 is blue", "pixel 2 is blue", "pixel 3 is blue", etc., one uses a pattern and codes "pixel 1 is blue", "equally pixels 2, 3, 4, etc". These blocks are regrouped in micro blocks of 16 x 16 pixels and they are then used in the removal of temporal redundancy. Finally, the micro blocks are grouped into slices corresponding to these basic units for data compression.

MPEG data streaming consists of three types of compressed frames: I- frames (Intra-frames), P-frames (predicted) and B-frames (bireactional). The removal of spatial redundancy, also known as intra-frame, as the information collected can be restored at the receiving end. The compression is lossless. It takes advantage of the fact that the difference between two consecutive frames is very small, which is why it is not necessary to transmit the entire of each frame as it is the repetition of the previous one. To describe the difference between a frame and the frame before it, two components are put to use: the motion vector and the frame difference. To explain how each reference is made we will use the following example: let us suppose that you have two frames (consecutive) shown in Figure B-6. The elements which are repeated in the second frame, those that are redundant, are: horse, frog, globe, light bulb, leaves, tree and traffic light. Next, to avoid redundancy, change only the image content of those described: the movement of the lion from cell A1 to cell B2 and the introduction of the airplane into cell A1. The movement vector describes the movement of the lion between the cell and combines with the first frame to produce a predicted frame (see Figure B-8).



First frame (Previous) **1.1.1.1.5 Second Frame (current)**

Figure B-7: Example, two successive frames (Ibrahim, 2007).

The frame difference (which describes the introduction of the airplane A1) is obtained with the subtraction between the predicted frame and the second frame (see Figure B-9). Both components (the motion vector and frame difference) are combined to form what is known as a P-frame.

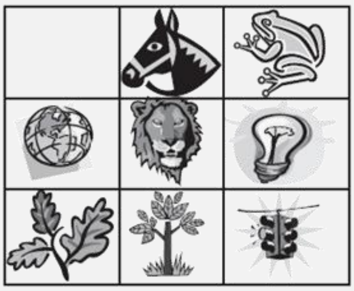
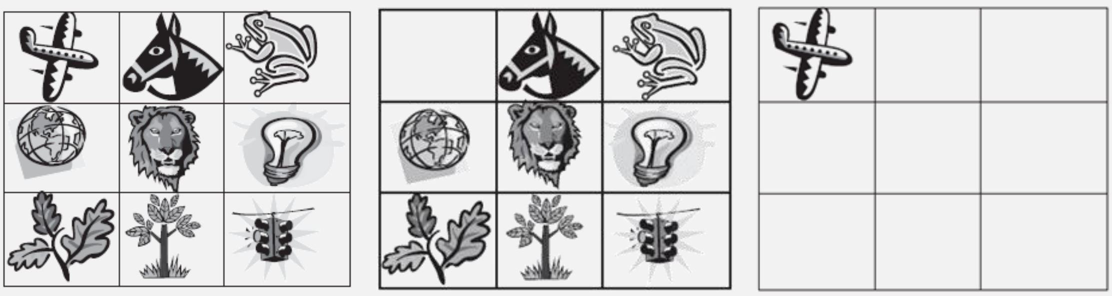


Figure B-8: Frame predicted from the sum of the previous frame and the motion vector.



Actual frame **1.1.1.1.6 Predicted Frame** **1.1.1.1.7 Frame difference**

Figure B-9: Frame difference obtained from the subtraction between the current frame and the predicted frame.

The vector motion compensation alone is just not enough to define video content for the frame in an image. The movement of a block fails to define the appearance of new elements, like the background that could be revealed after the blocks movement. This implies that more information is needed. This is obtained by the prediction on what the P-frame would be like if it were reconstructed using only the motion compression vector and then comparing it with the real frame. The difference between the two is where the additional information is found, which in conjunctions with the motion compensation vector defines the entire content of a frame. The P-frame is constructed with the addition of a motion vector at the same frame that was used to obtain the vector. Later, it is subtracted from the current frame to create a difference frame, which is also known as residual or prediction error. The difference frame contains a series of pixel values with its format appropriated for the next compression of spatial data compression. The bit rate of the output stream is highly dependent on the accuracy of the motion vector (Todorovic, 2006). Bidirectional prediction tries to improve the accuracy of the motion vector. This technique is based on the future position of a moving block as well as in the previous position.

B.6.2 MPEG-4

With the help of MPEG-4, video compression can be dramatically increased, enabling the distribution of content and services which vary from those with low bandwidth requirement up to high definition quality though broadcast systems, broadband web or wireless networks, etc. MPEG-4 is formed by 21 individual parts interrelated although distinct, which can be implemented in an individual manner or combined with others. The two important aspects for video are parts 2 (MPEG-4 Visual) and part 10 (MPEG-4 AVC – *Advanced Video Coding*). MPEG-4 Visual (1999) was defined for applications in the area of multimedia communications with low bit rates, but was later extended to broadcasting application. The impact it had on the last industry was not significant when compared with MPEG-2. It only achieves compression gains between 15% and 20%, which was not enough to change the current standard. The case of AVC/H.264 is different. It is an integrated part of MPEG-4 and in 2004 the DVB consortium amended its standard to also include AVC/H.264 as a high definition television codec. Other applications have already adopted this streaming standard of multimedia content on the Internet (with low bit rates), such as 3G mobile phones, digital cinema, the storage in HD-DVD and BD-ROM, etc. Comparing AVC/H.264 with MPEG-2, the first is at least twice as efficient at reducing the bit rate to obtain the same quality, at the expense of greater complexity in the software encoder/decoder (Sunna, 2005; Jack, 2005; Richardson, 2003; Institut Integrierte Schaltungen [IIS], 2008).

This method includes different profiles of which the most notable are the *main profile* and the *high profile*, used for *broadcasting applications with* (SDTV) standard definition and with high definition (HDTV), respectively; while the other two profiles (*baseline* and *eXtended*) are used for real time, mobile and *e-streaming applications* (Sunna, 2005; Sullivan & Ohm, 2005).

B.6.3 Video compression rates over time

Unfortunately, for video compression factors, there is not a good index of quality (like MOS for voice), so it is not possible to differentiate between the different storage devices and transmission technologies in accordance with the perceivable quality.

1986

Like other types of multimedia content, the compression of digital video was in full development and testing at the end of the 80s. That is why no compression is assumed at for this year.

1993

Storage

In this year, only in storage –mainly in CD-ROMs-, two compression algorithms were already in use: Cinepak and Indeo Intel Video (encoder owner). For lack of more information, it is assumed that Cinepak was the predominant. This is supported by the fact that the year following their commercialization (1992) they were already forming their part in the Apple Quicktime suite and in 1993 started to be supported by Microsoft Windows, also being used in the games of some SEGA consoles, the Atari Jaguar CD and Panasonic 3DO ("Cinepak", 2010).

Cinepak was designed to encode video with resolution 320 x 240 or 180 x 240 pixels, with frame rates between 12 and 15 frames per second, sub-sampling 4:2:0 to 150 [Kbps], achieving a theoretical compression rate ranging from 20:1 up to 200:1 (Wallace, 1994) and proving good video quality for action movies of moderate action. Even though Keyes (2000) indicates that the average compression rate is 60:1, the resulting image quality is quite poor at this level (Ermac Studios, 2004). Therefore, 20:1 is chosen to ensure an acceptable video quality.

2000

Storage

By this year, the revolution of digital video had already begun. Starting with storage, DVDs and video-CDs, were already available which codified videos with MPEG-2 and MPEG-1 with an average compression rate of 41: 1 y 27: 1, respectively (see Table B-24, the first factor, backed up by (Virtual Vision, 2009)). For its part, videos downloaded off the Internet and stored in hard disks were generally coded in the same format (and with the same quality) as video-CDs, for which the same compression rate should be considered. For all storage devices, except for DVD-video, we consider a compression factor of 27.

Broadcasting video

For standard quality television with MPEG-2 Video, with a rates that vary between 2 and 3 [Mbps] for NTSC y 4 to 6 [Mbps] for PAL/SECAM, we obtain the compression factors presented in Table B-25 (supposing the higher end of the mentioned range).

Table B-25: Factors of compression for TV transmission.

	Terrestrial		Cable		Satalite
	NTSC	PAL/SECAM	NTSC	PAL/SECAM	
Compression Factor	49.8	24.9	41.5	20.7	20.7

Source: Authors' own elaboration, based on various sources (see text).

Streaming video

Before 1998, the limited bandwidth of the Internet prohibited the streaming of videos in formats like MPEG, QuickTime or AVI (Acharya & Smith, 1998). For the case of video-conferences, compression algorithms were already used, such as H.263 (see Box 1), which has a resolution of 176 x 144 pixels at a rate of 100 [Kbps] for the 10 [fps], achieving a compression factor of 27:1 (Cherriman, 1997). While MPEG for video was already standardized and widely used in storage, the low bit rate coding did not present a comparatively higher quality than H.263, this being the main reason for its preference. Moreover, in the streaming of video (non-video conference), RealVideo encoder was one of the most widely used (Wang et al., 2001). It is based on H.263 and shows only mild improvements ("RealVideo", 2010). Given that (Wang et al., 2001) indicates that most videos are 10 [fps] (without stating the resolution), we assume that the compression rate achieved in this area is the same as that of H.263 (27: 1).

2007

Storage

Compared with compression storage methods, the big difference is found in the encoding of videos downloaded from the Internet (mainly through P2P). In 2007, XviD -one of the standard MPEG-4 parts for videos- was already considered to be the standard due to its good quality/bit rate and because it is not a proprietary algorithm, which allowed the provision of a large amount of free codecs in many devices (unlike DivX, which requires its users to pay for permission even though it should not be over looked that it is still a very popular program). While this encoder can achieve compression rates of up to 200:1 (XviD.org, 2010), the need to ensure excellent or near to excellent picture quality forces a lower rate to be chosen. The average coding rate achieved by said algorithm with the prior conditions is around 60:1 (Kane Computing, 2010).

Broadcasting

In 2007 the use of MPEG-4 AVC/H.264 was standardized as a DVB system encoder. It allows for larger number of programs over the same bandwidth with standard definition, or fewer with high definition. However its use in 2007 was marginal and was only being tested at that time, reason why we assume the same compression rate as in 2000.

Streaming video

MPEG-4 AVC/H.264 is the most used algorithm, being the standard on YouTube. It allows for a saving of up to 60% of the bandwidth requirements compared with other compression methods (Haivision, 2006). The typical video resolution is 320 x 244 pixels at a bit rate of 192 [Kbps] and the compression ratio achieved is around 50:1. In the case of streaming video in mobile phones and in teleconferences, the typical resolution is 176 x 144 pixels, with rates ranging from 64 to 192 [Kbps], achieving average compression of 60:1.

Optimal

Since we do not have much information on the compression achieved by MPEG-4 for the different applications we are looking at, we will extrapolate from the case of digital TV. Bodecek & Novotny (2005), Wenger et al. (2005), Rainville & Segev (2003), ScientifiA-Atlanta Inc. (2005), European Broadcasting Union [EBU] (2010) and Diepold & Moeritz (2005) all indicate that for SDTV and HDTV reductions of about 50% are achieved. Therefore, for all technologies that use MPEG-2, we assume that MPEG-4 doubles the compression ratio of MPEG-2, that means to about 60:1. We use this as the optimal compression benchmark for video. For other technologies which are already using MPEG-4, the compression factors are kept the same.

B.7 References

Acharya, S., & Smith, B. (1998). An experiment to characterize videos stored on the Web. *Proceedings of S&T/SPIE Conference on Multimedia Computing and Networking (MMCN)*.

Acharya, T., & Ray, A. (2005). *Image processing: principles and applications.* Hoboken, New Jersey: Wiley-Interscience.

Acharya, T., & Tsai, P. (2005). *JPEG2000 standard for image compression: concepts, algorithms and VLSI architectures*. Hoboken, New Jersey: Wiley-Interscience.

Alphonso, A. (2007). DAB+ technical summary. Retrieved November 2010, from Broadcast Papers Website: http://www.broadcastpapers.com/

Amorim, R. (2006). *Results of 128 kbps extension public test*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20071029193847/http://www.rjamorim.com/test/128extension/results.html

Andersen, B. (2006). *The DK-domain: in Words and Figures*. Retrieved November 2010 from: http://netarchive.dk/publikationer/DFrevy_english.pdf

Apple. (n.d.). *HTTP live streaming overview*. Retrieved November 2010 from Apple iOS Reference Library Website: http://developer.apple.com/library/ios/#documentation/

Arnold, J., Frater, M. R., & Pickering, M. (2007). *Digital television: technology and standards*. Hoboken, New Jersey: Wiley-Interscience.

Austerberry, D. (2005). *The technology of video and audio streaming* (2nd ed.). Oxford, UK: Focal Press.

Autti, H., & Biström, J. (2004, November 30). Mobile audio, from MP3 to AAC and further. Helsinki University of Technology. Retrieved November 2010, from ARCADA Website: http://people.arcada.fi/~johnny/MobileAudio7.pdf

Barlow, J. (2007). *MP3 & streaming: The transom tool columns*. Retrieved November 2010, from: http://transom.org/tools/webaudio/200403.mp3_streaming.html

Bellis, M. (2009). The history of MP3: Fraunhofer Gesellschaft and MP3. Retrieved November 200, from About.com Guide: http://inventors.about.com/od/mstartinventions/a/MPThree.htm

Benesty, J., Sondhi, M., & Huang, Y. (2008). *Springer handbook of speech processing*. Berlin: Springer.

Benoit, H. (2002). *Digital television: MPEG-1, MPEG-2 and principles of the DVB system* (2nd ed.). Oxford, UK: Focal.

Bodecek, K., & Novotny, V. (2007). *From Standard Definition to High Definition Migration in Current Digital Video Broadcasting*. Paper presented at the International Multi-Conference on Computing in the Global Information Technology, ICCGI 2007. doi: 10.1109/ICCGI.2007.25

Bouvigne, G. (2003). *MPEG-2/MPEG-4 AAC*. Retrieved November 2010, from MP3' Tech Website: http://www.mp3-tech.org/aac.html

Bovik, A. C. (2000). *Handbook of image and video processing*. San Diego, CA: Elsevier Academic Press.

Brandenburg, K. (1999). MP3 and AAC explained *In Proceedings of the Audio Engineering Society 17th International Conference on High Quality Audio Coding*. Retrieved November 2010, from Universität Bonn Website: http://www3.uni-bonn.de/

Brandenburg, K., & Popp, H. (2000, June). *An introduction to MPEG Layer-3*. Fraunhofer Institut für Integrierte Schaltungen (IIS). Retrieved 2010, from EBU Website: http://www.ebu.ch/en/technical/trev/trev_283-popp.pdf

Brown, P. (2000). *Modeling of an MPEG Layer-3 Encoder and Decoder in Ptolemy*. Retrieved November 2010, from the University of Texas Website: http://users.ece.utexas.edu/~bevans/courses/ee382c/projects/spring00/brown/LitSurveyReport.pdf

Chen, J., & Thyssen, J. (2008). Analisys by synthesis speech coding. In J. Benesty, M. Sondhi & Y. Huang (Eds.), *Springer handbook of speech processing*. Berlin: Springer.

Cherriman, P. (1997). H.263 video coding. Retrieved November 2010, from Communication Research Group, University of Southampton Website: http://www-mobile.ecs.soton.ac.uk/peter/h263/h263.html

Chu, W. (2003). *Speech coding algorithms: foundation and evolution of standardized coders*. Hoboken, New Jersey: Wiley-Intescience.

Ciciora, W., Farmer, J., & Adams, M. (2004). *Modern cable television technology: video, voice, and data communications*. San Francisco, CA: Elsevier/Morgan Kaufmann Publishers.

Cinepak. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Cinepak

Cisco (2006, February 02). *Voice over IP – per call bandwidth consumption* [Document ID: 7934]. Retrieved November 2010, from: http://www.cisco.com/en/US/tech/tk652/tk698/technologies_tech_note09186a0080094ae2.shtml

Cisco (2006). *Understanding Codecs: Complexity, Hardware Support, MOS and Negotiation* [Document ID: 14069]. Retrieved November 2010, from: http://www.cisco.com/warp/public/788/voip/codec_complexity.html

Cleary, J. G., & Witten, I. H. (1984). Data Compression Using Adaptive Coding and Partial String Matching. *IEEE Transactions on Communications, 32*, 396-402. doi: 10.1109/TCOM.1984.1096090

Comparison of audio formats. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Comparison_of_audio_codecs

Costello, S. (2006). *AAC vs. MP3, a sound quality test*. Retrieved November 2010, from About.com Guide: http://ipod.about.com/od/introductiontoitunes/a/sound_qual_test.htm

Cover, T., & Thomas, J. (2006). *Elements of information theory* (2nd ed.). Hoboken, New Jersey: Wiley-Interscience.

Data Compression. (n.d.). In *Encyclopedia Britannica*. Retrieved November 2010, from: http://www.britannica.com/EBchecked/topic/152168/data-compression

DeBoer, C. (2005) Acura, Cadillac & Land Rover models feature DTS Surround. *Audioholics Online A/V magazine*. Retrieved November 2010, from: http://www.audioholics.com/news/press-releases/2005-acura-cadillaA-land-rover-models-feature-dts-surround

DellaSala, G. (2004, August 30). Dolby Digital versus DTS: A guide to the Strengths of the formats. *Audioholics Online A/V magazine*. Retrieved November 2010, from: http://www.audioholics.com/news/press-releases/2005-acura-cadillaA-land-rover-models-feature-dts-surround

Diepold, K., & Moeritz, S. (2005). *Understanding MPEG-4*. Oxford, UK: Focal Press.

Digital audio broadcasting. (n.d.). Retrieved November 2010, from: http://en.wikipedia.org/wiki/Digital_Audio_Broadcasting

Digital compact cassette. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Digital_Compact_Cassette

DigitalRadioTech. (n.d.). *DAB vs DAB+ Technology*. Retrieved November 2010, from: http://www.digitalradiotech.co.uk/dab/dab_vs_dab+.htm

Edler, B. (1998). Speech coding in MPEG-4. *International Journal of Speech Technology,* 2(4), 289-303.

Ermac Studios. (2004). Advanced video compression: *Various codecs, formats and their pros and cons*. Retrieved November 2010, from: http://www.animemusicvideos.org/guides/avtech/video4_2.htm

European Broadcasting Union (EBU). (2010, March). *HDTV contribution codecs: Technology evaluation*. Retrieved November 2010, from: http://tech.ebu.ch/docs/techreports/tr008.pdf

Ewing, D. J., Hall, R. S., & Schwartz, M. F. (1992). *A Measurement Study of Internet File Transfer Traffic* [CU-CS-571-92]. Retrieved November 2010, from University of Colorado Website: www.cs.colorado.edu/department/publications/reports

Frerichs, D. (2003, April). New MPEG-4 high efficiency AAC audio: Enabling new applications. Retrieved November 2010, from Telos System

Website: http://www.telos-systems.com/techtalk/hosted/m4-in-30100%20(M4IF_HE_AAC_paper).pdf

Ghanbari, M. (2003). *Standard codecs: image compression to advanced video coding*. London, UK: Institution of Electrical Engineers.

Gibson, J. D. (2005). Speech coding methods, standards, and applications. *IEEE Circuits and Systems Magazine, 5*(4), 30-49. doi: 10.1109/MCAS.2005.1550167

Goldberg, R., & Riek, L. (2000). *A practical handbook of speech coders*. Boca Raton: CRC Press.

Haivision (2006). *Video compression: MPEG-4 AVC and why, only now, it can sabe 60% of the network bandwidth and storage requirements*. Retrieved November 2010, from InfoComm International Website: http://www.infocomm.org/cps/rde/xbcr/infocomm/VideoCompression MPEG4AVC(H.264).pdf

Herre, J., & Dietz, M. (2008). MPEG-4 high-efficiency AAC coding [Standards in a Nutshell]. *IEEE Signal Processing Magazine, 25*(3), 137-142. doi: doi: 10.1109/MSP.2008.918684

Ibrahim, K. F. (2007). *Newnes Guide to Television and Video Technology* (4th ed.). Amsterdam: Elsevier.

Institut Integrierte Schaltungen (IIS). (2008). *MPEG-4 video encoders and decoders on various platforms*. Retrieved November 2010, from Fraunhofer Gesellschaft-IIS Website: http://www.iis.fraunhofer.de/Images/IISMpeg4VideoSoftware_v21-1_tcm97-114945.pdf

International Telecommunications Union (ITU) . (1996). P.800: Methods for Subjective Determination of Transmission Quality. *P Series: Telephone Transmission Quality, Methods for Objective and Subjective Assessment of Quality*. Retrieved November 2010, from: http://www.itu.int/rec/T-REA-P.800-199608-I/en

Jack, K. (2005). *Video demystified: a handbook for the digital engineer* (4th ed.). Oxford, UK: Newnes/Elsevier.

Jacklin, M. (2002, November 19). *MPEG-4: The media standard*. Retrieved November 2010, from MPEG-4 Industry Forum Website: http://www.m4if.org/public/documents/vault/m4-out-20027.pdf

Jähne, B. (2002). *Digital Image Processing* (5th ed.). Berlin, Germany: Springer-Verlag.

Kane Computing. (n.d.). Compression ratio: Rules of thumb. Retrieved November 2010, from:

http://www.kanecomputing.co.uk/pdfs/compression_ratio_rules_of_thumb.pdf

Keyes, J. (2000). *Internet management*. Boca Raton: Auerbach Publications.

King, A. B. (2000, Febrero 24). Compression. In *Optimizing Web Graphics*. Retrieved November 2010, from Webreference Website: http://webreference.com/dev/graphics/compress.html

Kirsch, R.; Cahn, L.; Ray, C., & Urban, G. (1957). *Experiments in processing pictorial information with a digital computer*. Proceeding of the Eastern Computer Conference, Washington, DC, USA. Retrieved November 2010, from: http://www.mel.nist.gov/msidlibrary/

Lempel-Ziv-Welch. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved, November 2010, from: http://en.wikipedia.org/wiki/Lempel–Ziv–Welch

Levien, R. (2000). *JPEG2000 Comparison*. Retrieved November 2010, from: http://www.levien.com/gimp/jpeg2000/comparison.html

Lin, S. C. (2005). *MP3 vs. CD quality test*. Retrieved November 2010, from: http://www.lincomatic.com/mp3/mp3quality.html

Linggard, R. (1990). *Speech processing: past and future*. IEE Colloquium on Techniques for Speech Processing. Retrieved November 2010, from: http://ieeexplore.ieee.org/

Liu, Y., & Du, M. (2007). *Speech quality of IEEE 802.11b and 802.11g Wireless LANs*. International Conference on Computational Intelligence and Security Workshops. doi: 10.1109/CISW.2007.4425634

Long, M. E. (1999). *The digital satellite TV handbook*. Woburn, MA, USA: Newnes.

Mahoney, M. (2009a). *About the compressors: WinRAR (benchmark results)*. Retrieved November 2010, from Florida Institute of Technology: http://cs.fit.edu/~mmahoney/compression/text.html#1984

Mahoney, M. (2009b). *Large Text Compression Benchmark*. Retrieved November 2010, from Florida Institute of Technology: http://cs.fit.edu/~mmahoney/compression/text.html

Mahoney, M. (2009c). *About the Compressors: DURILCA (benchmark results)*. Retrieved November 2010, from Florida Institute of Technology: http://cs.fit.edu/~mmahoney/compression/text.html#1298

Malik, O. (2004, September 9). The Voice over IP insurrection. Retrieved November 2010, from: GigaOm News Website: http://gigaom.com/2004/09/19/the-voice-over-ip-insurrection/

Mares, S. (2005, December). *Results of the public multiformat listening test @128 kbps*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20080605005108/http://www.listening-tests.info/mf-128-1/results.htm

Marshall, C. (2008). *PNG is replacing GIF for Digital Image Storage*. Retrieved November 2010, from: http://www.streetdirectory.com/travel_guide/104337/photography/png_is_replacing_gif_files_for_digital_graphic_storage.html

Meares, D., Watanabe, K., & Scheirer, E. (1998, February). *Report on the MPEG-2 AAC Stereo verification test* [ISO/IEC JTC1/SC29/WG11 N2006] Retrieved November 2010, from David E. Weekly Website: http://david.weekly.org/audio/iso-aac.pdf

Meltzer, S. & Moser, G. (2006, January). *MPEG-4 HE-AACv2: Audio coding for today's digital media world*. Retrieved 2010, from EBU Website: http://www.ebu.ch/fr/technical/trev/trev_305-moser.pdf

Miano, J. (1999). *Compressed image file formats: JPEG, PNG, GIF, XBM, BMP*. New York, NY: Addison Wesley/ACM Press.

Mogul, J. C. (1995). *Network Behavior of a Busy Server and its Clients*. Retrieved from HP Labs: http://www.hpl.hp.com/techreports/

MP3. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/MP3

MPEG Industry Forum (2007). *Audio coding technology sounds good*. Retrieved November 2010, from: http://www.m4if.org/news/mpeg4.php?year=2007

Nelson, M., & Gailly, J. (1995) *The data compression book* (2nd ed.). New York, NY: M&T Books.

Network Instruments (2007, October). *Your Guide to Troubleshooting VoIP*. Retrieved November 2010, from: http://www.networkinstruments.com/assets/pdf/voip_wp.pdf

Nieminen, J. (2004). *Archiver comparison*. Retrieved November 2010, from: http://warp.povusers.org/ArchiverComparison/

Nyquist, H. (2002). Certain topics in telegraph transmission theory. *Proceedings of the IEEE, 90*(2), 280-305. doi: citeulike-article-id:966439

Ojala, P., Toukomaa, H., Moriya, T., & Kunz, O. (1998). Report on the MPEG-4 speech codec verification tests *ISO/IEC JTC1/SC29/WG11, MPEG98/N2424*. Retrieved November 2010, from the Internet Archive Website:

http://web.archive.org/web/*/http://sound.media.mit.edu/mpeg4/audio/public/w2424.pdf

Pierce, J. (1980). An introduction to Information Theory: Symbols, signals and noise (2nd rev. ed.). New York, NY: Dover Publications.

Purandare, A. (2008). *JPEG vs JPEG2000 Comparison*. Retrieved November 2010, from the Internet Archive: http://web.archive.org/web/20091024165135/http://geocities.com/ee00224/cncl.html

Rainville, M. & Segev, A. (2003, October 1). MPEG-4 AVC. *Magazines Articles*. Retrieved November 2010, from the Broadcasting Engineering Website: http://broadcastengineering.com/mag/broadcasting_mpeg_avc/

Rairhurst, G. (2001). *MPEG-2*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20071023065124/http://erg.abdn.ac.uk/research/future-net/digital-video/mpeg2.html

Rämo, A., & Toukomaa, H. (2005). *On comparing speech quality of various narrow- and wideband speech codecs*. Paper presented at the Proceedings of the Eighth International Signal Processing and Its Applications. doi: 10.1109/ISSPA.2005.1581010

RealVideo. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/RealVideo

Richardson, I. E. G. (2003). *H.264 and MPEG-4 video compression: video coding for next-generation multimedia*. West Sussex, England: Wiley.

Rosenberg, A., & Kemp, S. (2003). *CDMA capacity and quality optimization*. New York, NY: McGraw-Hill.

Russ, J. C. (2007). *The image processing handbook* (5th ed.). Boca Raton: CRC/Taylor and Francis.

Salomon, D. (2007). *Data Compression: The Complete Reference* (4th ed.). Berlin, Germany: Springer-Verlag.

Salomon, D. (2008). *A concise introduction to data compression*. London, UK: Springer.

Sayood, K. (2006). *Introduction to data compression* (3rd ed.). San Francisco, CA: Morgan Kaufmann Publishers.

ScientifiA-Atlanta Inc. (2005, June). *MPEG-4 Part 10 AVC (H.264) video encoding*. Retrieved November 2010, from: http://www.scientificatlanta.com/products/customers/white-papers/7007887B.pdf

Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal, 27*, 379-423. doi: citeulike-article-id:1584479

Shannon, C. E. (1951). Prediction and entropy of printed English. *Bell Systems Technical Journal, 30*, 50-64. doi: citeulike-article-id:5094820

Sullivan, G., & Ohm, J. (2005, July). *Coding of Moving Pictures and Audio – Introduction to MPEG-4 Advanced Video Coding* [ISO/IEC JTC1/SC29/WG11 N7314]. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20080614071143/http://www.chiariglione.org/mpeg/technologies/mp04-avc/index.htm

Sunna, P. (2005, April). *AVC/H.264 – An Advanced Video Coding System for SD and HD Broadcasting*. Retrieved 2010, from EBU Website: http://www.ebu.ch/en/technical/trev/trev_302-sunna.pdf

Tamo Soft. (n.d.). *Monitoring and Troubleshooting VoIP Networks with a Network Analizer: MOS and R-Factor*. Retrieved November 2010, from: http://www.tamos.com/htmlhelp/voip-analysis/mosandr_factor.htm

Todorovic, A. L. (2006). *Television technology demystified: a non-technical guide*. Oxford, UK: Focal/Elsevier.

Tudor, P. N. (1995). MPEG-2 video compression. *Electronics & Communication Engineering Journal, 7*(6), 257-264. doi: doi: 10.1049/ecej:19950606

Unuth, N. (n.d.). *VoIP codecs*. Retrieved November 2010, from About.com: http://voip.about.com/od/voipbasics/a/voipcodecs.htm

Virtual Vision. (n.d.). *DVD video encoding*. Retrieved November 2010, from: http://www.dvdduplicator.nl/uitleg/encoding.html

Wakefield, T., McNally, D., Bowler, D., & Mayne, A. (2007). *Introduction to mobile communications: technology, services, markets*. Boca Raton: Auerbach Publications.

Wallace, G. K. (1992). The JPEG still picture compression standard. *IEEE Transactions on Consumer Electronics, 38*(1), xviii-xxxiv. doi: citeulike-article-id:7512769

Wallace, L. (1994, March 7). Compression/decompression standards. *InfoWorld Magazine*, Retrieved November 2010, from Google Books: http://books.google.com/

Wang, Y., Claypool, M., & Zuo, Z. (2000). *An empirical study of RealVideo performance across the Internet*. Proceedings of the first ACM SIGCOMM Internet Measurement Workshop.

Watkinson, J. (2004). *The MPEG handbook: MPEG-1, MPEG-2, MPEG-4*. Oxford, UK: Elsevier/Focal Press.

Welch, T. A. (1984). A technique for high-performance data compression. *Computer, 17*(6), 8-19. doi: 10.1109/mc.1984.1659158

Wenger, S., Hannuksela, M., Stockhammer, T., Westerlund, M., & Singer, D. (2005. February). *RTP Payload Format for H.264 Video*. Retrieved November 2010, from: http://tools.ietf.org/html/rfc3984#ref-9

Wittle, R. (2001, March 22). *Comparing AAC, MP3 and TwinVQ lossy compression of audio*. Retrieved November 2010, from: http://www.firstpr.com.au/audiocomp/aaA-mp3-vq.html

Wolman, A., Voelker, G., Sharma, N., Cardwell, N., Brown, M., …Levy, H. (1999). *Organization-based analysis of Web-object sharing and caching*. Proceedings of the 2nd USENIX Symposium on Internet Technologies and Systems, 25-36. Boulder, Colorado, USA. Retrieved November 2010, from: http://www.usenix.org/events/usits99/wolman.html

Wolters, M., Kjörling, K., Homm, D., & Purnhagen, H. (2003). A closer look into MPEG-4 high efficiency AAC. *Proceedings 115th AES Convention*. Retrieved November 2010, from Telos System Website: http://www.telos-systems.com/techtalk/hosted/HE-AAC.pdf

Wootton, C. (2005). *A practical guide to video and audio compression: from sprockets and rasters to macroblocks*. Burligton, MA Oxford, UK: Focal/Elsevier.

World DMB (2007). *DAB, DAB+, DMB: Building of success*. Retrieved November 2010, from: http://www.worlddab.org

World DBM (2008a). *DAB+: The additional audio codec in DAB*. Retrieved November 2010, from: http://www.dab.com.mt/site/content/docs/dab_plus_brochure_200803.pdf

World DBM (2008b). *How DAB+ works – the performance of DAB+ in test fields*. Retrieved November 2010, from: http://www.worlddab.org/introduction_to_digital_broadcasting/dab_plus_digital_radio/how_dab_plus_works

XviD.org. (2010). *General information: Looking for the XviD codec?* Retrieved November 2010, from: http://www.xvid.org/Xvid-Video.3.0.html

Zölzer, U. (1997). *Digital audio signal processing*. Sttutgart: Wiley.

C Storage

In this Chapter, we present the methodologies employed for estimating the amount of bits contained in the following storage technologies: paper (periodicals, books, etc.), film (movies, photographs, and radiographs), electromechanical (vinyl), analog magnetic (cassette tapes, video tapes), and digital (hard disks, floppy disks, and magnetic tape data storage), optical (CDs, Minidics, DVD, Blu-ray), and solid state (console cartridges and memory cards, memory cards, portable media players, USB pendrives and internal memory present in digital cameras and cellphones/PDAs). Each chapter is divided into three sections, one regarding how the number of installed equipment in the world is estimated (we often present the numbers of devices shipped per year, and then specify the utility shelf life that contributes to the accumulation), another regarding the performance of each equipment, and lastly, on the applicable compression algorithms.

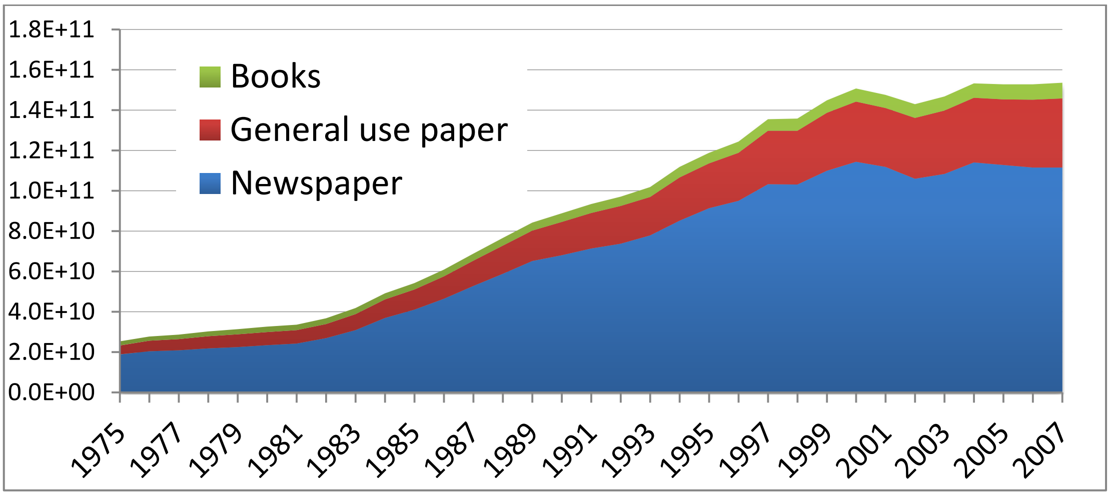
In this study we do not consider volatile storage, which is why RAM[10] is excluded. This is justified in that the ultimate end of volatile memory consists in computational processes, not in storage per se. Volatile memory acts like a notepad during computation and what is stored is automatically lost upon disconnection with the power supply. The capacities that we are measuring here contribute to information storage with the end of being stored, while RAM is utilized primarily to support computational power (which is measured in the section on computation).

C.1 Paper

We include three types of paper products: paper for book printing, paper for general use (for writing, printing, and photocopying), and paper for the printing of newspapers (Figure C-1).

Figure C-1. Storage capacity provided by books, newspapers, and general use paper (MB), without normalizing for compression (Hardware capacity).

10 RAM (*Random Access Memory*) is utilized to temporarily store data that the central processing unit requires for in functionality (Operating system, executed applications, instructions, as well as information that these applications process and the results they obtain). These are manufactured with semiconductive material that enables writing and reading information randomly (it is not necessary to arrange bytes in sequential order to obtain required data). All of the information that is stored during the functioning of the device is erased on restart or powering off.



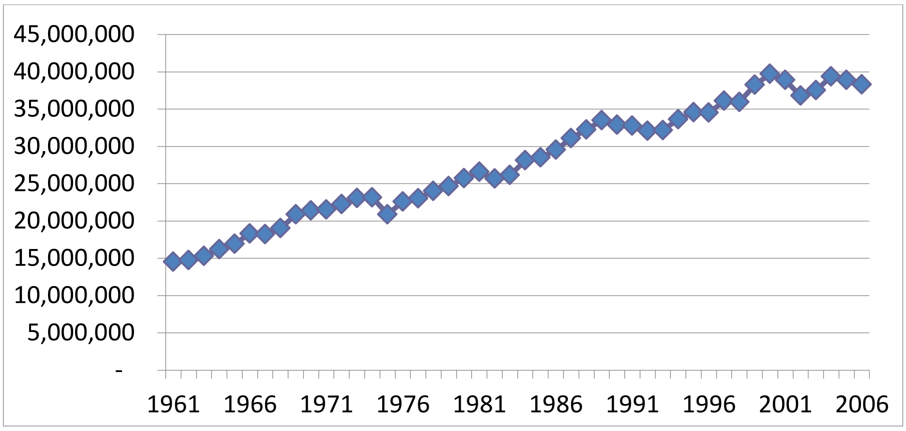
Source: Author's own elaboration.

C.1.1 Newspapers: quantity

The ForesSTAT database (Food and Agriculture Organization of the United Nations [FAO], 2010) provides the consumption of sheets of "newsprint" (in tons) in different countries in the world[11]. The FAO maintains the following definition for this category: "NEWSPRINT: Uncoated paper, unsized (or only slightly sized), containing at least 60% (percentage of fibrous content) mechanical wood pulp, usually weighing not less than 40 g/square m and generally not more than 60 g/square m of the type used mainly for the printing of newspapers."

11 In 1980, for 108 countries, representing 89.94% of 19080's world population; in 2007 for 192 countries, representing 99.18 of the world population.

Figure C-2: World consumption of paper for newspapers (in metric tons).



Source: Previous explanation, based on (FAO, 2010)

The grammage per m^2 is reported by (Government Printing Office [GPO], 1999). We opt for the simple average among the four most common alternatives (Table B-3).

Table C-1. Grammage of paper for newspaper

Newsprint	Option 1	Option 2	Option 3	Option 4	Simple Average
Grammage [g/m^2]	40	45	50	52	46.75

Source: (GPO, 1999)

For consistency in the method applied, we pick one sheet of the *New York Times* as a representative newspaper sheet, which corresponds to 13.5 inches (0.343 m) by 22.75 inches (0.578m)[12] (Seelye 2006), with an area equal to 0.1981 [m^2]. This results in a weight of a sheet of periodical = 0.1981 [m^2] * 46.75 [g/m^2] = 9.26 [g]. With this we calculate the [number of sheets] = ([tons consumed]/[weight per sheet]), which is multiplied by two to consider that each sheet is printed on both sides.

We consider the useful lifespan for periodicals to be a week on average, that is to say, we assume that after a week all newspapers are destroyed. In this sense, “periodical sheets” serve the same function as a large hard disk that is formatted and re-loaded with new content every week.

12 Today, the *New York Times* no longer uses this format. On August 6, 2007, the size of the *New York Times* was reduced to 13.5 inches by 12 inches, equal to the standards of other US Periodicals (New York Times, 2006). However, for the period being studied (for the analyzed pages), the older size applies.

C.1.2 Newspapers: performance

C.1.2.1 Distribution of images and text

Given that we are not familiar with any historical statistics that reveals the average number of characters, words, and images per sheet, we opted to select a representative sample. The *New York Times* (the third largest circulating newspaper in the United States after *USA Today* and *The Wall Street Journal*) was chosen, after considering that the newspaper maintains a ratio between text and images a bit more representatively than *USA Today* (which is recognized for its large images) and *The Wall Street Journal* (a newspaper with a history of primarily economic news and traditionally less focus on culture and entertainment).

We created a mechanism for a stratified random sample (safeguarding against seasonal effects during the year and uneven distribution within the newspaper). Each one of the years 1975, 1985, 1995, and 2005 have been divided into four parts (each one 365/4 = 91 days), and a day was chosen that corresponds to the mid-point of each division (February 14, May 16, August 15, November 14). The newspapers on those days were then separated into three equal parts (depending on the number of pages in each specific newspaper). We considered the first page (the *cover-page*, the most important page) and pages that are in the middle of the three parts that the newspaper consists of (after 1/6 of the total pages, 3/6 of the total, and 5/6 of the total). This process creates a sample of 16 newspapers between 1975 and 2005, of four pages each (see Table C-2).

Table C-2.Sample of historical newspapers of the *New York Times* between 1975-2005.

Date	14-Feb-75	16-May-75	15-Ago-75	14-Nov-75
Total # of pages	72	80	76	80
Pages sampled	1, 12, 26, 60	1, 13, 40, 67	1, 13, 39, 58*	1, 14, 41, 58*

Date	14-Feb-85	16-May-85	15-Ago-85	14-Nov-85
Total # of pages	120	112	96	120
Pages sampled	1, 20, 60, 100	1, 19, 56, 75	1, 16, 48, 80	1, 20, 60, 100

Date	14-Feb-95	16-May-95	15-Ago-95	14-Nov-95
Total # of pages	84	84	76	92
Pages sampled	1, 14, 42, 70	1, 14, 42, 70	1, 13, 38, 64	1, 15, 46, 77

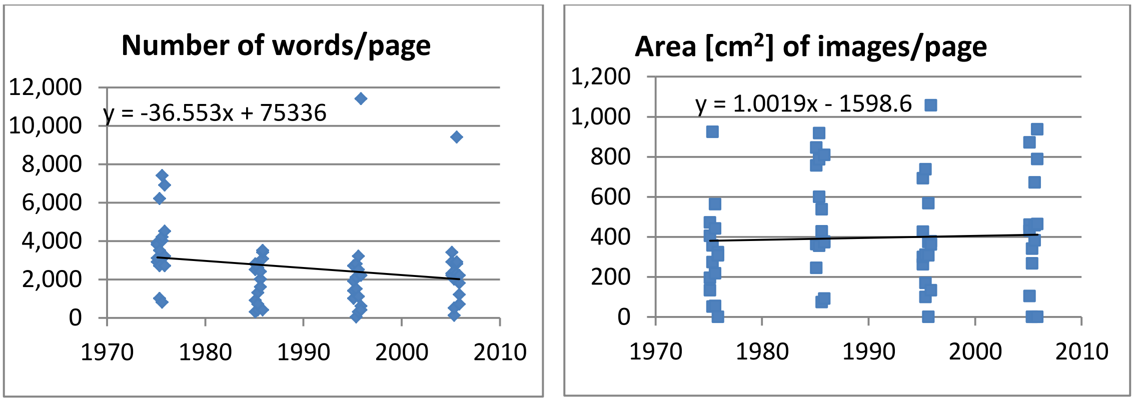
Date	14-Feb-05	16-May-05	15-Ago-05	14-Nov-05

Total # of pages	58	62	52	94
Pages sampled	1, 10, 29, 48	1, 10, 31, 52	1, 9, 26, 43	1, 16, 47, 78

Source: Previous explanation, based on ("News: The historical New York Times", 2008).
Note: * means that the page that corresponds to the sampling mechanism was not scanned in the ProQuest photo database, for which we chose the page closest to the faulty page

The 64 pages selected results in an average sample per page of 400 [cm^2] for images and about 2600 words. However, as was expected, the quantity of images per page has increased with time, while the number of words has diminished. We adopt a linear approximation for general estimation of the distribution between text and images per page.

Figure C-3. Quantity of words and images per newspaper page



Source: Previous explanation, based on ("News: The historical New York Times", 2008).

Since the source ("News: The historical New York Times", 2008) only offers scanned pages in black and white, it becomes necessary to make an additional estimation regarding the proportion of images in color. *USA Today* is the newspaper credited with the introduction of color in printed newspaper printing, with its appearance in 1982, while the last important newspaper to adopt color printing is the *New York Times*, in 1997. Today it is estimated that approximately one-third of the images in the New York Times are printed in color (samples taken from the *New York Times* from Thursday July 30, 2008, Sunday August 3, 2008, Wednesday September 10, 2008, Friday November 7, 2008). It is supposed that, for the year 1981, 0% color images appeared in newspapers worldwide and, afterward, with a linear growth period of 15 years, we suppose that 35% of images are in color in 1997.

C.1.2.2 Bit Estimation in gray-scale images

With regard to the printing of images on newspaper, we follow an idea similar to what we today recognize as the logic of "pixels", where in reality the printed images in the pre-digital era are not determined by the number of pixels in them, but in the amount of "lines" (LPI: lines per inch) and "dots"

(DPI: dots per inch). The standard is the technique known as “Half-tone printing”, in which the quantity of different tones and colors that can be printed depends on the number of dots (DPI) in each unit of LPI, and the granularity and clarity of the image depends on the amount of basic units (LPI) (Creamer, 2006).

Reviewing the quality of printing during the last decades, we have decided to differentiate between gray-scale images of lower quality (which were used in the 1980s), which utilized around 135 DPI and 60 units (LPI) (Bair, 2008; Lyytikäinen et al., 2007), or images of higher quality (as in the end of the 90s), of 225 dots per inch (DPI), and 85 units (LPI) (Bear 2008; Creamer 2006; Leurs 2007). This results in a bi-dimensional printing of $(135/60)^2 = 5$ dots (lower quality), and $(225/85)^2 = 7$ dots (better quality). With five dots per unit, one can produce 6 gray tones between total white and total black and with seven dots in one unit, one can produce 8 gray tones.

Translating this analog technology to a digital format implies that the six gray tonalities can be represented with 2.6 bits ($2^{2.6} = 6$); whereas with eighty tonalities, with 3 bits ($2^3 = 8$). Given that it is impossible to utilize 2.6 bits in the digital realm, 3 bits are always necessary for each basic unit (LPI), whether high or low quality. With 60 LPI (lower quality) you have 60*60 = 3600 basic units per inch^2, and with 85 LPI (higher quality) you have 85*85 = 7225 basic units per inch^2. This results in 3600*3 = 10,800 bits per inch^2 (equivalent to 4,252 [bits/cm^2]) for images of lower quality and 7225*3 = 21,675 bits per inch^2 (8,534 [bits/cm^2]) for higher quality images. It is supposed that the transition between lower quality images and higher quality images in newspapers followed the same pattern of diffusion as the transition from black/white to color images.

C.1.2.3 Bits estimate per color image

Newspaper printers normally use the four colors of CMYK (Cyan, Magenta, Yellow, Key = Black) (“CMYK Color Model”, 2010). Assuming that one color can be printed in each dot, a total of 330 combinations can be produced on the 7 dots of each of the basic units in a good-quality image.[13]

By translating this analogous printing logic to a digital format, the 330 color combinations can be represented with 8.37 bits, which can be found between $2^8 = 256$; and $2^9 = 512$. The lower value, 8, is selected with the consideration that an analogous impression is messy (i.e. the mixing of colors in the dots), which therefore lowers the quality of the resulting image. The assumption that 8 bits can adequately represent 256 colors rests upon the notion that the analogous color images in newspapers have the same image quality than digital images in GIF format (Graphics Interchange Format). GIF

[13] 5 color possibilities exist for each dot (Cyan, Magenta, Yellow, Black, White = without impression). The order of the colors inside the seven dots does not matter, what matters are how many of the dots have which colors (the intensity): [(5+7-1)!] / [(7!) * (4!)] = 330.

images have lower quality and are commonly found online (CompuServe Incorporated, 1987), which validates the choice of 256. With 85 LPI we have 85*85 = 7225 basic units per inch^2, resulting in 7225*8 = 57 800 bits per inch^2 (22 756 [bits/cm^2]) for color images in printed newspapers.

C.1.3 Books and other paper for printing/writing/reprographics: quantity

The ForeSTAT database (FAO, 2010) offers figures on the paper consumption (in tons) for different countries around the world[14]. FAO gives the following definition for this category: “Printing + writing paper: Paper, except newsprint, suitable for printing and business purposes, writing, sketching, drawing, etc. made from a variety of pulp blends and with various finishes. Included are such papers as those used for books and magazines, wallpaper base stock, box lining and covering calculator paper, rotonews, duplication, tablet or block, label, lithograph, banknote, tabulating card stock, bible or imitation bible, stationary, manifold, onionskin, typewriter, poster, etc.” These classifications are simplified and distributed among a “books” category, and the sub-item “others printing/writing/reprographics” according to that data drawn from the GreenPress Initiative (2006), which indicates that between 6% and 10% of the paper production from forests in the United States is used for book production. Considering the average for these statistics, we conclude that 8% of paper production is for books and that 92% is for “other printing/writing/reprographics.”

The global figure for paper pages, measured in tonnage, is derived at using the following formula: [number of pages] = ([tons consumed] / [weight per page]). The weight of a page is calculated according to weight relative to the dimensions: grams per page = (length [m] x width [m]) x weight [g/m^2]. The grammage [g/m^2] is reported by (GPO, 1999) (see Table C-3) and an average of the two common classifications is used.

Table C-3. Weight, printing and writing paper.

Grammage [g/m^2]	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6 (Bible)	Simple Average
Books	60	75	90	105	120	45	82.5
Other paper	45	60	68	75	-	-	62

Source: (GPO, 1999)

The size of page most commonly printed in the United States is 25” x 38” (Roberts and Etherington, 2007), after which being divided into 16 equal sections, gives us a book size of 0.0383 [m^2] (9 ½ “ x 6 ¼” or 0.241 x 0.159 [m]). For printing/writing/photocopying paper, the most common size format,

[14] In 1980, for 119 countries, representing 91.24% of the global population of 1980; and in 2007 for 198 countries, representing 99.27% of the population.

A4, is considered (Kuhn, 2006), which has dimension of 0.0624 [m^2] (0.21 [m] of width and 0.297 [m] of length) (see Table C-4).

Table C-4: Page weight averages.

Type of paper	Grammage [g/m2]	Page Area [m^2]	Weight per Page [g/page]
Books	82.5	0.0383	3.16
General use	62	0.0624	3.87

Source: Authors' own elaboration, based on (Kuhn, 2006; Roberts and Etherington, 2007).

An average usefulness life span of 10 years is assumed for books (the average between 5 years (Theriot, 2007), 10 years (Northern Arizona University NAU], 2006; University Controller, 2002) and 15 years (Office of the Comptroller, 2005)). For papers included in the category, "others printing/writing/reprographics" a life span of one month is considered. Based on these assumptions, the total amount of paper tonnage consumed by one country over the course of one year must be divided by 12 (months in a year). In this way, the paper for printing/writing/reprographics functions in the same way a hard disk does, whose content is updated on a monthly basis.

C.1.4 Books and other paper for printing/writing/reprographics: performance

Books are meant to contain only text (without images), and hold an average of 350 words per page (Writer Services, 2007) and 5.5 characters per word (Pierce, 1980), which yields a total of 1925 characters per page.

In the case of paper used for "other printing/writing/reprographics," it is assumed that half of the paper is used for printing and writing and the other half is used for reprographic purposes (this approximation is based on data corresponding to the United States in 1995 ("Paper purchasing", 2010). For the half that is used for reprographic purposes, such as photocopiers, the same grey-scale image content as newspaper is assumed, following the same transition from lower quality images (4252 [bits/cm^2]), to images of higher quality (8534 bits/cm^2]). The fact that a newspaper page is almost three times as large as an A4 format page (A4/newspaper = 0.0624 [m^2] / 0.1981 [m^2] ≈ 1/3) is taken into account. The other half used for printing and writing purposes is assumed to contain only printed text, with an average of 815 words per page (for an A4 size format), implying a total of 4482.5 characters per page (Writer Services, 2007). That average corresponds to the use of Times New Roman typeface, size 12 (the size most commonly considered most adequate for the human eye), and also assumed an average of 5.5 characters per word (Pierce, 1980). Selecting a page that is densely printed, with a smaller typeface, is justified with the aim of estimating the "maximum technological capacity installed" in the world, and this same logic allows for the consideration of a double-sided printed pages.

The codification of characters is tracked with ASCII (American Standard Code for Information Interchange), which is compatible with UTF-8, and both are the dominant computer and communications codification systems in the world (Moulton, 2001). In both cases, 8 bits represent each character, which allows for the possible representation of 256 different symbols, at maximum (see Table C-5).

Table C-5: Bit and characters per page, for books and paper for general use.

	Words per page	Characters per page	Bits per character	Impressions per page	Bits per page
Books	350	1,925	8	2	30,800
Paper for general use	815	4,482.5	8	2	71,720

Source: Authors' own elaboration.

C.1.5 Content compression

For comparative purposes in the case of normalizing optimal compression, Table C-6 presents figures for text and images. When considering the compression of images, GIF and JPEG measures are included in the calculation (more details in Appendix A). The "optimal" compression factors applied here are for high quality results obtained in 2007.

Table C-6: Compression factors for paper.

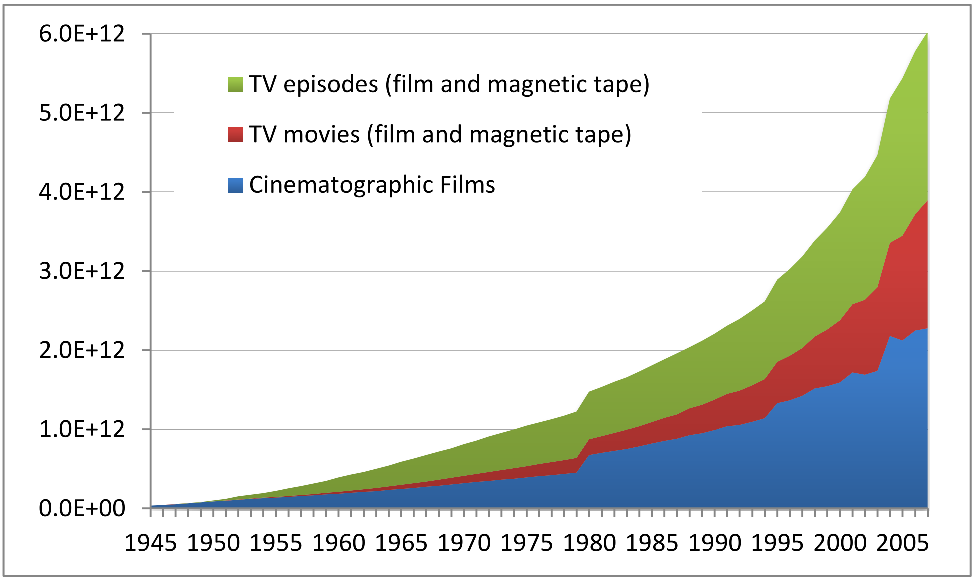
	"Optimal"
Text	6.6
Color Image	16
B&W Image	5.3

Source: Authors' own elaboration.

C.2 Films for cinema and TV

Films are essentially constructed from a series of individual frames that are shown in rapid succession (flip-book principal) (Ibrahim, 2007). A certain quantity of frames with a specified size and the number of pixels relative to the size of the frames are required. The world of cinema and television has been slow to enter the digital age (i.e. May 2002, with the film, *Stars Wars Episode II: Attack of the Clones)*. Even though digitalization has advanced quickly, it is assumed that in 2007 all film reels for movie theaters are still consisting of analog film (independently on how they were originally prepared for in the studio) (this assumption is confirmed by (Bohn and Short, 2010) in their 2009 assessment of the U.S.).

Figure C-4. Storage capacity provided for film (film and TV industries) (MB), without compression (hardware capacity).



Source: Author's own elaboration.

C.2.1 Motion Pictures: quantity

The figures denoting the quantity of films produced worldwide since 1888 were provided by (Internet Movie Database [IMDB], 2010). In order to separate cinematic film from movies on TV and video, we took a random sample (N=50) for 1946, 1965, 1985, 1995, 2000 and 2005, that identifies the quantity of the movies in each category. The result is that in 1946 almost all movies were produced for movie theaters. In 1965, 84% were produced for theaters, in 1985 about 74%, in 1995 approximately 66%, in 2000 about 53% and in 2005, roughly 42%. This trend is explained by the increase in production of films that are destined for the video niche of the market (including documentaries and pornography).

Table C-7: Quantity of films produced for theater release and preserved since 1888.

1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902
1	1	2	4	5	1	33	41	238	418	534	457	426	472	457
1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917
861	369	218	314	331	477	729	1,270	2,463	3,856	7,001	1,043	1,034	975	840
1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932
389	474	714	772	563	557	702	940	1,002	951	825	863	777	875	1,019
1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947
1,077	1,213	1,277	1,560	1,675	1,714	1,670	1,582	1,675	1,774	1,674	1,635	1,646	1,784	1,900
1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
2,037	2,212	2,215	2,210	2,395	2,491	2,496	2,533	2,592	2,689	2,717	2,736	2,923	2,994	3,100
1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
3,046	3,337	3,438	3,461	3,786	4,097	3,706	3,892	3,901	3,734	3,623	3,620	3,731	3,669	3,515
1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992

3,709	3,798	4,026	3,871	3,882	3,888	4,144	4,445	4,424	4,500	8,563	4,630	4,851	4,957	5,336

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
5,550	5,850	6,096	6,023	6,127	6,611	6,799	7,107	7,371	7,622	8,432	9,417	9,973	9,321	8,572

Sources: (IMDb, 2010), with (Lyman et al., 2003) pre-1945.

We consider the copies saved in production studios and in cinematographic archives. The majority of these films are “flops”. During the 1990s, only the 100 most popular films of the year were considered relevant movies (Anderson, 2006), and normally the motion pictures industry does not monitor more than the 200 most popular films produced every year (Box Office Mojo, 2009). This corresponds to no more than 5% of the films produced during the 1990s. Therefore, we estimate that the members of FIAF (International Federation of Film Archives), which houses the most important archives in the world (including the archives of the Academy of Motion Pictures Arts and Sciences that organizes the Oscars, among others) store one copy of 5% of the most outstanding motion pictures produced every year. FIAF (2009) reports having four members in 1938, 33 in 1960, 77 affiliates in 1987, 85 in 2006 and 132 in 2008 (linear interpolation). Apart from these archives, production studios also store originals of all their films. It is an industry practice that a studio stores three original copies in three different geographical locations (for security reasons), as well as several extra copies in its studio library[15]. Therefore we assume that every motion picture film was copied five times and stored by the production company (beginning 1945). If a film was produced before 1945, it can be assumed there remains only one copy, if it has been preserved (see the linear assessment between 1928, when only a third of the films produced were kept) (Lyman et al., 2003). The accumulative stock of film material stored by the studios and the archives is equal to the total amount of film that is stored for the long-term. For these we suppose the original quality, without any kind of reduction in resolution.

Other than material in long-term storage, an estimate of the quantity of commercial copies can be made. Given that we did not find a statistic for the global number of movie theaters, we made an estimation based on the number of movie theaters in the U.S., and then extrapolated to the rest of the world comparing the income of the U.S. motion picture industry with that of industries in other countries. The quantity of movie theaters and the number of screens in the United States is derived from (Box Office Mojo, 2010). First we consider the fact that the motion pictures industry in the U.S. has the capacity to show 100 films (Anderson, 2006). We suppose that the top twenty most popular films are copied for all movie screens in the United States where the most popular films are shown during their opening week (Box Office Mojo, 2010), which means that there is one copy per screen. For the remaining 80 films, it is suppose that one copy is sent to each theater. We suppose that other types of films that are not present in the mass market (alternative movies and short films) are sent to about 10 percent of the movie theaters in the U.S.

[15] Personal interview with Sony Pictures Entertainment, Hollywood, April 2009.

The extrapolation to the world total from the statistics of the U.S. market is based on the international distribution of the Box Office earnings (from movie theater visits) from different films in the world total and the U.S.. ("Box Office" in US$) (ShowBIZ Data, 2009). Before 1990, 2/3 of films distributed were from the U.S. and 1/3 from the rest of the world (this relationship was typical before India and China began to produce films in the mid-90s.). For the other years, see Table C-8. Normally, these copies are distributed, collected and destroyed by the production studio, and thus they are only in active circulation for a year and do not have any accumulative effect on storage statistics.

Table C-8. Box Office distribution in the U.S. and the rest of the world.

	1990	1991	1992	1993	1994	1995	1996	1997	1998
U.S.	63.9	61.3	63.5	62.5	61.4	44.4	46.7	47.1	45.6
Rest of World	36.1	38.7	36.5	37.5	38.6	55.6	53.3	52.9	54.4

	1999	2000	2001	2002	2003	2004	2005	2006	2007
U.S.	49	48	42.9	45.7	51.4	36.6	37	37.4	37.8
Rest of World	51	52	57.1	54.3	48.6	63.4	63	62.6	62.2

Source: (ShowBIZ Data, 2009),

C.2.2 Cinematographic Films: performance

There are different types of film and format for movies that are to be shown in the cinema ("35 mm film", 2010; ACVL, 2009; Kodak, 2007). Due to the lack of more detailed statistics, it will be assumed that all movies are filmed in 35 mm and for the ones from pre-1953 (introduction of *Cinemascope*), the aspect ratio was equal to 1.37:1 with the surface area equal to 22.05 x 16.03 [mm^2], while afterwards (*wide screen*), the "common" selection in the United States is 1.85:1 (plain) with a surface area of 20.96 x 11.33 [mm^2], and in Europe it's 1.66:1, with a surface area of 20.96 x 12.62 [mm^2] (Kodak, 2009; National Film & Sound Archive [NFSA], 2000).

In Table C-9, the approximate resolutions in pixels of the four main formats used by the film industry are shown. Given their similarities, it was decided to use the average resolution of 142.42 [pixel/mm] for our purposes

Table C-9. Most-used film format resolutions in the film industry.

Format	Period	Dimensions [mm2]	Resolution [pixel/frame]	[pixel/mm]
Academy Sound	<= 1955	15 x 21	2160 x 2970	142.71
Academy US Widescreen	> 1932	11 x 21	1605 x 2970	143.65
Anamorphic Panavision (*Scope*)	> 1958	17.5 x 21	2485 x 2970	141.71
Super-35	> 1982	10 x 24	1420 x 3390	141.62

Sources: ("35 mm film", 2010; ACVL, 2010; Kodak, 2007; "High-Definition video", 2010)

Using everything above, it is possible to estimate the resolution per frame (in pixels) for each one of the formats that are considered (see Table C-10). For film copies (i.e. for their commercial distribution), it is considered that their resolution is reduced to one-sixth ("High-Definition video", 2010).

Table C-10. Resolutions in pixel for the different formats.

Format 35 mm	AR	Dimensions [mm^2]	Resolution	
			[píxel/mm]	[píxel/frame]
Pre-1953	1.37:1	22.05 x 16.03	142.42	7 169 421
Wide screen EE. UU.	1.85:1	20.96 x 11.33	142.42	4 816 850

Source: Authors' own elaboration.

A 90 minutes duration is assumed for cinema movies from between 1945-2007, which refers to a duration found between commercial movies (that are normally longer, "long films"), and the short films (normally defined as movies shorter than 30 minutes). For pre-1945 movies (many of them silent), an average of 30 minutes is assumed. One additional estimate is that all silent movies (those before 1926) were shot in black and white, with a depth of field of 8 [bits/pixel]. It follows the standard of 24 frames per second to give the illusion of continual motion (Wyatt & Amyes, 2005), resulting in 129 600 frames for cinema movies from 1945-2007, and 43 200 frames for pre-1945. For cinema movies from 1926-2007, it is assumed that they have all been shot in color film with 24 bits per pixel (*True Color*).

Films also contain audio. It is assumed that each film contains only one audio format. The calculation of the bit rate for each analog technology is based upon the digitalization of the sound (Appendix A, chapter A.5); the estimate of the frequency rate is based on the consideration that it is set 10% higher than the maximum frequency (Nyquist's Theorem) and the result corresponds to the product between this value and the number of bits that are assigned per sample.

Table C-11. Bit rate for the different technologies for audio

Technology	Analog/Digital	Period	Frequency Ranges. [kHz]	Sample Rate [kHz]	Bits/ sample	Number of Channels	Bit Rate [kbps]
Vitaphone	A	1926-1930	0.03 - 4.3	10.32	8	1	82.56
SounB-on film	A	1930-1974	8	17.6	8	1	140.80
SVA (Dolby A)	A	1974-1980	0.031 - 12.5	27.5	16	2	880.00
SVA (Dolby SR)	A	1980-1990	0.031 - 12.5	27.5	16	4	1760.00
DTS	D	1993-	0.02 - 20	48	20	6	1440.00
Dolby Digital (compressed)	D	1991-	0.02 - 20	48	16	6	384.00

Source: (Petersen, 2004; Schoenherr, 1999; TriggerTone, 2010; authors' own elaboration.)

Regarding digital audio, consider the following: in accordance with (Barrat, 2004), Dolby Digital is the most used system in theatres, while DTS takes second place (in 2004, 42,970 theatres were equipped for Dolby Digital, versus the more than 23,000 with DTS (DeBoer, 2005)). It is supposed that since 1991, all movies have included audio coded with Dolby Digital. The total capacity per movie is shown in Table C-12. It should be noted that the weight decrease observed since 1991 is due to the sound that, apart from being stored digitally, uses a very efficient compression technique (AC-3).

Table C-12. Total performance in bytes of cinematographic films of distinct formats

Period	Format	Audio [MB]	Original Films		Copies	
			Image [MB]	Total [MB]	Image [MB]	Total [MB]
1888 - 1926	Pre-1953	0	309,719	309,719	51,620	51,620
1926–1930		18.6	929,157	929,176	154,860	154,878
1931–1944		31.7	929,157	929,189	154,860	154,891
1945–1952		95.0	2,787,471	2,787,566	464,579	464,674
1953–1973	Wide screen EE. UU.	95.0	1,872,792	1,872,792	312,132	312,227
1974–1979	Wide screen EE. UU.	594	1,872,792	1,872,792	312,132	312,726
1980–1990	Wide screen EE. UU.	1,188	1,872,792	1,872,792	312,132	313,320
1991-2007	Wide screen EE. UU.	259	1,872,792	1,872,792	312,132	312,391

Source: authors' own elaboration.

C.2.3 TV Films and TV episodes: performance

For a lack of more concrete statistics, it is assumed that all movies and television episodes are recorded in analog film. It is supposed that the resolution is the same for the film used in original motion pictures, that is to say, 142.42 [píxel/mm] ("Television movie", 2010), but with an aspect ratio for the TV standard of 1.33:1 (Kodak, 2007) with which the dimensions of film used for image storage is 24 x 18 [mm^2]. Furthermore, the sound is registered in stereo format with SVA stored with a rate of 880 [kbps] and durations of 90 minutes for TV movies and some 45 minutes for TV episodes (between 30 and 60 minutes) (see Table C-13).

Table C-13. Size in bytes of films and TV episodes stored on film.

Type	Video				Audio [MB]	Total [MB]
	Resolution [pixel/frame]	[frame/s]	Duration [s]	Size [MB]		
Movie	8,762,454	24	5,400	3,406,842	594	3,407,436

Episode	2,700	1,703,421	297	1,703,718

Source: authors' own elaboration.

As for commercial distribution copies (on magnetic film), these are stored –through a process called telecine[16]- on Betacam, films that since their appearance in 1982 (Media College, 2010) quickly turned into the standard of the television industry. ("Betacam", 2010; Sony, 2002). For a lack of information regarding the kind of magnetic film that was used before 1982, we may assume that since the appearance of the first TV movie or series since 1985, all have the same resolution as Betacam; and that since 1986, (the year in which Betacam SP was introduced) up to the present, all have Betacam SP resolution. (see Table C-14 and Table C-15).

Table C-14. Bit rate for video stored on Betacam film

Type	Standard	Vertical Resolution	Horizontal resolution [lines]	Horizontal resolution [pixel]	Resolution [pixel/ frame]	FPS	Pixel rate [pixel/s]	Bit rate [kbps]*
Betacam	NTSC	480	300	390	187,200	30	5,616,000	134,784
	PAL	576			224,640	25	5,616,000	134,784
Betacam SP	NTSC	480	340	422	202,560	30	6,076,800	145,843
	PAL	576			243,072	25	6,076,800	145,843

Sources: ("Image resolution", 2010; Media College, 2010; Sheldon et al., 1994; authors' own elaboration). Note: *It is assumed that all TV series and films were filmed in color, with a depth of 24 bits per pixel.

Table C-15. Size in bytes of copies of films and TV episodes stored on magnetic film.

Type	Duration [s]	<=1985	>=1986	<=1985	>=1986	<=1985	>=1986
		Video [MB]		Audio [MB]		Total Size [MB]	
Movie	5400	90,979	98,444	748	1,361	91,727	99 805
Espisode	2700	45,489	49,222	374	680	45,864	49,902

Source: authors' own elaboration.

C.2.4 Content compression

For entropic normalization (the optimal rate as of 2007), a compression rate of 60:1 is used for video (with MPEG-4 AVC XviD), and for audio, 9.6:1 (MPEG-4 AAC, "excellent" quality), for both devices. Audio codified with Dolby Digital is already in an average compression rate of 12:1.

Table C-16. Factors of compression for video and audio in a film

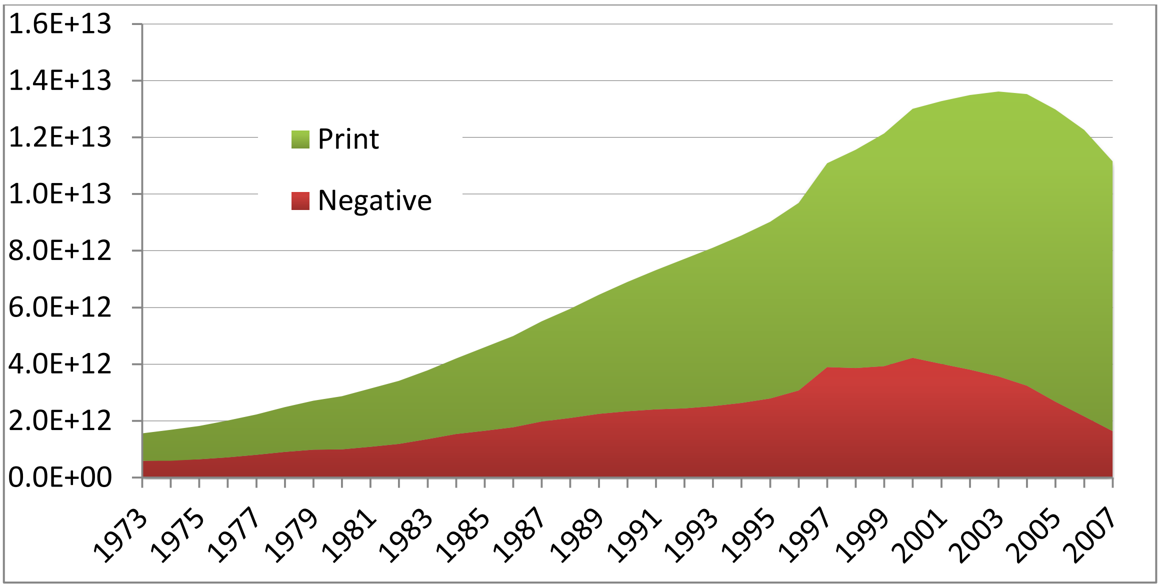
	Film (Optimal)	Magnetic Film (Optimal)
Video	60	60
Audio	9.6	9.6

Source: authors' own elaboration.

[16] With this procedure, the stored information on a film is transferred to a magnetic film, adjusting the resolution and refresh rate (frames per second) so that they can be reproduced in a correct manner on a corresponding device.

C.3 Analog Photography[17]

Figure C-5: Storage capacity of analog photographs, in MB, without standardized compression (hardware capacity).



Source: Authors' own elaboration.

C.3.1 Negatives: performance

The quantity of bits per photo is directly related with the size of the film, the distribution of silver particles in the emulsion (Vitale, 2007) (which is directly related to the "analogical" resolution of film, expressed in terms of pairs of millimeter lines [lp/mm]), and the number of bits per pixel.) According to (McBroom, 2000), if we assume that the width of a pair of lines is two pixels, we can establish the following relationship between the two: Number of bits/photo = Resolution [pixels] x No. of bits per pixel = {Width x Height of film [mm] x Resolution [lp/mm] x 2 [pixel/lp]} x No. of bits per pixel.

Of all existing film formats, 35 mm (also known as 135 film) has succeeded as the most used and most popular since the 1960's ("135 film", 2010; "35mm medium format…", 2010). The standard size of a frame in this format is 24 x 36 [mm^2] (approximately 0.9 x 13 [$inches^2$]) ("35mm medium format…", 2010).

The resolution of 35 mm films is 64.3 [lp/mm] (Vitale, 2007). However, this does not correspond to the "theoretical maximum" of a film, given that

[17] Storage concepts for digital photography are discussed in chapters D.15 and D.18.

we see a loss of 30% caused by the type of lens used (Russ, 2007; Williams, 2003). Considering the size of a frame in a film, we find that the digital resolution is equal to 14 288 797 [pixels/frame]. For black and white film, with the same loss of 30%, the average resolution is 77 [lp/mm] (Vitale, 2005), which results in 20 490 624 pixels/frame. This higher resolution, compared to that of color film, explains why primarily professional photographers use black and white film. As for disposable cameras, which also utilize the 35 mm format ("Disposable camera", 2010), the highest achievable resolution is 40 [lp/mm] (Williams, 2003), resulting in 5 529 600 [pixels].

To determine the quantity of bits per frame, an RGB *True Color* model is used for color images, with 24 [bit/pixel] (which reflects 2^{24} = 16 777 216 different colors); while an image in black and white (grayscale) has only 8 [bits/pixel] (which reflect 2^8 = 256 different shades of gray). The result is presented in Table C-17 and is in agreement with the fact that a digital file of a quality color photo weighs around 2MB when it is compressed with JPEG, which has a compression ratio in the range of 16:1 – 32:1.

Table C-17: Quantity of bits contained in a roll of film

	Resolution [pixels/ image]	Performance [bits/pixel]	Size [bits]	Size [MB]
B&W Film	20 490 624	8	163 924 992	20.5
Color Film	14 288 797	24	342 931 128	42.9
Disposable Camera Film	5 529 600	24	132 710 400	16.6

Source: Authors' own elaboration.

C.3.2 Printed photos: performance

Clark (2006) reports that a resolution of around 400 [dpi] is required to produce a lossless scan of a photograph (also Bustamante, 2005; Russ, 2007). It makes no difference whether the original photo was analog or digital, given that the bottleneck of a photograph on paper depends on the printer. Considering that the standard size of printed photographs in the United States, Canada, and many other countries is 6 x 4 [$inch^2$] (15 x 10 [cm^2]) ("Photo print sizes", 2010), we may say that a photo of this size contains {(6 x 4)[$inch^2$] x (400 x 400)[pixel/$inch^2$]} = 3 840 000 [pixels]. Color photos are comprised of 24 [bit/pixel], while black and white photos are comprised of 8 [bits/pixel], resulting in 92 160 000 bits for a color photograph, and 30 720 000 for one in black and white. It is assumed that prints made from photos shot on disposable cameras are in color.

C.3.3 Negatives and printed photographs: quantity

The following information on quantities of film and exposures (photographs that have been taken but not yet processed) has been received thanks to the kind assistance of Don Franz from Photofinishing News (Franz, 2008) (Table C-18). The estimated amounts of disposable cameras are based on (Krause, 2002), and on the rate of growth in the United States between 1994-2006 (Photo Marketing Association International [PMAI], 2006). We can assume the same for exposures/film for conventional film (in agreement with “Cámaras de fotos desechables”, 2008).

Table C-18: Quantity of film and exposures

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Sales of Conventional Film (millions of rolls)	447.9	496.7	541.9	577.6	617.3	651.7	674.5	718.5	789.1	792.2	825.7
Exposures of Conventional Film (billions)	8.9	9.7	10.4	11	11.8	12.7	13.1	14.2	15.8	16	16.7
Exposures/Film	19.8	19.5	19.1	19	19.2	19.5	19.5	19.8	20	20.2	20.2
Disposable Cameras (millions)	0	0	0	0	0	0	0	0	0	0	0

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Sales of Conventional Film (millions of rolls)	918.7	1013.4	1130.5	1184.2	1165.5	1246.3	1401.9	1544.4	1684.8	1816.7	1940.5
Exposures of Conventional Film (billions)	18.4	20.7	23.3	25	25.3	27.6	30.1	34.2	38.5	41.3	44.2
Exposures/Film	20.1	20.4	20.6	21.1	21.7	22.2	21.5	22.1	22.8	22.7	22.8
Disposable Cameras (millions)	0	0	0	0	0	0	0	0	0	0	0

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Sales of Conventional Film (millions of rolls)	2125.5	2270.8	2424.1	2507.2	2551	2533	2570	2688	2795	3015	3404
Exposures of Conventional Film (billions)	49	51.9	55.2	56.9	58.2	58.9	60.4	62.8	65.9	71.9	91
Exposures/Film	23	22.8	22.8	22.7	22.8	23.3	23.5	23.4	23.6	23.9	26.7
Disposable Cameras (millions)	0	14	28	42	56	71	85	99	141	188	230

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Sales of Conventional Film (millions of rolls)	3332	3440	3788	3739	3595	3058	2764	2241	1779	1317
Exposures of Conventional Film (billions)	89.3	90.3	96.9	91.3	86.1	79.8	72	59.1	47.3	35.5
Exposures/Film	26.8	26.3	25.6	24.4	24	26.1	26.1	26.3	26.6	27
Disposable Cameras (millions)	264	298	332	366	400	449	443	410	349	297

Sources: Conventional Film: (Franz, 2008), SinglB-use, authors’ own elaboration based on (Krause, 2002; PMAI, 2006). Note: Conventional films do not include instant film/Polaroid.

The estimates of the percentage of color and black and white films are based on the years 1963, 1964, 1969, 1974 for the United States, Japan, Germany, UK and France (Pakkala, 1977), and on Germany for the years 2001, 2002, and 2003 (GfkProphoto GmbH, 2002; 2003); the others were calculated in a linear fashion (cursives in Table C-19).

Table C-19: Percentages of color film[18].

Year	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
% Color	28.9	34.0	*39.0*	*44.1*	*49.1*	*54.2*	59.2	*63.3*	*67.4*	*71.4*
Year	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
% Color	*75.5*	79.6	*80.65*	*81.30*	*81.94*	*82.59*	*83.24*	*83.89*	*84.53*	*85.18*
Year	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
% Color	*85.83*	*86.48*	*87.12*	*87.77*	*88.42*	*89.07*	*89.71*	*90.36*	*91.01*	*91.66*
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
% Color	*92.31*	*92.95*	*93.60*	*94.25*	*94.90*	*95.54*	*96.19*	*96.84*	97.49	97.53
Year	2003	2004	2005	2006	2007					
% Color	97.53	*97.54*	*97.54*	*97.54*	*97.54*					

Source: Authors' own elaboration, based on (Pakkala, 1977; GfkProphoto GmbH, 2002; 2003).

Each image is counted one time in the roll (where the base information and the resolution of the negative is stored), and one time once it is developed (either as a print or a slide, which applies the resolution of the printed photo). In theory, printed photos and negatives in particular have a very long shelf life (between 10 and 100 years; Brown, Frey and Jones, 1999), however, according to online forums for photographers, the vast majority of persons do not keep them for long. Therefore, on average, we can consider a life expectancy of 10 years for printed photos[19], and of 1 year for negatives (strongly influenced by the majority, who discard their negatives after having them printed).

C.3.4 Content compression

To achieve the optimal level of compression, we can assume that printed images and images stored on film are to be compressed with high quality JPEG (to avoid affecting the resolution), with compression factors equal to 16 and 5.3 for photos in color and black and white, respectively.

Table C-20: Comparison of sizes of photographs with and without compression.

Type	Original size [bits]	Compression factor	Compressed size [bits]	Compressed size [MB]

[18] (Pakkala, 1977) specifies the percentage of color photographs (exposures) that have not yet been processed.

[19] This average of ten years could be seen as a weighted average, for example as the result of that 5% of photos are saved "forever" (in our study equal to 40 years); 15% for 20 years; 40% for 10 years, 30% for 3 years, and 10% of photos are not saved for any longer than 1 year.

Film	B&W	163 924 992	5.3	30 929 244	3.87
	Color	342 931 128	16	21 433 196	2.68
	Disposable	132 710 400	16	8 294 400	1.04

Source: Authors' own elaboration.

Table C-21: Annual compression of content factors.

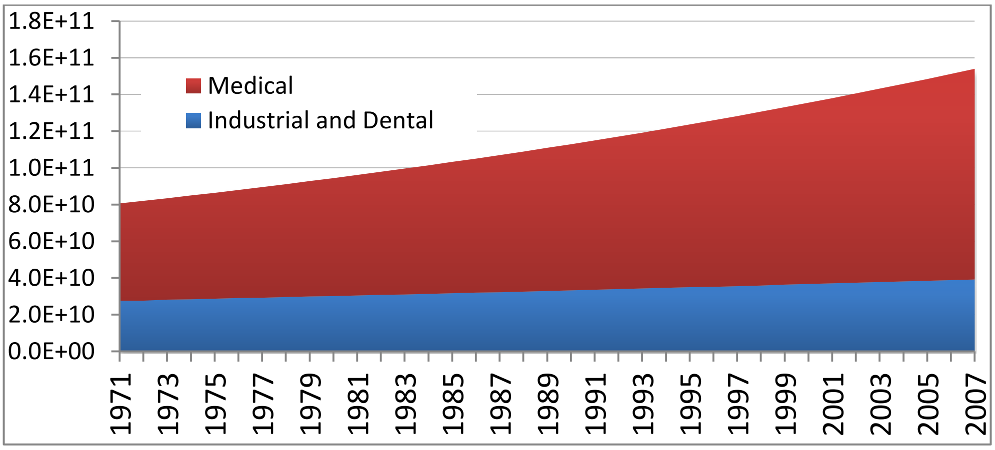
		Optimal
Film and print	Color	16.0
	B&W	5.3
Print	Color and disposable	16
	B&W	5.3

Source: Authors' own elaboration.

C.4 Radiography

A radiograph is the result of a photographic films (films) exposure to a high-energy radioactive source (generally an x ray or gamma ray). In film, the dense areas of an object placed between a radioactive source and the film show up in a grey tones, whose intensity is an inverse function of the density of the object (the less density, the darker it appears and vice versa). The uses of radiography can be medical (to detect bone fractures, cancer, etc.) as well as industrial (for the detection of defective materials and welds that are unable to be seen by the naked eye.)

Figure C-6: Storage provided by radiographs in [MB], without standardized compression (capacity hardware)



Source: Authors' own elaboration.

C.4.1 Radiographs: quantity

Concerning the number of units, we have the worldwide total of m^2 X ray images consumed in 1997 and 2002 for the medical, industrial, and dental industries (Krause, 2002). Throughout this period a CAGR growth rate of 2.2% was seen in medical X rays and of 1% in industrial and dental X rays. We may assume that this rate continued for the entire period, which is also in agreement with the development of sales of medical X ray films in North America between 1999 and 2005 (Lyra Research, 2002) (the United States represents more than one third of the entire world consumption of X ray film.).

Table C-22: Worldwide number of radiographs in millions of m^2.

	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Medical	208	212	217	221	226	231	236	241	247	252	257	263	269
Industrial & Dental	15.2	15.4	15.5	15.7	15.8	16.0	16.1	16.3	16.5	16.6	16.8	16.9	17.1
	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Medical	275	281	287	293	299	306	312	319	326	333	340	348	355
Industrial & Dental	17.3	17.4	17.6	17.8	18.0	18.1	18.3	18.5	18.7	18.9	19.0	19.2	19.4
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Medical	363	371	379	388	396	405	413	422	431	441	450	460	470
Industrial & Dental	19.6	19.8	20.0	20.2	20.4	20.6	20.8	21.0	21.2	21.4	21.6	21.8	22.1

Source: Authors’ own elaboration based on 1997 and 2002 (Krause, 2002.)

A radiograph can have a shelf life of from 20 to 30 years in optimum storage conditions (The U.S. National Archives, 2000), however; in normal conditions (such as in an office), its useful life will be shorter, from 1 to 10 years. On average, we can expect a shelf life of 5 years.

C.4.2 Radiographs: performance

C.4.2.1 Medical Radiographs

To determine the resolution of the films used in the capacity estimates, we have opted to use the specifications of pixel size in digital radiographic equipment. When put to practice, the linear size of the pixel in a digital medical radiograph varies between 0.1 and 0.2 [mm]. –although there do exist special cases, like mammograms, where the pixel size can be as small as 0.05 [mm] (Indrajit & Verma, 2007), – this assumption is in agreement with other sources that specify the aforementioned variables for the three most common types of radiographs (as shown in Table C-23).

Table C-23: Size in pixels of the most common categories of medical radiographs.

Category	Thorax	Spine	Extremities	Others
Pixel size [mm]	0.1 – 0.2	0.1 – 0.14	0.1 – 0.16	0.14 (Supposed)

Percentage of images	40%	10%	20%	30%
Weighted average	0.14 mm/pixel			

Sources: (Emergency Care Research Institute [ECRI], 2007; Wilson et al., 1991; Bansal, 2006; IDS HealthCare, 2002; Volk et al., 2000)

The estimation of the average linear resolution (0.14 [mm/pixel] is based on various studies that show the frequency with which different medical exams were carried out in Romania in 1995 and 2000 (Diaconescu & Iacob, 2002), France in 1982 and 1988 (Maccia, 1991), Korea in 2006 (You-hyun et al., 2006) and Norway in 1993 and 2002 (Borretzen et al., 2007). From them we get the percentages shown in the table above, which allow us to calculate the average linear resolution. We can ascertain that the resolution is equal to 5 098 [pixel/cm^2] (0.14 [mm/pixel] = 7.14 [pixel/mm] = 71.4 [pixel/cm] = 5 100 [pixel/cm^2]). Expressed in [pixel/m^2] makes: No. of pixels = (100 x 100 [cm^2]) x (5100 [pixel/cm^2]) = 51 000 000 [pixel/m^2].

C.4.2.2 Industrial and Dental Radiographs

A finer resolution is used in industrial and dental radiographs than in medical radiographs (a smaller pixel size); the typical values are summarized in Table C-24. To estimate the amount of pixels, we have taken an average of the values found in the table, that is to say, a size of 0.0525 [mm], which is expressed in [pixel/m^2] results: 0.0525 [mm/pixel]= 19.05 [pixel/mm]= 190.5 [pixel/cm]=36300[pixel/cm^2] = 363 000 000 [pixel/m^2].

Table C-24: Size of pixels in dental and industrial radiographs.

Category	Industrial	Dental
Size of pixel [mm]	0.05 – 0.1	0.02 – 0.04

Sources: (Radis GmbH, 2004; NOVA R&D Inc, 2008; Redmer et al., 2001; Blakeley & Spartiotis, 2006; Parks & Williamson, 2002; USAF, 2005)

Finally, regarding the number of bits with which each pixel is coded (the number of tones), it is known that the dynamic range of the image in a film is less than that of digital (Parks & Williamson, 2002). In the latter case, the depth of bits is usually 10 [bits/pixel] (ECRI, 2007); so it would be reasonable to assume the use of 8 [bits/pixel] for analog film.

Table C-25: Number of bits in medical radiographs.

	Resolution [pixeles/ m^2]	Performance [bits/píxel]	Size [kbits/m^2]
Medical Radiography	51,000,000	8	408,000
Industrial and Dental Radiography	363,000,000	8	2,904,000

Source: Authors' own elaboration.

C.4.3 Content compression

In agreement with (Dyro, 2004; Koff & Shulman, 2006; Fidler et al., 2006), the JPEG standard (lossless) is used when digitalizing an analog image. For normalizing at the entropic level, we can resolve to use JPEG with excellent quality.

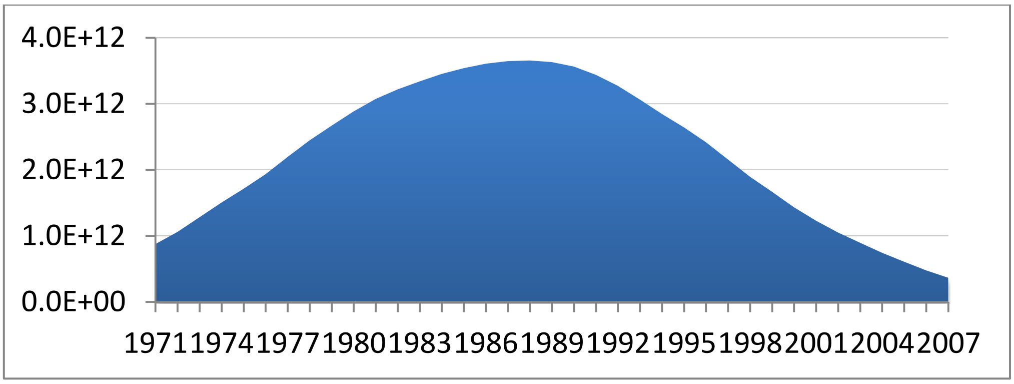
Table C-26: Compression factors by content per year.

	Optimal
Medical	5.3
Dental and Industrial	5.3

Source: Authors' own elaboration.

C.5 Vinyl

Figure C-7: Storage capacity provided by vinyl discs in MB, without compression (hardware capacity).



Source: Authors' own elaboration.

C.5.1 Vinyl LP: quantity

The quantity of LP vinyl is reported for the years 1984-1993 by (Syndicat National de l'Édition Phonographique [SNEP], 2001) and for around 70 countries between the years 1994 and 2004 by (International Federation of the Phonographic Industry [IFPI], 1995; 1998; 2001; 2002; 2003; 2004). The years pre-1984 and post-2004 have been estimated based on the growth rate of vinyl in Japan (beginning in 1956; according to Recording Industry Association of Japan [RIAJ], 2008), United States (from 1973 on; Recording Industry Association of America [RIAA], 1999; 2008; Boorstin, 2004) and the United Kingdom (from 1973 on; UK Office For National Statistics, 2002) (weighted by the inhabitants of those three countries). A shelf life of 20 years is assumed for vinyl.

Table C-27: Number of vinyl LPs sold, in millions.

1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
93.5	120.7	153.3	187.7	222.3	273.5	321.7	382.0	473.1	578.1	691.0
1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
825.9	969.1	1188.5	1194.6	1130.0	1191.7	1416.8	1392.7	1229.2	1227.4	1106.0
1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
935.2	826.0	800.0	730.0	690.0	590.0	510.0	450.0	338.0	157.0	115.0
1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
80.4	56.3	38.1	31.8	25.3	22.3	21.2	19.0	14.6	9.8	8.2
2004	2005	2006	2007							
7.8	5.9	5.6	6.3							

Sources: (SNEP, 2001; IFPI, 1995, 1998, 2001, 2002, 2003, 2004; RIAJ, 2008; RIAA], 1999; 2008; Boorstin, 2004; UK Office For National Statistics, 2002)

C.5.2 Vinyl: performance

If we follow the logic of Nyquist's theorem and consider the specific information given regarding this technology by (Damjanovski, 2005), we may assume that the performance of LP corresponds with the bit rate of 281.6 [Kbps]. We can suppose that LPs have a duration of 45 minutes, resulting in 95.04 MB on both sides of the disk, the equivalent of 190.08 MB per LP.

C.5.3 Content compression

An optimal compression factor is used to achieve excellent audio quality (Table C-28). The table shows that about 45 minutes of vinyl compressed at the optimal level for the year 2007 (10.3 MB) contains approximately the same information as two long songs in MP3 format (typically around 5MB), clearly demonstrating the inferior quality of vinyl.

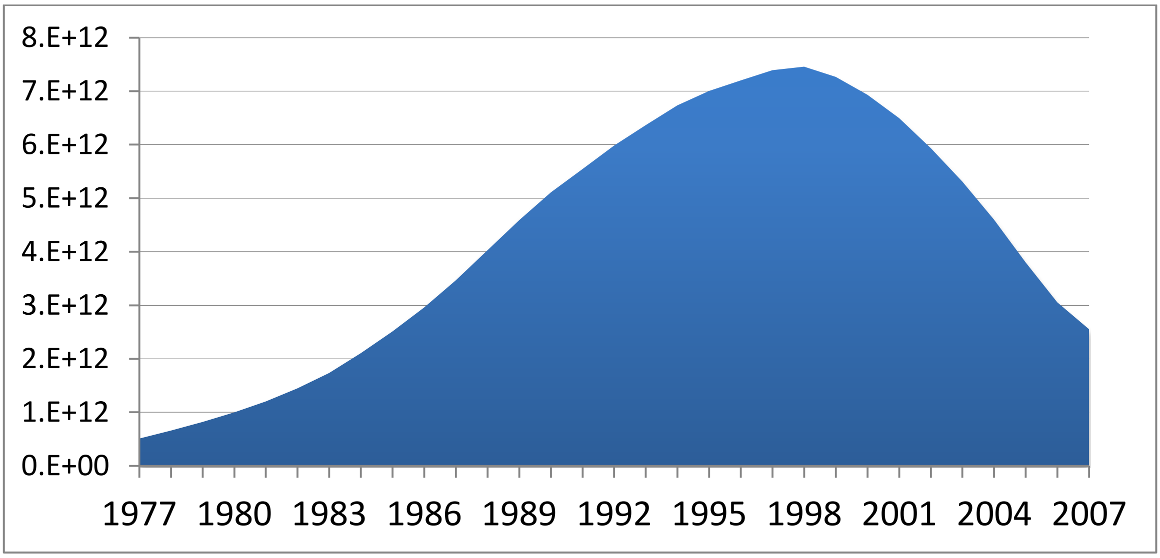
Table C-28: Compression factors and resulting storage in [MB], for vinyl.

	"Optimal"
Compression factors	9.6
Performance [MB for 45 min]	9.9

Source: Authors' own elaboration.

C.6 Audio Cassettes

Figure C-8: Storage capacity provided by cassettes in [MB], without compression (hardware capacity)

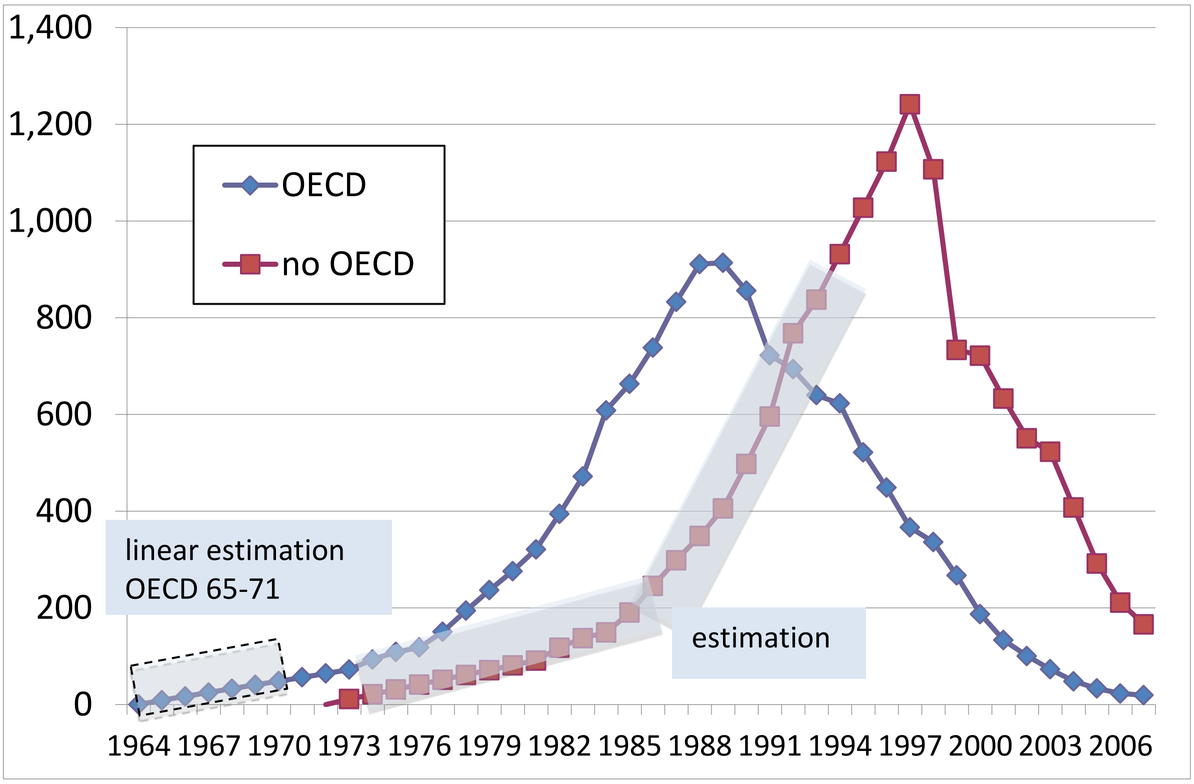


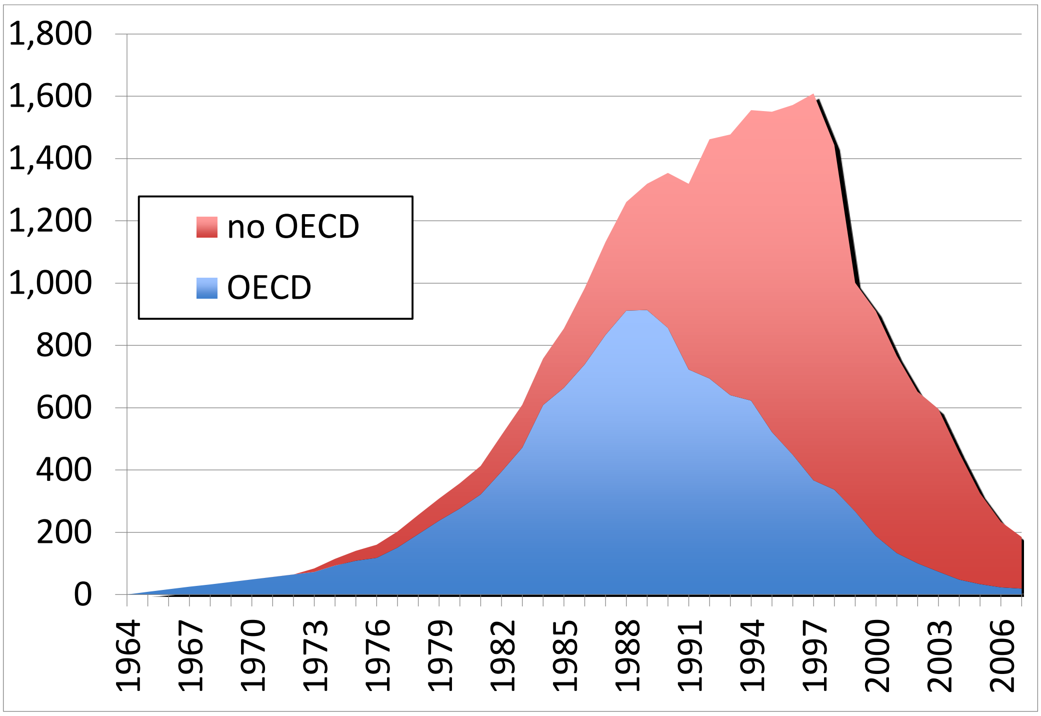
Source: Authors' own elaboration.

C.6.1 Audio Cassettes: quantity

The sales of cassettes by country (from a list of some 75 countries, representing 80% of the total global population of the year 2000) are reported between the years 1994 and 2004 by (IFPI, 1995; 1998; 2001; 2002; 2003; 2004; 2005). For countries from the OECD (industrialized nations), the estimates for the period of 1973-1993 have been based on the growth rate of cassette sales in the United Kingdom (UK Office for National Statistics, 2002), and the estimates for 1965-1972 have been calculated in a linear manner (based on the 9 million tapes sold worldwide in 1965 (Duke University, 2000). For non-OECD countries, it may be assumed that cassettes arrived with the commercialization of music cassettes in 1973 (after the appearance of the Advent 201 model), and we consider a growth rate of the first 20 years of cassette distribution in OECD (1964-1984), adjusted for the levels of those countries. For the years 2005 to 2007, the total number of cassettes recorded at the worldwide level has been estimated using the sum of all units in Japan (RIAJ, 2008), the United States (between 1973 and 2007, RIAA, 1999; 2000); and United Kingdom (UK Office for National Statistics, 2002; Zywietz, 2007). Countries that are not registered in the statistics of the IFPI were estimated according to the ratio of [cassettes/inhabitant] of neighboring countries in the same region (Africa, Asia, Europe, Latin America, Oceania), with adjustments made for the amount of inhabitants in each country.

Figure C-9: Amount of recorded audio cassettes in OECD and non-OECD countries (above, showing separate estimates; below, accumulated).





Source: Authors' own elaboration, based on various sources (see text)

In the case of blank (unrecorded) cassettes, we unfortunately only have global statistics for the years 2002-2006 (Japan Recording-Media Industries Association [JRIA], 2002, 2003, 2004, 2005, 2006, 2007). The previous years and 2007 have been estimated according to the trend of recorded cassettes, which were registered by the music and entertainment industry. Audiocassettes have a technical duration of some 15 years (VinylToDigital, 2010; A35SS, 2010), and an average shelf life of 8 years[20].

C.6.2 Audio cassettes: performance

(Damjanovski, 2005) states that this medium stores sound in stereo (two channels, from 1971 on) and its frequency response is within the range of 0.04 – 18 [kHz]. This follows the logic of Nyquist's theorem and defines a sampling frequency 10% higher than twice the maximum frequency (Ibrahim, 2007), assuming 8 bits per sample per channel, multiplied by two, since two audio channels are contained on a stereo tape. The chosen time duration is 60 minutes, to estimate the total capacity of audio cassette tapes that are not singles.

Table C-29: Capacity of audio cassettes

Type of cassette	Duration [minutes]	Sampling frequency [kHz]	Bit rate [Kbps]	Capacity per unit [MB]
Single	10	39.6	633.6	47.52
C60	60		633.6	285.12

Sources: Authors' own elaboration, based on (Damjanovski, 2005).

C.6.3 Content compression

The most efficient algorithm in 2007 (MPEG-4 AAC) achieves "excellent" quality with a compression factor of 9.6. This implies that the capacities are reduced to 29.7 [MB], comparable to 5 or 6 songs in MP3 form.

Table C-30: Compression factors and resulting storage in [MB], audio cassettes.

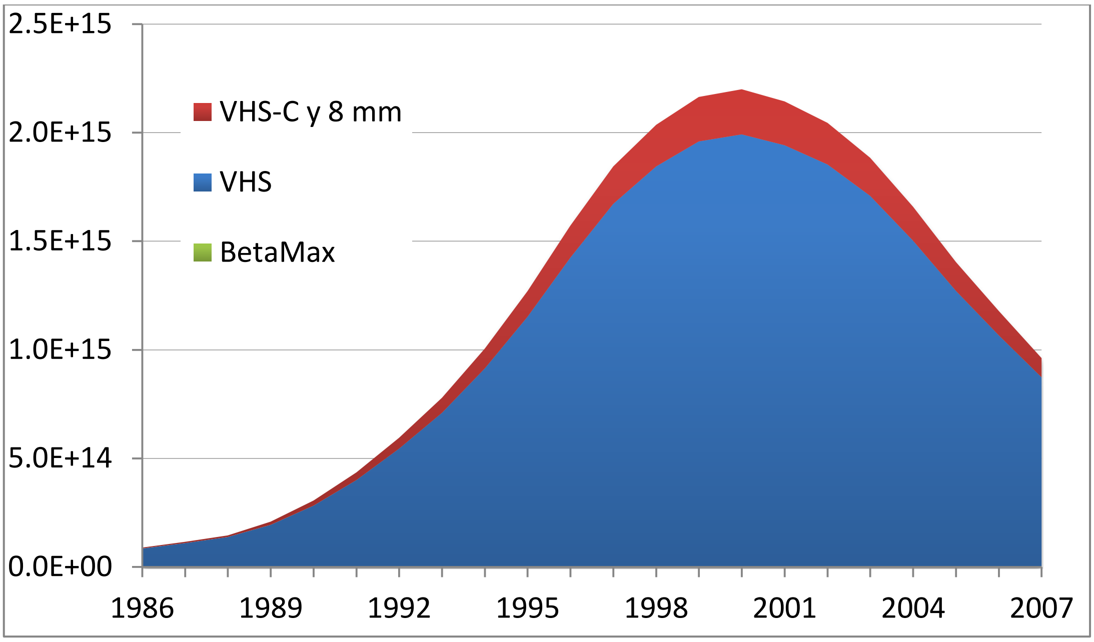
	"Optimal"
Compression factor	9.6
Performance [MB for 60 min]	29.7

Source: Authors' own elaboration.

[20] This averages follows a similar logic to that stated in footnote 13, and could be seen as the result of that 20% of analog video tapes are saved for 15 years; 40% for 10 years; 30% for 3 years; and 10% of tapes are not guarded for any more than 1 year.

C.7 Analog video tapes

Figure C-10: Storage capacities of analog video tapes, in [MB], without compression (capacity hardware)



Source: Authors' own elaboration.

C.7.1 VHS tapes: performance

180 minutes may be considered the standard size for VHS tapes (an average of the three most marketed formats, together with 120 and 140 minutes). The performance of a tape that is played on a conventional television set is based on the numbers of lines which divide the screen and the pixels that make up each line (Ibrahim, 2007). Along with this, using the number of frames per second (fps) defined in each of the standards (25 for the PAL/SECAM format and 30 for NTSC (Salomon, 2007)) and the horizontal resolution of a VHS video film (240 lines), we may estimate the performance of a video tape (see also the chapter about TV in notes of Communication).

Table C-31: Video resolutions of VHS tapes

	Vertical resolution [lines/frame]	Horizontal resolution [lines/mm]	Horizontal resolution [pixel]	Refresh rate [fps]
PAL/SECAM	576	240	312	25
NTSC	480	240	312	30

Sources: (Nagaoka, et al, 1988; Ibrahim, 2007)

A video image contains three fundamental components: one of luminance (Y) and two of chrominance (C_R y C_B) (Salomon, 2007). The chrominance components share the same number of pixels. It is maintained that the video is stored on the subsample structure 4:2:2, which implies that the luminance component is represented by 312 pixels per line, while each of the color components (the red and blue chrominances) are represented by only 156 pixels per line. It is worth noting that this differs from a TV transmission in broadcasting, where a structure of 4:2:0 is maintained to facilitate the transmission (by reducing the sharpness of the colors) (Arnold, Frater & Pickering, 2007). With a digitalization of 8 bits per pixel (Ibrahim, 2007) the following formula is used to reach Bitrate (PAL) = Bitrate (NTSC) = Bitrate (luminance) + Bitrate (Cr) + Bitrate (Cb) = 71.88 Mbps: N# [bit/s] = N# [lines/frame] * N# [pixels/line] *refresh rate [frame/seconds] * N# [bits/pixel].

For an estimate of audio storage on VHS tapes (see Table C-32), we follow the logic of Nyquist's theorem, while considering the change from mono to stereo in 1985, and the improvements in audio introduced by JVC in response to Sony's Betamax Hi-Fi technology.

Table C-32: Details of audio storage on VHS tapes and estimated bit rates.

Technology	Mono/ stereo	Bandwidth [kHz]	Sample rate [kHz]	Bits per sample[bits]	Rate per channel [kbps]	Rate [kbps]
VHS Lo-Fi (pre-1985)	Mono	0.04 – 10	*22*	8	176	176
VHS Hi-Fi (post-1985)	stereo	0.02 – 20	*44*	8	352	704

Source: ("VHS", 2010; "Compact cassette", 2010)

Finally, with the bit rates obtained before, we conclude with the storage capacities of VHS video tapes (Table C-33).

Table C-33: Estimated video capacity of VHS tapes.

		Video	Audio	Bitrate	Capacity
		Bitrate [Mbps]	Bitrate [Mbps]	Total [Mbps]	180 minute tape [GB]
Pre-1985	PAL/SECAM	72.59	0.176	72.06	**98**
	NTSC	72.59	0.176	72.06	**98**
Post-1985	PAL/SECAM	72.59	0.704	72.58	**98**
	NTSC	72.59	0.704	72.58	**98**

Source: Authors' own elaboration

C.7.2 VHS tapes: quantity

The number of units sold of pre-recorded VHS tapes was obtained from different sources (Cusumano et al., 1991; Arnold, 1998; "SB-2 SEC…", 2001; Symons, 2000; Answers.com, (n.d.)). The numbers for the year 2000 are estimated in a linear fashion, and 2004-2006 is an estimation based on the growth rate of blank VHS film (JRIA, 2002; 2003; 2004; 2005; 2006; 2007). For the number of blank VHS tapes, figures were obtained for the years 1985, 1994 and 2001-2006 (Ward, 1988; Gale Group, 2005; JRIA, 2002; 2003; 2004; 2005; 2006; 2007). The figures for the missing years were estimated according to the growth rate of pre-recorded VHS tapes. Video tapes have a technical life of around 15 years (Masters Audio Video, 2010), and a shelf life of an average of 8 years[21].

Table C-34: Global sales of VHS tapes in millions of units.

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Recorded VHS	0	0.1	0.3	0.9	1.3	2.9	6.5	9.4	13.6	23.5	41.0
Blank VHS	0	0.6	1.9	4.9	7.5	16.5	36.5	53.1	76.9	132.3	231.0

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Recorded VHS	29.6	39.8	44.8	131.9	219.1	306.3	393.5	480.6	567.8	655.0	742.2
Blank VHS	166.6	224.2	252.3	497.6	742.9	988.2	1233.4	1478.7	1724.0	2032.7	2341.5

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Recorded VHS	757.0	657.0	594.4	471.2	348.0	330.0	310.0	251.3	199.1	165.1	125,5
Blank VHS	2388.3	2072.8	1875.4	1486.7	1097.9	1054.0	903.0	732.0	580.0	481.0	365,6

Source: Authors' own elaboration based on: (Cusumano et al., 1991; Arnold, 1998; "SB-2 SEC Filling…"., 2001; Symons, 2000; Answers.com, (n.d.); Ward, 1988; Gale Group, 2005; JRIA, 2002; 2003; 2004; 2005; 2006; 2007).

.

C.7.3 VHS-C and 8mm: performance

We consider 120 minutes as a standard size for VHS-C and 8mm tapes. VHS-C tapes have a resolution of 400 lines/mm (Nagaoka, et al, 1988), while for 8mm tapes it comes to 420 lines/mm (Tsuneki et al., 1989). Therefore, the resolution of the two as a group is 410 lines/mm, the equivalent of 533 [pixel/line], resulting in 122.8 [Mbps]. Both formats take the same audio as VHS (Table C-35).

Table C-35: Capabilities of VHS-C and S-VHS tapes.

	Video Bitrate [Mbps]	Audio Bitrate [Mbps]	Total Bitrate [Mbps]	Capacity 120 minute tape

21 This average follows a logic similar to the one stated in footnote 13, and could be seen as the result of that 20% of analog video tapes are saved for 15 years; 40% for 10 years; 30% for 3 years, and 10% of tapes are not saved for any longer than 1 year.

				[GB]
PAL/SECAM	122.80	0.704	123.50	111.15
NTSC	122.80	0.704	123.50	111.15

Source: Authors' own elaboration.

C.7.4 VHS-C and 8mm tapes: quantity

Regarding VHS-C and 8mm as a set during the period of 2001-2006, we have the source (JRIA, 2002; 2003; 2004; 2005; 2006; 2007). For the previous years, an estimation was made according to the growth rate of conventional VHS, keeping in consideration that VHS-C was introduced to the market in 1982. These tapes have a useful lifetime of 8 years (Gantz, et al., 2007).

Table C-36: Worldwide number of sales of VHS-C and 8mm in millions.

1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
5.2	8.9	15.5	11.2	15.0	16.9	49.9	82.9	115.9	148.9	181.9	214.9	247.9
1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	
280.9	286.5	248.6	225.0	178.3	131.7	125.0	113.0	96.0	77.0	61.0	24.8	

Source: Authors' own elaboration.

C.7.5 BetaMax tapes: performance

The standard size for BetaMax tapes is 120 minutes. The BetaMax format has a resolution of 260 lines/mm (BetaMax PAL Site, 2010) and a structure of 4:2:2 (Table C-37), which implies that the luminance component is represented with 338 pixels per line, while each of the color components (red and blue) are represented by only 169 pixels per line, resulting in the capacities shown in Table C-39.

Table C-37: Video resolutions of BetaMax tapes.

	Vertical resolution [lines/frame]	Horizontal resolution [lineas/mm]	Resolution horizontal [pixel]	Refresh rate [fps]
PAL/SECAM	576	260	338	25
NTSC	480	260	338	30

Sources: (Ibrahim, 2007; BetaMax PAL Site, 2010).

The audio performance of BetaMax tapes is presented in Table C-38. It keeps in consideration that Sony launched a new version of the tape in 1983 that could store audio in high quality (a format called BetaMax Hi-Fi) ("Betamax", 2009).

Table C-38: Detalles del almacenamiento del audio en las cintas Betamax y de la estimación de las tasas de bits.

Technology	Format	Frequency response [kHz]	Sample rate [kHz]	Bits per sample [bits]	Rate per cannel [kbps]	Rate [Kibps]
BetaMax	Mono	0.05 - 10	22	8	176	176
BetaMax Hi-Fi	Stereo	0.02 - 20	*44*	8	352	704

Sources: (Betamax PALsite, 2010; "VHS", 2010).

Table C-39: BetaMax tape capabilities.

		Video	Audio	Total	Capacity:
		Bitrate [Mbps]	Bitrate [Mbps]	Bitrate [Mbps]	120 Minute tape [GB]
Pre-1983	PAL/SECAM	77.88	0.176	78.06	**70.25**
	NTSC	77.88	0.176	78.06	**70.25**
Post-1983	PAL/SECAM	77.88	0.704	78.58	**70.72**
	NTSC	77.88	0.704	78.58	**70.72**

Source: Authors' own elaboration.

C.7.6 BetaMax tapes: quantity

The numbers reported of BetaMax units sold for the years 1975-1988 are by (Cusumano, et al, 1991) and use a linear estimation for between 1989 and 2002. BetaMax tapes have a useful life of 8 years (Gantz, et al., 2007).

Table C-40: Number of BetaMax tapes sold in millions of units.

Year	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
#	0.02	0.18	0.42	0.59	0.85	1.49	3.02	3.72	4.57	6.04

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
#	3.39	1.11	0.67	0.15	*0.14*	*0.13*	*0.12*	*0.11*	*0.10*	*0.09*

Year	1995	1996	1997	1998	1999	2000	2001	2002
#	*0.08*	*0.07*	*0.06*	*0.05*	*0.04*	*0.03*	*0.02*	*0.01*

Source: Authors' own elaboration based on (Cusumano, et al, 1991)

C.7.7 Content compression

The compression factors from 2007 (optimal) are 60:1 for video (with MPEG-4 AVC XviD) and 16:1 for audio (MPEG-4 AAC, "good" quality). This implies that the tape storage capabilities are lower than what is shown in Table C-41. If we compare this result with a digital movie in MP4 (a 90 minute movie is about 1.6GB), we will find that a 180 minute VHS tape has only half the quality of its digital successor.

Table C-41: Storage capability by tape in [MB] with "optimal" compression applied.

Cinta	VHS		VHS-C	BetaMax	
Period	< 1985	>=1985	1983-2007	<1983	>=1983
[MB]	1 632	1 677	1 882	1 178	1 208

Source: Authors' own elaboration.

Table C-42: Compression factors for both contents of a video tape.

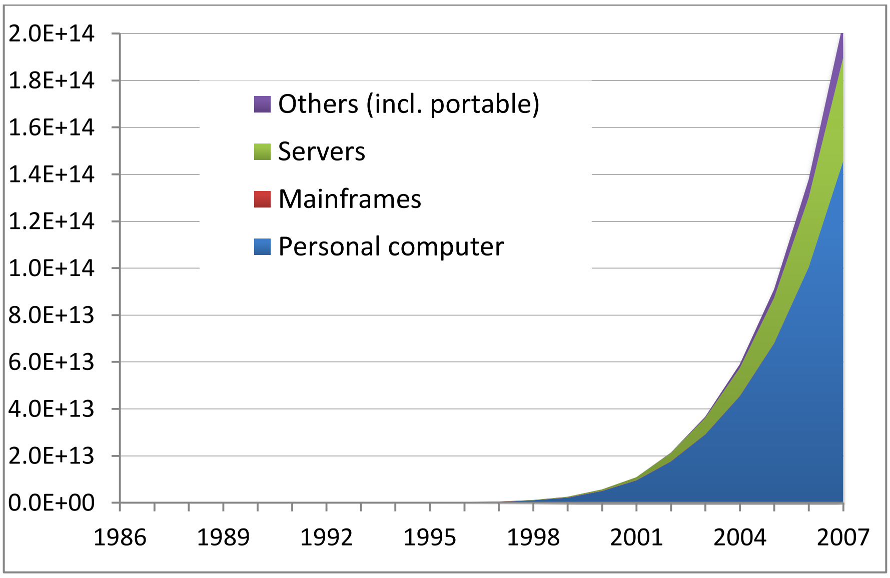
	"Optimal"
Video	60
Audio	9.6

Source: Authors' own elaboration.

C.8 Hard Disk Drives (HDD)

Hard disks are used for many different applications: computer systems (including desktop and portable computers, high performance servers, supercomputers, mainframes, etc.), PVR/DVR (personal/digital video recorder), video game consoles, iPods, digital cameras, etc. We present a distribution estimate of HDD for different types of devices. This distribution is not necessarily important in relation to the number of bits stored *per sé*, but it is significant to the estimation of the compression of content, and for the estimation of the respective computing power, both of which vary for different types of equipment (see Appendix A).

Figure C-11: Storage capacity provided by hard disks, in [MB], without normalizing by compression (capacity hardware).



Source: Author's own elaboration.

C.8.1 Hard Disks: quantity

The quantity of units shipped between 1976 and 1998 was obtained from (Porter, 1981; 1982; 1983; 1985; 1986; 1987; 1989; 1990; 1991; 1994; 1997; 1999), between 1999 and 2004 from (Peripheral Research Corporation, 1999; 2004), for 2005 and 2006 from (Coughlin, 2007), and for year 2007 from (Mearian, 2008; Coughlin, 2009; Xyratex, 2009) (see Table C-43).

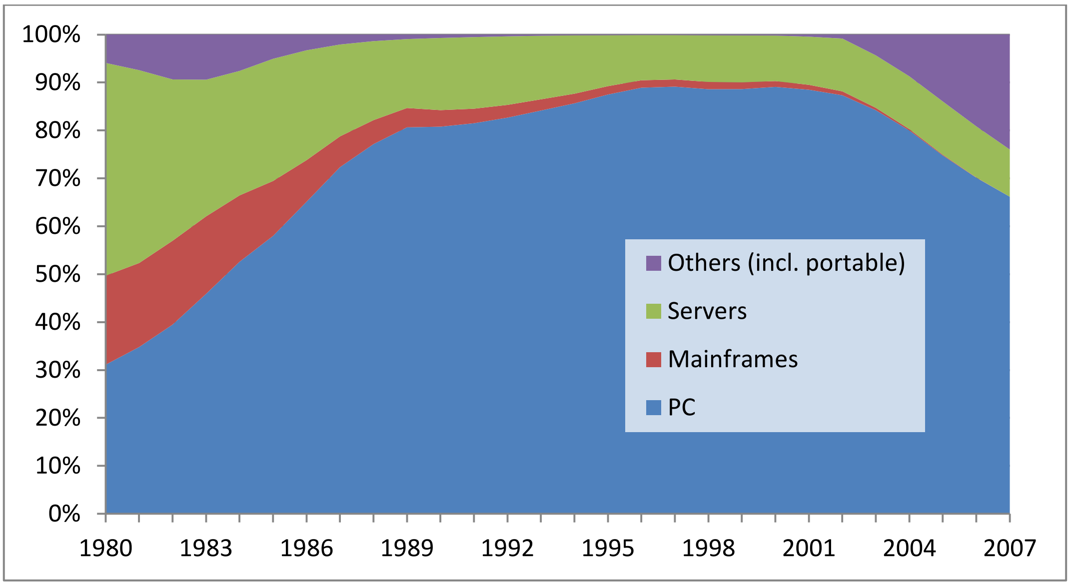
Table C-43: Quantity of hard disks shipped between 1976 - 2007 worldwide.

Years	Units [x1000]	Years	Units [x1000]	Years	Units [x1000]
1976	175.7	1987	13,191.9	1998	144,966.8
1977	235.2	1988	17,766.5	1999●	165,290.0
1978	306.1	1989	22,180.5	2000●	195,451.0
1979	386.3	1990	27,879.1	2001●	196,400.0
1980	493.5	1991	32,587.3	2002●	210,500.0
1981	700.7	1992	43,907.1	2003●	261,400.0
1982	950.3	1993	51,857.6	2004●	295,900.0
1983	1,964.7	1994	69,998.8	2005◘	358,881.0
1984	3,649.1	1995	89,556.9	2006◘	437,028.0
1985	4,855.0	1996	105,017.6	2007⊕	501,800.0
1986	7,941.9	1997	130,498.1		

Sources: *No symbol:* (Porter, 1981 – 1999), ●: (Peripheral Research Corporation, 1999 & 2004); ◘: (Coughlin, 2007); ⊕: (Mearian, 2008; Coughlin, 2009; Xyratex, 2009).

To determine the shelf life of hard disks, the total number of yearly shipments of HDDs for PCs from (Porter, 1981 – 1999) was compared with the amount of installed PCs reported by the ITU (2010). The difference between the two sources is minimized by assuming a shelf life of 10 years for HDDs produced between 1976 and 1986; of 7 years for the period between 1987 and 1989; and a shelf life of 5 years for between 1990 and 2007. This was a period of transition that coincides with the points in time when the Windows operating systems 2.0 (1987) and 3.0 (1990) were put on the market (Microsoft, 2006). This resulted in the break-up of IBM and Microsoft in 1990, owing to differences between them over which operating system was to be used in the PC (Brasington, 2003; Spector, 2001). It seems reasonable to assume that this development had an impact on the possible shelf life of computers. Considering this shelf life, the estimate of the total distribution according to different technologies (PC, mainframes, servers, portables and others) is presented in the following figure.

Figure C-12: Quantity of hard disk distribution (with accumulation).



Sources: (Porter, 1981 – 1999; Peripheral Research Corporation, 1999; 2004; Coughlin, 2007; Mearian, 2008; Coughlin, 2009; Xyratex, 2010).

C.8.2 Hard disks: performance

From the information reported in the "Disk Trend Report" (Porter, 1989 – 1999) and by Gartner (Monroe, 2002; 2008), we were able to put together the amount of capacity shipped, in terabytes (TB = 1 000 000 000 000 bytes), for 1988-1999, and for 2000 – 2002 and 2006, respectively. The three years between 2003-2005 are estimated with a constant annual growth rate of (48%) Given that the Disk Trend reports do not show the total number of TB for the years between 1976-1987, an estimate for those years has been created based on the statistics of the number of devices and their performance, both presented in the same reports (Porter, 1989 – 1999).

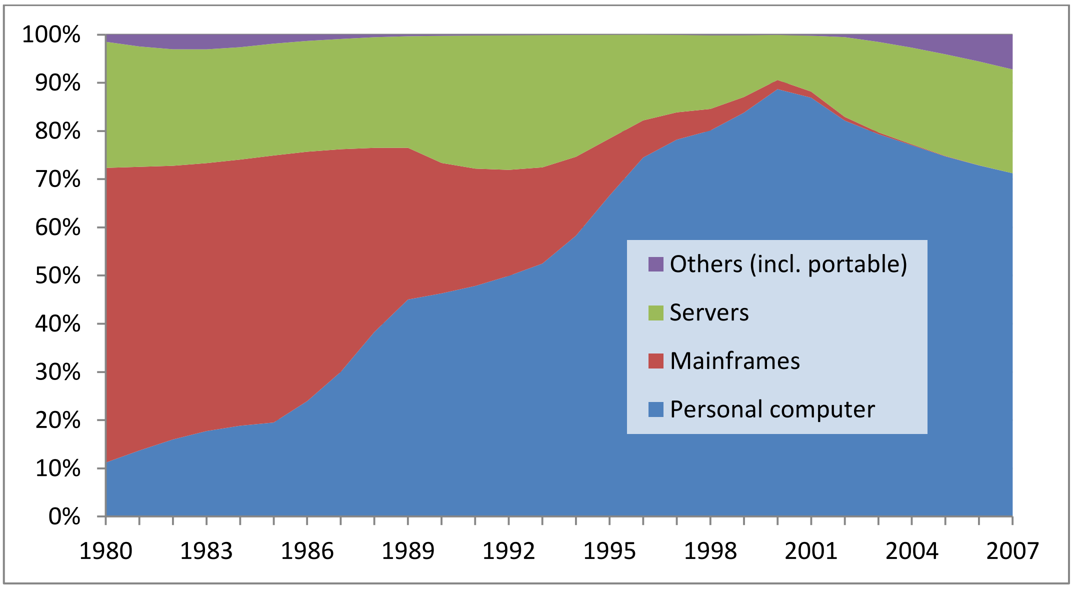
Table C-44: Capacity shipped per year, in terabytes 1980 - 2007.

Year	Capacity [TB]	Year	Capacity [TB]	Year	Capacity [TB]	Year	Capacity [TB]
		1981+	*74.3*	1990	3,727.1	1999	1,393,433.8
		1982+	*92.5*	1991	4,710.8	2000♦	3,194,000.0
		1983+	*157.9*	1992	8,180.4	2001♦	5,340,000.0
		1984+	*242.6*	1993	14,855.5	2002♦	10,788,000.0
1976+	10.7	1985+	*365.6*	1994	32,966.0	2003#	*15,999,050.4*
1977#	*16.2*	1986+	*492.7*	1995	80,677.2	2004#	*23,727,253.7*
1978#	*23.7*	1987+	*779.1*	1996	160,623.4	2005#	*35,188,499.0*
1979#	*33.3*	1988	1,769.9	1997	338,061.4	2006♦	52,186,000.0
1980+	55.4	1989	2,435.9	1998	694,338.2	2007#	*77,393,997.3*

Sources: *No symbol:* (Porter, 1999), #: Estimate of constant growth rate, ♦: (Monroe, 2002; 2008), +: Estimate based on data on number of devices and their performance

For the estimates on the capacity used by different types of computer systems, we consider the data given by Porter (1980 – 1999) concerning the percentage of hard disks sent to computer manufactures for each type of computer (PCs, mainframes, servers and others), and the average capacity of each respective category. The years without data (1988, 1992, 1994, 1995, 1997, 1999, 2001) were estimated in a linear manner; and as for the period of 2003-2007, the estimations were based on diverse estimates from (Monroe, 2002; 2008), IDC (2008) and Coughlin (2009) (**Error! Reference source not ound.**).

Figure C-13: Hard disk storage capacity distribution, in MB, without normalization by compression (hardware capacity) in different areas of application (with accumulation).



Source: Authors' own elaboration based on Porter (1980 – 1999), Monroe, 2002; 2008; IDC, 2008; Coughlin (2009).

Personal Computers

Table C-45: Capacity sent for personal computers in [TB].

Year	Capacity [TB]	Year	Capacity [TB]	Year	Capacity [TB]
1980	6.2	1989	1 359.4	1998	564 450
1981	13.7	1990	1 788.6	1999	*1 209 626*
1982	19.7	1991	*2 387.7*	2000	2 948 856
1983	*33.4*	1992	*4 336.9*	2001	*4 528 747*
1984	*50.8*	1993	8 330.9	2002	*8,338,167*
1985	76.0	1994	*21 165.3*	2003	*12,106,560*
1986	164.4	1995	*58 351.9*	2004	*17,569,998*
1987	325.1	1996	129 224.2	2005	*25,486,757*
1988	*863.1*	1997	*273 398.5*	2006	*36,952,171*
				2007	*53,547,326*

Sources: *No symbol:* Estimation based on Porter (1980 – 1999) and (Monroe, 2002; 2008; IDC, 2008; Coughlin, 2009).

Mainframes

Most available statistics stopped tracking mainframes after 2002. We assume that the remaining number of mainframes was incorporated into statistics on mid-range and high-end enterprise servers. We therefore often group mainframes with servers.

Table C-46: Capacity sent for mainframes [TB].

Year	Capacity [TB]	Year	Capacity [TB]	Year	Capacity [TB]
1980	33.9	1989	503.2	1998	25 551.7
1981	40.6	1990	741.8	1999	*32 425.8*
1982	48.1	1991	*895.0*	2000	31 112.0
1983	*84.1*	1992	*1480.1*	2001	*35 741.4*
1984	*132.2*	1993	2 553.4	2002	39 327.9
1985	203.9	1994	*4 288.5*	2003	-
1986	216.6	1995	*7 123.5*	2004	-
1987	276.1	1996	7 469.5	2005	-
1988	*496.5*	1997	*14 080.8*	2006	-
				2007	-

Sources: *No symbol:* Estimation based on Porter (1980 – 1999) and (Monroe, 2002; 2008; IDC, 2008; Coughlin, 2009).

Servers

Table C-47: Capacity sent for servers [TB].

Year	Capacity [TB]	Year	Capacity [TB]	Year	Capacity [TB]
1980	14.5	1989	572.6	1998	102 866.0
1981	16.9	1990	1 192.5	1999	*149 815.3*
1982	20.6	1991	*1 423.4*	2000	213 617.0
1983	*35.6*	1992	*2 326.2*	2001	*753 739.6*
1984	*55.2*	1993	3 960.0	2002	*2,323,938*
1985	84.1	1994	*7 494.8*	2003	*3,446,496*
1986	111.4	1995	*15 178.2*	2004	*5,111,296*
1987	177.0	1996	23 919.8	2005	*7,580,263*
1988	*409.0*	1997	*50 213.7*	2006	*11,241,844*
				2007	*16,672,120*

Sources: *No symbol:* Estimation based on Porter (1980 – 1999) and (Monroe, 2002; 2008; IDC, 2008; Coughlin, 2009).

Others (external, portable, etc)

Table C-48: Capacity sent for other computation systems [TB].

Year	Capacity [TB]	Year	Capacity [TB]	Year	Capacity [TB]
1980	0.8	1989	0.7	1998	1 470.8
1981	3.2	1990	4.2	1999	*1 566.4*
1982	4.1	1991	*4.7*	2000	415.1
1983	4.9	1992	*7.2*	2001	*21 772.2*
1984	4.3	1993	11.3	2002	*86,567*
1985	1.7	1994	*17.3*	2003	*445,994*
1986	0.4	1995	*23.7*	2004	*1,045,960*
1987	0.9	1996	9.9	2005	*2,121,478*
1988	*1.3*	1997	*368.5*	2006	*3,991,985*
				2007	*7,174,552*

Sources: *No symbol:* Estimation based on Porter (1980 – 1999) and (Monroe, 2002; 2008; IDC, 2008; Coughlin, 2009).

C.8.3 Content Compression

In the case of hard disks, just as for magnetic tape data, it is assumed that information that is communicated in real time (voice, video conferences, etc.) is not stored. The remaining contents are stored in accordance with the percentages shown in Table C-56. Regarding personal computer storage and the hard disks classified as "other", we have resolved that the content is distributed in the same way as Internet traffic was in 1986 and 1993, while in 2000 and 2007, as the average between the web and P2P[22]. As for servers, we will assume that they always behave in accordance with web traffic (see the content section in the notes on Internet for further details). The case of mainframes is different, as they are in general only used by large organizations (military, governmental, scientific, corporative) for critical applications for the processing of data, such as censuses and industrial/consumer statistics, the planning of business resources, and for the processing of financial transactions (Thomson Gale, 2005; "Mainframe computer", 2010). It so becomes necessary to make assumptions that depart from the context of Internet traffic. We assume that in 1986, 100% of the capacity contained text, whereas in 2000 we assume two thirds as text data, and one third as images (see data from Martino Neuroimaging Center and Center for Climate Change Study at MIT in (Madnick et al., 2009).

Table C-49: Distribution of different contents in hard disks according by type of computational system (Personal Computers, Servers, Mainframes).

		1986	1993	2000	2007
% Text	PC	100	43.1	22.9	22.9
	SV	100	43.1	43.5	34.9
	MF	100	83.3	67.7	-
% Image	PC	0	42.5	20.4	17.1
	SV	0	42.5	40.2	32.3
	MF	0	16.7	33.3	-
% Audio	PC	0	2.2	45.6	9.3
	SV	0	2.2	3.6	3.8
	MF	0	0	0	-
% Video	PC	0	2.8	8.2	50.7
	SV	0	2.8	8.0	29.1
	MF	0	0	0	-
% Compressed	PC	0	9.4	3.0	0.0
	SV	0	9.4	4.7	0.0
	MF	0	0	0	-

Source: Authors' own elaboration.

The mainframe compression factors are considered to be equal to those for the PC and "others", given that in both cases the type of compression that is usually used causes minimal losses. In general a very good quality is seen,

[22] We add the "compressed" part to audio, which turns out to bring the share of audio for PC -disks equal to the share of audio in P2P.

with the exception of servers, which store web content. Here, a higher compression factor is applied for web images of medium quality (Table C-71).

Table C-50: Compression factors for different types of PC and server content.

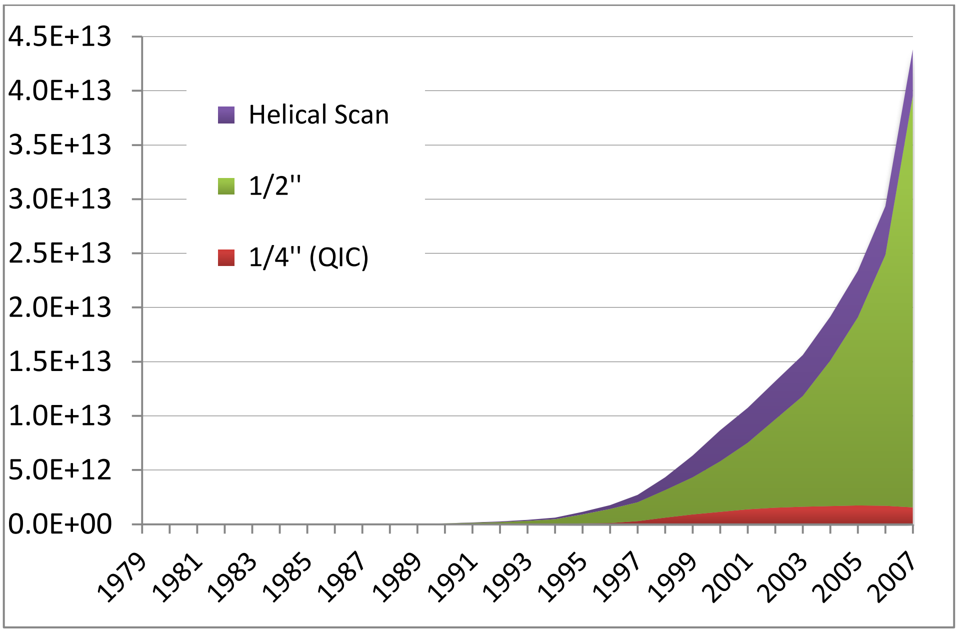
		1986	1993	2000	2007	Optimal
Text	**PC = SV**	2.2	2.9	4.6	4.7	6.6
Image	**PC**	1	7	8.5	11.3	16
	SV	1	7	14.3	27.6	48
Audio	**PC = SV**	1	1	6.8	6.8	12
Video	**PC = SV**	1	20	27	60	60
Compressed	**PC = SV**	2.2	2.9	4.6	4.7	6.6

Sources: Authors' own elaboration.

C.9 Magnetic Data Tapes

These tapes are mainly used for the backup of data, and are often put together in what are called *Tape Libraries* (**Error! Reference source not ound.**).

Figure C-14: The total storage capacity provided by digital data storage tapes, in [MB], without normalization by compression (capacity hardware).



Source: Authors' own elaboration.

C.9.1 Data Tapes: quantity

The data tapes considered include: QIC (Data Cartridge and Minicartridge/TRAVAN); Tapes and cartridges of ½'' [DEC ½" ½" Reel, format IBM (3480, 3490E, 3590); and Sun-StorageTek/Imation format (9840); DLT/SDLT; LTO; *helical scan tapes* (8 mm and 4 mm DAT). The quantity of units sold per year comes from different sources, among them the following: (Peterson & Casey, 1991); Peripheral Research Corporation, 1999; 2000; 2001; 2002) and (Eckard, 2001; 2002; Hughes, 2006; 2007; 2008; Mordock, 2006; Olfert, 2002; 2003; 2005). These list the number of units sold for 1990 and 1991 (all models except: DLT and IBM 3590, which were estimated in a linear fashion, keeping in mind the year they were both introduced to the market (1984)), 1998 – 2001 (all models with the exception of, ½" Reel[23]) and for 2002 (all models). For the period from 2003-2005, the estimate was made using the percentages represented by each model's total in 2002; while in 2007 the participations of the market reported by (HP, 2008) were used (Table C-51). A 10 year shelf life is assumed (Rothenberg, 1999), twice that of a hard disk.

Table C-51. Total quantity of data tapes sold worldwide, in millions.

		1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1/4" (QIC)	data cartridge	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0	19.5	20.4
	minicartr. /travan	0.4	0.7	1.1	1.4	1.8	2.1	2.5	2.8	3.2	3.5	3.9	4.2	5.8	7.7
1/2"	DEC 1/2" cartridge	-	-	-	-	-	-	-	-	-	-	-	2.5	2.3	2.1
	1/2" Reel	-	-	-	-	-	-	-	-	-	-	-	23.7	20.8	18.1
	DLT	0.0	0.0	0.0	0.0	0.0	0.7	1.3	2.0	2.7	3.4	4.0	4.7	5.4	6.0
	3480/ 3490e	0.0	0.0	0.0	0.0	0.0	5.6	11.1	16.7	22.2	27.8	33.3	38.9	37.6	32.6
	9840	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3590	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.3
	LTO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Helical scan	8mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0	1.6	2.7	4.3
	4mm DAT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	1.3	2.9
Data Cassette		-	-	-	-	-	-	-	-	-	-	-	1.9	2.2	2.4
TOTAL		1.8	3.7	5.5	7.4	9.2	17.5	25.7	33.9	42.1	50.9	59.8	96.8	98.6	97.7

		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1/4" (QIC)	data cartridge	18.0	15.6	13.2	10.8	8.4	6.0	5.9	6.2	6.1	4.3	3.5	2.7	1.9	1.1	*0.4*
	minicartr / travan	9.4	11.1	12.8	14.5	16.3	18.0	15.5	11.1	11.7	6.0	4.9	3.8	2.7	1.6	*0.6*
1/2"	DEC 1/2" cartridge	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[23] While this tape model began to be sold in 1969, the data is only available from 1990 and already shows a clear decrease. Because it is impossible to know how it performed before this time, (for example, it is not known in which year the tape hit its highest sales), it is not possible to make a realistic estimate. Following this logic, we only consider the data from 1990 forward.

	1/2" Reel	16.2	14.4	12.6	10.8	9.0	7.2	5.4	3.6	1.8	0.0	0.0	0.0	0.0	0.0	*0.0*
	DLT	6.7	7.4	8.1	8.7	9.4	10.1	12.6	17.1	12.8	10.5	9.4	8.4	7.3	6.3	*5.5*
	3480/ 3490e	29.5	26.4	23.3	20.2	17.1	14.0	7.9	4.7	1.8	0.9	0.8	0.7	0.6	0.5	*0.3*
	9840	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.1	1.4	1.5	1.4	1.2	1.1	0.9	*0.5*
	3590	1.5	1.6	1.8	1.9	2.1	2.2	2.9	3.2	3.2	3.4	3.0	2.7	2.3	2.0	*1.2*
	LTO	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.2	6.3	6.8	5.0	9.3	10.7	20.0	30.0
Helical scan	8mm	5.9	7.5	9.0	10.6	12.2	13.7	14.4	15.7	2.9	2.8	2.8	2.7	2.7	2.7	*0*
	4mm DAT	6.6	10.4	14.1	17.8	21.5	25.2	24.8	25.4	22.7	18.7	18.8	18.8	18.9	18.9	*11.5*
Data Cassette		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL		93.8	94.3	94.9	95.4	95.9	96.5	90.1	89.3	70.7	54.8	49.5	50.3	48.2	54.1	50.0

Source: Authors' own elaboration.

C.9.2 Data Tapes: performance

The performance of data tapes is shown in the following tables. The estimate is in agreement with the total capacity of TB shipped reported by (HP, 2008).

Table C-52: Storage capacity of ¼" tapes (QIC), in [GB].

	1979-1988	1989-1990	1991-1992	1993-1995	1996	1997	1998-2007
Data Cartridge	0.02	0.11	0.24	0.50	0.97	4.13	10.53
Minicartridge/TRAVAN	0.02	0.11	0.21	0.87	2.47	7.67	15.33

Sources: Authors' own elaboration based on (QIC Tape Solutions, 2005; Sprague Margnetics, 1995)

Table C-53: Storage capacity of ½" tapes in [GB].

	1979-1986	1987-1988	1989-1990	1991-1992	1993	1994-1995	1996-1997	1998-2001	2002-2003	2004-2007
DEC ½"	0.13	0.26	0.26	1.01	2.30	2.30	2.30	2.30	2.30	2.30
½" Reel	0.18	0.18	0.18	0.23	0.23	0.23	0.23	0.23	0.23	0.23
DLT	0.10	0.20	1.00	2.97	6.20	12.00	21.67	55.00	101.67	190.00

Sources: Authors' own elaboration based on (Sun Storage Tek, 2010; Imation Corp., 2010; IBM, 2010; Quantum, 2010)

Table C-54: Storage capacity of IBM and *StorageTek tapes in [GB].**

	1984-1985	1986-1988	1989-1990	1991-1992	1993-1994	1995-1999	2000-2001	2002	2003-2004	2005-2007
3480/3490e	0.20	0.30	0.47	0.93	1.60	11.33	11.33	30.80	196.67	196.67
9840*	-	-	-	-	-	50.00	55.00	103.33	103.33	103.33
3590	-	-	-	-	-	30.00	30.00	45.00	45.00	96.67
LTO	-	-	-	-	-	100.00	100.00	100.00	150.00	233.33

Sources: Authors' own elaboration based on (Sun Storage Tek, 2010; Imation Corp., 2010; IBM, 2008)

Table C-55: Storage capacity of *HelicalScan* tapes en [GB].

	1987-1988	1989-1990	1991-1992	1993	1994-1996	1997	1998	1999-2007
8mm	2.40	2.45	3.30	5.83	5.83	11.67	21.67	35.00
4mm DAT	-	1.30	1.65	1.65	2.43	9.00	9.00	12.00

Sources: Authors' own elaboration based on (ECMA International, 1990a; 1990b, 1992, 1995, 1996; 1999)

C.9.3 Content Compression

Regarding servers, we can assume that they behave about the same as web content (see Table C-56). The compression methods used are between the quality of servers (highly compressed for web content) and PCs (less compressed, which is to say, higher quality).

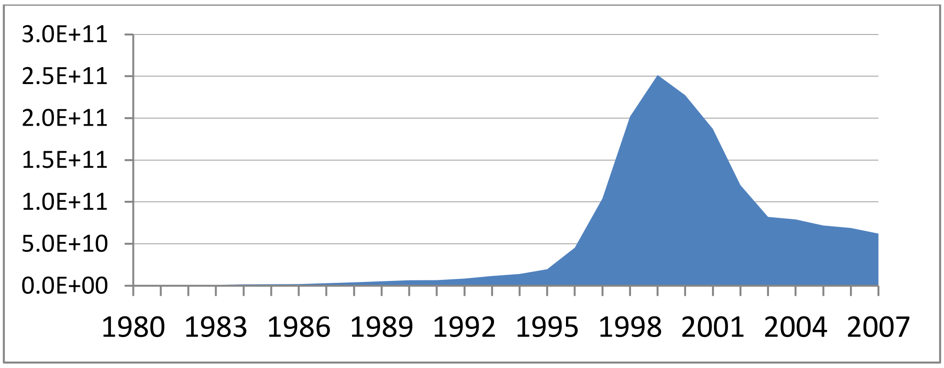
Table C-56: Compression factors for different types of digital tapes by content.

	1986	1993	2000	2007	Optimal
Text	2.2	2.9	4.6	4.7	6.6
Image	1.0	7.0	10.7	17.6	32.0
Audio	1.0	1.0	6.8	6.8	12.0
Video	1.0	20.0	27.0	60.0	60.0
Compressed	2.2	2.9	4.6	4.7	6.6

Source: Authors' own elaboration.

C.10 Flexible Disks (FD, Floppy Disks)

Figure C-15: Storage capacity provided by floppy disks in [MB], without compression (capacity hardware).



Source: Authors' own elaboration, based on various sources (see text).

C.10.1 Floppy Disks: quantity

The global production of Floppy Disks is reported for the years 1990 and 1991 by (Kader, 1992) and for 2002-2007 by (JRIA, 2002-2007). For the years between 1969-1989 and 1992-1998, the global figure is estimated in proportion to the growth of the number of Floppy Disk Drivers indicated by Disk/Trend Report (Porter, 1981b-1999b) for the years 1976 to 1998, assuming that the growth rate between such disks and their drives is similar. A linear estimation is made for the years 1998-2000. Given the fragility of floppy disks, we assume a useful lifetime of 2 years. (Kozierok, 2001; Dicks, 2004; Gantz, 2007).

Table C-57. Global quantity of floppy disks produced (units in millions).

1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
13	26	47	86	129	231	335	800	1,215	1,101	1,478
1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
1,856	2,243	2,452	2,845	3,052	3,767	4,201	4,812	5,279	5,907	6,766
1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	
8,020	6,344	4,668	2,992	1,316	1,250	987	858	764	592	

Source: Authors' own elaboration, based on (JRIA, 2002-2007; Kader, 1992; Porter, 1981b-1999b).

C.10.2 Floppy Disks: performance

To calculate the performance of floppy disks, we have worked with the average performances of random sample disc diameters (8", 5.25", <3.5" y HC) presented in the inventory of the Disk/Trend Report for the period of 1976-2002 (Porter, 1981b; 1982b; 1983b; 1984b; 1987b; 1989b; 1990b; 1991b; 1994b; 1999b) (

Table C-59). They are weighted by the distribution of floppy disc readers (Porter, 1999c), assuming that there is a similar relationship between the readers and the discs. The figures are interpolated linearly for the years 2003-2007.

Table C-58: Weighted capacity per floppy disk [MB].

1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
0.63	0.63	0.87	0.67	0.71	0.60	0.56	0.80	0.80	0,72	0,78	0,78
1988	**1989**	**1990**	**1991**	**1992**	**1993**	**1989**	**1994**	**1995**	**1996**	**1997**	**1998**
1.01	0.97	0.97	1.27	1.27	1.20	0.97	1.59	2.29	5,65	10,45	16,36
1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**			
18.96	22.93	26.80	30.31	33.82	37.33	40.84	44.35	47.86			

Source: Authors' own elaboration, based on (Porter, 1981b – 1999b).

Table C-59: Percentage of different diameters of floppy disk readers and average capacity.

Year	Percentage [%]				Average Capacity [MB]			
	8"	5.25"	<3.5"	HC	8"	5.25"	<3.5"	HC
1976	99.50	0.50	0.00	0.00	0.64	0.15		
1977	89.27	10.73	0.00	0.00	0.67	0.24		
1978	82.54	17.46	0.00	0.00	0.97	0.39		
1979	63.27	36.73	0.00	0.00	0.90	0.27		
1980	57.07	42.93	0.00	0.00	0.97	0.36	0.01	
1981	39.12	60.75	0.14	0.00	1.08	0.29	0.05	
1982	31.03	68.48	0.49	0.00	0.95	0.39	0.09	
1983	12.85	83.63	3.49	0.02	1.92	0.65	0.15	
1984	7.47	81.95	10.35	0.24	1.92	0.78	0.17	10.26
1985	5.24	75.26	18.93	0.58	1.92	0.58	0.41	18.20
1986	2.48	70.28	26.75	0.49	1.92	0.66	0.71	15.72
1987	1.49	55.75	42.37	0.38	1.92	0.86	1.07	13.23
1988	1.03	47.11	51.49	0.36	1.92	0.83	1.01	10.75
1989	0.64	38.71	60.37	0.28	1.92	0.83	1.48	16.08
1990	0.32	33.50	66.00	0.18	1.92	0.83	1.33	21.40
1991	0.16	31.28	68.35	0.21	1.92	0.83	1.12	21.00
1992	0.09	29.17	70.51	0.23	1.92	0.83	1.48	44.60
1993	0.04	22.26	77.39	0.32	1.92	0.83	1.48	58.45
1994	0.03	12.96	86.74	0.27	1.92	0.83	1.48	72.30
1995	0.03	6.44	92.54	1.00	1.92	0.83	1.48	86.15
1996	0.00	1.28	94.47	4.24	1.92	0.83	1.48	100.00
1997	0.00	0.17	92.26	7.57	1.92	0.83	1.48	120.00
1998	0.00	0.03	89.85	10.11	1.92	0.83	1.48	148.57
1999	0.00	0.02	86.49	13.50	1.92	0.83	1.48	131.00
2000	0.00	0.01	83.43	16.56	0.00	0.83	1.48	131.00
2001	0.00	0.00	80.46	19.54		0.00	1.48	131.00
2002	0.00	0.00	77.75	22.25			1.48	131.00
2003	0.00	0.00	*75.04*	*24.96*			1.48	131.00
2004	0.00	0.00	*72.33*	*27.67*			1.48	131.00
2005	0.00	0.00	*69.62*	*30.38*			1.48	131.00
2006	0.00	0.00	*66.90*	*33.10*			1.48	131.00
2007	0.00	0.00	*64.19*	*35.81*			1.48	131.00

Source: Authors' own elaboration, based on (Porter, 1981 – 1999).

C.10.3 Content compression

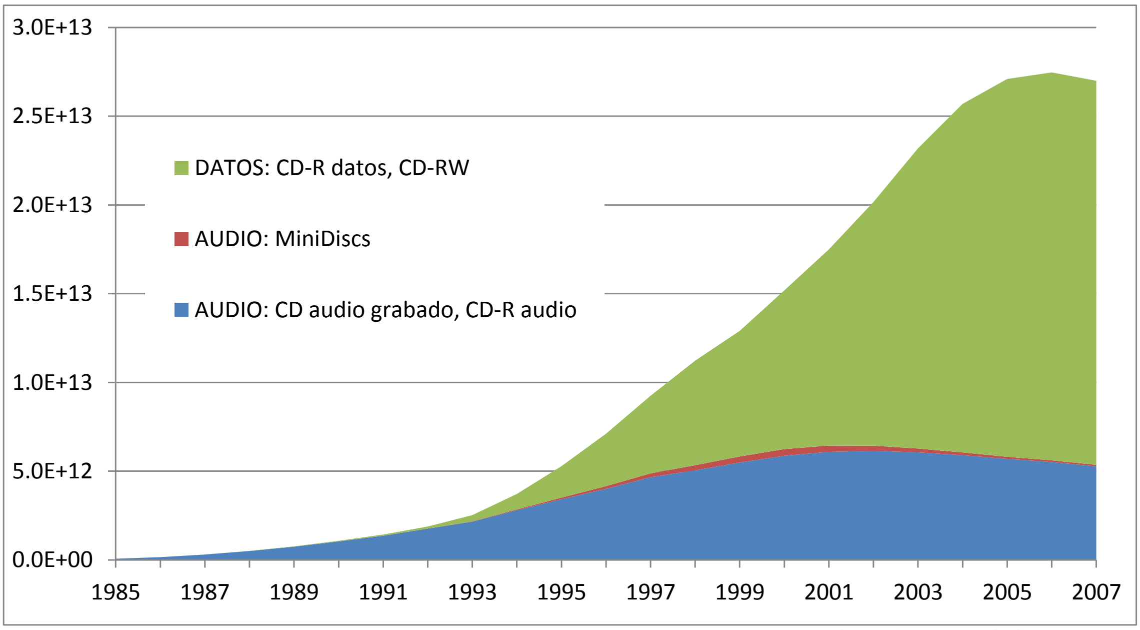
Regarding their respective compression rates, we assume that:

- Floppy disks of 8'', 5.25'' and <3.5" only store text. Considering their capacity, they could almost store a JPEG photograph, but not an audio or video file.

- High capacity disks (HC) can store images, text, and sound, but because of their small size, not video. For lack of a better statistics, it is assumed that these contents are distributed equitably.

C.11 CD (Compact Disc) y MiniDisc

Figure C-16: Total storage capacity of CDs and MiniDiscs in [MB], without compression (capacity hardware).



Source: Authors' own elaboration.

C.11.1 CD and MiniDisc: quantity

The number of units sold of CDs with recorded audio content was obtained using the information reported by (IFPI, 1995; 1998; 2001; 2002; 2003; 2004; 2005) (data for 70 countries, with estimates for missing countries based on the figures of neighboring countries of similar socio-economic standings, as in (Verna, 2007). There are also statistics on blank audio CDs and data CDs (audio CB-R; CB-R and data CB-RW, respectively), which are based on reports published by the *Japanese Recording-Media Industries Association* (Perenson, 2000; JRIA 2002-2007). These reports contain a global estimate, and individual estimates for Japan, North America, and Europe. For previous years, in the case of audio CB-Rs (1993-2001), the figures were extrapolated with the growth rate of audio CDs. To estimate the quantity of data CB-Rs and CB-RWs for the years 1985-2001, we look to the growth rate of

Optical Disc Drives, which is registered and estimated by Porter (1999b). Furthermore, some information is included on the number of Mini Discs (MDs) (JRIA, 2002-2007). For the previous period (1993-2001), estimates were made based on the growth rate of Optical Disc Drives (Porter, 1999).

Table C-60: Number of CDs in millions of units.

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Recorded audio CDs	31	81	154	258	376	503	671	817	1,076	1,183	1,789	1,885
Audio CB-Rs	-	-	-	-	-	0	0	0	0	0	1	9
MiniDiscs	-	-	-	-	-	-	-	-	-	101	201	302
Data CB-Rs	-	0	0	1	4	11	13	27	47	207	450	781
CB-RW	-	0	0	1	3	7	8	17	30	131	285	495
TOTAL	**31**	**82**	**155**	**260**	**383**	**521**	**693**	**860**	**1,154**	**1,623**	**2,726**	**3,470**
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Recorded Audio CDs	2,071	2,262	2,384	2,499	2,556	2,441	2,324	2,213	2,186	2,055	1,981	1,819
Audio CB-Rs	25	60	84	150	210	262	246	285	303	289	273	263
MiniDiscs	402	540	666	687	599	411	219	206	196	144	107	98
Data CB-Rs	1,040	1,396	1,722	1,777	3,270	4,500	6,120	6,940	7,683	7,144	7,015	6,771
CB-RW	659	885	1,091	1,126	982	674	359	327	303	290	243	201
TOTAL	**4,198**	**5,143**	**5,946**	**6,239**	**7,618**	**8,288**	**9,268**	**9,971**	**10,671**	**9,922**	**9,619**	**9,152**

Source: Authors' own elaboration, mainly based on (IFPI, 1995; 1998; 2001; 2002; 2003; 2004; 2005; Perenson, 2000; JRIA, 2002-2007).

In technical terms, some sources argue that CDs have a useful life of more than 20 years if properly kept (Byers, 2003), but experts insist that the real shelf life is between 2 and 5 years (Blau, 2006; The Independent, 2004). We will assume a lifetime of 4 years, a little less than that of hard-disks.

C.11.2 CD and MiniDisc: performance

CDs have a performance of 730 [MB], which corresponds to 700 [MiB]. For MiniDiscs, we consider a performance of 150 [MB], which makes 143,05 [MiB][24]. CDs with recorded music frequently do not use all of this potential. Considering an average of the most-sold recorded music CDs from the years 2000-2005, we consider 575 [MB] for music CDs recorded commercially.

[24] Contrary to other storage solutions, the CD industry usually presents the capacity of devices in binary units –meaning 2^10 = 1024 bits, which is referred to as kibit— and not in decimal units, which define that one kb = 1000 bits. This particularity comes from the closeness of the optical storage industry to the computer and software industry, which tends to count bits in binary units.

C.11.3 Content compression

Audio CDs store audio digitally, without using any compression algorithm. Other types of applications for CDs exist as well, which do use compression; for example, VCD (MPEG-1), SVCD (MPEG-2), Picture-CD (JPEG) and CD±R (various, depending on the user), but as only separate statistics are available for audio CDs (recorded and to be recorded) and data CDs (-R an -RW), it is assumed that:

- Audio CDs and MiniDiscs only store audio
- CD-Rs and CD-RWs can store any kind of content, distributing it the same way as do PCs (see Table C-49).

Table C-61 reports the compression factors considered for audio CDs and MiniDiscs. For data CD-R and CD-RWs, we can assume the same compression rates as PC (Table C-50).

Table C-61: Most common compression factors of CD and MiniDisc.

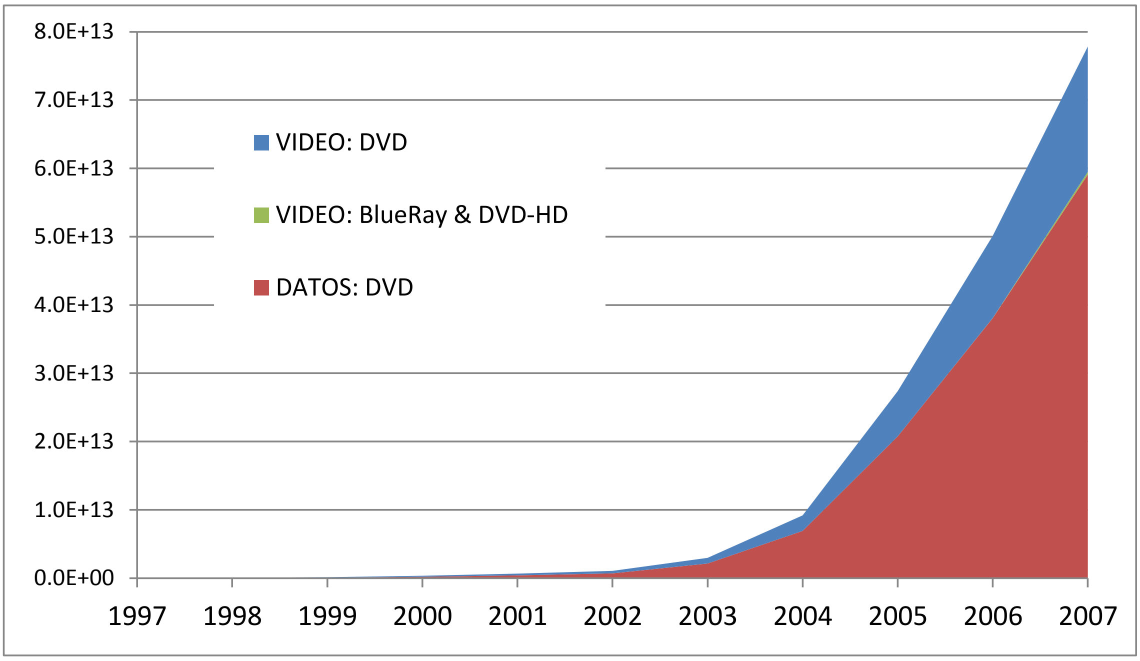
		1986	1993	2000	2007	Optimal
CD Audio[25]	Sound	1	1	1	1	9.6
MiniDisc	Sound	-	5 (ATRAC)	10 (ATRAC3)	15 (ATRAC3plus)	16

Source: Authors' own elaboration. Note: The family of compression algorithms with losses used in MiniDisc is known as ATRAC (*Adaptive Transform Acoustic Coding*); and in previous versions: ATRAC3 (1999), ATRAC3plus (2002) y ATRAC Advanced Lossless (2006) (Hoult, 2002; Sony Corp, 2010; "Adaptive transform acoustic coding", 2010).

[25] These compression factors are valid for recorded audio CDs and audio CB-Rs.

C.12 DVD, HB-DVD, DVD 8cm and Blu-Ray

Figure C-17: Storage capacity of DVDs and Blu-ray Disks, in [MB], without compression (capacity hardware).



Source: Authors' own elaboration.

C.12.1 DVD, B-DVD, DVD 8cm y Blu-Ray: performance

DVDs (*Digital Versatile Disc*) were commercialized in 1996 and have a capacity of 4.7 GB (4.38 GiB). MiniDVDs (8cm) have a capacity of 1.4 GB. For Blu-Ray Discs, we used a figure of 25 [GB] (23.28 [GiB]), while for HB-DVDs we assumed 15 [GB] (13.97 [GiB]).

C.12.2 DVD, HB-DVD, DVD 8cm y Blu-Ray: quantity

JRIA (2002-2007) reports on the write-once and the re-writable DVD for the period of time of 2002-2007. The amounts for 1996 and 2001 are based on the growth rate of DVD players and recorders during that time, drawn from (Morgan Stanley, 2006). The worldwide number of units was taken from JRIA (2006), following the same logic of CDs (Blau, 2006; The Independent, 2004). Blu-Ray is mainly used for videogames (i.e. Sony's Playstation 3). A 4 year shelf life is assumed.

Table C-62: Quantity of DVD, DVB-HD, Blu-Ray in millions.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Video: DVD	0.6	2.7	10.3	17.9	23.3	26	109	325	943	1,165	1,431
Datas: DVD	0.6	3.1	11.2	27.5	44.6	65	318	1,044	2,989	3,750	4,791

Datas: DVD 8cm									22	43	74
Datas: DVB-HD										0.5	5
Datas: Blu-Ray										1	12
TOTAL	**1.2**	**5.8**	**21.5**	**45.5**	**68.0**	**91**	**427**	**1,369**	**3,954**	**4,959**	**6,313**

Source: Authors' own elaboration, based on various sources (see text).

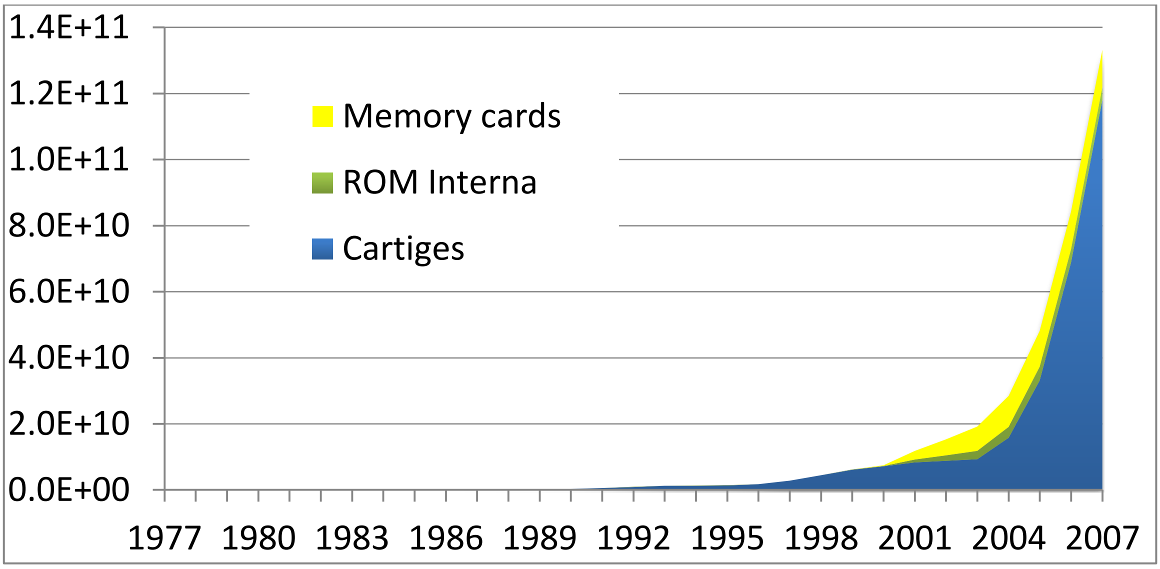
C.12.3 Content compression

Given that we lack statistics which indicate what percentage of DVD-Rs and DVD-RWs are used exclusively in video and which may serve for all types of data, we make an estimation based on the content of their analog equivalents. Since we know that 96.5% of the compressed content of VHS and BetaMax is dedicated to video and the rest to audio, we assume the same distribution for DVD. As for DVD video content, we use the compression method of MPEG-2 with a compression rate of 41.1:1 (for 2000 and 2007) and for the optimum level we will assume MPEG-4, with a compression factor of 60. In audio we suppose factors of 5.36 for 2000 and 2007 (excellent MP3 quality) and 9.6 for optimal compression (excellent MPEG-4 quality). For all types of data on DVDs, we assume the same content as for PCs (Table C-49), as well as the same compression rate (Table C-50). As for Blu-Ray discs and HB-DVDs that are not videogames, we assume that the complete number sold are video "originals" and therefore, the compression algorithm that is used is MPEG-4 AVC for video, with a compression rate of 12.6:1, which is also the optimal rate at this level of quality. Audio compression factors are assumed at 5.36 for 2000 and 2007 (excellent MP3 quality), and 9.6 for optimal compression (excellent MPEG-4 quality).

C.13 Video-Game Consoles

The storage technology used by video-game consoles considered is broken up into two groups: those that store only games (mainly cartridges in this section, given that optical devices are already included in the respective sections on CD and DVD), and those that store another type of information directly linked to the console (mainly ROM memories and proprietary external memories or memory cards, since hard disks and generic memory cards are already counted in the respective sections).

Figure C-18: Video game storage capacity that has not been included in hard-discs and optical device sections (CD and DVD), without compression (capacity hardware).



Source: Authors' own elaboration.

C.13.1 Videogame software: performance

Table C-63 presents the different consoles included in the study with their respective storage technologies as well as their associated storage capacity. Modern day consoles support more than just one type of storage technology, such as CB-ROM, DVB-ROM, BB-ROM, and proprietary formats (like Nintendo).

Table C-63: Storage Capacity. Video-game software.

Make	Platform	Technology	Capacity
Nintendo	Wii	Wii Optical Disc	4.7 GB
Sony	PlayStation 3	DVD & Blu-Ray-ROM	4.7 GB
Microsoft	Xbox 360	DVD & HB-DVD	4.7 GB
Nintendo	Nintendo DS	Nintendo DS Game Card	256 MB
Sony	PlayStation Portable	UMD™	1.8 GB
Nokia	N-Gage	MMC	1 GB
Nintendo	Game Boy Advance	Flash Cartridge	32 MB
Microsoft	Xbox	DVB-ROM	4.7 GB
Nintendo	GameCube	GameCube Disc	1.4 GB
Sony	PlayStation 2	DVB-ROM	4.7 GB
Sega	Dreamcast	GB-ROM	1.4 GB
SNK	Neo Geo Pocket and Neo Geo Pocket Color	Cartridge	4 MB
Nintendo	Nintendo 64	Cartridge	32 MB
Sega	Nomad	Cartridge	*4 MB*
Sony	PlayStation	CB-ROM	730 MB
Sega	Saturn	CB-ROM	730 MB
Panasonic	3DO Interactive Multiplayer	CB-ROM	730 MB
Sega	Mega-CD	Sega CD	730 MB
Nintendo	Super Nintendo Entertainment System	Cartridge	4 MB
Sega	Game Gear	Cartridge	*64 KB*
NEC	TurboExpress	HuCard	512 KB

Nintendo	Game Boy and Game Boy Color[2]	Cartridge	64 KB
Sega	Mega Drive/Genesis	Cartridge	64 KB
NEC	TurboGrafx-16	HuCards	2.5 MB
Sega	Master System	Cartridge	512 KB
Nintendo	Nintendo Entertainment System	Cartridge	512 KB
Coleco	ColecoVision	Cartridge	24 KB
Mattel	Intellivision	Cartridge	16 KB
Atari	Atari 2600	Cartridge	4 KB

Sources: Authors own elaboration, based on (“Console”, 2010; “Console index”, 2010; “The gaming console…”, 2010; “Video game console”, 2010).

C.13.2 Consoles: performance

For reasons of completeness, the table shows the storage capacity of a hard drive, an internal ROM memory drive, and external memory drive for each one of the systems studied. Some of the consoles, marked by an asterisk(*), use the same memory card as other equipment. (SD, memory stick, Compact flash, SmartMedia, MMC, xD), which are included in the worldwide total reported in the respective section on Memory Cards. However, in other cases, companies have developed their own memory card formats which were sold separately. They are considered below.

Table C-64: Storage performance of video game consoles.

Make	Platform	HDD	Internal ROM Memory	External Memory
Nintendo	Wii	No	512 MB	*
Sony	PlayStation 3	60 GB	No	*
Microsoft	Xbox 360	60 GB	No	256 MB
Nintendo	Nintendo DS	No	256 KB	*
Sony	PlayStation Portable	No	32.7 MB	*
Nokia	N-Gage	No	3.4 MB	*
Nintendo	Game Boy Advance	No	32 MB	64 MB
Microsoft	Xbox	8 GB	No	8 MB
Nintendo	GameCube	No	40 MB	2 MB
Sony	PlayStation 2	No	4.2 MB	8 MB
Sega	Dreamcast	No	128 KB	128 KB
SNK	Neo Geo Pocket and Neo Geo Pocket Color	No	8 KB	No
Nintendo	Nintendo 64	No	*64 KB*	256 KB
Sega	Nomad	No	2.5 KB	8 MB
Sony	PlayStation	No	64 KB	128 KB
Sega	Saturn	No	64 KB	256 KB
Panasonic	3DO Interactive Multiplayer	No	1 MB	No
Sega	Mega-CD	No	133 KB	125 KB
Nintendo	Super Nintendo Entertainment System	No	*48 KB*	No
Sega	Game Gear	No	*2.5 KB*	No
NEC	TurboExpress	No	*4 KB*	No
Nintendo	Game Boy and Game Boy Color[2]	No	32 KB	No
Sega	Mega Drive/Genesis	No	512 KB	No
NEC	TurboGrafx-16	No	4 KB	No
Sega	Master System	No	128 KB	No
Nintendo	Nintendo Entertainment System	No	48 KB	No

Coleco	ColecoVision	No	No	No
Mattel	Intellivision	No	7.2 KB	No
Atari	Atari 2600	No	No	No

Sources: Authors' own elaboration, based on ("Console", 2010; "Console index", 2010; "Consoles review", 2010; Saunders, 2004; "The gaming console…", 2010; "Video game console", 2010; Ziegler, 2010)

C.13.3 Videogame software: quantity

To find the total number of gaming units, we multiply the number of consoles sold per year (see Table D-11 in Appendix D) by the *tie ratios* of the consoles (the number of cartridges) which are portable (handheld) and those that are not (as in Nintendo, 2010; SCEI, 2010a, 2010b, 2010c, 2010d; PVC Forum, 2005; 2006; Polsson, 2008). A shelf life of 5 years is assumed (Gantz, et al., 2007). It is important to take note that the total number of optical devices which store video games are reported in write-once CD and DVD in the section CDs and DVDs.

Table C-65: Tie Ratios, number of games per console.

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Cartridge non-portable	3,3	3,3	3,3	3,3	3,3	3,7	4,0	5,0	3,8	4,9	5,5

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Cartridge non-portable	5,8	6,0	5,6	5,9	6,0	5,6	6,2	5,1	5,3	4,7	4,1
Cartridge - portable	-	4,8	4,3	4,3	4,3	4,3	4,3	4,3	4,3	4,8	4,1

	1999	2000	2001	2002	2003	2004	2005	2006	2007
Cartridge non-portable	4,7	4,8	5,8	5,8	-	-	-	-	-
Cartridge portable	5,2	4,4	1,8	2,3	-	-	-	-	-
Flash Cartridge portable	-	2,6	2,8	3,8	4,3	3,7	5,6	5,8	4,8

Source: Authors' own elaboration based on (Nintendo, 2010; SCEI, 2010; PVC Forum 2010; Polsson, 2008).

C.13.4 Consoles: quantity

Just as we presented in Table C-64, video game consoles have only a hard drive or a ROM memory (Coughlin et al., 2004); in the case of memory cards, we can assume that every console sold (Table D-11 in Appendix D) has one of them (Business Wire, 1995). A shelf life of 5 years can be assumed (Gantz, et al., 2007). Regarding hard disks, the total used for the consoles can be found in the section on disk drives.

C.13.5 Content compression

There are five different types of storage devices used by consoles. Since no information is available on how different types of information are distributed on them, we can presume that the device contains all content types. These are distributed out equally on the PC (see Table C-49). If the content is less diverse, the storage capacity will be divided equally (see Table C-66). Finally, for compression factors used (Table C-56) the same rate as for digital tapes is assumed.

Table C-66: Assumptions about the distribution of content storage devices used by video game consoles.

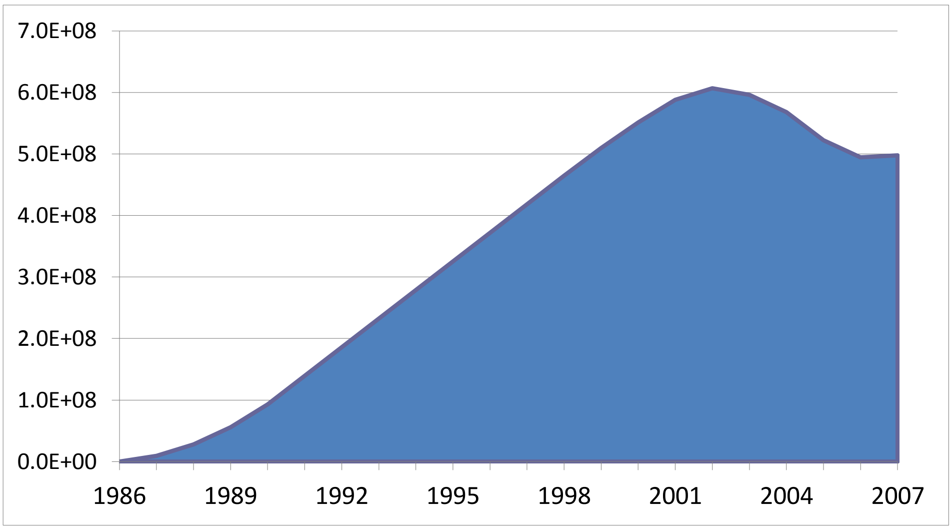
	1986	1993	2000	2007
HDD	-	-	-	All equals to PC
Memory Card	Text	Text	Text + Imagen	Text + Imagen
ROM- Internal	Text	Text	Text	Text
Cartridge	Text + Image + Sound	Text + Image + Sound	Same as PC	Same as PC
Optical	-	Same as PC	Same as PC	Same as PC

Source: Authors' own elaboration.

C.14 Chip Card

Chip Cards are used for identification purposes, as in credit cards, consumer aspects, mobile phone SIM cards and in the encryption of personal information. Use of plastic cards with identification information dates back to the early 1950s, when Diners Club began to give out magnetic cards for commercial transactions (Petri, 1999). For lack of information on the subject we only considered cards with integrated circuits that operated inside the card and whose use began in 1986 (History of Smart Cards, 2010).

Figure C-19: ***Chipcard storage capacity in*****, MB, without compression (capacity hardware).**



Source: Authors' own elaboration.

C.14.1 Chip cards: performance

The average capacity of chip cards manufactured yearly is an average of the performance of different cards weighted by their importance in each area of use (Table C-67).

Table C-67: Percentage distribution of chip card applications and their weighted performance

	Performance [KB] (2)	1986-1998 % (1)	1999 % (2)	2000 % (2)	2001 % (2)	2002 % (2)	2003 % (2)	2004 % (2)	2005 % (2)	2006 % (2)	2007 % (2)
Telecom	128	77,2	77,9	86,7	82,2	77,3	77,4	76,1	75,0	70,4	43,6
Healthcare	128	8,6	4,0	2,3	1,8	3,5	3,2	2,8	3,2	9,5	29,7
Others	128	3,7	5,4	2,1	1,7	2,0	1,6	1,9	2,2	1,5	7,9
Transport	120	1,9	3,0	0,8	2,0	4,2	3,3	3,2	3,5	4,5	15,8
Banking	4	4,9	7,6	6,9	8,1	*	*	*	*	*	*
Pay TV/IT	4	2,5	2,1	1,2	1,4	2,0	1,8	2,4	2,1	1,8	-
Royalty	4	1,2	**	**	2,7	11,1	12,6	13,6	13,9	12,3	3,0
Weighted performance in KB		117.2	115.7	117.9	112.6	111.5	109.8	107.9	107.8	110.2	123.0

Sources: (1) Choi & Whinston, 1998; (2) EuroSmart, 2004-2008; Note: *Royalty is considered together with Banking ** Banking is considered together with Royalty.

C.14.2 Chip cards: quantity

The number of chip card units is reported for the years 1986 and 1999-2006 by (Arnaud 1995; Bialick, 2001; Choi & Whinston, 1998; Cardlogix, 2001; EuroSmart 2004; 2005; 2006; 2007; 2008). For the remaining years (1987-1998) a linear growth rate is applied. A shelf life of five years can be assumed. (Cheng, 2000; Hearst Sem. App., 2004)).

Table C-68: Quantity of Chip Cards (thousands).

1986	1987	1988	1989	1990	1991	1992	1993
64	*79,367*	*158,670*	*237,972*	*317,275*	*396,578*	*475,881*	*555,183*
1994	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
634,486	*713,789*	*793,092*	*872,394*	*951,697*	1,031,000	1,062,000	1,152,000
2002	**2003**	**2004**	**2005**	**2006**	**2007**		
1,085,000	919,000	845,000	738,000	925,000	1,010,000		

Sources: Authors' own elaboration, based on various sources, Arnaud 1995; Bialick, 2001; Choi & Whinston, 1998; Cardlogix, 2001; EuroSmart 2004-2008; Larduinat, 2008).

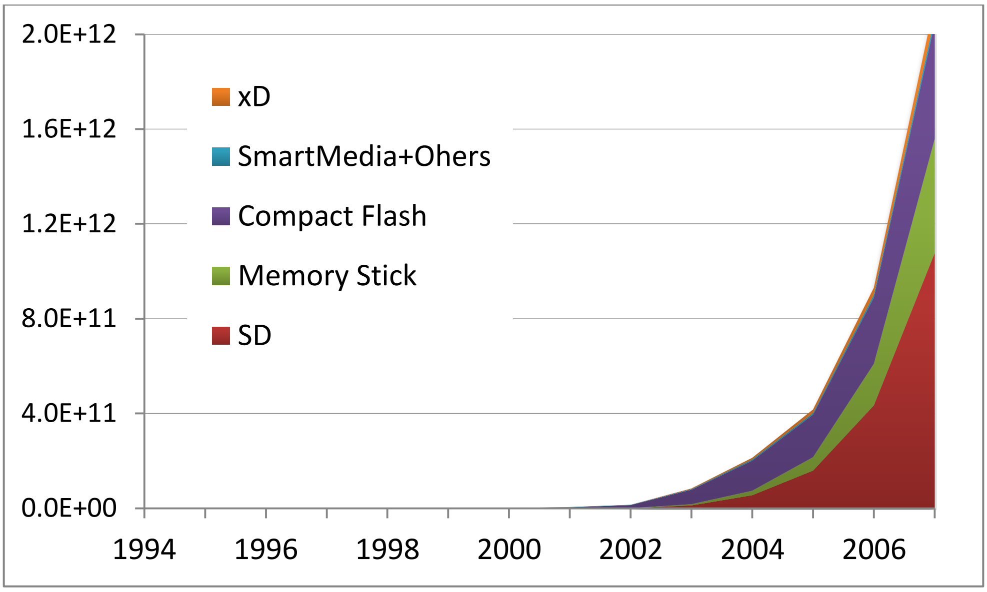
C.14.3 Content compression

As the information which is stored is only text, the same rates are assumed as those for text compression on hard disks (Table C-50).

C.15 Memory Cards

Memory cards are used in many electronic devices, including digital cameras, mobile phones, MP3 players, digital picture frames, and video game consoles. The formats considered in this study are as follows (with year of commercialization): Compact Flash (1994); SmartMedia (1995); Multimedia Card (MMC) (1997); Memory Stick (1998); Security Digital (SD) y MicroSD (1999); xD (2002).

Figure C-20: Cumulative storage capacity provided by flash memory cards, in [MB], without compression (capacity hardware).



Source: Authors' own elaboration.

C.15.1 Memory Cards: quantity

To calculate the world wide number of units, we combine the figures for the total number of Memory Cards (which show six formats already included) reported by different sources (Hetzler, 2009; Rihey CO, 2010; "Storage: 53 removable…", 1998; ZDNet, 2003) and the number of memory sticks (a special format developed by Sony (Business Wire, 2001; Hissink, 2005; JCN Newswire, 2003; SanDisk, 2006; Sony Corp., 2000). The estimated worldwide total of units of SD, Compact Flash, SmartMedia y MMC, and xD is based upon the percentage of each format of all memory cards sold in Japan

(JRIA, 2002-2006; 2007), weighting these percentages with the global total of memory cards.

Table C-69: Memory Card manufactured worldwide.

Nº units worldwide [millions]						
Year	SD	Memory Stick	Compact Flash	SmartMedia + MMC	xD	Total
1994	0.0	0.0	0.8	0.0	0.0	*0.8*
1995	0.0	0.0	0.9	0.6	0.0	*1.5*
1996	0.0	0.0	1.5	1.0	0.0	*2.6*
1997	0.0	0.0	2.7	1.8	0.0	4.5
1998	0.0	*1.0*	3.2	3.7	0.0	7.9
1999	0.2	3.0	4.3	5.2	0.0	*12.7*
2000	0.3	8.0	5.5	6.6	0.0	*20.4*
2001	0.5	10.4	9.9	12.0	0.0	*32.8*
2002	9.2	*13.5*	17.3	10.8	1.9	52.7
2003	76.1	20.3	52.9	19.9	30.9	200.0
2004	140.5	*34.5*	42.8	16.4	35.2	270.0
2005	207.4	58.6	28.4	9.9	36.2	*340.6*
2006	278.9	99.6	34.5	12.1	44.9	470.0
2007	*362.5*	*1144.7*	*39.7*	*13.9*	*51.7*	*541.0*

Sources: Hetzler, 2009; Rihey CO, 2010; "Storage: 53 removable…", 1998; ZDNet, 2003; Business Wire, 2001; Hissink, 2005; JCN Newswire, 2003; SanDisk, 2006; Sony Corp., 2000; (JRIA, 2002-2006); Cursive: Authors' own estimates.

With proper care, memory cards can last up to 10 years (Kingston, 2005; "Memory card reliability", 2010; SanDisk, 2003 and expert forums), but the years under warranty that the manufactures offer vary between 5 and 10 years. To be consistent with other digital equipment, we will suppose a shelf life of 5 years.

C.15.2 Memory Cards: performance

We used 77 reference models (Memory Stick: 12 models, SD: 11 models; xD: 8 models; CF: 32 models and SmartMedia/MMC/Others: 15 models) (Business Wire, 1997, 1998b, 1998c, 1998d; Fujifilm, 2003; Haren, 2007; Kingston, 2001, 2004; Mander, 2010; Olympus, 1999, 2002a, 2002b, 2006; Pretec, 1999a, 1999b, 2001, 2002, 2003, 2004, 2005, 2006a, 206b, 2006c, 2007; SanDisk, 2000a, 2000b, 2001a, 2001b, 2001c, 2001d, 2002, 2003a, 2003b, 2003c, 2003d, 2003e, 2004a, 2004b, 2004c, 2005;Samsung, 2007; Schoenherr, 2004; Silicon Storage Technology (SST), 1999; Sony, 2000, 2007; Toshiba, 1991, 1999, 2000, 2007). Considering that there is more than one capacity per format, the estimation was based on the format in Japan in 2007, we make an estimation based on the distribution per capacity in Japan in 2007, which consists of: 8.8% low performance; 23.2% medium to low performance; 25% average performance; 38% medium-high; and 5% High performance (JRIA, 2007). The result of this estimate is shown in Table C-70 and is in agreement with the independent estimates by Coughlin Associates (2008) for 2006.

Table C-70: Performance by unit of Memory Card formats

Estimated Performance by Unit [MB]					
Year	SD	Memory Stick	Compact Flash	SmartMedia + MMC	xD
1994	0.0	0	5.5	0	0
1995	0.0	0	5.9	0.6	0
1996	0.0	0	7.7	2.0	0
1997	0.0	0	8.7	2.9	0
1998	0.0	5.7	38.7	10.7	0
1999	8.0	19.6	72.1	19.4	0
2000	31.5	21.6	137.9	22.5	0
2001	43.1	24.4	222.2	30.8	0
2002	85.9	43.0	479.7	38.8	32.2
2003	240.1	226.0	939.2	60.7	92.7
2004	379.8	371.3	1 552.9	147.7	123.4
2005	890.0	650.0	1 867.9	289.2	188.7
2006	1 297.0	1 196.3	2 927.1	510.8	334.6
2007	2 396.6	2 367.8	4 856.0	818.5	600.4

Source: Author's own elaboration based on ((Business Wire, 1997, 1998b, 1998c, 1998d; Fujifilm, 2003; Haren, 2007; Kingston, 2001, 2004; Mander, 2010; Olympus, 1999, 2002a, 2002b, 2006; Pretec, 1999a, 1999b, 2001, 2002, 2003, 2004, 2005, 2006a, 206b, 2006c, 2007; SanDisk, 2000a, 2000b, 2001a, 2001b, 2001c, 2001d, 2002, 2003a, 2003b, 2003c, 2003d, 2003e, 2004a, 2004b, 2004c, 2005;Samsung, 2007; Schoenherr, 2004; Silicon Storage Technology (SST), 1999; Sony, 2000, 2007; Toshiba, 1991, 1999, 2000, 2007; JRIA, 2007).

C.15.3 Content compression

Memory cards are used for storage purposes in many different kinds of devices, such as mobile phones, PDAs, digital cameras (video and photography), digital media players, handheld computers, netbooks, GPS systems, video games, navigation devices, and more. Memory cards store many kinds of content, with the exception of xD memory cards, which are used mainly in digital cameras that store only images. Given that there is scarce information regarding content distribution, we assume that it is distributed in the same fashion as PCs for the years 2000 and 2007 (Table C-49).

Regarding compression factors, the same compression factors are used in PCs as for all cards (Table C-50) except for image cards. For these, given that after reviewing the technical specifications of 20 different camera models produced in 2000, and 86 models from 2007 (Imaging Resource, 2010; Steve's Digicam, 2010), it was seen that in 2000 only three models supported the GIF format and none in 2007 (all use JPEG), high quality JPEG and color were selected. The next table shows the compression factor used.

Table C-71: Compression factors for still images

	2000	2007	Optimal

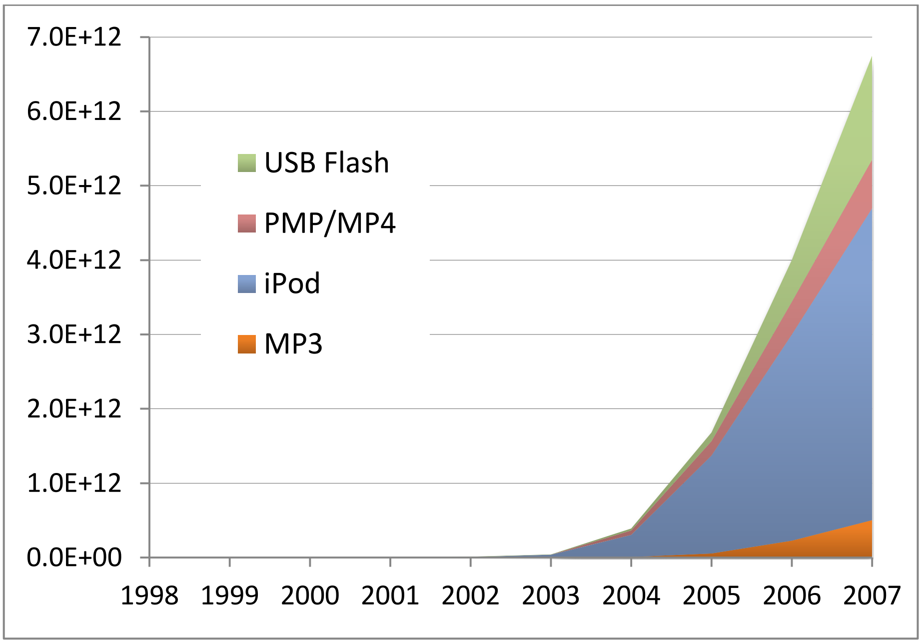
JPEG high quality	14.0	14.0	16.0

Source: Authors' own elaboration.

C.16 Portable Media Player and USB Flash

Portable media players and flash drives (USB flash) correspond to devices without connectivity that store information using semiconductors (just as in mobile phones and digital cameras). These are known as "flash" memories.

Figure C-21: Storage capacity provided by portable media players and USB flash, in MB, without compression (capacity hardware)



Source: Authors' own elaboration, based on various sources (see text).

C.16.1 iPod, MP3, MP4, USB flash: quantity

Morgan Stanley (2006) reports the number of MP3 players sold worldwide from 2003-2006. We know the number of sold units in 1998 (U.S Securities and Exchange Comision, 1998), and the increase in sales (in dollars) of Diamond Multimedia, the first company to commercially manufacture portable MP3 players. The sales are converted into units according to the average price of an MP3 player for that year (the most popular MP3 player in 1998 was the Rio PMP300, valuing US$200 in the U.S. market "Rio PMP300", 2010), and in this way we can estimate the total units sold for the period 1998-2002. IPods have a better performance than traditional MP3 players, and are reported by (Apple, 2002, 2003, 2004a, 2004b, 2004c, 2004d, 2005a, 2005b, 2005c, 2005d, 2006a, 2006b, 2006c, 2006d, 2008; Dairymple, 2003; Moren, 2008). MP4 players are reported by (Gilroy, 2007). Regarding USB flash pendrives, the number of units sold is reported by (Gilroy, 2007) for the years 2005-2006; and for 2007 by (Ethier, 2007; 2008). The assumed useful lifetime of these technologies is 3 years (the same as for mobile phones ("Continued growth…", 2000).

Table C-72: Worldwide number of manufactured portable devices (millions).

	MP4	MP3 (without iPod)	USB flash	iPod
1998	0	0.8	0	0
1999	0	3.7	0	0
2000	0	6.6	0.8	0
2001	0	9.4	2.0	0.1
2002	0.2	11.9	5.0	0.5
2003	0.5	14.2	13.0	1.1
2004	3.4	26.7	54.0	8.3
2005	5.5	96.7	93.5	32.0
2006	9.8	172.2	150.0	46.4
2007	10.8	186.2	171.0	52.7

Sources: (U.S Securities and Exchange Commission, 1998; Morgan Stanley, 2006: Apple, 2002, 2003, 2004a, 2004b, 2004c, 2004d, 2005a, 2005b, 2005c, 2005d, 2006a, 2006b, 2006c, 2006d, 2008; Gilroy , 2007; "Computing…", 2005; JC Derrick's Founders Blurb, 2005; "What is a USB…", 2007).

C.16.2 iPod, MP3, MP4, USB flash: performance

The performance of MP3 players is estimated based on 9 different models. For iPod, we focus on the storage capacity that comes from flash memories, without considering those that use 2.5' inches hard drives (*microdrives*); considering 24 different models ("iPod", 2010); for MP4 players we have based our estimations on 8 models (Amazon, 2010a); and for USB pendrives on 10 IBM models (Amazon, 2010b).

Table C-73: Performance of portable media players and USB flash drives in (MB)

	MP3 (without iPod)	USB flash	iPod	MP4
1998	32	0	0	0
1999	32	0	0	0
2000	64	8	0	0
2001	64	32	5000	0
2002	128	128	15000	5000
2003	128	160	23000	5000
2004	256	384	32000	17000
2005	512	1000	32000	25000
2006	1000	3000	32000	25000
2007	1488	5000	32000	25000

Sources: ("iPod", 2010; Amazon, 2010a; Amazon, 2010b)

C.16.3 Content compression

The stored contents in each of the devices considered in this section are in agreement with the storage of the device and its area of application (Table C-74).

Table C-74: Types of content stored on portable devices. [26]

	PMP/MP4	MP3 (without iPod)	USB flash	iPod
1993	-	-	-	-
2000	-	Audio	Text + Image	-
2007	Audio + Video	Audio	All	All

Source: Authors' own elaboration, based on various sources (see text).

For devices that only use two types of content, we assume that each occupies 50% of the total capacity. For devices that are used to store all kinds of contents, we can assume that they are spread out just as the contents in a PC (see Table C-49). With regard to compression rates, those used are shown in Table C-75.

Table C-75: Compression rate by content , per year.

	1993	2000	2007	Optimal
Texto	2.9	4.6	4.7	6.6
Image	7.0	8.5	11.3	16.0
Audio	-	6.8	6.8	12
Video	-	-	60.0	60.0

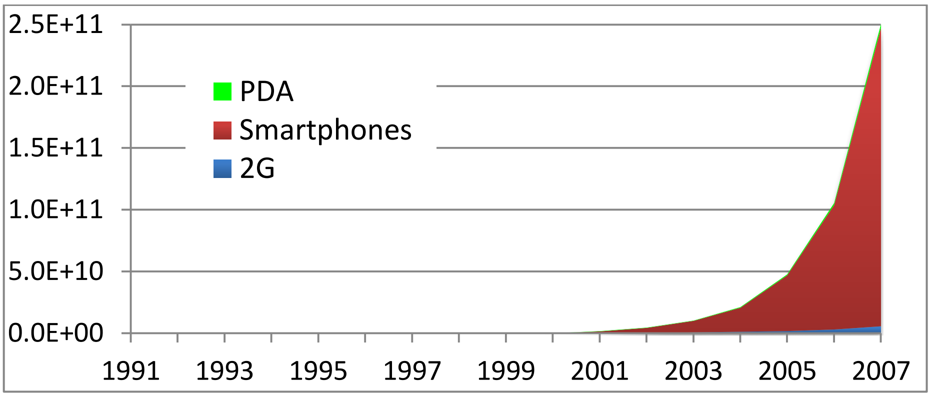
Source: Authors' own elaboration.

C.17 Mobile Telephones and PDA

Besides the use of memory cards, mobile phones have a memory space (Flash, mainly), used primarily for storing configuration codes, but also used for storing messages, sounds, and games. This type of internal memory has gained importance with PDA devices (personal digital assistant) and so-called Smartphones.

Figure C-22: Storage capacity of mobile telephones, in MB, without compression (capacity hardware).

[26]. "All" refers to: text, images, sound, video, and compressed files.



Source: Authors' own elaboration.

C.17.1 Mobile telephones: quantity

We have obtained the number of units of mobile phones using the figures indicated in (ITU, 2010). We apply the same distinction between users of 2G, 2.5G and 3G as identified in the media notes (see Appendix E, chapter E.7). By definition, mobile phones of 2.5G and 3G can be considered smartphones. The number of PDAs and hanB-held computers was obtained from (Britton & McGonegal, 2007; etForecast, 2006; Lenard & Pickford, 2005; Nomura Research Institute 2003) (Table C-76). These devices have a shelf life of 3 years ("Continued growth…", 2000).

Table C-76: Number of sold PDAs (millions)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998
#	0.01	0.02	0.03	0.05	0.10	0.17	0.39	0.92	2.12

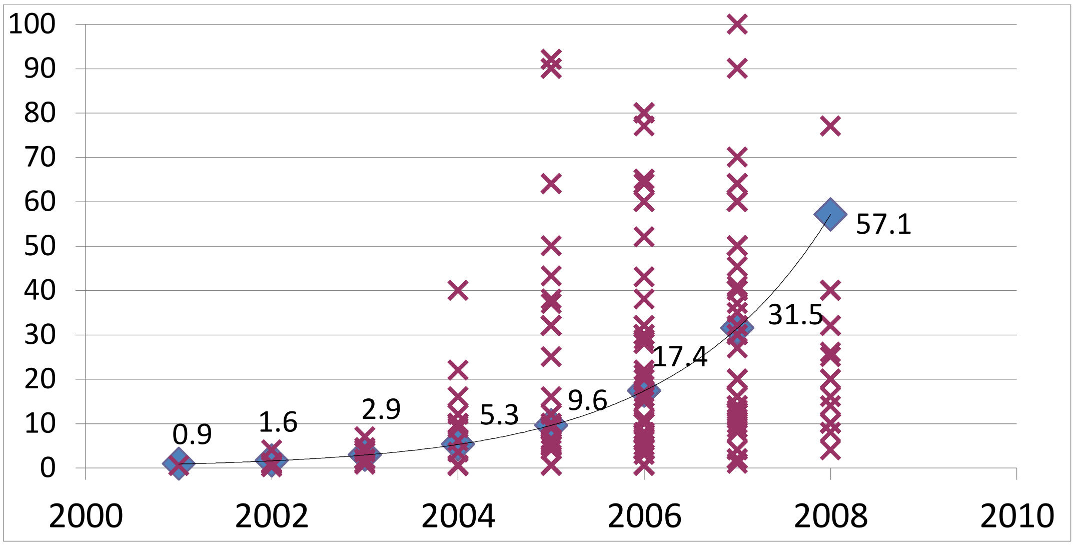
Year	1999	2000	2001	2002	2003	2004	2005	2006	2007
#	4.93	11.43	11.85	12.29	12.75	13.12	13.52	13.96	14.56

Source: (Britton & McGonegal, 2007; etForecast, 2006; Gartner, 2008; Jokkela, 1999; Lenard & Pickford, 2005; Nomura Research Institute 2003)

C.17.2 2G Mobile phones: performance

We have considered 234 models of 2G mobile phones from the four principal providers at the worldwide level: Nokia, Samsung, Motorola and Sony Ericsson (who dominate more than 75% of the global market) (Esato, 2010; "List of Motorola…", 2010; "List of Nokia..", 2010; "List of Sony Ericsson…", 2010). Based on this data, we estimate an exponential trend between 2000 and 2007. We estimate the previous years (1992-1999) on basis of the smallest performance found among the data collected: the Motorola V70 from 2002, which has 0.15 [MB].

Figure C-23: Cellular phone storage performance in [MB] (n=234) (hardware capacity)

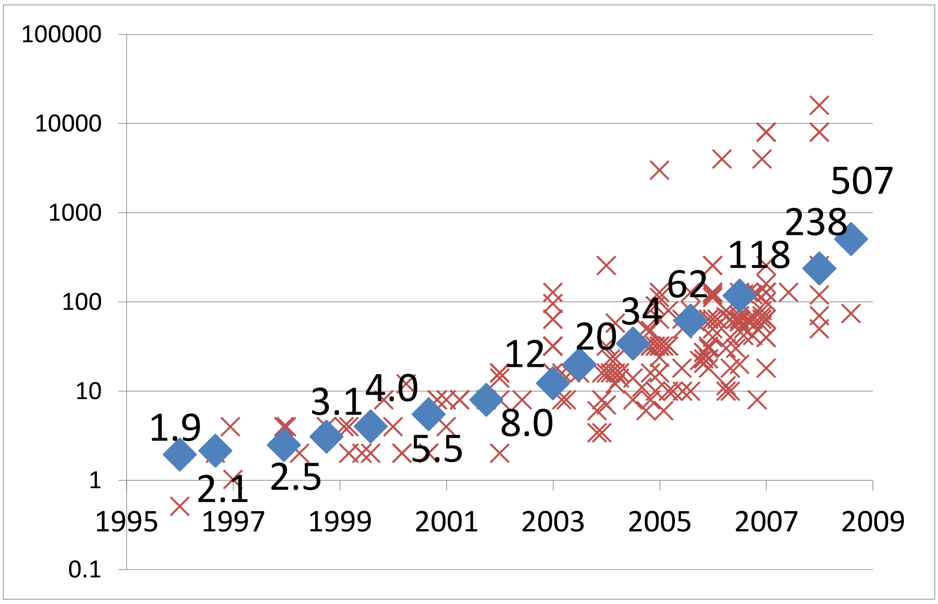


Sources: Authors' own estimation based on (Esato, 2010; "List of Motorola…", 2010; "List of Nokia..", 2010; "List of Sony Ericsson…", 2010). Note: The figure does not show the 22 cellular phones that have a storage capacity higher than 100MB.

C.17.3 Smartphones (2.5G y 3G) and PDA: performance

The results from the trend line are based on 197 models of PDAs and smartphones (PDA Database, 2010) (Table C-76).

Figure C-24: Storage performance of smartphones/PDA en [MB] (n=197) (hardware capacity)



Sources: Authors' own elaboration based on (PDA Database, 2010). Note: A performance of 1 MB is estimated for the years 1990-1996.

C.17.4 Content compression

It is assumed that the type of content stored depends on the ability of the device, and its area of application. Since there is no information to indicate what percentage the content would occupy, we can say that each is distributed uniformly (with the exception of smartphones, which store all types of content). Smartphones and servers (which handle mostly web content) distribute content in the same manner (Table C-77). With regard to compression rates, we use the same factors that were used for portable media players in Table C-75.

Table C-77: Types of content stored on cellular phones

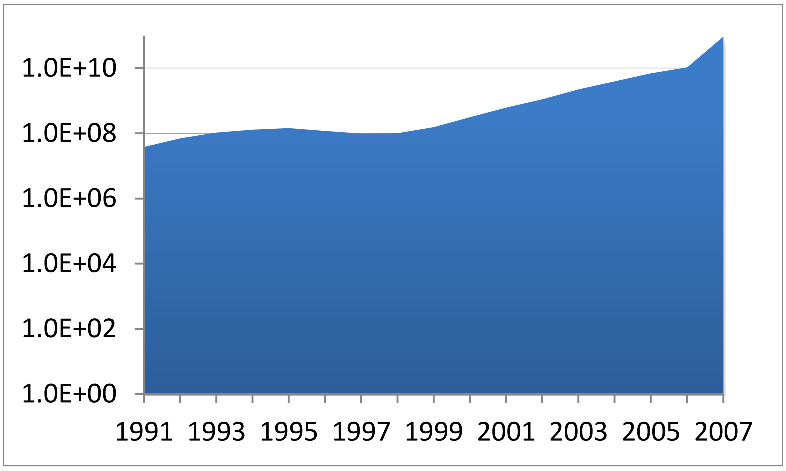
	1993	2000	2007
2G	Text	Text	Text + Photo
Smartphones/PDA	-	Text + Photo	All

Source: Authors' own elaboration

C.18 Digital cameras and camcorders

Like mobile phones, digital cameras and camcorders use memory cards, but also employ Flash memory technology for their internal memories[27].

Figure C-25: Storage capacity of digital camera internal memory in [MB], without compression (capacity hardware), semi-logarithmic plot.



Source: Authors' own elaboration.

[27] The first digital cameras used hard disks for storage, but the emergence of memory cards and the improvements in image compression made it possible to have smaller internal memories at lower costs.

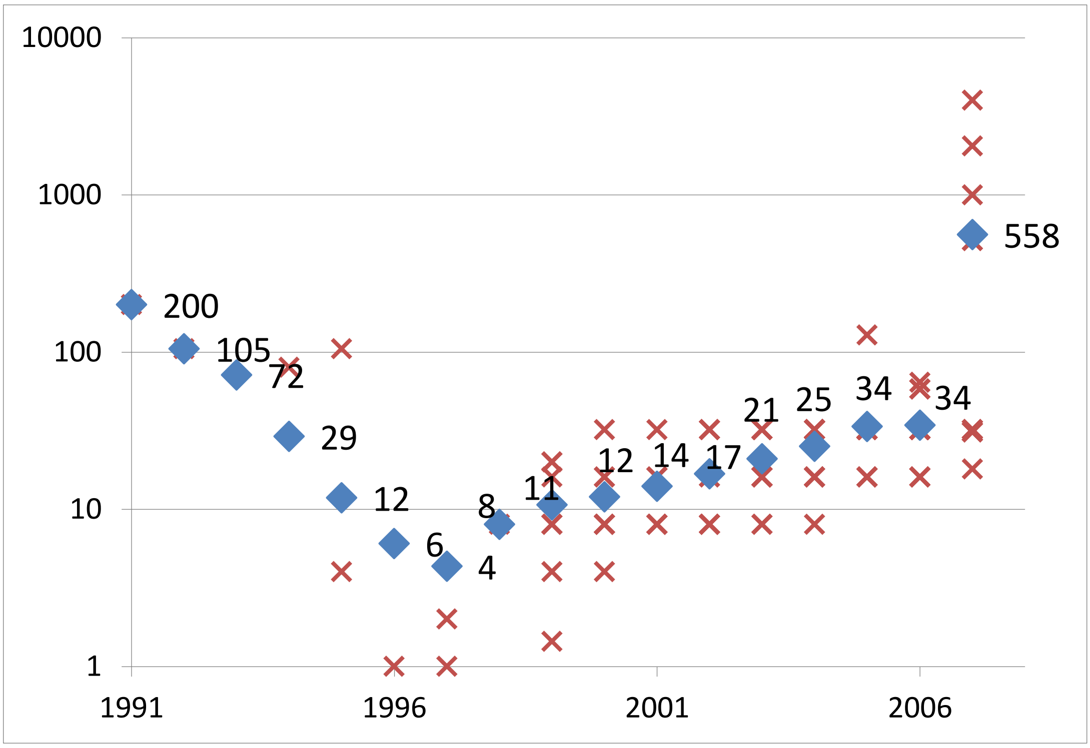
C.18.1 Digital cameras and camcorders: quantity

We report our estimate on the quantity of digital cameras and camcorders in the Appendix D, chapter D.8.2.3. Since a significant part of the camcorders does not count with any internal storage, we only consider half of the camcorders of each year to be relevant for storage.

C.18.2 Digital cameras: performance

The average performance is estimated based on 112 models from the years 1991-2006 by the three largest manufacturers of digital cameras in the world: Canon, Kodak, and Sony ("Cyber-shot", 2010; Digital Photography Review, 2010; Henshall, 1993, 1994, 1995; "List of Canon…", 2010; "List of products…", 2010). Storage capacity was extremely high during the first years, during which digital images were not yet compressed (the Kodak DCS100 of 1991 had more storage than the average PC hard-disk of those days). The subsequent fall (see **Error! Reference source not found.**) is based n the introduction of external memory during the second half of the 90s and the advancement of image compression algorithms.

Figure C-26: Storage performance of digital cameras (n=127) in [MB]



Source: Authors' own elaboration based on ("Cyber-shot", 2010; Digital Photography Review, 2010; Henshall, 1993, 1994, 1995; "List of Canon…", 2010; "List of products…", 2010; Digital Camcorders, 2010)

C.18.3 Content compression

While most digital cameras since the late 90s have included the necessary hardware to record and store video, for our studies we only consider the internal memory (whose storage capabilities are not great enough to store this type of content), where usually only high quality JPEG images are stored. This implies a compression rate that varies between 12:1 and 16:1, assuming that 100% of the photographs have been taken in color[28]) (Table C-78).

Table C-78: Compression factors by content per year

	1993	2000	2007	Optimal
High quality JPEG	14.0	14.0	14.0	16.0

Source: Authors' own elaboration

C.19 References

135 film. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/135_film

35 mm film. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/35_mm

35mm, medium format, and large format film photography, (n.d.). In *Guide to film photography*. Retrieved November 2010, from: http://www.guidetofilmphotography.com/photography-film-types.html

A35SS. (2010). *Audio cassette tape transfer to MP3 or audio CD*. Retrieved November 2010, from: http://www.affordable-35mm-slidB-scanning.com/audio-cassettB-tapB-MP3.html

Adaptive transform Acoustic Coding. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Adaptive_Transform_Acoustic_Coding

Amazon.com (n.d.). *MP3 players and accessories*. Retrieved November 2010, from: http://www.amazon.com/

[28] In agreement with what was reported in the previous chapter on Photography, in terms of the percentages of use of color and black and white film, the assumption is made that all photos have been taken in color. Although from 1991 to 1997, the use of black and white film represented between 5 and 9%; the downward trend in 2001 was carried forward to not exceed 3%, a negligible percentage.

Amazon.com (n.d.). *USB flash drives*. Retrieved November 2010, from: http://www.amazon.com/

Anderson, C. (2006). *The long tail*. London: Random House Business Books.

Answers.com. (n.d.). *US Industry Profile: Magnetic Recording Media*. Retrieved November 2010, from: http://www.answers.com/topic/magnetic-anB-optical-recording-media

Apple (2002, January 16). Apple reports first quarter profit of $38 Million. *Apple Press Release Library*. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2003, October 15).Apple Reports Fourth Quarter Results: Revenue Increases 19 percent. *Apple Press Release Library*. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2004, April 14).Apple Reports Second Quarter Results: Earning per Share Triples *Apple Press Release Library*. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2004, January 14). Apple Reports First Quarter Results: Revenue Increases 36 percent Year-over-Year. *Apple Press Release Library*. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2004, July 14).Apple Reports Third Quarter Results: Revenue Increases 30 percent and Profits Triples Year-over-Year. *Apple Press Release Library*. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2004).Apple Reports Forth Quarter Results: Revenue Increases 37 percent Year-over-Year, iPod Shipments Top 2 million. *Apple Press Release Library*. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2005, April 13). Apple Reports Second Quarter Results: Revenue Increases 70 percent and Net Income Increases over 500 percent Year-over-Year. *Apple Press Release Library*. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2005, January 12). Apple Reports First Quarter Results: Quarterly Revenue & Net Income Highest in Apple’s History. *Apple Press Release Library*. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2005, July 13).Apple Reports Third Quarter Results: Apple Delivers Record Revenue & Earnings. *Apple Press Release Library*. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2005, October 11).Apple Reports Fourth Quarter Results: Apple Concludes Best Quarter & Best Year in Compañny History. *Apple Press Release Library*. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2006, April 13).Apple Reports Second Quarter Results: Revenue Grows 34 percent percent Year-over-Year and Earnings 41 percent. *Apple Press Release Library*. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2006, January 18). Apple Reports First Quarter Results: Apple Delivers Record Revenue & Earnings. *Apple Press Release Library*. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2006, July 19).Apple Reports Third Quarter Results: Post Second Highest Quarterly Revenue and Earning in Company's History. *Apple Press Release Library*. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2006, October 18).Apple Reports Preliminary Fourth Quarter Results: Ships Record 1.61 Million Macs. *Apple Press Release Library*. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2008, January 22). Apple reports first quarter results: Best quarterly revenue & earnings in Apple History; Mac, iPod & iPhones sales break previous records. *Apple Press Release Library*. Retrieved November 2010, from: http://www.apple.com/pr/library/

Arnaud D. (1995, July). *Security status & issues & electronic commerce on the Internet*. Retrieved November 2010, from: http://denis.arnaud.free.fr/perso/reports.html

Arnold, J., Frater, M., & Pickering, M. (2007). *Digital television, technology and standards*. New Jersey: Wiley-Interscience.

Arnold, T. K. (1998, April 16). Industry alarmed over slowing video sales. *Los Angeles Times Article Collections*. Retrieved November 2010, from: http://articles.latimes.com/

Association of Cinema & Video Laboratories (ACVL). (n.d.). *Glossary of video terms: Telecine formats*. Retrieved November 2010, from: http://www.acvl.org/acvl_manual/video_terms6.html

Bair, R. (n.d.). *Reproduction from digital images (tips for best results)*. Retrieved November 2010, from: http://www.tssphoto.com/repro.html

Bansal, G. J. (2006). Digital radiography: A comparison with modern conventional imaging. *Postgraduate Medical Journal 82,* 425-428. Retrieved November 2010, from: DOI:10.1136/pgmj.2005.038448

Barrat, A. (2004). *Dolby Digital, DTS and DVD: A history*. Retrieved on November 2010, from the SpannerWorks Website: http://www.spannerworks.net/reference/10_1a.asp

Bear, J. H. (2008). *The DPI dilemma. Resolution basics for beginners*. Retrieved November 2010, from About.com Guide: http://desktoppub.about.com/od/resolution/a/resolutiondots.htm

Betacam. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Betacam

BetaMax PAL. (n.d.). BetaMax, the better format. Retrieved November 2010, from: http://www.palsite.com/format.html

Betamax. (n.d.). In *Encyclopedia PRO*. Retrieved November 2010, from: http://www.encyclopediapro.com/mw/Betamax

Bialick, B. (2001). *USB tokens: The reader-less Smart Card* [PowerPoint slides]. Spyrus, Inc. Retrieved November 2001, from Center for Applied Cryptographic Research, Canada: http://www.cacr.math.uwaterloo.ca/conferences/2001/isw-seventh/Bialick.ppt

Blakeley, B., & Spartiotis, K. (2006). Digital radiography for the inspection of small defects. *Insight 48*(2). Retrieved November 2010, from: http://www.twi.co.uk/content/spbbfeb2006.html

Blau, J. (2006, Jan 10). Do burned CDs have a short life span? *IDG News*. Retrieved November 2010, from PC World Website: http://www.pcworld.com/article/124312/do_burned_cds_have_a_short_life_span.html .

Bohn, R., & Short, J. (2009). *How much information? 2009 Report on American consumers*. Retrieved November 2010, from San Diego: Global Information Industry Center at the University of California: http://hmi.ucsd.edu/howmuchinfo_research_report_consum.php

Boorstin, E. S. (2004). *Music sales in the age of file sharing*. A. B. Thesis, Princeton University, NJ, United States. Retrieved November 2010, from: http://www.cs.princeton.edu/~felten/boorstin-thesis.pdf

Borretzen, I., Lysdshl, Kristin Bakke, O., & Hilde, M. (2007). Diagnostic radiology in Norway: Trends in examination frequency and collective effective dose. *Radiation Protection Dosimetry 124*(4) 339-347. Retrieved November 2010, from: http://rpd.oxfordjournals.org/

Box Office Mojo. (2010). *Yearly box office*. Retrieved November 2010, from: http://www.boxofficemojo.com/yearly/

Brasington, L. (2003). 25 Moments that mattered: Major events that have shaped the PC-platform plus some famous flops. Retrieved November 2010, from: http://www.leighb.com/pchist.htm

Britton, D., & McGonegal, S. (2007). The digital economy fact book (9th ed.). *The Progress and Freedom Foundation*. Retrieved November 2010, from: http://www.pff.org/issues-pubs/books/factbook_2007.pdf

Brown, K., Frey, F., & Jones, V. A. (1999). How long will it last? Life expectancy of information media. *ARMA International Conference* Cincinnati, Ohio. Retrieved November 2010, from Rutgers School of Communication and Information: http://www.scils.rutgers.edu/~lesk/spring06/lis556/lifB-expect.pdf

Business Wire. (1995). Sony PlayStation game console sales reach 300,000 units; more than 1 million pieces of software sold in six weeks since debut. Retrieved November 2010, from CBS Business Network (BNET): http://findarticles.com/

Business Wire (1997, February 19). *SanDisk announces that Canon selects SanDisk CompactFlash memory cards as the digital film in the new Canon PowerShot 350 digital camera*. Retrieved November 2010, from CBS Business Network (BNET): http://findarticles.com/

Business Wire (1998, February 11). *SanDisk introduces 30, 40 and 48 MB CompactFlash cards; 48 MB card industry's highest capacity CF card*. Retrieved November 2010, from The Free Library Website: http://www.thefreelibrary.com/

Business Wire (1998, July 27). Samsung Introduces Worl'd First 16 MB SmartMedia Card. Press Release: July 27, 1998. http://www.allbusiness.com/electronics/computer-equipment-computer/6849310-1.html

Business Wire (1998, October 28). *CF+ compliant cards from Pretec; World's first I/O cards in Type II package*. Retrieved November 2010, from AllBusiness.com: http://www.allbusiness.com/

Business Wire (2001, October 10*). Memory Stick media hits the road for the first time with Sony's in-car audio player*. Retrieved November 2010, from CBS Business Network (BNET): http://findarticles.com/

Bustamante, L. A. (2005). *Hablando de resolución: Aclaremos la confusion de terminus ¿ppi, dpi o lpi?* Retrieved May 2008, from the Virtual printing consulting website: http://www.vpcon.com/articulos/ppi.pdf

Byers, F. (2003). Information technology: Care and handling of CDs and DVDs —A guide for librarians and archivists. *National Institute of Standards and Technology (NIST) Special Publication 500-252*. Retrieved November 2010, from:

http://www.itl.nist.gov/iad/894.05/papers/CDandDVDCareandHandlingGuide.pdf

Cámaras de fotos desechables. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://es.wikipedia.org/wiki/Cámara_de_fotos_desechable

Cardlogix. (2001). Cardlogix facts and forecasts. *Cardlogix Press Room*. Retrieved May 2008, from: http://www.cardlogix.com/corporate_press_factoids.asp

Cheng, L. M. (2000). *Comments on Hong Kong Special Administration Region Identity Card* [LC Paper No. CD(2= 204/00-01(04)]. Hong Kong Legislative Council, 2000. Retrieved November 2010, from: http://www.legco.gov.hk/yr00-01/english/panels/se/papers/b204e04.pdf

Choi, S. Y., Whinston, A. (1998). *Smart Cards: Enabling smart dommerce in the digital age*. KPMG & Center for Research in Electronic Commerce (The University of Texas in Austin). Retrieved May 2008, from: http://cism.mccombs.utexas.edu/works/articles/smartcardswp.html

Clark, R. N. (2006). *Image detail (How much detail can you capture and scan?)*. Retrieved November 2010, from: http://www.clarkvision.com/imagedetail/scandetail/index.html

CMYK Color Model. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/CMYK_color_model

Digital Camcorders (2010). Retrieved November 2010, from CNET Reviews: http://reviews.cnet.com/digital-camcorders/

Compact cassette. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Compact_audio_cassette

CompuServe Incorporated. (1987). *GIF™: Graphics Interchange Format™. A standard defining a mechanism for the storage and transmission of raster-based graphics information*. Retrieved November 2010, from World Wide Web Consortium: http://www.w3.org/Graphics/GIF/spec-gif87.txt

Computing – USB Thumb Drives. (2005). Retrieved November 2010, from Google Answers: http://answers.google.com/answers/threadview?id=510517

Console index (2010). Retrieved November 2010, from the Videogame console library Website: http://www.videogameconsolelibrary.com/main-list-name.htm

Console. (n.d.). Retrieved November 2010, from PVC Website: http://www.pcvsconsole.com/features/consoles/

Consoles reviews. (n.d.). Retrieved November 2010, from CNET Reviews: http://reviews.cnet.com/video-gamB-consoles/

Continued growth in mobile phone sales. (2000, October 7). *Helsingin Sanomat*, Business & Finance – International Edition. Retrieved November 2010, from: http://www2.hs.fi/english/archive/

Coughlin, T. (2007). *2007 entertainment content creation and digital storage report*. Retrieved November 2010, from Coughlin Associates: http://www.tomcoughlin.com/techpapers.htm

Coughlin, T. (2008). *Storing your life. Consumer digital storage – Personal, shared, hierarchical and virtual*. Retrieved November 2010, from Coughlin Associates: http://www.tomcoughlin.com/techpapers.htm

Coughlin, T., Waid D., & Porter J. N. (2004). *The disk drive: 50 years of progress and technology innovation (the road to 2 billion drives).* Retrieved November 2010, from Coughlin Associates: http://www.tomcoughlin.com/techpapers.htm

Coughlin. (July 2009). Digital storage technology newsletter. *Coughlin Associates, XXII*(1). Retrieved November 2010, from Storage Networking Industry Association (SNIA): http://www.snia.org/

Creamer, D. (2006). *Understanding resolution and the meaning of DPI, PPI, SPI, and LPI*. Retrieved November 2010, from I.D.E.A.S. Publishing Consultant & Trainer: http://www.ideastraining.com/PDFs/UnderstandingResolution.pdf

Cusumano, M. A., Mylondadis, Y., & Rosenbloom, R. S. (1991). Strategic maneuvering and mass market dynamics: The triumph of VHS over Beta. *The MIT Japan Program* (Working Paper Series). Retrieved November 2010, from: http://hdl.handle.net/1721.1/17091

Cyber-shot. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Cyber-shot

Dairymple, Jim (2003). Apple/Analyst on the iTunes Music Store, iPod. *MacCentral*. Retrieved November 2010, from MacWorld News: http://www.macworld.com/news/2003/10/17/analysts/

Damjanovski, V. (2005). *CCTV, networking and digital technology* (2nd ed.). Oxford, UK/Massachusetts, US: Elsevier/Butterworth-Heineman.

DeBoer, C. (2005). Acura, Cadillac & Land Rover models feature DTS Surround. *Audioholics Online A/V magazine*. Retrieved November 2010, from:

http://www.audioholics.com/news/press-releases/2005-acura-cadillac-lanB-rover-models-featurB-dts-surround

Diaconescu, C., & Iacob, O. (2002). National Survey of Diagnostic X-Ray Examinations (2000). *The Journal of Preventive Medicine 10*(4), 3-11. Retrieved November 2010, from: http://www.jmpiasi.ro/

Dicks, C. (2004). *FAQ on Caring for Computer Hard Disks and Diskettes*. Retrieved November 2010, from Canadian Conservation Institute (CCI): http://www.preservation.gc.ca/info/faq_2_e.asp

Digital Photography Review. (n.d.). *Digital camera products review/preview*. Retrieved November 2010, from: http://www.dpreview.com/reviews/

Disposable camera. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Disposable_camera

Duke University. (2000). 1960's - 1980's. *The History of Recorded Music*. Retrieved November 2010, from Sociology Department, Duke University: http://www.soc.duke.edu/~s142tm01/history4.html

Dyro, J. F. (2004). *Clinical engineering handbook*. Amsterdam: Academic Press, Biomedical engineering series.

Eckard, R. (2001, November 5). Linear TapB-Open program ships one million Ultrium tapes in first 12 months of availability. *LTO Press Release Archive*. Retrieved November 2010, from: http://lto.org/News/pressarchive.html

Eckard, R. (2002, March 25). Linear TapB-Open program hits new milestone with 2 million tape cartridges shipped to date. *LTO Press Release Archive*. Retrieved November 2010, from: http://lto.org/News/pressarchive.html

Emergency Care Research Institute (ECRI). (2007). *Healthcare product comparison system: Radiographic units, chest*. Retrieved November 2010, from: https://www.ecri.org/Products/Documents/Radiographic%20Units%20Public%20Site.pdf

Esato. (n.d.). *Esato Phone Reviews*. Retrieved November 2010, from: http://www.esato.com/reviews/

eTForecasts. (2006). Worldwide PDA & smartphone forecast. *eTForecasts, Executive Summary*. Retrieved November 2010, from: http://www.etforecasts.com/products/ES_pdas2003.htm

Ethier, S. (2007, August). *Worldwide demand remains strong for MP3 and Portable Media Players*. In-Stat Report Summary. Retrieved November 2010, from: http://www.instat.com/

Ethier, S. (2008, December). The *worldwide PMP/MP3 player market: Shipment growth to slow considerably*. In-Stat Report Abstract. Retrieved November 2010, from: http://www.instat.com/

European Computer Manufacturers Association (ECMA) International. (June, 1990). *Standard ECMA-139: 3,81 mm Wide Magnetic Tape Cartridge for Information Interchange – Helical Scan Recording – DDS Format*. Retrieved November 2010, from: http://www.ecma-international.org/publications/files/ECMA-ST/Ecma-139.pdf

European Computer Manufacturers Association (ECMA) International. (December, 1990*). Standard ECMA-146: 3,81 mm Wide Magnetic Tape Cartridge for Information Interchange – Helical Scan Recording – DATA/DAT Format*. Retrieved November 2010, from: http://www.ecma-international.org/publications/files/ECMA-ST/Ecma-170.pdf

European Computer Manufacturers Association (ECMA) International. (June, 1992). *Standard ECMA-170: 3,81 mm Wide Magnetic Tape Cartridge for Information Interchange – Helical Scan Recording – DDS Format Using 60 m and 90 m Length Tapes*. Retrieved November 2010, from: http://www.ecma-international.org/publications/files/ECMA-ST/Ecma-146.pdf

European Computer Manufacturers Association (ECMA) International. (June, 1995). *Standard ECMA-198: 3,81 mm Wide Magnetic Tape Cartridge for Information Interchange – Helical Scan Recording – DDS-2 Format Using 120 m Length Tapes* (2nd ed.). Retrieved November 2010, from: http://www.ecma-international.org/publications/files/ECMA-ST/Ecma-198.pdf

European Computer Manufacturers Association (ECMA) International. (June, 1996). *Standard ECMA-236: 3,81 mm wide magnetic tape cartridge for information interchange – Helical scan recording – DDS-3 format using 125 m length tapes*. Retrieved November 2010, from: http://www.ecma-international.org/publications/files/ECMA-ST/Ecma-236.pdf

European Computer Manufacturers Association (ECMA) International. (June, 1999). *Standard ECMA-288: 3,81 mm Wide Magnetic Tape Cartridge for Information Interchange – Helical Scan Recording – DDS-4 Format*. Retrieved November 2010, from: http://www.ecma-international.org/publications/files/ECMA-ST/Ecma-288.pdf

Eurosmart. (2004). *Eurosmart Market Figures 2004 – 1999*. Retrieved November 2010, from:

http://www.eurosmart.com/images/doc/WorkingGroups/Mkt-technoWG/eurosmart-figures-archives.pdf

Eurosmart (2005). *Eurosmart Market Figures 2005*. Retrieved November 2010, from: http://www.eurosmart.com/index.php/publications/market-overview/65-figures-2005.html

Eurosmart (2006). *Eurosmart Market Figures 2006*. Retrieved November 2010, from: http://www.eurosmart.com/index.php/publications/market-overview/64-figures-2006.html

Eurosmart (2007). *Eurosmart Market Figures 2007*. Retrieved November 2010, from: http://www.eurosmart.com/index.php/publications/market-overview/63-figures-2007.html

Eurosmart (2008, November 4). *2008: The industry benefited from a sustained growth in its three main segments*. Retrieved August 2009, from CARTES and identification Website: http://www.cartes.com/ExposiumCms/cms_sites/SITE_464002/ressources464002/eurosmart_smart_cards_shipments_nov08_final2.pdf

Fidler, A., Likar, B., Pernus, F., & Skaleric, U. (2002). Comparative evaluation of JPEG and JPEG2000 compression in quantitative digital subtraction radiography. *Dentomaxillofacial Radiology, 31*(6), 379-384. Retrieved November 2010, from: doi:10.1038/sj.dmfr.4600724

Fisk University. (2003). *Digital Radiography and CZT Based Imaging System. VaNTH Program*. Retrieved May 2008, from: http://www.fisk.edu/~mguo/VanTH/Vanth_DR.pdf

Food and Agriculture Organization of United Nations (FAO). (2010). S*tatistical database ForesSTAT* [data file]. Retrieved November 2010, from http://faostat.fao.org/site/626/default.aspx

Franz, Don (personal communication, September 12, 2008). Photofinishing News, Inc: www.photo-news.com

FujiFilm (2003, May 27). *FujiFilm announce 512 MB xD picture card*. Retrieved November 2010, from DPReview Press Room: http://www.dpreview.com/

Gale Group, Inc. (2005). Magnetic and optical recording media (SIC 3695). *The Gale's Encyclopedia of American Industries*. Retrieved November 2010, from HighBeam Business Website: http://business.highbeam.com/industry-reports/equipment/magnetic-optical-recording-media

Gantz J., Reinsel D., Chute C., Schlichting W., McArthur J., Minton S. et al. (2007). IDC - The Expanding Digital Universe: A forecast of worldwide information growth through 2010. Retrieved November 2010, from: http://www.emc.com/utilities

Gartner Research (2008, July 22). *Trascend world's third largest USB Flash Drive manufacturer in 2007*. Retrieved November 2010, from Web Newswire: http://www.webnewswire.com/node/445059

GfkProphoto GmbH. (2002). *Photography and visual communications in Germany: Trends in the amateur market 2002*. Retrieved November 2010, from PhotoindustriB-Verband e.V.: http://www.photoindustriB-verband.de/artikel/Amateur-market-Developments-2002

GfkProphoto GmbH. (2003). *Amateur market: Developments in 2003*. Retrieved November 2010, from PhotoindustriB-Verband e.V.http://www.photoindustriB-verband.de/artikel/Amateur-market-Developments-in-2003

Gilroy, A. (2007, June 5). *iSuppli: Flash Memory wins 65% of PMP market*. Retrieved November 2010, from This Week In Consumer Electronics (TWICE) Website: http://www.twice.com/article/CA6449227.html

Government Printing Office (GPO). (1999). *Government Paper Specification Standards, February 1999 No. 11*. Retrieved November 2010, from http://www.gpo.gov/customers/vol11.htm

GreenPress Initiative. (2006). *Paper consumption statistics*. Retrieved November 2010, from Internet Archive: http://web.archive.org/web/*/http://www.greenpressinitiative.org/documents/Paper%20Stats1.doc

Haren, Allen (2007). *Flash memory timeline*. Retrieved May 2008, from http://allen.treklog.net/work/edc638/timeline.html

Hearst Semiconductor Applications. (2004). Smart Cards overview (new products). Retrieved May 2008, from: http://www.semiapps.com

Henshall, J. (1993, June). Kodak digital cameras: The Kodak DCS100 and DCS200. *The Photographer Magazine*, British Institute of Professional Photography. Retrieved November 2010, from: http://www.epi-centre.com/reports/9306cs.html

Henshall, J. (1994, August). Kodak DCS420 camera. *The Photographer Magazine*, British Institute of Professional Photography. Retrieved November 2010, from: http://www.epi-centre.com/reports/9408cs.html

Henshall, J. (1995, March). Kodak DCS460 digital camera. *The Photographer Magazine*, British Institute of Professional Photography. Retrieved November 2010, from: http://www.epi-centre.com/reports/9503cs.html

Hetzler, S. (2009, February). *The storage chasm: Implications for the future of HDD and solid state storage; an examination of the storage hierarchy from an economic point of view*. IBM Corp. Retrieved November 2010, from Chinese American Information Storage Society (CAISS) Website: http://www.caiss.org/docs/DinnerSeminar/TheStorageChasm20090205.pdf

Hewlett-Packard (HP). (July 2008). Hewlett-Packard Development Company. *HP Tape It! Tape Storage Newsletter for OEM Customers*. Retrieved May 2008, from http://www.sundds-lto.com/uploadLinks/HP%20Jul%2008%20Newsletter.pdf

High-Definition video. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from http://en.wikipedia.org/wiki/High-definition_video#Film_to_high-definition_transfer

Hissink, D. (2005, September 30). SanDisk memory stick micro. *Let's Go Digital Online Magazine*. Retrieved November 2010, from: http://www.letsgodigital.org/en/news/articles/story_4641.html

History of Smart Cards. (n.d.). CardWerk 1999-2009. Retrieved November 2010, from: http://www.cardwerk.com/smartcards/smartcard_history.aspx

Hoult, C. (2002, November 18). *A Comparison of the ATRAC and MPEG-1 Layer 3 Audio Compression Algorithms*. University of Southampton. Retrieved November 2010, from MiniDisc,org: http://www.minidisc.org/keep/atracmp3.pdf

Hughes, J. (2006, September 25). LTO Ultrium format maintains momentum with more than 1,500,000 tape drives and 50,000,000 cartridges shipped. *LTO Press Release Archive*. Retrieved November 2010, from: http://lto.org/News/pressarchive.html

Hughes, J. (2007, September 5). More 2,000,000 LTO Ultrium format tape drives and 80,000,000 cartridges shipped. *LTO Press Release Archive*. Retrieved November 2010, from: http://lto.org/News/pressarchive.html

Hugues, J. (2008, June 17). LTO Ultrium tape technology sales grow by double digits according to latest leading market research firm's report. *LTO Press Release Archive*. Retrieved November 2010, from: http://lto.org/News/pressarchive.html

IBM Corporation. (2008). IBM system storage tape library guide for open systems. Retrieved November 2010, from: http://www.redbooks.ibm.com/redbooks/pdfs/sg245946.pdf

IBM Corporation. (n.d.). IBM Tape Storage Systems. *System Storage*. Retrieved November 2010, from: http://www-03.ibm.com/systems/storage/tape/

Ibrahim, K. F. (2007). *Newnes Guide to Television and Video Technology* (4th ed.). Amsterdam: Elsevier.

IDS Healthcare. (2002). Radiography applications-film screen systems and Canon CXDI-40G general DR system. In *Canon medical systems*. Retrieved November 2010, from: http://www.ids-healthcare.com/hospital_management/us/Canon_Medical_Systems/Consumer_Imaging_Equipment/35_0/g_supplier.html

Image resolution. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Image_resolution

Imaging Resource. (2010). *Digital camera reviews by manufacturer (Olympus, Fujifilm)*. Retrieved November 2010, from: http://www.imaging-resource.com/DIGCAM01.HTM

Imation Corporation. (n.d.). Tape cartridge & accessories. *Imation Products*. Retrieved November 2010, from: http://www.imation.com/

Indrajit, I. K., & Verma, B. S. (2007). Digital imaging in radiology practice: An introduction to few fundamental concepts. *Indian Journal of Radiology Imaging 17*(4), 230–236. Retrieved November 2010, from: http://www.ijri.org/

International Data Corporation (IDC). (2008). *Worldwide hard disk drive forecast*. Retrieved June 2009, from http://www.idc.com/

International Federation of Film Archive (FIAF). (2010). *Membership information*. Retrieved November 2010, from: http://www.fiafnet.org/uk/members/

International Federation of the Phonographic Industry (IFPI). (1995). *World record sales 1994 & 1995*. Retrieved November 2010, from: http://www.zobbel.de/stat/wrs_9594.htm

International Federation of the Phonographic Industry (IFPI). (1998). *World record sales 1997/1998*. Retrieved November 2010, from: http://www.zobbel.de/stat/wrs_98.htm

International Federation of the Phonographic Industry (IFPI). (2001). 2000 recording industry music sales. Retrieved November 2010, from: http://www.ifpi.org/content/library/worldsales2000.pdf

International Federation of the Phonographic Industry (IFPI). (2002). *The recording industry world sales 2001*. Retrieved November 2010, from: http://www.ifpi.org/content/library/worldsales2001.pdf

International Federation of the Phonographic Industry (IFPI). (2003). *The recording industry world sales 2002*. Retrieved November 2010, from: http://www.ifpi.org/content/library/worldsales2002.pdf

International Federation of the Phonographic Industry (IFPI). (2004). *The recording industry world sales 2003*. Retrieved November 2010, from: http://www.ifpi.org/content/library/worldsales2003.pdf

International Telecommunications Union (ITU). (2010). ITU world telecommunications ICT indicators 2010 [data file].

Internet Movie Database (IMDb). (2010). *Years*. Retrieved November 2010, from: http://www.imdb.com/year/

iPod. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/IPod

Japan Recording-Media Industries Association (JRIA). (November, 2002). Another quantum leap for recordable DVDs – Forecast for recording media in 2003, global demand and production. *JRIA Press Release*. Retrieved November 2010, from: http://www.jria.org/english/pdf/e_pres0211.pdf

Japan Recording-Media Industries Association (JRIA). (November, 2003). Recordable DVD market enters the era of full-scale global popularization – Forecast for recording media in 2004, global demand and production. *JRIA Press Release*. Retrieved November 2010, from: http://www.jria.org/english/pdf/e_pres0311.pdf

Japan Recording-Media Industries Association (JRIA). (November, 2004). Recordable DVDs propel recording media business – Forecast for recording media global demand and production in 2005. *JRIA Press Release*. Retrieved November 2010, from: http://www.jria.org/english/pdf/e_pres0411.pdf

Japan Recording-Media Industries Association (JRIA). (November, 2005). Global recordable DVD demand approaches level of CB-R – Forecast for recording media global demand and production in 2006. *JRIA Press Release*. Retrieved November 2010, from: http://www.jria.org/english/pdf/e_pres0511.pdf

Japan Recording-Media Industries Association (JRIA). (November, 2006). Media changes accelerated by optical disks and compact memory cards – Next 3 years forecast for recording media global demand and production. *JRIA Press Release*. Retrieved November 2010, from: http://www.jria.org/english/pdf/e_pres0611.pdf

Japan Recording-Media Industries Association (JRIA). (November, 2007). Demand for recordable DVDs gains momentum to surpass recordable CDs - Next 3 years forecast for recording media global demand and production. *JRIA Press Release*. Retrieved November 2010, from: http://www.jria.org/english/pdf/e_pres0711.pdf

JC Derrick's Founders Blurb. (2005). USB Flash Drive "I told you so". Retrieved May 2008 from: http://www.pronetworks.org/forum/viewtopic.php?t=47727

JCN Newswire. (2003, August 6). *Samsung to manufacture memory stick*. Retrieved November 2010, from DPReview Press Room: http://www.dpreview.com/

Jokela, S. (1999). *Short introduction to Personal Digital Assistants*. Retrieved November 2010, from Helsinki University of Technology (Computer Science Department): http://www.tml.tkk.fi/Opinnot/Tik-111.550/1999/Esitelmat/PDA/pda_final.htm

Kader, V. (1992, June 1). New frontiers for floppy disks. *Business America*. Retrieved November 2010, from CBS Business Network (BNET): http://findarticles.com/

Kingston Technology (2001, September 26). *Kingston Technology introduces 512 MB high capacity CompactFlash storage cards*. Retrieved November 2010, from the Internet Archive: http://web.archive.org/web/20030709015714/kingston.com/press/2001/flash/prf0109a.asp

Kingston Technology (2004, May 17). *Kingston Technology first to release MultiMediaCard 4.0 to worldwide market*. Retrieved November 2010, from the Internet Archive: http://web.archive.org/web/20050312195435/www.kingston.com/press/2004/DigitalMedia/05b.asp

Kingston Technology (2005, November). Portable digital media for computers, digital cameras and other devices. *Digital media guide, ShutterBug Online Magazine*. Retrieved November 2010, from: http://www.shutterbug.com/industryvoice/1105kingston/

Kodak. (2007). Film types and formats. In *The essential reference guide for filmmakers*. Retrieved November 2010, from: http://motion.kodak.com/US/en/motion/Publications/Film_Essentials/index.htm

Kodak. (2009). *Cinematographer's field guide* (3rd ed.). Retrieved June 2009, from: http://motion.kodak.com/US/en/motion/Publications/Cinematographers_Field_Guide/index.htm

Koff, David A. & Shulman, H. (2006). An overview of digital compression of medical images: Can we use lossy image compression in radiology?

Canadian Association of Radiology Journal, 57(4), 211-217. Retrieved May 2008, from: http://www.carj.ca/issues/2006-Oct/211/211.pdf

Kozierok, C. M. (2001, April 17). Media Use and Storage Life. *The PC Guide*. Retrieved November 2010, from: http://www.pcguide.com/care/care/mediaLifB-c.html

Krause, P. (2002). *Silver consumption for photography expected to increase through 2002*. Retrieved November 2010, from the Internet Archive (originally on Silver News of Silver Institute): http://web.archive.org/web/20060923102433/http://www.silverinstitute.org/news/6a1998.htm

Kuhn, M. (2006). *International standard paper sizes, application examples*. Retrieved May 2007, from University of Cambridge: http://www.cl.cam.ac.uk/

Larduinat, X. (2008, May 14). *Vision 2020: Smart secure devices*. Eurosmart, WISTP'08, Sevilla. Retrieved November 2010, from Docstock Website: http://www.docstoc.com/docs/2125104/Xavier-Larduinats-EuroSmart-Keynote

Lenard, T., & Pickford, M. (2005). The digital economy fact book (7th ed.). *The Progress and Freedom Foundation*. Retrieved November 2010, from:

Leurs, L. (2007). *Design basics: Image resolution*. Retrieved November 2010, from http://www.prepressure.com/design/basics/resolution

List of Canon products. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/List_of_Canon_products

List of Motorola products. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/List_of_Motorola_products

List of Nokia products. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/List_of_Nokia_products

List of products manufactured by Kodak. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/List_of_products_manufactured_by_Kodak

List of Sony Ericsson products. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/List_of_Sony_Ericsson_products

Lyman, P., Varian, H. R., & Swearingen, K. (2003). *How much information? 2003*. Retrived November 2010, from School of Information Management and Systems, University of California at Berkeley: http://www2.sims.berkeley.edu/research/projects/how-much-info-2003/

Lyra Research. (2002). *Medical and Dental X-Ray Film: Demand Trends in Worldwide Markets*. Lyra industry report 2002. Retrieved November 2010, from the Internet Archive: http://web.archive.org/web/20071118132102/http://lyra.ecnext.com/coms2/summary_0290-77_ITM

Lyytikäinen, M., Hyttinen, M., Väätänen, S., & Niemi, E. (2007). *Optimizing your content for OTA delivery: Graphics*. Retrieved May 2010, from Internet Archive (originally on Adobe.com Developer Connection): http://web.archive.org/web/*/http://www.adobe.com/devnet/devices/articles/ota_delivery_04.html

Maccia, C. (1991). Trends in medical diagnostic radiology in France: Comparison of patient age distribution between 1982 and 1988. *Radiation Protection Dosimetry 36*(2), 253-256. Retrieved November 2010, from: http://rpd.oxfordjournals.org/

Madnick, S., Smith, M., & Clopeck, K. (June 2009). How much information? Case studies on scientific research at MIT. *HMI? Case Studies*, Global Information Industry Center at the School of International Relations and Pacific Studies, University of California. Retrieved November 2010, from: http://hmi.ucsd.edu/

Mainframe computer. (n.d.). In *Wikipedia*, the free encyclopedia. Retrieved November 2010, from the BookRags Website: http://en.wikipedia.org/wiki/Mainframe_computer

Mander Ian (2010, March 15). *Flash memory card types: CompactFlash™*. Retrieved November 2010, from Aqualab Website: http://www.videofoundry.co.nz/ianman/laboratory/research/flash.shtml#cf

Masters Audio Video, LLC. (n.d.). *Media conversion and transfer service*. Retrieved November 2010, from: http://www.mastersav.com

McBroom, M. (2000). *McBroom's camera bluebook: The complete up-to-date price and buyer's guide for new and used cameras, lenses and accessories* (6th ed.). Buffalo, N.Y.: Amherst Media, Inc.

Mearian, L. (2008, December 7). Hard drive shipments drop. *ComputerWorld News*. Retrieved November 2010, from PC World Business Center: http://www.pcworld.com/businesscenter/

Media College (n.d.). *The Betacam format*. Retrieved November 2010, from: http://www.mediacollege.com/video/format/beta/betacam.html

Memory Card Reliability. (n.d.). *All memory cards*. Retrieved November 2010, from: http://www.allmemorycards.com/glossary/reliability.htm

Microsoft Corp. (2006). Windows Desktop products history. *Windows History*. Retrieved November 2010, from: http://www.microsoft.com/windows/winhistorydesktop.mspx

Monroe, J. (2002, September 23). Alchemy and rigorous science: The evolution of hard disk drives. *Gartner Dataquest*. Retrieved May 2008, from: http://www.bus.umich.edu/

Monroe, J. (2008). Gartner on flash SSDs and HDD price trends. Retrieved November 2010, from the Internet Archive: http://web.archive.org/web/20080531020626/http://www.blocksandfiles.com/article/5315

Mordock, G. (2006, February 22). LTO technology program reaches new milestone in 2005. *LTO Press Release Archive*. Retrieved November 2010, from: http://lto.org/News/pressarchive.html

Moren, Dan (2008, January 31). *Analysis: Inside Apple's iPod Sales Figures*. Retrieved November 2010, from MacWorld News: http://www.macworld.com/article/131874/2008/01/ipodsales.html

Morgan Stanley. (2006, March 3). *Q1 2006 Global technology data book*. Retrieved November 2010, from: http://www.morganstanley.com/institutional/techresearch/pdfs/global_techdatabook0306.pdf

Moulton, P. (2001). *Telecommunication Survival Guide*. New Jersey: Prentice Hall PTR.

Nagaoka, Y., Tsuruta, M., & Fujiwara, H. (1988). High performance VTR based on the S-VHS format. *IEEE Transactions on Consumer Electronics, 34*(3), 560-565. Retrieved November 2010, from: DOI: 10.1109/30.20154

National Film & Sound Archive (NFSA). (n.d.). *Technical glossary of common audiovisual terms: Format*. Retrieved November 2010, from: http://www.nfsa.gov.au/preservation/audiovisual_terms/

News: The historical New York Times (2008) [Database of scanned images]. Retrieved May 2008, from ProQuest on the World Wide Web http://proquest.umi.com/pqdwe

Nintendo Homepage (2010). *Consolidated sales transition by region. Retrieved November 2010, from:*

http://www.nintendo.co.jp/ir/library/historical_data/pdf/consolidated_sales_e0912.pdf

Computer Industry Report. (1997, July 15). *Digital camera market size*. Retrieved November 2010, from CBS Business Network (BNET): http://findarticles.com/

Computer Industry Report. (1997, July 15). *Digital camera market size*. Retrieved November 2010, from CBS Business Network (BNET): http://findarticles.com/

Computer Industry Report. (1997, July 15). *Digital camera market size*. Retrieved November 2010, from CBS Business Network (BNET): http://findarticles.com/

Computer Industry Report. (1997, July 15). *Digital camera market size*. Retrieved November 2010, from CBS Business Network (BNET): http://findarticles.com/

Nomura Research Institute Ltd. (2003, November). Perspectives of the market scale and its trend of the IT market until the year 2008 (3) - PC and mobile phone markets to mature, and car navigation to reach 24 million terminals. *Nomura Research Institute News Release*. Retrieved November 2010, from: http://www.nri.co.jp/english/news/

Northern Arizona University (2006). *Comptroller's Office Policies and Procedures Manual: Capitalization and Depreciation*. Retrieved May 2008, from http://www4.nau.edu/comptr/com130.html

NOVA R&D, Inc. (2008). *Mary™ charge readout chip*. Retrieved November 2010, from: http://www.novarad.com/documents/MARY_Brochure.pdf

Office of the Comptroller. (2005). *Depreciating libraries*. Retrieved May 2008, from the Texas Comptroller of Public Accounts Website: https://fmx.cpa.state.tx.us/fmx/spa/meetings/2005/05/depreciat_librari.pdf

Olfert, C. (2002, December 3). More than 5 million LTO Ultrium format cartridges ship, milestone demonstrates preference for Super Tape drive leader. *LTO Press Release Archive*. Retrieved November 2010, from: http://lto.org/News/pressarchive.html

Olfert, C. (2003, July 22). LTO Ultrium format reaches milestone with more tha 10 million cartridges, 350,000 drives shipped. *LTO Press Release Archive*. Retrieved November 2010, from: http://lto.org/News/pressarchive.html

Olfert, C. (2005, February 2). LTO technology program reaches new milestone in 2004. *LTO Press Release Archive*. Retrieved November 2010, from: http://lto.org/News/pressarchive.html

Olympus (1999, June 4). Olympus announces 32MB SmartMedia™ card. *Olympus Press Center*. Retrieved November 2010, from: http://www.olympusamerica.com/oai_newsevents.asp

Olympus (2002, July 07). *Olympus announce xD picture card*. Retrieved November 2010, from DPReview Press Room: http://www.dpreview.com/

Olympus (2002, July 30). Olympus announces development of xB-picture card™, a revolutionary ultra-compact digital camera memory media. *Olympus Press Center*. Retrieved November 2010, from: http://www.olympusamerica.com/oai_newsevents.asp

Olympus (2006, August 8). Olympus introduces high capacity 2 GB xB-picture card. *Olympus Press Center*. Retrieved November 2010, from: http://www.olympusamerica.com/oai_newsevents.asp

Pakkala, A. L. (1977). The market for amateur photography. *Financial Analyst Journal 3*(5), 44-52. Retrieved November 2010, from: http://www.jstor.org/stable/4478068

Paper purchasing (n.d.). In *Cutting paper – counting*. Retrieved November 2010, from: http://eetd.lbl.gov/paper/counting/html/index.htm

Parks, E. T., & Williamson, G. F. (2002). Digital radiography: An overview. *The Journal of Contemporary Dental Practice 3(*4), 23-39. Retrieved November 2010, from: http://www.thejcdp.com/

PCV Forum (2005, February 6). *Xbox hardware and software sales* [Msg #1]. Message posted to PVC Forum. Retrieved November 2010, from: http://forum.pcvsconsole.com/

PCV Forum (2006). SEGA sardware and software sales? [Msg #3,8]. Message posted to PVC Forum. Retrieved November 2010, from: http://forum.pcvsconsole.com/

PDA Database. (n.d.). *Release History: January 01, 1990 – November 30, 2010 time table*. Retrieved November 2010, from: http://www.pdadb.net/index.php?m=pdahistory

Perenson, M. J. (2001, May 8). CB-R media prices to triple this summer. *PC World News*. Retrieved November 2010, from: http://www.pcworld.com/article/49504/cdr_media_prices_to_triple_this_summer.html

Peripheral Research Corporation (1999). *1999 tape drive head/media market & technology report*.

Peripheral Research Corporation (2000). *2000 tape drive head/media market & technology report*.

Peripheral Research Corporation (2001). *2001 tape drive head/media market & technology report*.

Peripheral Research Corporation (2002). *2002 tape drive head/media market & technology report*.

Peripheral Research Corporation. (1999). *Rigid disk drive, magnetic head/media market and technology report 1999/2000*.

Peripheral Research Corporation. (2004). *Rigid disk drive/component statistical data and forecast report 2004/2005*.

Petersen, G. (2004). *25 audio innovations than changed the (pro audio) world: Western Electric/Bell Labs Vitaphone film sound (1926)*. Retrieved November 2010, from TECnology Hall of Fame 1877 – 1950, Technical Excellence & Creativity (TEC) Awards: http://tecfoundation.com/tec/04TECnologyHOFdetails.html

Peterson, M. L. & Casey, D. C. (1991). *Tape head/media market & technology report*. Peripherical Strategies, Inc.

Petri, S. (1999, September/October). An introduction to Smart Cards. *Messaging Magazine, featuring Security Issues and Electronic Commerce*. Retrieved November 2010, from The Open Group Website: http://www.opengroup.org/comm/the_message/magazine/mmv5n5/SmartCards.htm

Photo Marketing Association International (PMAI). (2006). *Film and singlB-use camera sales, in North America*. Retrieved on September 2007, from: http://www.pmai.org/

Photo print sizes. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Hagaki

Pierce, J. (1980). An introduction to Information Theory: Symbols, signals and noise (2nd rev. ed.). New York: Dover Publications.

Polsson, K. (2010). Chronology of video game systems. Retrieved November 2010, from: http://www.islandnet.com/~kpolsson/vidgame/index.htm

Porter, J. N. (1981). Rigid disk drives 1981. *Disk Trend Report*.

Porter, J. N. (1982). Rigid disk drives 1982. *Disk Trend Report*.

Porter, J. N. (1984). Rigid disk drives 1984. *Disk Trend Report*.

Porter, J. N. (1985). Rigid disk drives 1985. *Disk Trend Report*.

Porter, J. N. (1986). Rigid disk drives 1986. *Disk Trend Report*.

Porter, J. N. (1987). Rigid disk drives 1987. *Disk Trend Report*.

Porter, J. N. (1989). Rigid disk drives 1989. *Disk Trend Report*.

Porter, J. N. (1990). Rigid disk drives 1990. *Disk Trend Report*.

Porter, J. N. (1991). Rigid disk drives 1991. *Disk Trend Report*.

Porter, J. N. (1994). Rigid disk drives 1994. *Disk Trend Report*.

Porter, J. N. (1997). Rigid disk drives 1997. *Disk Trend Report*.

Porter, J. N. (1999). Rigid disk drives 1999. *Disk Trend Report*.

Porter, James N. (1981b). Flexible disk drives 1981. *Disk Trend Report*

Porter, James N. (1982b). Flexible disk drives 1982. *Disk Trend Report*

Porter, James N. (1983b). Flexible disk drives 1983. *Disk Trend Report*

Porter, James N. (1984b). Flexible disk drives 1984. *Disk Trend Report*

Porter, James N. (1986b). Flexible disk drives 1986. *Disk Trend Report*

Porter, James N. (1987b). Flexible disk drives 1987. *Disk Trend Report*

Porter, James N. (1989b). Flexible disk drives 1989. *Disk Trend Report*

Porter, James N. (1990b). Flexible disk drives 1990. *Disk Trend Report*

Porter, James N. (1991b). Flexible disk drives 1991. *Disk Trend Report*

Porter, James N. (1994b). Flexible disk drives 1994. *Disk Trend Report*

Porter, James N. (1999b). Optical and removable disk drives 1999. *Disk Trend Report*

Porter, J. N. (1999c). Disk Drives Evolution. *100th Anniversary Conference: Magnetic recording and information storage*, Santa Clara University. Retrieved November 2010, from: http://www.disktrend.com/

Pretec Electronics Corporation (1999, December 31). Colorful CompactFlash™ Cards from Pretec, more Colors than any other Small Form Factor Card Today. *Pretec Press Release*. Retrieved November 2010, from CompactFlash Association Press Release Archive: http://compactflash.org/press-releasB-archives/

Pretec Electronics Corporation (1999, March 18). 128 MB CompactFlash™ card from Pretec, the world's highest CompactFlash card. *Pretec Press Release*. Retrieved November 2010, from the Internet Archive:

http://web.archive.org/web/20000118194528/www.pretec.com/PR/press_CF+_2.htm

Pretec Electronics Corporation (2001, June 25). Ricoh and Pretec team up to show 640 MB Compact Flash card. *Pretec Press Release*. Retrieved November 2010, from the Internet Archive: http://web.archive.org/web/20030618080547/www.pretec.com/PR/PR_640MB+CF+_Ricoh+final.doc

Pretec Electronics Corporation (2002, November 18). Pretec introduces the world's largest Capacity 1.5 GB, 2 GB and 3 GB CompactFlash card. *Pretec Press Release*. Retrieved November 2010, from CompactFlash Association Press Release Archive: http://compactflash.org/press-releasB-archives/

Pretec Electronics Corporation (2003, September 22). Pretec demonstrates 6 GB rugged CF card – Highest capacity, most reliable and fastest in the world. *Pretec Press Release*. Retrieved November 2010, from the Internet Archive: http://web.archive.org/web/20040426014931/www.pretec.com/PR/2003Computex_PR_CF+Card+03.pdf

Pretec Electronics Corporation (2004, January 8). Pretec 1 GB MMC world's largest capacity and fastest. *Pretec Press Release*. Retrieved November 2010, from the Internet Archive: http://web.archive.org/web/20040325221450/www.pretec.com/PR/PR_1GB+MMC++010804.pdf

Pretec Electronics Corporation (2005, July 27). Pretec introduces 4 GB SD card, B-Disk II and reduces price for 12 GB CF card. *Pretec Press Room*. Retrieved November 2010, from: http://www.pretec.com/news-event/press-room/

Pretec Electronics Corporation (2006, March 31). Pretec 8 GB SDHC card, the highest capacity SD card in the world! *Pretec Press Room*. Retrieved November 2010, from: http://www.pretec.com/news-event/press-room/

Pretec Electronics Corporation (2006, September 26). Pretec 16 GB CompactFlash card, more space than you can imagine. ! *Pretec Press Room*. Retrieved November 2010, from: http://www.pretec.com/news-event/press-room/

Pretec Electronics Corporation (2006, September 5). Pretec MMCplus 266x extendable to 4GB, the fastest memory card in the world. ! *Pretec Press Room*. Retrieved November 2010, from: http://www.pretec.com/news-event/press-room/

Pretec Electronics Corporation (2007, April 3). Pretec announces the world's fastest and most rugged industrial CompactFlash™ card. *Pretec Press*

Release. Retrieved November 2010, from CompactFlash Association Press Release Archive: http://compactflash.org/press-releasB-archives/

QIC Tape Solutions. (2005). Development Standards Adopted by QIC: Minicartridge Drives & Data Cartridge. *Development Standards Cross Reference*. Retrieved November 2010, from: http://www.qic.org/

Quantum Ltd. (n.d.). History of DLT Tape Technology. Retrieved May 2008, from: http://learning.quantum.com/demo/history.htm

Radis GmbH. (2004). *RADIS-401, the technology jump in digital industrial radiology*. Retrieved May 2008, from: http://www.radis-gmbh.com/Radis401_engl.pdf

Recording Industry Association of America (RIAA). (2008). *2007 year-end shipment statistics*. Retrieved November 2010, from: http://76.74.24.142/81128FFB-028F-282B-1CE5-FDBF16A46388.pdf

Recording Industry Association of America (RIAA). (n.d.). *RIAA annual report data* [data file]. Retrieved November 2010, from: http://www.resortrecords.com/downloads/RIAAdata.xls

Recording Industry Association of Japan (RIAJ). (2009). *Statistics trend, RIAJ yearbook 2009*. Retrieved November 2010, from: http://www.riaj.or.jp/e/issue/pdf/RYB2000E01.pdf

Redmer, B., Bellon, C., Sölter, B., & Malitte, H. J. (2001). Reduction of radiation exposure through the application of new detector techniques in industrial radiography. *Fifth EAN Workshop on Industrial Radiology: Improvements in radiation protection*, Rome, Italy, October 2001. Retrieved November 2010, from the Internet Archive: http://web.archive.org/web/20050105015901/http://ean.cepn.asso.fr/pdf/program5/session+2/4_Bellon.pdf

Rihey CO. Ltd. (n.d.). *Why should you wholesale memory cards from China, from Rihey?*. Retrieved November 2010, from: http://www.goodscool.com/china-wholesalB-electronics/Memory-Cards/

Rio PMP300. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Rio_PMP300

Roberts, M., & Etherington, D. (2007). *A dictionary of descriptive terminology*. Retrieved November 2010, from Internet Archive (originally on Bookbinding and the Conservation of Books): http://web.archive.org/web/*/http://palimpsest.stanford.edu/don/dt/dt0408.html

Rothenberg, Jeff. (1999). *Ensuring the Longevity of Digital Information*. Retrieved November 2010, from Council on Library and Information Resources (CLIR) Website: http://www.clir.org/

Russ, J. C. (2007). *The image processing handbook* (5th ed.). Boca Raton: CRC/Taylor and Francis.

Salomon, D. (2007). *Data Compression: The Complete Reference* (4th ed.). Berlin, Germany: Springer-Verlag.

Samsung (2006, July 27). *Samsung introduces high-performance MMC cards*. Retrieved November 2010, from Mobiledia News: http://www.mobiledia.com/news/49223.html

SanDisk (2000, February 24). SanDisk to supply MultiMediaCards for SK global MP3 music player. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2000, June 27). SanDisk supports palm's selection of the SD (Secure Digital) card for new Palm handheld computers. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2001, January 6). SanDisk SD cards will be used in new MP3 player for Palm computers. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2001, March 21). SanDisk announces first shipments of secure digital (SD) memory cards to retail stores. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2001, November 5). SanDisk introduces 1-Gigabyte CompactFlash card – World's largest capacity CompactFlash card in standard Type I format. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2001, October 4,). SanDisk to supply compaq with secure digital cards for Compaq's new iPaq Pocket PC. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2002, October 22). SanDisk SD Flash memory cards supported by new Microsoft Windows for Smartphone 2002 software. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2003, August 15). SanDisk introduces new Memory Stick Duo and Memory Stick Pro Duo storage cards. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2003, January 9). SanDisk introduces Memory Stick Pro – For new generation Memory Stick devices. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2003, March 13). SanDisk introduces 1 GB, 512 MB SD cards. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2003, March 13). SanDisk introduces four gigabytes CompactFlash card, world's highest capacity CompactFlash memory card. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2003, March 3). SanDisk offers 256 MB Memory Stick with Select fuction – Doubles capacity for existing Memory Stick devices. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2004, January 8). SanDisk unveils the highest capacity Memory Stick Pro storage card in the world – 2 Gigabytes. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2004, November 9). SanDisk introduces 4 and 8 Gigabyte industrial CF cards and 8 and 16 GB industrial PC cards. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2004, October 26). SanDisk introduces world's highest capacity Memory Stick Pro, Memory Stick Pro Duo and SD cards. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2005, March 10). SanDisk introduces one Gigabyte xB-picture card. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk (2006, December 11). SanDisk and Sony develop "Memory Stick PRO-HG" format. *SanDisk Press Release*. Retrieved November 2010, from: http://www.sandisk.com/about-sandisk/press-room/press-releases

SanDisk Corporation (2003, October). *SanDisk flash memory cards, wear leveling*. Retrieved November 2010, from Scribd Website:

http://www.scribd.com/doc/7010332/SANDISK-Flash-Memory-Cards-Wear-Leveling

Saunders, J. (2004, October 15). *PlayStation technical specifications*. Retrieved November 2010, from: http://www.jlsnet.co.uk/

SB-2 SEC Filling of Dynamic Media Inc. (2001). Retrieved November 2010, from EDGAR Online, Inc. Website: http://sec.edgar-online.com/

Schoenherr, S. E. (1999). Motion picture sound 1910 – 1929. In *Recording technology history*. Retrieved on November 2010, from Internet Archive (originally on History Department at the University of San Diego): http://web.archive.org/web/20070429191100/http://history.sandiego.edu/gen/recording/motionpicture1.html

Schoenherr, S. (2004). *The digital revolution*. Retrieved May 2008, from The University of San Diego: http://history.sandiego.edu/gen/recording/digital.html

Seelye, K. (2006, December 4). In tough times, a redesigned journal. *The New York Times*. Retrieved November 2010, from http://www.nytimes.com/

Sheldon, I., Morikawa, S., Chiva, Y., Nagasawa, T., & Ishizaka, K. (1994). The missing piece of the jigsaw: The development of the Digital Betacam Camcorder. *IEE Conference Publication 1994*(CP397), 103-109. Retrieved November 2010, DOI: 10.1049/cp: 19940736

ShowBIZ Data. (2009). *World box office*. Retrieved November 2010, from: http://www.showbizdata.com/worldshares.cfm

Silicon Storage Technology Inc. (SST). (1999, August 24). *SST introduces 32 MB and 48 MB CF Cards*. Retrieved November 2010, from DPReview Press Room: http://www.dpreview.com/

Sony Corporation (n.d.). *ATRAC3 and ATRAC3plus*. Retrieved November 2010, from MiniDisc.org: http://www.minidisc.org/www.sony.net/Products/ATRAC3/atrac/index.html

Sony Corporation. (2000, May 23). Sony to establish Taiwan memory stick forum. *Sony Press Release*. Retrieved November 2010, from: http://www.sony.net/SonyInfo/News/Press/archive.html

Sony Corporation. (2000, September 22). Sony announces Memory Stick™ for audio application. *Sony Press Release Archive*. http://www.sony.net/SonyInfo/News/Press/archive.html

Spector, L. (2001, June 20). The PC at 20. *PC World News*. Retrieved November 2010, from: http://www.pcworld.com/article/52503-7/the_pc_at_20.html

Sony Corporation. (2002). The arrival of Betacam. In: *Sony history*. Retrieved November 2010, from the Internet Archive: http://web.archive.org/web/20071218155915/http://www.sony.net/Fun/SH/1-16/h2.html

Sony Corporation. (2007, January 8). *Sony Memory Stick Duo format expands to eight gigabytes*. Retrieved November 2010, from DPReview Press Room: http://www.dpreview.com/

Sony Computer Entertainment Inc. (SCEI). (2010a). *PlayStation®3 worldwide hardware unit sales*. Retrieved November 2010, from: http://www.scei.co.jp/corporate/data/bizdataps3_sale_e.html

Sony Computer Entertainment Inc. (SCEI). (2010b). *PlayStation®2) worldwide hardware unit sales*. Retrieved November 2010, from: http://www.scei.co.jp/corporate/data/bizdataps2_sale_e.html

Sony Computer Entertainment Inc. (SCEI). (2010c). *PSP® (PlayStation®Portable) worldwide hardware unit sales*. Retrieved November 2010, from: http://www.scei.co.jp/corporate/data/bizdatapsp_sale_e.html

Sony Computer Entertainment Inc. (SCEI). (2010d). *PlayStation® cumulative production shipments of hardware*. Retrieved November 2010, from: http://www.scei.co.jp/corporate/data/bizdataps_e.html

Sprague Magnetics Inc. (1995). *Introduction to QIC Tape Drives*. Retrieved November 2010, from: http://www.spraguB-magnetics.com/library/qicintr.pdf

Steve's Digicam. (2010). *Camera reviews*. Retrieved November 2010, from: http://www.steves-digicams.com/camera-reviews/

Storage: 53 removable data storage manufacturers: different recording technologies, different product forms, but aiming at many of the same target markets. (1998, August 10). *Edge: Work-Group Computer Report*. Retrieved November 2010, from CBS Business Network (BNET): http://findarticles.com/

Sun StorageTek Corp. (n.d.). Tape products for archive and data protection. *StorageTek Products*. Retrieved November 2010, from Sun Storage Website: http://www.sun.com/storage/products.xml

Symons, A. (2000, May 22). Video and blank tape soft, DVD on rise. *Drug Store News*. Retrieved November 2010, from CBS Business Network (BNET): http://findarticles.com/

Syndicat National de l'Édition Phonographique (SNEP). (2001). *L'Economie du disque 2000*. Retrieved November 2010, from the Internet Archive: http://web.archive.org/web/20010803180509/http://www.disqueenfrance.com/actu/economie_disque/default.asp

Television movie. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Television_movie

The gaming console, nearly 50 years old. (n.d.). Retrieved November 2010, from the Internet Archive: http://web.archive.org/web/20080322101517/http://www.gamingdump.com/consoleevolution.html

The Independent (2004, April 4). *The myth of the 100-year CB-Rom*. – Retrieved November 2010 from Rense.com (UK): http://www.rense.com/general52/themythofthe100year.htm

The U.S. National Archives. (2000). *Managing X-ray films as federal records*. Retrieved November 2010, from: http://www.archives.gov/records-mgmt/publications/managing-xray-films.html

Theriot, S. (2007). *Library collection: Suggested information for recording and depreciating*. Retrieved November 2010, from Internet Archive (originally on Louisiana Legislative Auditor Website): http://web.archive.org/web/*/http://www.lla.state.la.us/gasb34/Libcoll.pdf

Thomson Gale. (2005). Mainframe. *World of Computer Science*. Retrieved November 2010, from: http://www.bookrags.com/research/mainframB-wcs/

Toshiba. (1997, December 10). Toshiba develops double density SmartMedia™. *Toshiba News Releases*. Retrieved November 2010, from: http://www.toshiba.co.jp/about/press/date.htm

Toshiba. (1999, July 30,). Toshiba introduces world's first 64 Megabyte SmartMedia™ Card *Toshiba News Releases*. Retrieved November 2010, from: http://www.toshiba.co.jp/about/press/date.htm

Toshiba. (2000, September 26). *Toshiba announce 128 MB SmartMedia™*. Retrieved November 2010, from DPReview Press Room: http://www.dpreview.com/

Toshiba. (2007, August 22). Toshiba Adds new 32 GB and 16 GB High Density SDHC and 8 GB microSDHC Card to Extensive Memory Card LinB-Up. *Toshiba News Releases*. Retrieved November 2010, from: http://www.toshiba.co.jp/about/press/date.htm

TriggerTone (n.d.). SVA (Stereo Variable Area). In *Audio post-production knowledge base*. Retrieved on November 2010, from: http://www.triggertone.com/term/Stereo_Variable_Area

Tsuneki, K., Ezaki, T., Hirai, J., & Kubota, Y. (1989). Development of the high-band 8mm video system. *IEEE Transactions on Consumer Electronics, 35*(3), 436-441. Retrieved November 2010, from: DOI: 10.1109/30.44301

U.S. Securities and Exchange Commission. (1998, December 31). *Annual report pursuant to section 13 or 15 (d) of Securities Exchange Act of 1934*. Retrieved November 2010, from: http://www.sec.gov/Archives/

UK Office For National Statistics. (2002). Sales of CDs, LPs, cassettes and singles, 1973-2001 [data file]. Retrieved November 2001, from: http://www.statistics.gov.uk/StatBase/Expodata/Spreadsheets/D6507.xls

United States Air Force (USAF). (2005). Direct dental digital radiography systems (CCD, CMOS). Retrieved May 2008 from: https://decs.nhgl.med.navy.mil/2QTR05/PRODUCTEVALUATIONS/dirdigrad.pdf

University Controller. (2002). *Capitalization & Depreciation for Capital Assets*. Retrieved November 2010, from the State University of New York Website: http://www.suny.edu/sunypp/documents.cfm?doc_id=559

Verna, Paul (2007). Recorded Music: Digital Falls Short. *eMarketer report's summary*. Retrieved November 2010, from: http://www.emarketer.com/Report.aspx?code=emarketer_2000472

VHS. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/VHS

Video game console. (n.d.). In *Wikipedia, the free library*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Video_game_console

Vinyl to Digital. (2010). *Transfer audio cassette tape to CD or MP3*. Retrieved November 2010, from: http://www.vinyltodigital.co.uk/audio/audio-cassettB-to-cd.html

Vitale, T. (2005). Why is digital imaging superior? In *Notes on digital documentation* (version 14). Retrieved November 2010, from the American Institute for Conservation of Historic and Artistic Works (AIC) Website: http://cool.conservation-us.org/coolaic/sg/emg/library/pdf/vitale/2005-06-21_digital_documentation_001.pdf

Vitale, T. (2007). *Film grain, resolution and fundamental film particles* (version 20). Retrieved November 2010, from the American Institute for Conservation of Historic and Artistic Works (AIC) Website: http://cool.conservation-us.org/coolaic/sg/emg/library/pdf/vitale/2007-04-vitalB-filmgrain_resolution.pdf

Volk, M., Strotzer, M., Holzknecht, N., Manke, C., Lenhart, M., Gmeinwieser, J. et al. (2002). Digital radiography of the skeleton using a largB-area detector based on amorphous silicon technology: Image quality and potential for dose reduction in comparison with screen film radiography. *Clinical Radiology 55*(8), 615-621. Retrieved November 2010, from: DOI:10.1053/crad.2000.0493

Ward, R. J. (1988). *U.S. Patent No. 06/896227*. Washington, D.C.: U.S. Patent and Trademark Office. Retrieved November 2010, from: http://www.patentstorm.us/patents/4724484/description.html

What is a USB Flash Drive? [Web Log Entry]. (2007, July 16). Retrieved November 2010, from Custom USB Memory Stick, Pen Drive, USB Flash Drive: http://jtsmart.blogspot.com/

Williams, P. (2003). *Digital photography: Film vs. digital*. Retrieved November 2010, from: http://www.williamsphotographic.com/digital/dig1.html

Wilson, A. J., Mann, F. A., Murphy, W. A., Monsees, B. S., & Linn, M. R. (1991). Photostimulable phosphor digital radiography of the extremities: Diagnostic accuracy compared with conventional radiography. *American Journal of Roentgenology 157*, 533-538. Retrieved November 2010, from: http://www.ajronline.org/

Writer Services. (n.d.). *Word count to page: How to match page sizes*. Retrieved November 2010, from: http://www.writersservices.com/wps/p_word_count.htm

Wyatt, H., & Amyes, T. (2005). *Audio post-production for television and film: An introduction to technology and techniques* (3rd ed.). Oxford, UK: Focal Press.

Xyratex. (November 2009). *Driving storage innovation* [PowerPoint Slides]. Retrieved November 2010, from: http://www.xyratex.mobi/company/Xyratex_Corporate_Presentation_10V102.ppt

You-hyun, K., Jong-hak, C., Chang-kyun, K., Jung-min, K., Sung-soo, K., Yu-whan, O., et al. (2006). Patient dose measurements in diagnostic radiology procedures in Korea. *Radiation Protection Dosimetry 123*(4), 540-545. Retrieved November 2010, from: http://rpd.oxfordjournals.org/

ZDNet-Australia. (2003, March 14). *SanDisk updates flash card line*. Retrieved November 2010, from: http://www.zdnet.com.au/

Ziegler, R. (n.d.). Retrieved November 2010, from: http://www.ziegler.desaign.de/

Zywietz, T. (2007). UK record sales 1964-2008: Albums by quarter and format, trade deliveries. *Statistical Handbook and Yearbook of the British Phonographic Industry (BPI) Ltd*. Retrieved November 2010, from: http://www.zobbel.de/stat/uksales_a.htm

D Communication

During the second half of 2011, we updated parts of our work on telecommunication (i.e. telephony and Internet, fixed and mobile) and extended the estimates of the installed capacity from 2007 to 2010. Given several updates in databases (i.e. ITU, 2011) and some methodological refinements (i.e. regarding FTTH/B), this introduces slight changes in comparisons to our estimates for the year 2007 published in López and Hilbert (2011).

D.1 General concepts

In the field of communication, a “transmission” is the act of sending information from one place to another (Laplante, 1999), i.e., the process of sending, propagating and receiving an information signal (which may be analog or digital) over a point-to-point or point-to-multipoint, wired or wireless medium. Some technologies (such as the Internet and telephony) permit bi-directional transmissions; in other words, the receiver and transmitter may switch roles. Other technologies, such as broadcasting, are focused on the unidirectional diffusion of information. In our study, we have defined “upstream” as a process for sending information, while “downstream” refers to a process for receiving information (both regardless of who initiates the communication)[29]. For example, in an analog broadcast channel, the “upstream” may be disregarded, whereas in a telephone channel, the size of the “downstream” and “upstream” channels are the same, so both parties could potentially speak (or sing together) at the same time, without any technological restriction whatsoever. An Internet connection will usually provide a larger "downstream" than "upstream", since users tend to “download” more information than they send. The transmission of a letter sent by post is considered per mail (not per communication), while a telephone channel has to consider both sides of the communication.

We present estimations on the quantities (we often present the numbers of devices shipped per year, and then specify the utility shelf life that contributes to the accumulation of the installed stock), performance and the resulting installed capacity in kilobytes per second (kbps). We have also estimated the effective use of technology per year (=365.2422 days = 52.18 weeks). In order to give a better idea about the average performance rates per telecommunication device and the contribution of normalizing on compression rates, we present here the resulting average hardware performance per device, and the optimally compressed performance for the year 2007.

[29] We refer to the “downstream” and “upstream” capacity of communication, which refers to the flow of information, instead referring to “download” and “upload” capacity, which refers to bringing data from a remote source to local storage and storing it there (Laplante, 1999), or “downlink” and “uplink”, which is mainly used for wireless and mobile communication.

Table D-1: Average performance rates per device or subscription resulting from our inventory of the installed Capacity in 2007.

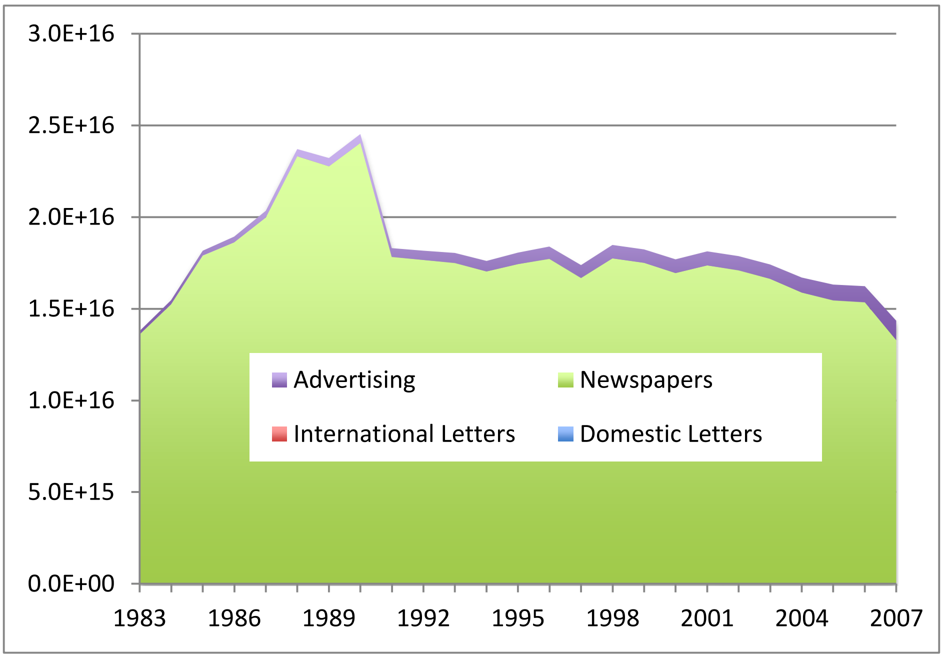
Category	Technology	Hardware bandwidth (in kilo-binary-digits per second) Downstream/ Upstream	Informational capacity (in optimally compressed kilobits per second) Downstream/ Upstream
	Broadcasting (unidirectional)		
Postal	Paper Newspapers^	0.015 / 0	0.0016 / 0
	Paper advertisement^	0.00025 / 0	0.00003 / 0
Radio	Radio analog	706 / 0	35 / 0
	Radio digital	192 / 0	71 / 0
GPS	*Personal navigation device*	0.46 / 0	0.23 / 0
Television	TV-Terrestrial analog (black & white)	59,921 / 0	1,010 / 0
	TV-Terrestrial analog (color)*	87,849 / 0	1,487 / 0
	TV-Cable analog*	87,255 / 0	1,477 / 0
	TV-Satellite analog	90,560 / 0	1,533 / 0
	*TV-digital (x3):** Terrestrial / Cable / Satellite*	4,256 / 15	2,144 / 11
	Telecommunications (bidirectional)		
Fixed-line telephony	Fixed-line phone analog	104 / 104	8.6 / 8.6
	Fixed-line phone digital	64 / 64	12 / 12
Fixed-line Internet (wireline and wireless)++	*Dial-up*	56 / 48	44 / 38
	ISDN BRI	128 / 128	102 / 102
	ISDN PRI	1,935 / 1,935	1,539 / 1,539
	Cable Modem	8,271 / 1,282	6,577 / 1,019
	DSL	2,890 / 834	2,297 / 662
	FTTH/B	26,736 / 8,027	21,272 / 6,387
	Other/unidentified	1,189 / 1,106	940 / 873
Voice mobile telephony	Analog (1G)	102 / 102	6.4 / 6.4
	GSM (2G)	8.5 / 8.5	8.0 / 8.0
	cdmaOne (2G)	13 / 13	4.0 / 4.0
	PDC (2G)	6.7 / 6.7	6.5 / 6.5
	TDMA (2G)	8.0 / 8.0	4.0 / 4.0
	iDEN (2G)	4.0 / 4.0	4.0 / 4.0
	GSM/GPRS (2.5 G)	8.5 / 8.5	8.0 / 8.0
	GSM/EDGE (2.5 G)	8.5 / 8.5	8.0 / 8.0
	CDMA2000 1x (3G)	8.6 / 8.6	5.6 / 5.6
	WCDMA / UMTS (3G)	15 / 15	11 / 11
	CDMA2000 1xEV-DO(3G)	13 / 13	12 / 12
Data mobile telephony	*GSM (2G)*	14 / 14	11 / 10
	cdmaOne (2G)	19 / 14	15 / 5
	PDC (2G)	29 / 29	22 / 20
	TDMA (2G)	10 / 10	7.4 / 6.7
	iDEN (2G)	19 / 19	15 / 13
	GSM/GPRS (2.5 G)	46 / 14	35 / 10
	GSM/EDGE (2.5 G)	100 / 42	77 / 29
	CDMA2000 1x (3G)	80 / 80	61 / 55
	WCDMA / UMTS (3G)	350 / 350	268 / 243
	CDMA2000 1xEV-DO (3G)	500 / 80	383 / 55
Postal	Postal letters^	0.000013 / 0.000013	0.000002 / 0.000002

Notes: ^Paper based communication devices are presented in "weekday units", which means that we assume that they are only delivered on the 261 weekdays of a year5. *The average performance of analog terrestrial TV is higher than the average performance of analog cable TV because there are proportionally more cable TV subscription in the U.S. and Japan (where NTSC is the standard), and NTSC has a lower performance than PAL/SECAM. ++The difference between fixed-line telecom (wireline or wireless, like WiFi) and mobile telecom is that the last one does not loose connectivity when the user is moving from one source of connectivity to another (with fixed-line connectivity the user has to reestablish connectivity once the source changes). ** We make one exception in our distinction between one-way broadcasting and two-way telecommunications. Technically, digital television counts with an upstream link and could therefore be classified as a telecommunication device. However, this upstream link is very small in comparison to the downstream link (roughly the bandwidth of 2G short-messaging-service) and has only been used very sporadically by users until the years 2007/2010 (mainly for some selected video-on-demand applications, which were very poorly developed until 2007). We therefore decided to count digital TV as part of the broadcasting capacity.

D.2 Postal Service

The following figure reports the total installed capacity in kilobits for each year.

Figure D-1: Transmission capacity of items sent by the postal service in [kb], without compression (hardware performance).



Source: Authors' own elaboration, based on various sources (see text). Note: The sharp decline between the years 1990-1992 has its origins in the collapse of the Soviet Union. During this time, the mail system in this region was re-organized as each country became independent. This was a fall that could not be recovered from in terms of bits, as the simultaneous declining trend of the amount of newspapers brought down the average performance. See also

Figure D-2.

D.2.1 Postal Service: Quantity

The amount of post sent per year by country is published by the *Universal Post Union* [UPU] (2010), who has kept statistics on the subject since the year 1980. The UPU publishes the total quantity of letter-post items by country, differentiating national traffic from international: "*Letter-post items basically consist of letters, postcards, printed papers (newspapers, periodicals, advertising, etc.), small packets, literature for the blind and, as applicable in the domestic service, commercial papers, samples of merchandise, "Phonopost" items, postal packets, etc*" (UPU, 2007).

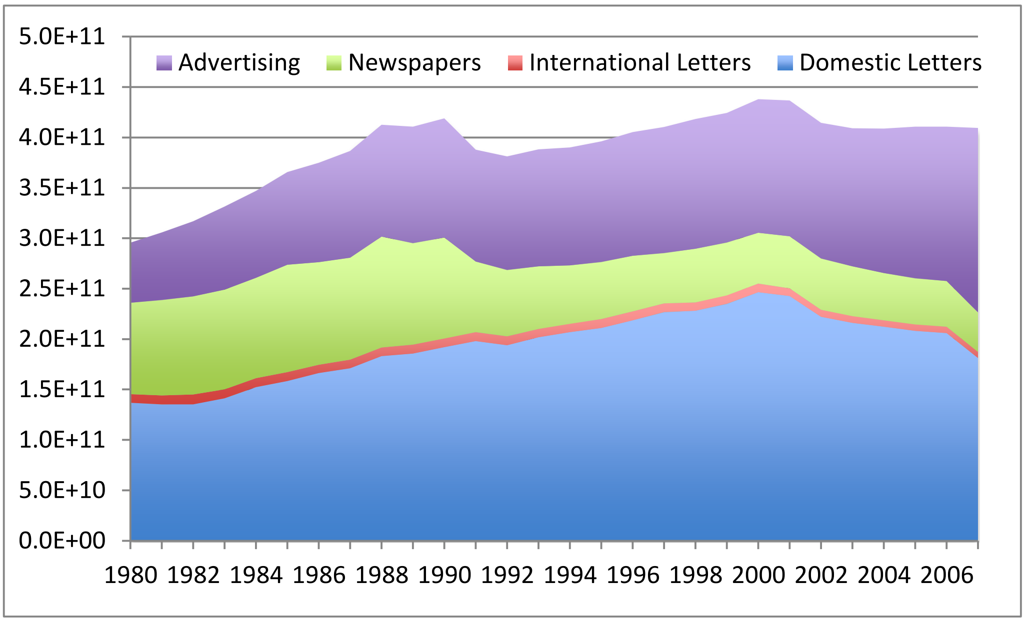
The total of letter-post items is divided between domestic service (sent = dispatched) and international (dispatched and receipt), opting to use the quantity received for the latter (given that, interestingly, it turns out to be more complete). For international traffic we have supposed that the total consists of letters with text. For domestic traffic, we have assumed that the total of letter-post items is made up of letters, newspapers, and advertisements. He have also assumed that whatever post items are neither newspapers or advertisements are text letters. The quantity of newspapers sent is published by the UPU as well. The information reported on advertisements is less complete, and only includes data for the years 1999-2007. Estimations for the years before 1999 are based on the relation between the complete series for the United States (Schmid, 2003; Strasser, 2003) and a sample of various other countries from many regions: during the period of 1999-2007 in the United States, 48% of all mail items were advertisements, while in the rest of the world, advertisements only made up for 37% of the total (averages of 9 years). We use this relation (year by year) to estimate the amount of advertising in the other countries for the years before 1999 (see Table D-2).

Table D-2: Percentage of letter-post items that were advertising (worldwide).

Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
%	*22*	*24*	*26*	*28*	*27*	*28*	*29*	*30*	*29*	*30*	*30*	*32*	*32*	*33*
Year	1994	1995	1996	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	
%	*32*	*33*	*33*	*33*	33	33	33	35	36	38	40	40	48	

Source: Authors' own elaboration, based on (UPU, 2010)

Figure D-2: Total postal traffic (amount of shipments)



Source: Authors' own elaboration, based on Universal Post Union (2010). Note: The sharp decline between the years 1990-1992 has its origins in the collapse of the Soviet Union. During this time, the mail system in this region was re-organized. As the chart shows, it took almost a decade (between 1990 and 1998) for the quantity of worldwide shipments to return to the pre-collapse level.

The amount of postal shipments (as reported in

Figure D-2) can not be directly compared with other communication technologies, because postal mail is counted by the quantity of messages, not by the amount of established communication channels (such as for phones or the Internet). To make both somewhat comparable, we suppose that a user who sends a postal mail per working day represents “one unit of mail”. We have divided the quantity of periodicals/advertisements/letters by 260.9 (5 working days per week * 52.2 weeks/year) and have obtained what is called “units of working days of postal mail”

D.2.2 Postal Letters: Performance

The United States tariff system supposes that the weight of a letter is 20 grams (TNT, 2007). Furthermore, the type of paper used is considered to be A4 (each with a weight of 3.87 grams)[30], which would imply that a letter may contain up to 4 pages and an envelope. We assume that both sides of each sheet of paper have been written on. Since the vast majority of letters are not sent from homes (only about 10% each side in the United States (United States Postal Service [USPS], 2007)), we may assume that they are written by machines (typewriters or computers) using the “Times New Roman font style with a text size of 12”, with 815 words on one side of the paper used (Writer Services, 2010). This means that a letter would contain 6520 words (8 sides x 815 words), resulting in 35860 individual characters (considering an average of 5.5 characters per word (Pierce, 1980)). According to the encoding used by most information programs (i.e. ASCII, American Standard Code for Information Interchange, pronounced [AS-kee], and Unicode UTF-8) 8 binary digits (one byte) are used to encode each character (2^8 = 256 symbols) (Korpela, 2006; Moulton, 2001). The result comes to a total of 286880 binary digits per letter. This performance is multiplied by the amount of letters sent per year. To calculate the upstream and downstream capacities, we have divided the total number of letters into two equal parts.

We have also calculated the average speed of postal mail (this number is not needed for most of the exercises that we do, since we simply work with yearly totals, but it does matter when one wants to calculate something like a Gini coefficient, for which one needs the average performance). For national mail, it takes on average between 3 and 5 days for a letter to arrive; while international mail takes between 8 and 10 (USPS, 2010; Correos de Chile, 2010; Correos de España, 2010). Considering the alternative of express mail, we opt for the lowest limit of the estimates found: 3 days for domestic mail and 8 days for international (see Table D-3). The low bandwidth of postal mail explains its little contribution to the global technological capacity to communicate.

Table D-3: Bit transmission rates (bandwidth) for national and international postal mail

	National Mail	International Mail
Letter sent by post (kilobits/second)	0.001107	0.000415

Source: Authors’ own elaboration, based on various sources (see text).

[30] in Table D-4, Appendix D.

D.2.3 Newspapers: Performance

To calculate the performance of newspapers, we have kept the same assumptions made for storage technology (see Appendix D, chapter D.1). Using samples taken from the New York Times (from between 1975-2005), we assume that the performance of a newspaper depends on the year of its publication, the amount of images and text, and the quality of the images. Therefore, the values in Table D-4 are achieved by multiplying 60 [pages/periodical] with the number of periodicals published per year. The average of 60 pages was obtained by comparing the number of periodicals sent with the statistics on produced (stored) newspapers (the number of produced periodicals should be higher, since they are also sold at newsstands[31]). We consider the total of periodicals as downstream capacity.

Table D-4: Kilobits per printed page in periodicals (incl. images and text), without compression (hardware performance).

1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1,616	1,621	1,625	1,629	1,633	1,638	1,642	1,904	2,163	2,419	2,672
1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
2,921	3,167	3,410	3,649	3,884	4,117	4,345	4,570	4,792	5,010	5,224
1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
5,434	5,448	5,461	5,475	5,488	5,502	5,516	5,529	5,543	5,556	5,570

Source: Authors' own elaboration, see Appendix D.

D.2.4 Advertising: Performance

Many different types and sizes of mail are used for the purpose of advertising (Reinfeld, 2010; JWM Direct Marketing, 2010, International Paper Knowledge Center, 2010), which is also sometimes called "direct mail" (UPU, 2007). In agreement with (Romano, 2007), the formats of direct mail in the United States are as follows: 51% are letters in envelopes, 16% are post cards, 22% are self-mailers, with the remaining 11% being made up of other types, such as posters or free samples. For lack of better information, we assume that printed advertisements in envelopes (with the recipient's address, such as advertisements for businesses and banks) make up for half of all direct mail; with the other half being composed of self-mailers (without addresses). For advertisements in envelopes (with address), we adopt the same estimations as were made for postal mail letters. While it is assumed that mail letters include about 4 pages, advertisements have only two, with

[31] The New York Times has an average of 85 pages per edition (see Table D-2 in Appendix D, section 1.1.2), but this assumption would mean that more periodicals are sent than are produced. We suspect that the New York Times is an extraordinarily extensive newspaper, in comparison with many local newspapers, which are less pagC-intensive.

writing on both sides (Sharpe, 2005). So we obtain a total of 3260 x 5.5 = 14930 characters, coming to 143440 bits. As for self-mailers, they are nothing more than pieces of sturdy pre-folded paper, or else pamphlets or flyers which do not require any envelope (Hahn et al., 2003). Their size is typically smaller than that of a sheet of newspaper (Sharpe, 2008; Batra, 1999; Hahn et al., 2003), and the distribution of images to text depends on the content of the advertisement. We may suppose that they are designed in the same way as newspapers (two pages) but are half the size. Considering that a self-mailer consists of 4 pages of advertising, we multiply the figures from Table D-4 by 2 [pages of newspaper], and then multiply that value with the amount of sent advertisements by year. We can consider the advertising total as downstream capacity.

D.2.5 Compression of Content

For compression of content, we use the compression factors reported in Table D-5. These correspond to the "optimal" factors achieved in 2007 (6.6 for text (PPMd), 16 for images in gray scale and 48 for high quality JPEG images in color), and the typical factors for the years 1986, 1993, 2000 and 2007 (for more information, see Appendix A).

Table D-5: Compression factors

	1986	1993	2000	2007	"Optimal"
Text	2.2	2.9	4.6	4.7	6.6
Color image	1	7.0	14.0	14.0	16.0
B&W image	1	4.7	4.7	4.7	6.0

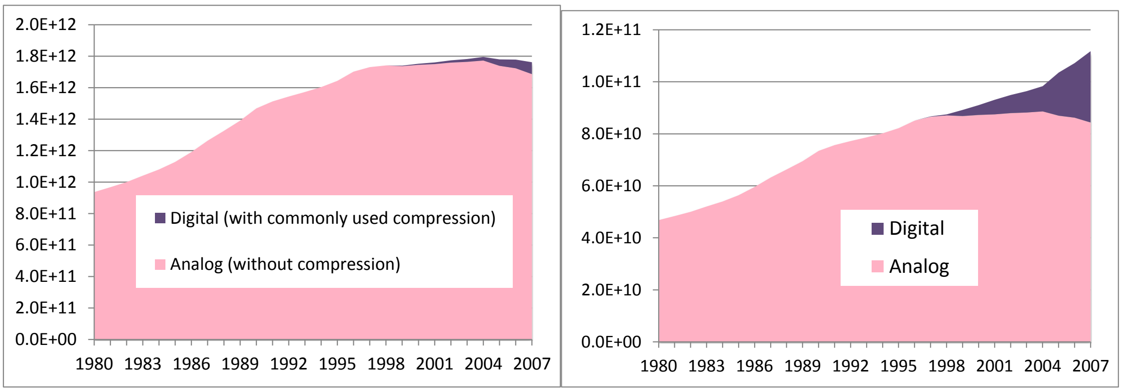
Source: Authors' own elaboration, based on various sources (see text).

D.3 Radio

For the analog transmission of signals from radiostations, two forms of modulation are used: AM (Amplitude Modulation) and FM (Frequency Modulation). Of the two, FM provides a higher fidelity than AM, as it is able to minimize the noise effect. Since radio has the ability to reproduce information from a station at a given moment, it is assumed that only FM radio is transmitted, and with this we estimate the maximum installed transmission capacity.

Figure D-3(a) shows the capacity "hardware" (which reports the quantities of data "just as they are sent": digital being compressed and analog without compression) and (b) normalized on optimal compression. We can see the trend of digital technologies which make it possible to send fewer and fewer "binary digits", while more "bits of information" are received. This clearly shows the importance of normalizing by rate of compression.

Figure D-3: Transmission capacity of radio in [kbps]; (a): without compression (hardware performance); (b): normalized with optimal compression of 2007.



Source: Authors' own elaboration, based on various sources (see text).

D.3.1 Radio: Quantities

The total number of radio receivers for each country is registered in the database at (International Telecommunications Union [ITU], 2009). For lack of information of digital radio, we make the assumption that every home that receives digital TV also receives digital radio. Specifically, we assume that for every digital television, whether it be terrestrial, cable, or satellite (see D.4.1.2), the house will have a digital radio. However, we apply this logic only for those countries that count with digital radio, from the year of its introduction (Table D-6). This results in the estimation that in the year 2000, 2% of the world's radios received digital signals, and in 2007, 14%.

Table D-6: Countries with DAB deployments (*Digital Audio Broadcasting*).

Country	Intro	Country	Intro	Country	Intro	Country	Intro
Austria	1999	Hungary	1997	Spain	2000	China	1996
Belgium	2000	Ireland	2005	Sweden	1995	India	1997
Croatia	1997	Israel	1996	Switzerland	1999	Singapore	1999
Czech Rep.	2006	Italy	1995	Netherlands	2004	South Korea	2005
Denmark	1999	Lithuania	2001	UK	1995	Taiwan	2000
Finland	1999	Norway	1999	South Africa	1999	Australia	1999
France	1997	Poland	2003	Canada	1999	Japan*	2005
Germany	1997	Portugal	1998	USA	1999	Malta	2006

Sources: (Hoeg & Lauterbach, 2003; World DMB, 2007; Peter Fleming Consulting, 2006; Digital Radio, 2010, "Countries using DAB/DMB", 2010)

D.3.2 Radio: Performance

The estimate of the rate of bits per second in the transmission of an analog FM radio signal is made following Nyquist's theorem (2002), which makes it possible to calculate the bit rate according to the following formula: rate of bits per second = sample rate * number of bits per sample. Given that two channels are sent in an FM radio transmission (stereo sound), the result shown in the equation must be multiplied by two.

Table D-7: Bit rate for the analog transmission of AM and FM radio signals.

Quality	Sample Rate [Hz = 1/s]	Sample Rate	Bit rate/channel [kbps]	Total Bit rate (stereo) [kbps]
Radio FM	22 050	16	352.8	705.6

Source: Marshall, 2001; Smith, 1997.

Regarding digital radio, the audio signal is not only digitized, but also compressed with MPEG- Layer II with MUSICAM (Masking pattern adapted Universal Sub-band Integrated Coding and Multiplexing). This technology is applied to help reduce the rate of bits necessary for the transmission. The first implementation of these systems towards the end of the 90's in the United Kingdom and United States used a rate of 128 [kbps], providing medium to high quality audio ("Digital audio broadcasting", 2010). To improve quality, round the middle of the year 2000, stations in different countries increased the bit rate to 192 [kbps]. For a lack of more exact information, we suppose a linear transition between 128 [kbps] in 2000, up to 192 [kbps] en 2007. Radio is considered as downstream capacity.

D.3.3 Compression of content

The content of radio is sound. The only difference between radio at 128 [kbps] and at 192 [kbps] is that the latter allows more redundance (less compression), therefore achieving a more robust transmission. The first achieves a compression factor of 11.025 and the second a factor of 7.35. Using the most efficient compression available in 2007 (MPEG-4 HC-AAC), we get a factor of 20. Compressed at the optimal level, analog radio transmits 35.3 kbps and digital radio 70.6 [kbps], clearly showing the superior quality of the latter.

Table D-8: Compression factors

	1986	1993	2000	2007	"Optimal"
Factor	1	1	11.025	7.35	20

Source: Authors' own elaboration, based on Appendix A.

D.3.4 Effective use

Estimates based on various sources are reported in Table D-9.

Table D-9: Effective use in hours per week.

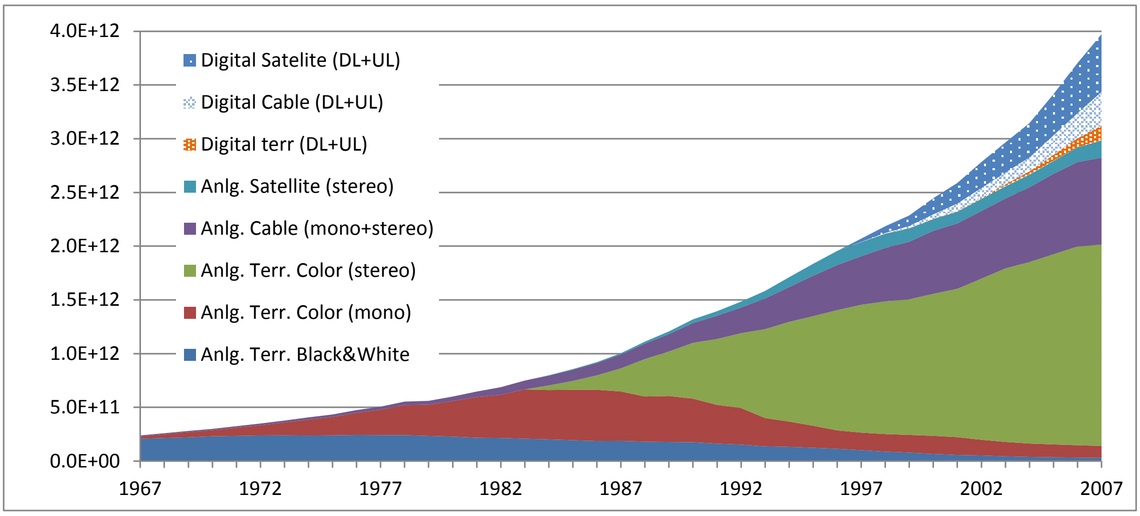
	1986	1993	2000	2007
OECD	16.8	13.9	13.2	13.2
Non OECD	28.7	23.8	22.5	18.2

Sources: Authors' own elaboration based on (Arbitron, 2006; Arredondo, 2007; Bolea, 2009; Chahdi, 2001; Dutton, 2007; Ewing & Thomas, 2008; Fábián et al., 2007; Findahl, 2008; Godoy, 2004, 2009; Hornik & Schlinger, 1981; Ibarra & Arabito, 2005; Koenan et al., 2003; Lebo, 2002; Liang, 2005, 2007; Mayer, 1993; Media InfoCenter, 2010; Mediascope Europe, 2008; Mediatica, 2006; Mikami et al., 2002, 2005; MK Marketing, 2004; Nielsen, 2007; Patiño, 2007; Pineda, 2003; Reitze & Ridder, 2005; Reyes & Vorher, 2003; Rideout et al., 2010; Secretaria Nacional de Ciencia, Tecnología e Innovación [SENACYT], 2006; Shepherd, 2009; Statistics New Zealand, 1999; Statistics Norway, 2002; WIP-Mexico, 2008; Zamaria & Fletcher, 2008). Note: the values shown for 1986 and 1993 for non-OECD countries were estimated based on the relation to OECD for the year 2000.

D.4 Television

There are three methods of transmitting analog or digital television signals: terrestrial (or land-air), satellite or cable. The following figure reports the total installed capacity in [kbps] for each corresponding year.

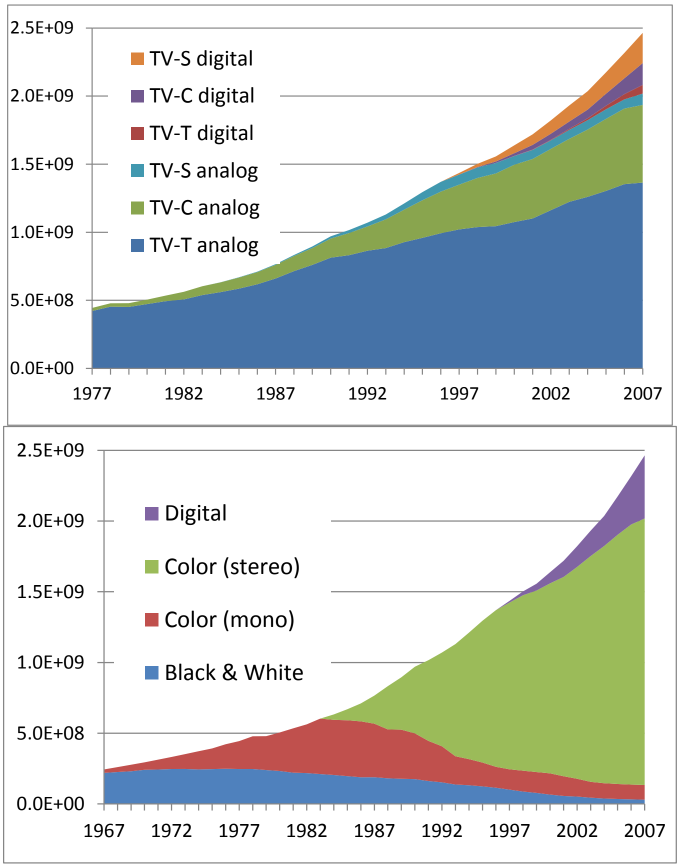
Figure D-4: Transmission capacity of TV in [kbps], normalized with optimal entropic compression.



Source: Authors' own elaboration, based on various sources (see text).

D.4.1 Television: Quantity

Figure D-5: Quantity of TV receivers by technology



Source: Authors' own elaboration, based on ITU (2011).

D.4.1.1 Analog Television: Quantity

The number of television receivers in each country for the period 1960 - 2007 is reported by ITU (2011). Empty gaps are filled using linear estimates, considering the years of introduction of TV in each respective country. Monocromatic television is separated from color TV, considering the year of introduction of color TV presented in Table D-10. Missing countries were estimated by taking a simple average of the five world regions.

Table D-10: Years of introduction of television and color transmissions.

Country	Intro. TV	Intro. color	Country	Intro. TV	Intro. color	Country	Intro. TV	Intro. color
Albania	1960	1981		1963	1973	Nicaragua	1956	1973
Western Germany	1950	1967	Ghana	1965	1980	Nigeria	1959	1974
Eastern	1952	1969	Gibraltar	1962	1969	Norway	1960	1972
Netherlands Antilles	1960	1973	Greece	1966	1976	New Caledonia	1965	1971
Saudi Arabia	1965	1973	Greenland	1958	1970	New Zealand	1961	1973
Algeria	1956	1979	Guadalupe	1964	1972	Pakistan	1964	1976
Argentina	1978	1978	Guam	1956	1967	Panama	1959	1972
Australia	1956	1967	Guatemala	1956	1970	Papua New Guinea*	1986	1986
Austria	1955	1969	Equatorial Guinea	1968	1976	Paraguay	1965	1981
Bahrain	1973	1973	French Guyana	1967	1974	Peru	1958	1972
Bangladesh	1964	1980	Haiti	1959	1975	French Polynesia	1965	1971
Belgium	1953	1971	Holland	1951	1968	Poland	1954	1971
Bermuda	1958	1968	Honduras	1959	1973	Portugal	1957	1976

Bolivia	1963	1979	Hong Kong	1967	1970	Qatar	1970	1974
Brasil	1951	1972	Hungary	1954	1969	United Kingdom	1936	1967
Brunei*	1975	1975	India	1959	1979	Dominican Republic	1952	1969
Bulgaria	1959	1970	Indonesia	1962	1977	Reunion	1964	1972
Burundi	1984	1985	Iran	1956	1973	Romania	1957	1983
Bhutan*	1995	1995	Iraq	1966	1968	America Samoa	1964	1969
Cambodia	1962	1980	Ireland	1961	1971	Senegal	1965	1975
Canada	1947	1966	Iceland	1966	1973	Sierra Leone	1963	1978
Czechoslovakia	1954	1973	US Virgin Islands	1961	1968	Singapore	1963	1974
Chile	1958	1972	Israel	1966	1977	Syria	1960	1980
China	1958	1977	Italy	1952	1977	Sri Lanka	1979	1979
Chipre	1964	1976	Jamaica	1963	1975	South Africa*	1976	1976
Colombia	1954	1973	Japan	1953	1960	Sudan	1976	1976
Congo	1966	1975	Jordan	1968	1974	Sweden	1956	1970
North Korea	1963	1974	Kenya	1962	1978	Switzerland	1953	1968
South Korea	1961	1975	Kuwait	1961	1974	Suriname	1965	1977
Ivory Coast	1963	1970	Lebanon	1959	1975	Thailand	1955	1973
Costa Rica	1960	1973	Liberia	1964	1975	Taiwan	1956	1969
Croatia*	1992	1992	Libya	1968	1976	Trinidad and Tobago	1962	1969
Cuba	1949	1975[32]	Lithuania	1957	1991	Tunisia	1966	1976
Denmark	1955	1969	Luxembourg	1955	1972	Turkey	1972	1981
Djibouti	1967	1974	Macao*	1981	1981	Ukraine	1951	1984
Ecuador	1959	1974	Madagascar	1967	1977	Uganda	1963	1975
Egypt	1960	1973	Malasia	1963	1972	Uruguay	1961	1980
El Salvador	1958	1973	Malawi*	1999	1999	USSR	1938	1968
United Arab Emirates	1969	1974	Malta	1962	1978	Venezuela	1965	1973
Spain	1959	1972	Morocco	1964	1973	Vietnam	1968	1978
United States	1941	1953	Martinique	1964	1969	North Yemen	1964	1979
Estonia	1955	1967	Mauritius	1965	1973	South Yemen	1975	1981
Ethiopia	1964	1979	Mexico	1950	1963	Yugoslavia**	1956	1971
Fiji*	1991	1991	Monaco		1973	Zaire	1963	1980
The Phillipines	1953	1974	Mongolia	1967	1975	Zambia	1961	1979
Finland	1954	1969	Nicaragua	1956	1973	Zimbabwe	1960	1984
France	1944	1967						
Average years of introduction of color TV by continent to estimate countries not included in the list above.								
Africa		1977	Asia		1975	Oceania		1977
Latin America and the Caribbean		1973	Europe		1972	North America		1962

Source: ("Timeline of the introduction of color…", 2010; "Timeline of the introduction of televisión…", 2010). Notes: (a) The countries marked with an asterisk (*) received their first TV transmissions in color (never before having transmitted in black and white). (b) For countries such as Germany or Yemen, who have since united, we consider the earliest date of introduction for our estimations. (c) Since 1992, Yugoslavia corresponds to the nations of Serbia, Bosnia and Herzegovnia, Macedonia, Montenegro and Slovenia.

Since there is no data available on the speed of technological replacement for color TV, we estimate a process of substitution registered for the case of the United States (U. S. Census Bureau, 2010; Television History, 2001; see Table D-11). This assumption has two problems: (a) together with Japan, the U.S. was the first country to adopt television in color. One would expect that followers (countries that began the transition later on) would have speeded up the replacement process, since the technology was already older and for that reason, less expensive; (b) most countries are poorer than the United States, which results in a reverse effect, which is to say, a slower

[32] In Cuba, the transmission of color signals began in 1958 and ended in 1959, only to return again in 1975.

diffusion. Instead of getting lost in adjustments and counter-adjustments, we will assume that the two effects cancel each other out, thus justifying the use of the United States' diffusion S-curve as an approximation for all countries.

Table D-11: Percentage of homes with color TVs in the United States (1964 – 1978).

1960	1961	1962	1963	1964*	1965	1966*	1967
0.74	*1.39*	*1.98*	*2.55*	3.10	5.31	9.65	16.33
1968*	1969	1970	1971*	1972*	1973*	1974*	1975
24.16	32.00	35.23	45.32	52.56	60.06	67.29	68.47
1976	1977	1978	1979	1980	1981	1982	1983
73.56	77.11	78.05	80.94	82.89	87.61	88.72	90.45
1984	1985	1986	1987	1988	1989	1990	1991
91.76	93.25	94.62	95.51	96.67	97.83	97.85	98.91
1992	1993	1994	1995	1996	1997 – 2007		
98.91	98.92	98.94	98.95	98.96	100.00		

Source: Authors' own elaboration, based on U. S. Census Bureau, 2008; * Television History, 2001.

With regard to technological advances in audio transmission, we consider that monochrome televisions always use monaural sound ("FM broadcasting", 2010). It is assumed that in 1984, all countries belonging to the OECD (Organisation for Economic Co-Operation and Development) began transmitting in stereo, and that after 1984, all new televisions came equipped with stereo technology. For the rest of the world (non-OECD), an average gap of 15 years between the year of introduction of color TV and the introduction of stereo may be assumed, based on data from four developing countries (TVN Chile, 2010; Brazil, Rudinei, 2010; Malaysia "TV3 (Malaysia), 2010; ArgentinaRock.com.ar, 1996). We may also suppose that all satelite television channels broadcast in stereo.

Starting out with the total number of TV subscriptions reported by ITU (2011), we subtract the number of TVs subscriptions that receive cable, satellite or digital signals from the total number of color TV subscriptions, since we have supposed that (i) subscription to one of these services does not include reception to terrestrial analog TV; and (ii), all who subscribe to cable, satellite, or digital TV services have color televisions. To complete the gaps for the missing years based on the ITU (2011), we look to several sources (Arab Advisor Group, 2006; BDA, 2009; Business Wire, 2008; CableLabs, 2006; Centro de Investigaciones de las Telecomunicaciones [CINTEL], 2008; China Cablecom, 2008; Comisión Nacional de Defensa de Competencia [CNDC], 2007; Comisión Nacional de Televisión-Colombia [CNTV], 2009; Directorate General of Press and Information, 2010; Domain-b.com, 2008; European Comission Information Society, 2008; Forrester, 2008; Informa Telecoms & Media, 2009; IP-Network, 2007, 2008, 2009; Koren, 2010; KPMG, 2009; Laboratorio de Industrias Culturales [LIC], 2008; Mazumdar, 2010; OECD, 2009; Quinde & Borja, 2006; Research in China, 2009; Sportcal, 2010; Subsecretaría de Telecomunicaciones-Chile [SUBTEL], 2010; Thomas & Nain, 2004; TV History, 2010; Vergara, 2007; Yes, 2009) and also assume that all countries belonging to the OECD already had cable television subscribers before 1960 (Reina, 2002; “Cable television”, 2010; Kurachi, 1986), with the exception of France, who only had a penetration of 2% in 1984 (“The cable and…”, 2010). For the remaining countries, we consider that cable television services began in 1990 (“Cable television”, 2010). Linear interpolation is used between this year and the first year when statistics were had. As for satellite televisions, we consider that OECD countries began to have their first subscribers in 1990, given that companies such as Sky, PrimeStat and DirecTV appeared around this time (“Satellite television”, 2010; Marples, 2004). We interpolate in a linear fashion.

Given that data from the ITU (2011) reports subscribers of both cable and satellite, and because we want to estimate how much information is displayed (after effectively being communicated), we must multiply this figure by the number of receivers per household in order to obtain the total quantity of televisions receivers (Table D-12). We estimate the shelf life of a television at 10 years (South Dakota Official State Government, 2005).

Table D-12: Average number of TV receivers per home.

Year	60-75	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
OECD Average	1.23	1.25	1.25	1.28	1.31	1.28	1.34	1.31	1.34	1.34	1.34	1.37	1.38	1,37	1,40
Average for the rest of the world	1.10	1.15	1.16	1.16	1.27	1.18	1.21	1.22	1.26	1.22	1.22	1.24	1.26	1,23	1,20
Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002		2003 - 07
OECD Average	1,44	1.45	1.43	1.44	1.49	1.52	1.51	1.53	1.55	1.51	1.53	1.64	1.69		1.72
Average for the rest of the world	1,23	1.23	1.19	1.23	1.29	1.30	1.31	1.34	1.36	1.34	1.36	1.37	1.37		1.37

Source: Authors’ own elaboration.

D.4.1.2 Digital TV: Quantity

Up until 2007, only 35 countries had digital TV networks deployed and up and running (see Table D-13); of which 28 used DVB (DVB, 2008); 5, ATSC and only 1 DMB and ISDB technology.

Table D-13: Years of introduction for digital TV service.

Country	Year	Country	Year	Country	Year
Albania	2003	Andorra	2005	Australia	2001
Austria	2005	Belgium	2002	Czech Republic	2005
Denmark	2006	Estonia	2006	Faroe Islands	2002
Finland	2001	France	2005	Germany	2002
Norway	2007	Italy	2003	Lithuania	2006
Luxembourg	2006	Malta	2005	Mauritius	2005
Namibia	2005	Holland	2003	Spain	2000
Saudia Arabia	2006	Sweden	1999	Switzerland	2001

Taiwan	2004	Slovenia	2007	Ukraine	2006
United kingdom	1998	Mexico [ATSC]	2004	South Korea [ATSC]	2001
United States [ATSC]	1998	Japan [ISDB]	2003	Canada [ATSC]	1998
Puerto Rico [ATSC]	1998	Hong Kong [DMB]	2006	Poland	2007
Brasil	2007	Croatia	2007		

Sources: (Digital Video Broadcasting [DVB], 2010; Ricker, 2006; DTV Status, 2007)

The data used is recorded by the OECD (2001; 2005 y 2007), among other sources (Autoridade Nacional de Comunicações [ANACOM], 2008, 2009; Association of Regulatory Authorities [ALM], 2005, 2008; ASTRA, 2008; Australian Communications and Media Authority [ACMA], 2008; Berni, 2007; Briel, 2008; Business Wire, 2006; Cable Europe, 2009; Canadian Radio-Television and Telecommunications Commission [CRTC], 2009; Convergence Korea, 2009; Datamonitor, 2008; Dataxis, 2006; Davies & Delaney, 2005; Digitalisierungsbericht, 2008a, 2008b; Hana Institute of Finance, 2007; IDATE, 2000a, 2000b; Informa Media Group, 2004Ishiyama, 2003; MAVISE, 2010Media Partners Asia Ltd. (MPA), 2005; Ministry of Internal Affairs and Communications [MIC], 2009; National Cable & Telecommunications Association [NCTA], 2009, 2010; NHK, 2006; Nippon Network Television Corporation [NTV], 2006; OfCom, 2003, 2004, 2005, 2007a, 2007b, 2007c, 2008a, 2008b, 2009a, 2009b 2009c; Regulatory Authority for Broadcasting and Telecommunications [RTR], 2005, 2007, 2008, 2009; ResearchInChina, 2010; Statistics Canada, 2005; Summerfield, 2006; Tam, 2001; United Nations Educational, Scientific and Cultural Organization [UNESCO], 2007; Werner et al., 2004), to show the number of households with digital and cable TV subscriptions in 1997, 1998, 1999, 2001, 2003 and 2005. Linear interpolation has been applied to estimate the missing statistics. It is supposed that non-OECD countries behave in the same way, but adjusted according to the year of introduction in the respective country from Table D-13. This applies to the total number of receivers reported by the ITU (2011).

Table D-14: Average percentage of households with digital TV subscriptions.

	1997 Intro. year TV-d	98/ Year 2	99/ Year 3	00/ Year 4	01/ Year 5	02/ Year 6	03/ Year 7	04/ Year 8	05/ Year 9	06/ Year 10	07/ Year 11
Terr. [%]	0.00	0.04	0.09	0.15	0.48	0.78	1.67	3.17	5.23	8.27	15.12
Cable [%]	0.04	0.26	0.66	1.56	2.46	2.62	2.75	4.64	4.96	7.93	10.87

Source: Authors' own elaboration, based on various sources (see text).

There is not a single source on basis of which to estimate the worldwide trend of digitization of satellite TV. There is data available for digital satellite TV for some of the OECD countries (2001; 2005 and 2007), which we complete with various other sources (ANACOM, 2008; Datamonitor, 2007; Ofcom, 2008c; RTR, 2005; Statistics Canada, 2005; Yamamoto, 2004; Informa Media Group, 2004). The remaining part of Europe is estimated with the simple average of the European countries, for which we have statistics (OfCom, 2008c). The distribution of digital/analog is also reported for Brazil, India, Russia and China. The simple average of these four major developing countries results in a division of almost 50% digital and 50% analog for 2007.

This formula is used for the rest of the countries for which we have no better information. Based on the information that we have, it is estimated that in the year 2000, a third of satellite televisions were digital, and that in 1996 satellite television made its mass introduction on the market outside the United States (where it began in 1994). For countries without better data, we use linear interpolation.

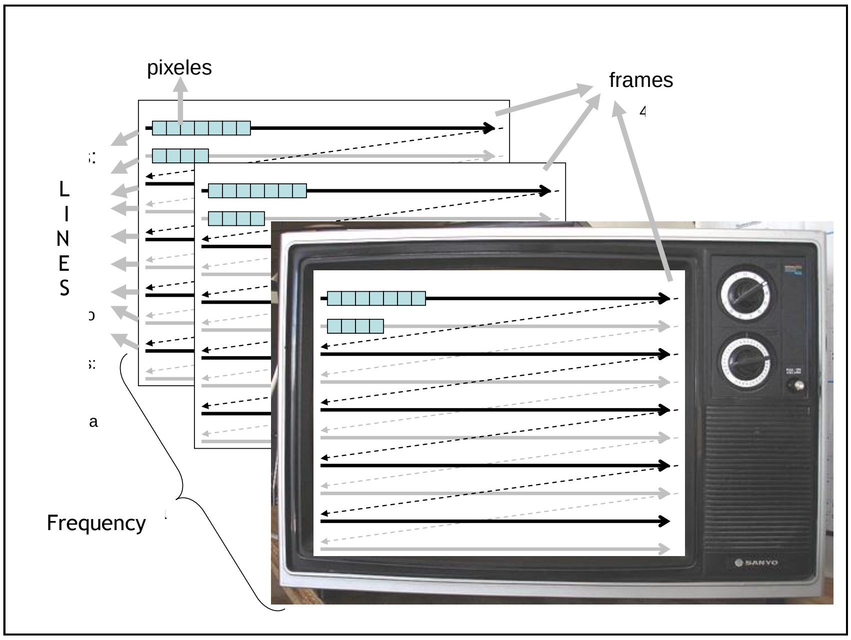
D.4.2 Television: Performance

D.4.2.1 Analog TV in Black and white: Performance

What follows should be considered an approximation of the performance of a typical TV, always taking into consideration that there were 14 different standards in use in the world, of which the number of brand lines varied from 405 (United Kingdom) to 819 (France) (Benoit, 2008).

In order to obtain an estimation on the number of binary digits which are transmitted per second, we must follow the procedure of continuous signals, which consists of sampling and quantization. First of all, we assume that one sample corresponds to a pixel (picture element), that means the smallest sub-division of a TV image (Jack & Tsatsulin, 2002), which in the analog practice is not a pixel, but corresponds to a tiny section with its shape and dimension defined in the phosphor-coated screen of the television (Salomon, 2007). We have to consider: (i) the resolution of the TV image (total number of pixels in a frame) and (ii) the pixel rate per second in accordance with the frame refresh rate used, both following the specifications of each standard. With this last result, what remains is to assign to each pixel the number of bits needed for the representation of the corresponding brightness intensity.

Figure D-6: Breakdown of the display on a television screen



Source: Authors’ own elaboration.

In Table D-15, we summarize all the variables necessary to make an estimate on the transmission rate for standard quality television. The amount of time that it takes to scan a complete line (line length (active) in Table D-15) and to change a line (12 [us] in PAL/SECAM and 10.9 [us] in NTSC)[33] corresponds to the length of the line (total) in Table D-15 and the inverse of this sum, the line frequency. On the other hand, once you have finished scanning the field lines, the cannon returns to the top of the screen. This "return" takes close to 8% of the total scan time (Wootton, 2005), for which the total number of lines in a frame, almost 92%, are actually displayed on the screen (active lines per frame in Table D-15). For its part, the duration of field is nothing more than the product between the line length (total) and the number of lines which each field has. The horizontal-vertical ratio (*ratio aspect*) of 4:3 was chosen by Thomas Edison when he created the first projectors and cameras. It is the standard for transmitting SDTV (Salomon, 2007). This means that for every 4 parts that measure the base (ex. 1 [m]), there is a height of three of these parts (e.g. 0.75 [m]).

Table D-15: Black and white TV: CIF (*Common Image Format*) SDTV (*Standard Definition*) for PAL/SECAM and NTSC.

Item	Characteristics	NTSC	PAL/SECAM
1	Frame rate [fps]	30 (29.97)	25
2	Field frequency [Hz]	60 (59.94)	50
3	Type of scan	Interlaced (2:1)	Interlaced (2:1)
4	Lines per frame (total)	525	625
5	Lines per frame (active)	480	576
6	Horizontal resolution (active) [pixel][34]	442	520
7	Line frequency [kHz]	15.75 (15.734)	15.625
8	Line length (total) [us]	63.5 (63.55)	64
9	Line length (active) [us]	52.6	52
10	Interval length blanking [us]	10.9	12
11	Field length [ms]	16.7	20
12	Horizontal/vertical screen	4:3	4:3
13	Broadband for videos [MHz]	4.2	5.0

Source: (Ibrahim, 2007, Arnold, Frater & Pickering, 2002; Couch, 1997). Note: The specifications correspond to the standards of analog color televisions. This is justified in the following: The standards shown in the table are "evolutions" of the monochrome TV systems in use at the time of its formation; for example, NTSC (National Television System Committee) is based on and is compatible with the RS-170 used in North America of 525-lines, 60 fields per second and interlaced 2:1, the same way in which PAL (Phase Alternation Line) and SECAM (Sequentiel Couleurs á Memoire) come from the standard which was defined by the CCIR in Europe of 625-lines, 50 fields per second and interlaced 2:1 (Jack, 2005; Benoit, 2008).

[33] 17% of the total line length is used in the synchronization pulses for NTSC, in the same way 19% of it is PAL/SECAM, so 83% and 81% are used to transmit videos.

[34] The horizontal resolution is an approximation of the number of pixels per line that an analog TV would have if it were digital. This value is calculated as a broadband function which the standard in question has available for the transmission of a video signal (BW) and the line length (active), i.e., the difference between the total line length (T_h) and the time it takes to change from one line to another (blanking, T_b), according to the following formula: $Resolution_{horizontal}$ [pixels/line] = $2 * BW_{video} * (T_h - T_b)$ (Couch, 1997). Concerning PAL and SECAM, which have different "sub-standards" according to the width of band available for video signals, we have decided on those with: PAL -B/G/H and SECAM-B/G, both with 5 [MHz]. It is important to note that for standard digital television, the horizontal resolution is in agreement with what is defined by BT.601 of ITU-R, which is to say, 720 pixels per line, which explains the better quality of the image.

The digitization of a TV image, which means to show the content of a signal frame by frame and line by line, requires that there be just as many lines per sample as there are pixels in each of them, in order to keep the quality of the image. For domestic applications, like the transmission of TV and DVD, black and white encoding with 8 bits is considered appropriate (Ibrahim, 2007), i.e., they can represent up to 256 different shades of gray between black and white. That is how standard definition TV has the resolution shown in Table D-16, which was calculated with the equation: byte rate per second [bits/s] = {[No. Pixels per line] * [No. Active lines per frame] * [Frames per second] * [bits per pixel]}.

Table D-16: Resolution for standards of analog TV in black and white and rate transmitted.

Standard	No. Active lines	No. Pixels per Líne	Resolution [píxels/frame]	Refresh rate [frames/s]	Pixel rate [píxels/s]	Depth [bits/píxel]	Bit rate [bits/s]
NTSC	480	442	212 160	30	6 364 800	8	50 918 400
PAL/SECAM	576	520	299 520	25	7 488 000	8	59 904 000

Source: Authors' own elaboration, based on various sources (see text).

The audio signal is transmitted separately from the video. All bandwidth is assigned to one TV channel (6 MHz for NTSC and 8 MHz for PAL/SECAM[35]), 50 kHz are used to transmit analogically with an FM modulation (Ibrahim, 2007). For monochrome television, we assume that only a monaural sound is transmitted. The frequency response of the transmitted audio signal corresponds to 0.02 – 20 [kHz] (Youngquist, 1978), which implies that for its digitization, it is necessary to have a sampling frequency of at least 44 [kHz], in agreement with Nyquist's theorem, and the recommendations of Ibrahim (2007). Assuming that each sample is assigned 8 bits, we get that the transmitted rate (uncompressed) would be equal to 352 [kbps], the same as the quality in analog radio (see Table D-17). We look at the total of black and white analog TV and the downstream capacity.

Table D-17: Complete rate of binary digits for analog TV in black and white.

Standard	Black and White TV signal	Binary digit rate [bps]	Binary digit rate [Mbps]
NTSC	Video	50 918 400	*50.92*
	Audio (mono)	352 000	*0.35*
	Total	**51 270 400**	***51.27***
PAL/SECAM	Video	59 904 000	*59.90*
	Audio (mono)	352 000	*0.35*
	Total	**60 256 000**	***60.26***

Source: Authors' own elaboration, based on various sources (see text).

[35] While PAL and SECAM standards define the use of 7 or 8 for the transmission of their signals, we have selected the latter because it is the most-used.

D.4.2.2 Analog color TV: Performance

Analog color TV follows the specifications of the monochrome television shown in Table D-15, but adds chrominance to the luminance, which is the video signals component which contains the color information (saturation and hue, see Jack and Tsatsulin, 2002). A color image is generally described with the RGB color model (Red-Green-Blue), which is a numerical representation of the possible mix of the primary colors into different intensities and tones to produce a specific color. The rate of "1's and 0's" generated by the chrominance components depends on the structure of the sample which is used, indicated by $Y:C_B:C_R$. There are various combinations of sub-samples (Wootton, 2005). In this case, we have decided to use 4:2:0, as it is one of the most efficient and is used in video transmission applications[36] (Arnold, Frater and Pickering, 2007) (Table D-18). Finally, just as for monochrome TV, each one of the pixels are represented by a code 8 binary digits in length, with which it is possible represent more than 16 million shades of different colors ($2^8 * 2^8 * 2^8 = 2^{24}$).

Table D-18: Resolution of each color signal component and the total number of pixels per second.

Standard	Comp-onent	No. Active lines	No. Pixels per line	Resolution [pixels/frame]	Refresh rate [frames/s]	Pixel rate [pixels/s]	Depth [bits/píxel]	Bit rate [bits/s]
NTSC	Y	480	442	212 160	30	6 364 800	8	
	C_R	240	221	53 040		1 591 200		
	C_B	240	221	53 040		1 591 200		
	Total					**9 547 200**		**76 377 600**
PAL/SECAM	Y	576	520	299 520	25	7 488 000	8	
	C_R	288	260	74 880		1 872 000		
	C_B	288	260	74 880		1 872 000		
	Total					**11 232 000**		**89 856 000**

Source: Authors' own elaboration, based on various sources (see text).

After color TV signals began to be broadcast, stereo sound was introduced. Using the same sampling rate (44 [kHz]) and the same number of binary digits per sample (8 bits) used in monochrome TV, we find that the transmission rate of stereo sound is equal to double the rate of mono sound 704 [kbps] (King, 1999) (Table D-19).

Table D-19: Total rate of binary digits for the transmission of analog color TV signals

Standard	Color TV Signal	binary [bps]	Standard	Color TV Signal	Rate of binary digits [kbps]
NTSC	Video	76,377,600	PAL/	Video	89,856

[36] In the case of 4:2:0, the sampling of the components C_R and C_B applies to 4:2:0 in a line (only luminance and the component C_R, are sampled while C_B, is not) and in what follows, we apply 4:0:2, where the component C_R is what is not sampled. Unlike with broadcast video, with stored video we normally opt for an image with more color intensity (therefore, in VHS and BetaMax, for example, a structure of 4:2:2 is maintained).

Audio (mono)	352,000	SECAM	Audio (mono)	352
Total (mono)	**76,729,600**		**Total (mono)**	**90,208**
Video	76,377,600		Video	89,856
Audio	704,000		Audio	704
Total (stereo)	**77,081,600**		**Total (stereo)**	**90,560**

Source: Authors' own elaboration, based on various sources (see text).

For lack of more specific information, we will assume the same rates for analog satellite and analog cable as for analog terrestrial color TV (making the difference between PAL/SECAM and NTSC), both mono and stereo, respectively (this assumption has also been adopted by Bohn & Short, 2009). We take into consideration the total number of color analog TV as downstream performance.

D.4.2.3 Digital Television: Performance

For digital TV we look at the standard MPEG-2 encoding which is associated with standard definition TV broadcasting (SD) and used by all standards, i.e. (until 2007): ATSC (i.e. U.S.A and Canada), ISDB (i.e. Japan and Brazil) and DVB (i.e. Europe and the rest of the world). From a technological point of view, Digital TV can transmit multiple channels at standard quality, or one or two channels at high-definition and others at standard quality. This may be done utilizing the same bandwidth which transmits only one analog signal, which turns out a maximum performance of between a 20-40 Mbps (European Standard Telecommunications Institute [ETSI], 2004, 1997a, 1997b; Advanced Television System Committee [ATSC], 2006; Digital Broadcasting Expert Group [DiBEG], 2007; Oyamadaet al., 2001; Saitoet al., 2000; "Multiplex (TV)", 2010). Single channel transmission has a rate of around 3-7 Mbps (LinoWSat, 2010; Rairhurst, 2001; 21st-satellite, 2010). Up until 2007, the better part of receiving equipment was not prepared to deploy more than one channel simultaneously and the users were not known for taking advantage of this possibility. Given what we just mentioned, we can suppose that an average rate of 4 Mbps (Table D-20) is used. Considering the aforementioned, this is a conservative estimation.

Table D-20: Transmission rate used to estimate the performance of digital satellite, cable and satellite television in [Mbps] (hardware performance).

	Video	Audio	Total
Bitrate [Mbps]	4.0	0.256	4.26

Source: Authors' own elaboration based on (LinoWSat, 2010; Wooton, 2005; Rairhurst, 2001; Wenger et al., 2005; 21st-satellite, 2010).

Digital television introduced two way communications. A return channel (upstream) is provided with which the service provider is able to know the preferences or demands of the viewer. On-demand video service is an example of one of these. Its performance is overshadowed by that of downstream (video transmission from the service provider to the TV) and is estimated from the rate of DVB-RCT, equal to 15 [kbps]. The upper end of the rate can vary–the lowest possible rate is 0.6 [kbps] (DVB, 2001). RCT is the solution created for DVB to offer a wireless interaction channel for interactive digital satellite.

D.4.3 Content compression

Each factor is calculated considering that 124416 [kbps] is the standard bit rate of digital television without compression, i.e., the rate achieved after the digitization of the analog video signal in accordance with the ITU Rec. B.601 standard, used by MPEG-2 (without yet applying the compression scheme). We also consider that 1411.2 [kbps] is the corresponding bit rate for digital stereo sound without compression. In 2007, the optimal compression method was MPEG-4 for video as well, and MPEG-4 HC-AAC for audio, with the same rate used in the broadcasting of digital radio (64 [kbps], achieving excellent quality). This results in a compression factor of 31 for MPEG-2 and of 60 for MPEG-4, which is consistent with empirical experiments which show that MPEG-4 has been able to reduce the bit rate to 50% of that achieved by MPEG-2 (Bodecek & Novotny, 2005). For upstream traffic, it is assumed that it can only transmit texts in ASCII format.

Table D-21: TV compression factors.

	1986	1993	2000	2007	"Optimal"
Video NTSC/PAL	1	1	31.1	31.1	60.0
Audio	1	1	5.5	5.5	20
Text (upstream)	-	-	4.7	4.7	6.6

Source: Authors' own elaboration, based on Appendix A.

Table D-21 contains the transmission rates resulting from the application of optimal compression. The results show us that digital TV transmits 1.4 times the amount of information of an analog stereo color TV channel (satellite, cable or land). It can be expected that this gap will continue to increase rapidly, while providers and consumers begin to use various channels simultaneously through one digital-TV transmission channel.

Table D-22: Bit rate for analog TV using optimal compression in [Mbps].

	NTSC	PAL/SECAM/Satellite
Analog black and white	0.866	1.016
Color (mono) analog	1.291	1.515
Color (stereo) analog	1.308	1.533
Digital (DL&UL)	2.144	2.144

Source: Authors' own elaboration, based on various sources (see text).

D.4.4 Effective use

For both OECD countries and those not affiliated with OECD, information was collected from various sources to estimate the average number of hours a person watches TV in a week. As some sources reported contradictory numbers, we have chosen the most conservative estimates.

Table D-23: TV usage in hours per week.

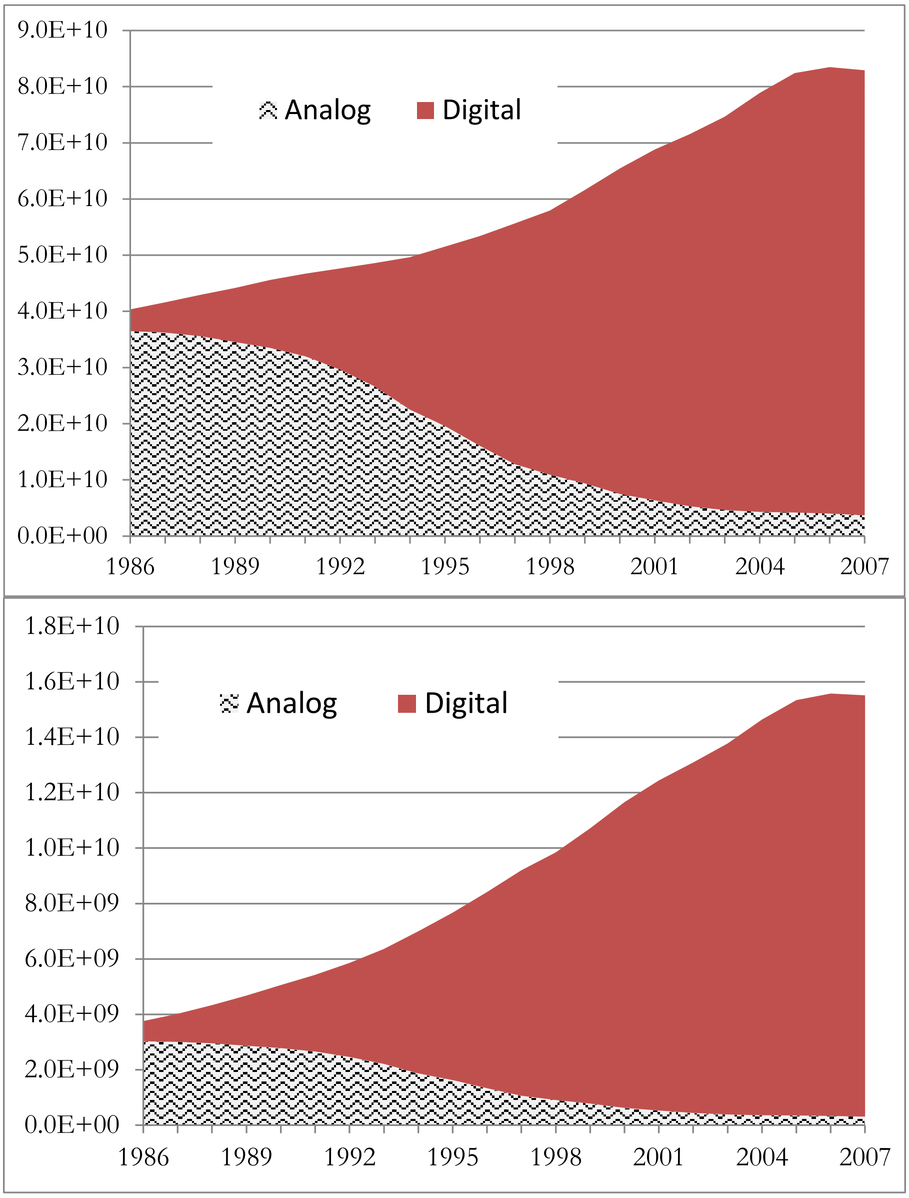
	1986	1993	2000	2007
OECD	20.1	20.5	21.1	21.8
Non-OECD	16.3	16.6	18.3	18.9

Sources: Authors' own elaboration, based on (Arredondo, 2007; Bolea, 2009; Bureau of Labor Statistics, 2004, 2010; CNTV-Colombia, 2006; Dutton & Helsper, 2007; Equipo TIC-SUC, 2001; Ewing & Thomas, 2008; Fábián et al., 2007; Findahl, 2008; Godoy, 2004, 2007; Gorman, 1996; Grande, 2007; Guzmán, 1996; Harrison & Cantor, 1997; Hornik & Schlinger, 1981; INC-Chile, 2009; Jorge, 2008; Jung, 2001; Mayer, 1993; Meattle, 2007; Mediascope Europe, 2008; "Media Statistics…", 2010; Mikami, et al., 2002, 2005; MK Marketing, 2004; Navarro, 2005; NielsenWire, 2009; Lebo, 2005; Liang, 2005, 2007; OECD, 2007, 2009; Patiño, 2007; Pronovost, 1996; Reitze & Ridder, 2005; Rideout et al., 2010; Riley, 1994; SENACYT, 2006, 2008; Sheperd, 2009; Statistics New Zealand, 1999; Television Bureau of Advertising, 2008; TV-Free America, 2000; Universidad de Palermo, 2009; Vergeer et al, 2009; Vioque, 2000; WIP-Mexico, 2008; Zackon, 2009; Zamaria & Fletcher, 2008)

D.5 Fixed-line Telephone

The infrastructure of fixed-line telephone networks are used just as much for voice calls as for Internet dial-ups. Here we only look at the use of it for voice, while dial-up is recorded in the section about Internet, considering the complementary effective usage of both technologies (expressed in minutes per week per subscriber) for 1986, 1993, 2000 and 2007. The following graph shows the complete installed capacity [kbps] in each corresponding year.

Figure D-7: Fixed-line capacity (voice): (a) without compression; (b) optimal compression; both in [kbps].



Source: Authors' own elaboration, based on various sources (see text).

D.5.1 Fixed-line telephone: Quantity

In order to separate the number of analogue lines from digital ones we weigh the total of main lines actually in use, reported by the ITU data base (2009), with the percentage of digital lines[37] (taken from the same source). The missing values from ITU (2011) are estimated in a linear fashion. In 1986, 14% of the total number of land lines in use around the world were digital, and in 2007 some 97% (ITU, 2009). We assume that 100% of the land lines were digital by 2010.

During a connection two lines are needed to transmit the data: one for the transmission of the voice of the subscriber who calls, and the other for the transmission of the voice of the receiver (Freeman, 2005). Therefore, in contrary to what is often supposed, the respective rates (Table D-24) should be weighed by a factor equal to two, accounting for the upstream and the downstream, both with the same bit rate.

D.5.2 Fixed-line telephone: Performance

In the case of digital lines, the voice coding is done in accordance with the recommendation G.711 of the ITU-T. In the process of digitalization, samples are taken from the voice signal at 8000 times per second, i.e., a sampling frequency of 8 [kHz] and is then assigned 13 or 14 bits to each one of them, depending on the different standards used in the United States, Japan and Australia (13 bits) or in Europe and the rest of the world (14 bits) (ITU, 1988). These samples are normalized and sent to a non-linear quantizer[38] that produces a sample of 8 bits in length, achieving a final transmission rate of 64 [kbps] (sampling rate * No. of bits per sample).

To estimate the transmission rate in the analog network, we assume that the signal is digitized in the same fashion as the digital network (G.711), but that each sample is not compressed down to 8 bits, that means, 8 thousand samples taken per second are coded with 13 or 14 bits –depending on the country. The resulting rates are 104 and 112 [kbps]. Starting from this rate, an adjustment is made for analog signal quality based off the signal-to-noise ratio (SNR) (Sklar, 2001). This takes into consideration that the analog signal is less complete, since it loses parts of its quality due to interference or crosstalk (Bigelow et al., 2001). The rule used is known as Rule 6 [dB] for PCM telephone (see Couch, 1997; Lathi, 1998), which gives an estimate of the SNR of the signal received as a function of the number of bits used to encode the value of each sample (Anderson and Johannesson, 2006). A good voice quality requires a SNR of at least 40 [dB] and if this number drops down below 27 [dB] the conversation is understandable, but with a quite disturbing noise

[37] This percentage covers lines which are completely digital (ISDN) just as much as those which are only partly digital, i.e., those where the last phase is still analog.

[38] The methods which produce samples from 13 and 14 bits are called Law-A and Law-µ, respectivelyeach one of them has a function based on natural logarithm to transform the samples from 13 and 14 bits into one of 8 bits (Salomon, 2007; Laplante, 1999).

(Anderson and Johannesson, 2006; Bellamy, 2000). An average quality of 34.84 [dB] means samples with an encoding of 7 bits ($SNR_{dB} = 6.02 * n - 7.3$). Therefore, we can conclude that noise reduces the number of bits used for encoding the samples by one bit (from 13 to 12, and from 14 to 13 bits), for which we obtain effective rates of 96 and 104 [kbps].[39] For long distance calls, we assume the average of these rates (100 [kbps]).

Table D-24: Landline telephone performance (voice) analog.

	Transmission rate Law-A (Europe and the rest of the world) [Kbps]	Transmission rate Law-μ (United States Japan, Australia) [Kbps]	International transmission rate [Kbps]
Analog (without compression)	104	96	100
Digital (with compression)	64	64	64

Source: Authors' own elaboration, based on (Salomon, 2007).

D.5.3 Content Compression

Considering the compression rate used in G.711 (112:64 = 1.75: 1, a compression at 0.57 for the Law-A; and 104:64 = 1.63, a compression at 0.62 of the original at Law-μ), a correction is made to the analog transmission rate, so that comparability between the two rates can be achieved. We get is a reduction in the bit rate from 104 and 96 [kbps] to 59.4 and 59.1 [kbps], which shows the inferiority of analogue (with 64 [kbps]).

The estimate of the optimum compression factor is based on data presented by (Ojala et al., 1998), which show the compression rate achieved for the algorithms looked at in el Speech Profile de MPEG-4 (CELP y HVXC) (MOS between 3.6-4.1). We have selected those which reflect the previously assumed quality (Table D-25).

Table D-25: Compression factors and the respective transmission rates.

		Analog	Digital	
		"Optimal"	1986-2007	"Optimal"
Compression factors	Ley-A	12.05	1.75	9.00
Bit rate [kbps]	Ley-A	8.63	64	12.44
Compression factors	Ley-μ	12.05	1.63	9.00
Bite rate [kbps]	Ley-μ	7.97	64	11.56

Source: Authors' own elaboration, based on various sources (see text).

[39] $[2^7/2^8] = [2^x/2^{13}]$ => x=12 => 8000*12 = 96 kbps; $[2^7/2^8] = [2^x/2^{14}]$ => x=13 => 8000*13 = 104 kbps

D.5.4 Effective Use

Based on data reported by the ITU (2010) regarding telephone traffic, a calculation is made of the average amount of minutes weekly weighed according to the number of telephone lines in use, utilized by the consumer (see Table D-26), for those countries which belong to the OECD and for the rest of the world. The total corresponds to the sum of the national traffic (which includes local and long distance calls and international calls.)

Table D-26: Fixed-line telephone traffic, in minutes per fixed-line per week.

		1986	1993	2000	2007
National traffic	OECD	*113.59*	115.10	145.58	91.36
	no-OECD	*34.07*	34.07	47.19	68.27
International traffic	OECD	1.03	1.65	2.95	4.90
	no-OECD	0.91	1.40	1.14	1.24

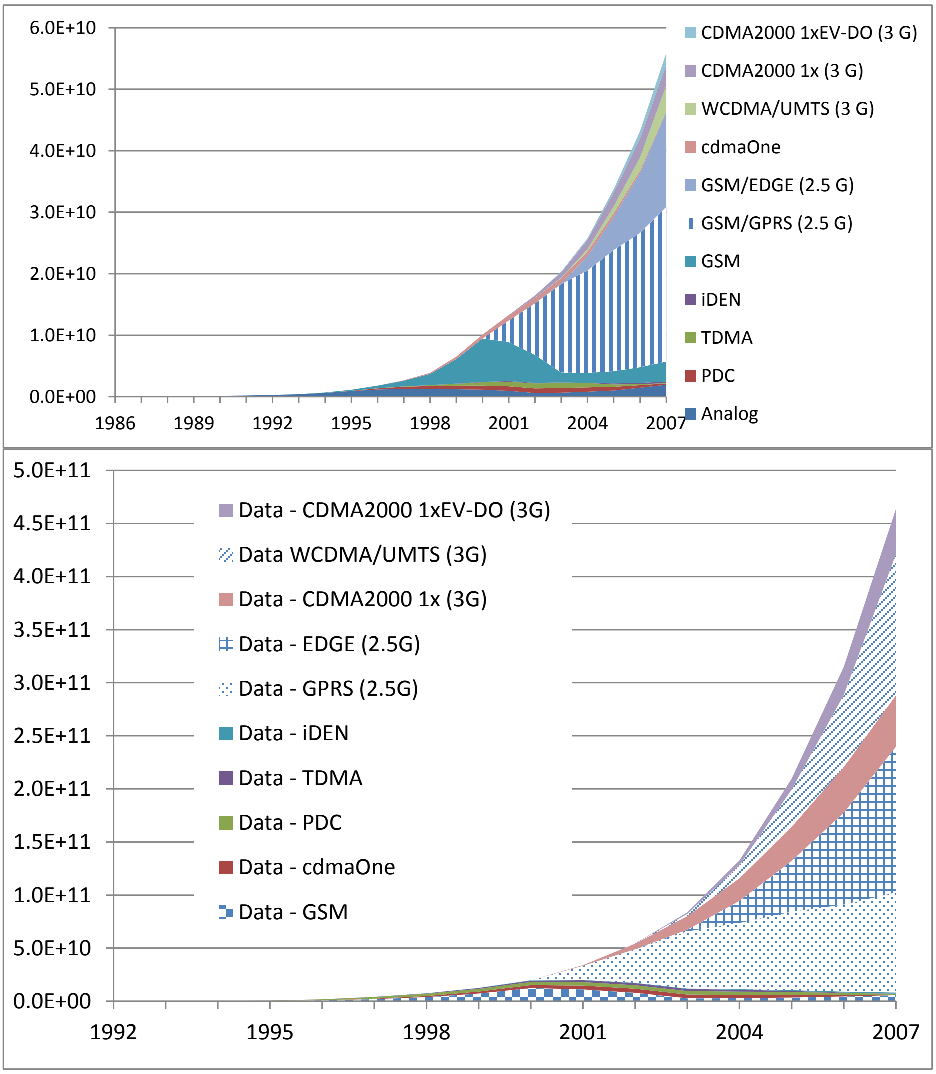
Source: Authors' own elaboration, based on (ITU, 2010).

For the separation between upstream and downstream, we may consider that upstream corresponds to the "speaking" part of the call, and downstream to the "hearing" part. Since there is no information available on how much time is spent speaking or hearing, we will assume that they are both distributed equally (50%-50%).

D.6 Mobile Telephones

In this section, we present the capacity of the mobile telephone to transmit voice and data. The mobile technologies considered in this study correspond to those of the second generation (2G): TDMA (IS-54), PDC, iDEN, GSM and cdmaOne (IS-95); generation 2.5G: GPRS and EDGE; and those of the third generation (3G): WCDMA (UMTS), CDMA2000 1x and CDMA2000 1xEV-DO. We updated the installed capacity (without effective usage) until 2010.

Figure D-8: Total capacity (in kbps) of cellular technologies, (a) voice and (b) data service.



Source: Authors' own elaboration, based on various sources (see text).

D.6.1 Mobile telephony: Quantity

The information on the total amount of mobile subscriptions is provided by the ITU (2011). The classification of families according to IMT-2000 (ITU, 2008) is provided by GSM World (2010, 2011) and CDMA Development Group [CDG] (2008, 2011). Because there is no information available at the country level (except for the PDC in Japan), we estimate of distribution according to regional percentages (Table D-27 and Table D-28). For TDMA, the assumption can be made that there are only subscribers in America (Gruber, 2005); and iDEN subscribers are distributed in countries where it is deployed (Motorola, 2008), in proportion to mobile telephone subscribers.

Table D-27: Regional diffusion of the GSM family of mobile technologies.

GSM 2G/2.5G Technologies [in millions]											
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Africa	*0.01*	*0.05*	*0.19*	0.50	0.89	1.62	3.00	5.60	10.20	16.20	77.9
Middle East	*0.00*	*0.03*	*0.10*	0.26	0.73	1.43	2.40	4.40	*10.30*	17.20	
Asia-Pacific	*0.03*	*0.22*	*0.77*	2.01	6.72	17.0	36.10	71.70	140.40	229.50	314.0
Europe*	*0.16*	*1.10*	*3.92*	10.20	24.16	49.7	93.70	170.1	*283.80*	*346.30*	383.0
Latin America	*0.00*	*0.00*	*0.00*	0.00	0.00	0.00	0.20	0.70	1.70	3.60	9.50
North America	*0.00*	*0.01*	*0.02*	0.05	0.25	1.36	3.10	5.90	9.60	13.50	24.9
Worldwide	0.20	1.40	5.00	13.02	32.75	71.1	138.50	258.40	456.00	626.30	809.3

	2003	2004	2005	2006	2007	2008	2009	2010
Africa + ME	105.1	146.0	219.5	305.6	352	461	580	700
Latin America	29.0	66.7	137.6	207.5	298	353	418	496
Asia-Pacific	394.6	494.4	631.2	824.5	1 110	1 405	1 700	1 950
Europe*	445.5	536.3	645.8	740.7	732	783	794	755
USA/Canada	37.8	52.6	75.2	88.16	100	114	130	140
Worldwide	1 012	1 296	1 709	2 166.5	2 593	3 116	3 623	4 041

GSM 3G Technologies (2001 - 2010) [in millions]										
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Africa + ME	0.00	0.00	0.00	0.04	0.35	1.48	3.74	7.7	15.7	32.1
Latin America	0.00	0.00	0.00	0.00	0.00	0.00	0.1	0.64	4.2	26.8
Asia-Pacific	0.03	0.15	1.99	9.47	24.39	46.34	84.2	109.9	143.5	187.3
Europe*	0.00	0.00	0.71	7.71	25.23	48.00	95.5	123.7	163.8	224.7
USA/Canada	0.00	0.00	0.00	0.00	0.05	1.07	3.7	9.7	24.9	64.2
Worldwide	0.03	0.15	2.70	17.23	50.03	96.89	187.3	265.7	377.0	535.0

Sources: (GSM World, 2010b, 2010c, 2010d; 2011; Bienamé, 2007)

Table D-28: Regional subscriptions of the CDMA family of technologies.

2G CDMA Technology (cdmaOne, 1997 - 2010) [in millions]														
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Asia-Pacific	6.30	14.90	28.00	35.73	37.74	33.35	31.40	29.10	20.10	21.13	6.22	5.3	3.4	1.6
North America	1.50	6.80	16.50	38.70	48.42	50.93	39.63	28.50	19.80	14.18	2.69	0.6	0.33	0.07
Latin America	0.00	1.22	5.10	14.95	19.90	26.97	29.86	33.50	34.60	12.25	2.92	1.0	0.53	0.3
Europa+ME+Africa	0.00	0.09	0.50	1.06	1.65	2.33	2.30	2.30	2.30	0.90	0.79	0.5	0.04	0.04
Worldwide total	7.80	23.00	50.10	80.44	107.70	113.58	103.19	93.40	76.80	48.45	12.62	7.4	4.3	2.1

CDMA 3G Technologies (CDMA2000 1x/1xEV-DO)[in millions]													
	CDMA2000 1x							CDMA2000 1xEV-DO					
	2001	2002	2004	2005	2006	2007	2010	2002	2004	2005	2006	2007	2010
Asia-Pacific	3.65	21.08	61.35	91.45	120.81	155.54	285.2	0.17	11.55	19.35	28.09	33.84	52.2
North America	0.00	11.57	63.10	83.25	84.71	79.79	71.9	0.00	0.50	4.45	24.49	45.10	97.6
Latin America	0.00	0.24	8.70	23.70	57.45	57.27	24.4	0.00	0.00	0.43	1.90	4.02	5.1
Europa+ME+Africa	0.00	0.07	1.57	2.70	7.01	10.78	30.9	0.00	0.04	0.20	0.59	1.05	7.7
Worldwide total	3.65	32.95	134.7	200.7	269.9	303.3	412.3	0.17	12.1	24.4	55.1	84	162.6

Sources: (CDG, 2008b, 2011)

As available statistics do not separate between GSM, GRPS and EDGE (2G and 2.5G of the GSM family), we assume that since the first commercial deployment of GPRS and EDGE technologies in a specific country (see Table D-29 for regions), all new equipment incorporate the new technology (considering that the useful lifetime of a mobile telephone is three years) ("Continued growth…", 2000).

Table D-29: First years of commercial deployment of GPRS and EDGE.

Technology	Africa	Asia	Europa	Latin America	North America	Oceania
GPRS	2005	2000/1	2000/1	2002	2000/1	2000/1
EDGE	2004	2003	2003	2007	2004	2005

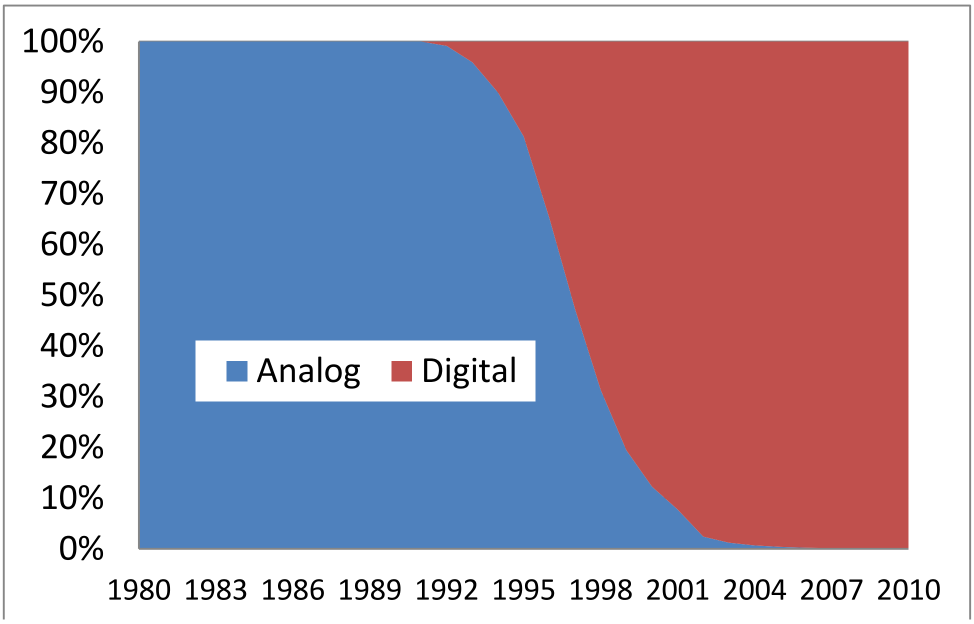
Sources: (Swapcom, 2005; Business Wire, 1999; Broersma, 2000; Comisión Interamericana de Telecomunicaciones [CITEL], 2007; Cellular Online, 2010; Nikkei Business Publications, 2000;O2, 2010; 3G Americas, 2008). The first commercial GPRS networks were deployed in 2000, but the phones did not have GPRS functionality until 2001. For this reason, we include GPRS starting in 2001 for those countries.

The quantity of analog mobile phone users corresponds to the difference between the total amount of subscribers to these digital technologies and the total reported by the ITU (2011)[40] (

[40] In cases where this difference resulted negative, we corrected to 0 (this was the case in some developed countries for the years between 2003 and 2007, for which it is known that analog transmission were gradually turned off.

Figure D-9). From 2002 onward we calibrate this difference with worldwide analog subscription statistics from (GSM World, 2010).

Figure D-9: Quantity of analog mobile phones in the world.



Source: Authors' own elaboration, based on ITU, 2009; GSM *World*, 2008a; 2010; CDG, 2008; O2, 2008; 3G Americas, 2008.

Table D-30: Summary of the distribution of different mobile technologies in the period 1980-2007 (percentages)[41].

	1980-1991	1992	1993	1995	1997	1999	2000	2002	2004	2006	2007
Analog	100.0	99.1	95.9	81.3	47.3	19.4	12.2	5.2	2.2	0.6	0.1
GSM/GPRS/EDGE	0.0	0.9	4.1	14.3	33.1	52.5	59.8	68.1	73.9	79.1	80.9
cdmaOne	0.0	0.0	0.0	0.0	3.6	10.2	10.9	9.6	5.3	1.8	0.4
PDC	0.0	0.0	0.0	3.6	12.5	9.1	6.9	4.8	3.1	1.2	0.5
TDMA	0.0	0.0	0.0	0.8	2.9	7.7	9.1	8.5	5.2	0.8	0.2
iDEN	0.0	0.0	0.0	0.0	0.7	1.0	1.1	1.0	1.0	1.0	0.9
1x	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	7.7	10.0	8.9
WCDMA (UMTS)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3.6	5.6
1xEV-DO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	2.0	2.5

Source: Authors' own elaboration, based on various sources (see text).

D.6.2 Mobile voice: Performance

Digital mobile technologies (2G onward) encode and compress voice signals (Table D-31).

Table D-31: Details of voice encoders.

Technology	Encoder	Complexity	Standard year	Period	Bit rate [kbps] with compression

[41] The GSM table refers to the sum of subscribers of GSM, GPRS and EDGE, CDMA2000 1x to 1x and 1xEV-DO to CDMA2000 1xEV-DO.

GSM/GPRS/EDGE	GSM.FR	4.5 MIPS	1986	1992 – 1996	13
GSM/GPRS/EDGE	GSM-EFR	18 MIPS	1997	1997 – 1998	12.2
GSM/GPRS/EDGE	GSM-AMR	20 MIPS	1999	1999 - 2010	4.75 – 12.2 (8.48)
WCDMA (UMTS)	AMR-WB G.722.2	38 WMOPS	2001	2001- 2010	6.6 – 23.85 (15.23)
cdmaOne	QCELP13	20-25 MIPS	1995	1997 – 2010	13.3
CDMA2000 1x	EVR-C	25 MIPS	1994	2001 – 2010	8.55
CDMA2000 1xEV-DO	VMR-WB	38 WMOPS	2002	2002 – 2010	6.6/8.85/12.65 (12.65)
iDEN	VSELP	20 MIPS	1989	1996 – 2002	4.2/4.4/8 (8)
iDEN	AMBE++	-	2003	2002 – 2010	4
TDMA	IS-54	25 MIPS	1989	1994 - 2010	8
PDC	PDC-FR	18.7 MOPS	1993	1994 – 1996	11.2
PDC	PDC-EFR	18 MIPS	1997	1997 - 2010	6.7

Source: (Chen & Thyssen, 2008; “Vector sum…,”, 2010; “Personal digital cellular”, 2010; VoiceAge, 2008; Ditech Network, 2008). Note: GPRS and EDGE are only used for the transmission of information and use the GSM network for voice transmission.

It is assumed that: (i) the encoder is implemented in all the networks deployed from the year of standardization, (ii) for encoders that present a range of rates (such as GSM-AMR, AMR-WB), the rate is chosen using a simple average of the measurements; (iii) of the VSELP profiles available for transmission in iDEN, the most-used is 8 [kbps] (Ditech Network, 2008); and (iv) in the case of VRM-WB (CDMA2000 1x EV-DO), the lowest rates are used (12.65 [kbps]) to ensure compatibility with those networks that do not use the same codification.

Regarding analog cellular technology, the assumption has been made that the transmission rate without compression is the same as that of land line telephony: 96 [kbps] for the United States, Japan and Australia; and 104 [kbps] for Europe and the rest of the world.

Cellular telephones, like landlines, use two frequencies per call (a duplex channel): one for the person who calls and the other for the person who is called. This suggests that the voice transmission rate must be multiplied by two.

D.6.3 Mobile Voice: Compression of Content

Presented below are the resulting compression factors of various voice encoders used by different technologies.

Table D-32: Compression rate achieved by voice encoders.

Technology	Sampling Frequency [kHz]	Bits per Sample	Bit rate (s/ compression) [kbps]	Bit rate (c/ compression) [kbps]	Compression Factor
GSM(GSM.FR 1992-1996)	8	13	104	13	8.0
GSM(GSM-EFR 1997-1998)	8	13	104	12.2	8.5
GSM/GPRS/EDGE(GSM-AMR 1999-2007)	8	16	128	8.48	15.1
WCDMA(UMTS) (3G)	16	16	256	15.23	16.8
cdmaOne	8	8	64	13.3	4.8
CDMA2000 1x	8	16	128	8.55	15.0
CDMA2000 1xEV-DO (3G)	16	16	256	12.65	20.2
iDEN	8	8	64	8.0	8.0
iDEN	8	13	64	4.0	16
TDMA	8	8	64	8	8.0
PDC	8	13	104	11.2	9.3
PDC	8	13	104	6.7	15.5

Source: Authors' own elaboration, based on (Chen & Thyssen, 2008; "Vector sum…", 2010; "Personal digital cellular", 2010; VoiceAge, 2008; Ditech Network, 2008). Note: as shown by the Table, GSM has evolved during 1996-99. We suppose that every new equipment counts with the most up to date standard, while others keep their standard during a lifetime of three years. This results in the fact that in 2000 some 17 % of GSM were GSM-EFR and 83 % GSM-AMR, which results in a transmission rate of 9.1 kbps and a compression factor of 14.

In order to harmonize the performance of digital telephony with analog in a given year (which transmit at 104 [kbps] and 96 [kbps]), we find an average compression factor by considering the factors utilized in digital technologies and their respective percentage of subscribers (Table D-33). The optimal compression factor is based on the compression rates achieved by the algorithms considered in MPEG-4 Speech Profile (CELP-NB and HVXC for 2G and 2.5G technologies; AMR-WB and CELP-WB for 3G; see Appendix A for further detail) (Ojala et al., 1998), choosing the one that reflects in the best way the quality characteristic of the mobile telephone (MOS between 2.91 and 3.16, according to Rämö & Toukomaa, 2005). To double check the estimate, we may compare the resulting rates with those of fixed line telephones. For example, voice transmitted in GSM/GPRS/EDGE (with GSM-AMR) will result in an entropic rate of 8 [kbps] (128 [kbps] bit rate without compression /16 with optimal compression), which is similar to the entropic transmission rate of analog fixed-line telephony, and lesser in quality than digital fixed-line (which has around 12 [kbps]).

Table D-33: Compression factors, weighted averages.

Year	1980-1992	1993	1994	1995	1996	1997	1998	1999	2000
Factor	8.0	8.0	8.1	8.3	8.4	9.9	9.3	13.1	13.0
Year	2001	2002	2003	2004	2005	2006	2007	"Optimal 2G/2.5G"	"Optimal 3G"
Factor	13.1	13.4	14.0	14.3	14.8	15.1	15.4	16.0	22.9

Source: Authors' own elaboration, based on Appendix A. Note: 3G is compressed more than 2G, since 3G transmits voice in higher quality, and therefore also contains more redundancy that may be compressed.

D.6.4 Mobile Voice: Effective use

The ITU database (2010) reports mobile traffic data classified into the following categories: national mobile traffic (equal to the amount of traffic on one mobile network to another), and international and roaming traffic; call traffic from fixed networks to mobile, and from mobile networks to fixed. For roaming minutes, only digital technologies are considered, given that this concept was only introduced with 2G GSM technology.

Also included in Table D-34 is traffic from fixed networks to mobile networks. For the separation between upstream and downstream, we make the same assumptions as were made in fixed-line telephony, dividing the final rates by two.

Table D-34: Summary of traffic of mobile telephone networks, in minutes. Mobile subscriptions per week.

		1986	1993	2000	2007
National mobile traffic (incl. mobilC-fixed and fixed-mobile)	OECD	6.83	17.35	27.88	33.60
	non-OECD	6.48	13.60	20.71	22.43
International mobile traffic	OECD	-	-	0.59	0.97
	non-OECD	-	-	0.12	0.13
Roaming	OECD	-	-	0.95	0.99
	non-OECD	-	-	0.75	0.87

Source: ITU (2010).

D.6.5 Mobile data: Performance

The average rates achieved in mobile devices for commercial applications are shown in Table D-35. This data represents a values which can be achieved in each piece of equipment, with which we can calculate the "potential hardware capacity" for each user in [kbps]. The values for 2010 are average value of provided bandwidth, so we interpolate with a constant growth rate between the performances of 2004, 2007 and 2010, and multiply it with the respective number of installed devices (not the newly acquired).

Table D-35: Different mobile technologies hardware data transmission rates.

Technology	Generation	Data transmission rate 2004		Data transmission rate 2007		Data transmission rate 2010	
		Upstream [Kbps]	Downstream [Kbps]	Upstream [Kbps]	Downstream [Kbps]	Upstream [Kbps]	Downstream [Kbps]
GSM	2G	14	14	14	14	14	14
cdmaOne	2G	14	19	14	19	14	19
PDC	2G	28.8	28.8	28.8	28.8	28.8	28.8
TDMA	2G	9.6	9.6	9.6	9.6	9.6	9.6
iDEN	2G	19.2	19.2	19.2	19.2	19.2	19.2
GPRS	2.5 G	14	28	14	28 a 64 (46)	28.8	57.6
EDGE	2.5 G	26	60	42	100	237	237
WCDMA (UMTS) (3GSM, HSDPA)	3G	150	150	350	350	384	625
CDMA2000 1x	3G	70	60	70 a 90 (80)	60 a 100 (80)	153	153
CDMA2000 1xEV-DO	3G	70	300	70 a 90 (80)	300 a 700 (500)	153	625

Sources: (Steele, Lee & Gould; 2001;GSM World, 2008d; CDG; 2008c; 3G Americas, 2006; Motorola, 2000; Mallick, 2003; "List of device bit rates", 2011; Cisco Systems, 2011a)

D.6.6 Mobile data: Effective use

However, if all the equipment were used at this capacity all at once, the network would collapse (an effect that we informally call "midnight on New Year's Eve effect"). In other words, given the altering use of shared network infrastructure, the installed capacity in the world is far less than that of the sum of the hardware provided by the different devices. We need a more realistic estimate on the actual traffic of mobile networks. We estimate the actual use of data by mobile networks through the use of SMS (Short Message Service) and MMS (Multimedia Messaging Service). A SMS has up to

160 characters, of 7 bits for each one, so containing 1,120 bits in all, while an interoperability agreement between networks (MMS Conformance Document 1.2) regulates that MMS can have up to 300 kB per message (Bodic, 2003).

Based on data by the ITU (2010), an estimate is formed on the number of SMS and MMS sent per week. The first SMS was sent in December of 1992 ("Hppy brthdy", 2002), for that reason we consider 1993 as year 0. We multiply the number of SMS by the subscribers of 2G, 2.5G and 3G, and the amount of MMS by the subscribers of 2.5G and 3G.

Table D-36: Number of SMS and MMS sent by subscribers in a week.

		1993	2000	2007
SMS	OECD	0	3.92	13.59
	non-OECD	0	0.93	9.17
MMS	OECD	-	-	0.46
	non-OECD	-	-	0.08

Source: Authors' own elaboration, based on ITU (2010)

For data traffic, we consider the year 0 to be 2001. From Kalden (2004) and Ricciato et al. (2006), we know that throughout 2003-2005, MMS traffic for 2.5G and 3G cell phones represented between 0.5% and 7% of all mobile data traffic. It is also known that during the last few years, the participation of MMS in all traffic has decreased, owing to the expansion of the use of the Web and streaming in mobile devices (Ricciato et al., 2006; Verkasalo, 2007). Therefore we assume that the bottom of this range, specifically that of MMS, represents 1.2% of all data traffic in mobile devices (100% in 2001). If we add the 98.8% of missing traffic (which consists of WAP, Web, Email, FTP, streaming), it results that the total traffic coincides with the total mobile traffic estimated by Cisco (2008a, 2008b) in their estimation on mobile IP traffic (which estimates 80,055 TB/month), reconfirming the validity of our estimate with independent sources.

D.6.7 Mobile data: Content compression

D.6.7.1 SMS

2G technologies can only support SMS traffic (Short Message Service) of text, which is also enabled for 2.5G and 3G. Half of SMS are upstream and the other half are downstream.

Table D-37: 2G content compression factors.

	2000	2007	"Optimal"
Text	4.6	4.7	6.6

Source: Authors' own elaboration, based on Appendix A.

D.6.7.2 2.5G and 3G content

Table D-38 shows the distribution of the protocols and applications most utilized by 2.5G and 3G network users. For the estimation of effective use in 2007, we employ the downstream distribution and we count half of SMS, MMS and Email traffic as upstream. For the estimation of compressed hardware capacity, we use the distribution from Table D-38 for downstream, and the proportions of SMS, MMS and Email for upstream (which results in that 17.1 % of upstream capacity is MMS, Email 82.5 %, and SMS 0.4 %). For 2010 we use the general average provided by Cisco Systems (2011a).

Table D-38: Percentage of protocols/applications used by 2.5G and 3G mobile users.

	2007		2010
MMS	1.2 %	Data	31.2 %
Email	5.8 %	File sharing/ music streaming	14.2 %
WAP	10.0 %	Video	49.8 %
Other	10.0 %	VoIP	1.7 %
Streaming	15.0 %	Text	3.2 %
Web	58.0 %		
SMS	0.03 %		

Sources: Authors' own elaboration; based on (Kalden, 2004; Ricciato et al., 2006; Verkasalo, 2007; Cisco Systems, 2011a).

We assume that the MMS (Multimedia Message Service) consists of a combination of text, photos, sound and video (Table D-39). WAP Technology (Wireless Application Protocol) only supports texts and images, so for that reason we will assume that the distribution follows the same relation which is seen in fixed-line Internet Web traffic, same for other applications (Web, C-mail, FTP among others) (D.7.5).

Table D-39: Content distribution.

	MMS				WAP		Streaming	
	Text	Image	Sound	Video	Text	Image	Video	Sound
2007	5%	75%	10%	10%	52%	48%	95%	5.0%

	DL Data		DL File sharing and music streaming		UL	
	Text	Image	Sound	Image	Text	Image
2010	50 %	50 %	50 %	50 %	67 %	33 %

Source: Authors' own elaboration, source Web traffic D.7.5.

The following compression factors are used (following the rate used for computer servers), with the exception of streaming for mobile devices, which uses MPEG-4 (AACv2). This factor compresses audio a little more than for streaming used in Fixed-line Internet (to facilitate transmission over a wireless channel)

Table D-40: Different kinds of contents compression factors.

	Text	Image	Audio (download)	Audio (streaming)	Video (download & streaming)	Compr.
2007/10	4.7	27.6	6.8	27.0	60.0	4.7
Optimal	6.6	48.0	12.0	32.0	60.0	6.6

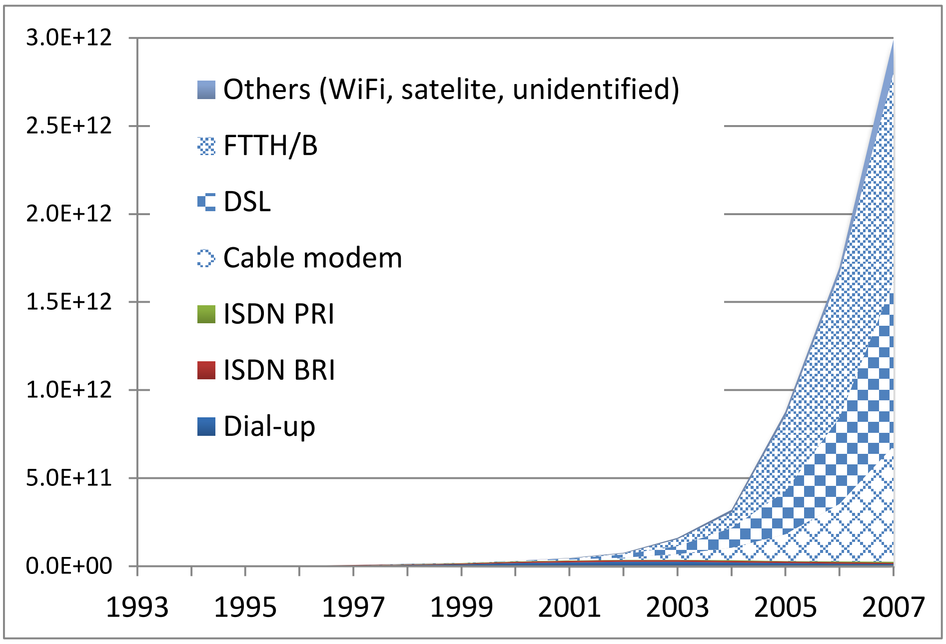
Source: Authors' own elaboration, based on Appendix A.

Applied to existing content, it turns out that in 2000, the compression factor (ratio between hardware capacity and optimally compressed capacity) is 1.43 (all content was SMS text: 6.6/4.6). In 2007, hardware upstream capacity was not very affected, given that most upstream is text, but for downstream 2007 has a compression factor of 1.3 (given that, for example, video content is already more compressed than text).

D.7 Internet

In the following we look at upstream and downstream capacity in dial-up, ISDN, xDSL, FTTH/B (Fiber-To-The Home/Building, sometimes also grouped as FTTP: Fiber-To-The-Premises), cable modem and “others” (including wireless WiFi, microwaves or satellites, by electric cable (PLC), and non-identified). The following graph shows the complete installed capacity of [kbps] in each corresponding year until 2007. We updated the installed capacity (without effective usage) until 2010.

Figure D-10: Total capacity of data transmission throughout Internet Access technologies, in [kbps], including upstream and downstream, without normalization by compression (capacity hardware[42]).



Sources: Authors’ own elaboration, based on various sources (see text).

D.7.1 Internet: Quantity of dial-up, ISDN, xDSL, FTTH/B cable modem and others

Based on the number of subscribers to the different fixed-line Internet technologies (ITU, 2010) (not the users), we assume that the difference between the total of fixed-line internet subscribers and the sum of dial-up, ISDN, DSL, FTTH/B, and cable modem fall into the group “others” (wireless, satellite, power line, etc. and other technologies that are not identified by the available base of information).[43]

---

[42] One should take note that in this graph, there has been no normalization by compression. In other words, here we show the transmission “just as is occurs” in the transmission of data (in the sense of hardware use), while more recent compression algorithms can actually transmit more per unit of data.

[43] During 2010, the ITU (2010) changed its definition of fixed-line internet subscriptions, creating two different categories: Fixed- line Internet and wireless internet. Unfortunately, there is still no data

We use data provided by the OECD Outlooks (2003, 2005, 2007 and 2009, 2011) to fill in missing data about dial-up technology; for DSL and cable modem we use data from the (ITU, 2010). Furthermore, these sources enable us to complete the beginning of the time series of subscribers based on the commercial introduction of the Internet (which supposedly coincides with the connection of one particular country to the NSFNET (National Science Foundation Network), see Table D-41), and based on the growth rates of internet users, which are (interestingly) more complete than subscribers (ITU, 2010). In many cases, countries did not put any more effort into the reporting of the final days of dial-up and ISDN. We estimate the death of dial-up based on the longest series of data available (Sweden 1995 – 2008), and we assume that all countries without corresponding data behave in the same way as the dial-up in Sweden. Concerning ISDN, the ITU reports the subscribers total to ISDN-BRI (Basic Rate Interface) and ISDN-PRI (Primary Rate Interface) (besides those subscribers to ISDN, which correspond to the sum of both, this value is used to make an estimation in the case of a certain year not being registered).

Time series for subscribers to FTTH/B are completed with additional sources (Baudry & Bismut, 2006; Cheng, 2008; European Communities Trade Mark Association [ECTA], 2007 Foster, 2008; Home Chinese Forum, 2010; Hutcheson, 2009; Kunigonis, 2004, 2005; Montagne, 2008a, 2008b; Nique et al., 2007; Paul Budde Communication, 2010, OECD, 2011). Comparing these sources, each subscription from FTTH is counted (Fiber-To-The-Home) and FTTB (Fiber-To-The-Building) as only one single subscription (which we call FTTH/B) which assigns an average capacity (sometimes also referred to as FTTP: Fiber-To-The-Premises)[44].

Table D-41: Years in which different countries connected to the NSFNET network (National Science Foundation Network) and the introduction of more advanced technologies.

Year	Countries
1988	Canada, Denmark, France, Iceland, Norway, Sweden
1989	Australia, Germany, Israel, Italy, Japan, Mexico, Netherlands, New Zealand, Puerto Rico y United Kingdom

concerning the latter, and it looks as if countries still report wired and wireless technologies together in the category "wired internet". To settle our doubts, we have compared the new data from the ITU ("wired internet") with those from the OECD (2009) (broadband + dial-up, for the 30 countries in the OECD in 2007), which explicitly include fixed wired and wireless Internet ("OECD broadband subscriber statistics count the broadband subscriptions which supply connectivity to a Wi-Fi hotspot in a home or office. The OECD also counts any leased lines or business DSL connections which furnish Internet access to commercial Wi-Fi hotspots in a cafés, etc."). Both sources turn out to be similar (with overestimates for some countries and underestimates for others.), with a general difference of less than 1%. So in conclusion, we have found that the statistics from ITU (2010) for fixed-line internet still include wired and wireless technology, and we have taken this basis as the estimate of the total subscribers (since it is the most complete source found in the world). In case the difference between the reported total and the sum of the specified technologies (dial-up, ISDN, DSL, cable, FTTH/B) turned out to be negative, we set it to 0.

[44] This implies that some of the FFTB connections, that provide more than one subscription, are counted as "other" subscriptions, which have a lower performance (the group "other" is calculated as the difference between the total and all the rest of the access groups). In other words, it is possible that we underestimated the contribution of the FTTH/B to the total.

1990	Argentina, Austria, Belgium, Brazil, Chile, Spain, Greece, India, Ireland, Korea and Switzerland
1991	Croatia, Hong Kong, Hungary, Poland, Portugal, Singapore, South Africa, Taiwan and Tunisia
1992	Antarctica, Cameroon, Cyprus, Ecuador, Slovenia, Estonia, Kuwait, Latvia, Luxembourg, Malaysia, Thailand and Venezuela
1993	Bulgaria, Costa Rica, Egypt, Fiji, Ghana, Guam, Indonesia, Kazakhstan, Kenya, Liechtenstein, Peru, Romania, Turkey, Ukraine United Arab Emirates and Virgin Islands (US)
1994	Algeria, Armenia, Bermuda, Burkina Faso, China, Colombia, Philippines, Jamaica, Jordan, Lebanon, Lithuania, Macao, Morocco, New Caledonia, Nicaragua, Niger, Panama, Senegal, Sri Lanka, Swaziland, Uruguay and Uzbekistan.
1995*	Ivory Coast, Ethiopia, Cook Islands, Cayman Islands, Gibraltar, Vatican Kiribati, Kyrgyzstan, Madagascar, Mauritius, Micronesia, Monaco, Mongolia, Nepal, Nigeria, Samoa (western), San Marino, Tanzania, Tonga, Uganda and Vanuatu.
1996*	Qatar, Central African Republic, Oman, Tuvalu, Fresh Polynesia, Syria, Aruba, Cambodia, French Guiana, Eritrea, Cape Verde, Burundi, Benin, Bosnia-Herzegovina, Andorra, Guadeloupe, Guernsey, Jersey, Laos, Maldives, Marshall Island, Mauritania, Northern Mariana Islands, Rwandan, Togo, Yemen and Zaire
1997*	Timor (east), Republic of Congo, Gambia, Guinea-Bissau, Hate, Iraq, Libya, Malawi, Martinique, Montserrat, Myanmar, Reunion, Seychelles, Sierra Leone, Somalia, Sudan, Tajikistan, Turkmenistan, Georgia, Liberia, American Samoa, Niue, Equatorial New Guinea, Bhutan, Palau and the Republic of Congo
1998*	Comoros, Nauru, Bangladesh and Palestine
Introduction of diverse technologies: ISDN: 1988; Dial up: 1990, HDSL: 1992, Cable modem: 1996; ADSL: 1998	

Sources: (Zakon, 2010; Fachhochschule für Technik Esslingen [FHTE], 2001; Computer Hope ™, 2010; Starr, 1993; Motorola, 2002; Sanchez-Klein, 1998; Moulton, 2001).

D.7.2 Internet Dial-up: Performance

Dial-up uses the infrastructure of the telephone network with modems, a system which has evolved over time (Table D-42).

Table D-42: Dial-up transmission rate, in [kbps]

Year	<1982	<1984	<1991	<1994	<1996	<1998	<2000	<=2006
Downstream [Kbps]	0.3	1.2	9.6	14.4	28.8	33.6	56.0	56.0
Upstream [Kbps]	0.3	1.2	9.6	14.4	28.8	33.6	33.6	48.0

Source: Authors' own elaboration, based on (ITU, 2010b; Calem, 2004; ARC Electronics, 2010; Westelcom, 2009, Anttalainen, 2003).

D.7.3 Internet ISDN: Performance

The ISDN (Integrated Services Digital Network) has two variants: ISDN BRI (Basic Rate Interface) for homes, and ISDN PRI (Primary Rate Interface) for businesses (Marcus, 1999). The first of these offers symmetrical rates of 64 or 128 [Kbps], depending on how the operator configures the network. We suppose 128 [kbps]. As for ISDN PRI, we will suppose that it offered rates of 768 [Kbps] until 1997 (PR Newswire, 1990; Newman & Willis, 1996), and later on, rates of 1544 [kbps] in The United States, Canada and Japan; and 2048 [kbps] in the rest of the world, all being symmetrical.

D.7.4 Internet FTTH/B, xDSL, Cable Modem and others: Performance

Estimating the performance of FTTH/B, DSL, and Cable Modems is not as easy as dial-up and ISDN, since the capacity varies significantly between different markets. The same goes for those grouped as "others", which constitute the difference between the total of Internet subscriptions and the sum of subscriptions for the rest of the technologies[45]. Here we have access technologies like wireless (WiFi), those of microwaves or satellite, by electric cable (PLC), etc[43].

For example, Table D-43 shows the large speed variations available in some DSL technologies. There is no information on what kind of DSL was launched in what time period. It is even harder to find the true rates for DSL users, since DSL is the internet access technology which receives the highest amount of complaints from users about the unwillingness of operators to provide the promised rates (DSL Reports, 2008). The challenge is similar when measuring the access to Internet through cable modems. Theoretically, they achieve rates up to 40 [Mbps], with modulation 64QAM or 256QAM for data downloading, and up to 10 [Mbps] with QPSK for data upload (Anttalainen, 2003; Turner, 2005; Regulatel, 2005; European Regulators Group [ERG], 2007; Mitchell, 2009; OECD, 2009), but this rate is not achieved in practice. Different from DSL, Internet access by cable or wireless are shared by a defined amount of subscribers that connect to the same cable (Castelli, 2003). This makes it even more difficult to find the average speed offered by subscription.

Table D-43: Description of DSL.

	Year of standard	Downstream (max)	Upstream (max)	Analog telephony	Distance max. [km]
IDSL	-	< 128 kbps	< 128 kbps	No	5
HDSL	1994	<1.5 Mbps	< 1.5 Mbps	No	3.6
ADSL	1998	< 8 Mbps	< 1 Mbps	Yes	3
G.dmt ADSL	1999	< 8 Mbps	< 1.5 Mbps	Yes	3
G.lite ADSL	2001	1.5 – 6 Mbps	128 – 384 kbps	Yes	3
ADSL2	2002	< 12 Mbps	< 1 Mbps	Yes	2
ADSL2+	2003	< 24 Mbps	< 2 Mbps	Yes	1.5
SDSL, G.shdsl	2004	< 2.3 Mbps	< 2.3 Mbps	No	5.5
VDSL	2006	< 52 Mbps	< 16 Mbps	Yes	0.1 – 2

Source: (Anttalainen, 2003; Bingham, 2000; EFMA, 2004; Department of Communications, Information Technology and the Arts [DCITA], 2007; OECD, 2009)

[45] In some countries, the difference: total subscription – [dial-up,ISDN,DSL,CableModem,FTTH/B] has negative results. In these instances the negative number is converted into 0, assuming an incomplete record on the part of the ITU (2010).

That being said, we have opted to use the average bandwidth of countries reported by NetIndex (Ookla, 2011). NetIndex compiles the results of two bandwidth velocity meters (Speedtest.net and Pingtest.net) and in this way estimates the average upstream and downstream speed for countries worldwide since 01/01/2008 (for 2008, a daily average of 84,671 tests per country day for 128 countries; for 2009 and average of 129,852 tests per country per day for 150 countries; for 2010 an average of 179,822 tests per country per day for 160 countries). A recent independent analysis by a group of academic researchers arrived at the conclusion that Ookla's methodology gives a "realistic estimation" of the bandwidth speed for the most common uses of the web (Bauer et al., 2010). Countries without information, or those where we suspect a bias in the measurement, are estimated on basis of countries with simmilar socio-economic profile, or the average of the region to which the country belongs (see
Table D-44). It is supposed that users of FTTH/B, DSL and cable modem and wireless perform speed tests (e.g. because of DSL speed delivery problems, the sharing of bandwidth with cable modem), while we suppose that users of dial-up and ISDN do not make a significant number of such tests on these sites. Since we do not have data fro mid-2007, but for 01/01/2008, after various checks we decided to use 80% of the national average data from 01/01/2008 as an approximation on the average speeds of 2007 for each country (supposing that the average bandwdith grew some 20% beteen mid-2007 and 01/01/2008), and the simple yearly average from daily tests from 2008 to estimate that year's bandwidth speeds.

It is well known that cable modem is generally faster than DSL. Revising several speed-tests which distinguish between the type of technology used, it is assumed that cable modem download speed is 3 times faster than DSL, and cable modem upload speed is 1.5 times faster than DSL (FTTH Council, 2010; OECD, 2011; Beal, 2005; UltTex Speed Tester, 2006). Specifically:

$$[\%\ FTTH/B\ user] + [\%\ DSL\ user] + [\%\ CM\ user] = 100\%\ [of\ FTTH/B,\ DSL,\ CM\ user]$$

$$[CM\ performance\ download] = 3 * [DSL\ performance\ download]$$
$$[CM\ performance\ upload] = 1.5 * [DSL\ performance\ upload]$$

With these assumptions, we can calculate the typical speed of FTTH/B, DSL and cable modem in each country, taking the results from NetIndex as a weighted average for each country:

$$[\%\ FTTH/B\ user]*[FTTH/B\ perf.]+[\%\ DSL\ user]*[DSL\ perf.]+[\%\ CM\ user]*[CM\ perf.] = [NetIndex\ performance]$$

if we have an estimate for either FTTH/B performance, DSL performance, or cable modem performance. For example, to estimate the DSL download performance for a certain country, we reorganize the equation to:

$$[DSL\ perf.DL] = \frac{[NetIndex\ performanceDL] - [\%\ FTTH/B\ user]*[FTTH/B\ perf.DL]}{[\%\ DSL\ user] + [\%\ CM\ user] * 3}$$

We estimate FTTH/B performances on the basis of either the diverse advertised FTTH/B speeds in a country (OECD, 2011) (assuming that the actual speed is less than half of the advertised speed, in agreement with the findings of Ofcom, 2010, for speeds faster than 20 Mbps; also OECD, 2009; 2011[46]); the average speeds "consumer-tested performance" rates reported by FTTH Council (2010): 2006 (DL/UL): 5Mbps/1mbps; 2007 (DL/UL): 5.2Mbps/1Mbps; 2008 (DL/UL): 7Mbps/1.8Mbps; 2009 (DL/UL): 12.2Mbps/2.4Mbps; 2010 (DL/UL): 16.6Mbps/4.5Mbps; or, last but not least, on basis of the case by case reasonability of the results that the above formula gives us for DSL and cable performance, which gives provides good (and mutually reconfirming) feedback on the vaility of the chosen mechanism to estimate bandwidth (leading to a kind of "bootstrapping" strategy to estimate the badnwidth of each). The first deployments of FTTH began in Japan in 1997 (Shinohara, 2005), but subscriber statistics start in 2001, which we will consider as the starting with that year, and use the 2006 rate for 2001-2005. For Japan and South Korea, which have a very significant penetration of FTTH/B (half of the broadband users are FTTH/B by 2009), we anker the calculation in the DSL performance (we estimate that those two countries have the same average DSL performance as European countries). Note that this procedure to estimate FTTH/B differs from our earlier approach that we used in López and Hilbert (2011), where we assumed a fixed performance for FTTH/B to make estimations until 2007. We decided to change this aspect of our methodology, since FTTH/B became increasingly pervasive and important during the period 2007-2010.

Additionally, given the lack of further information, we estimate that "others" (fixed Internet connections like wireless WiFi, satellite, power line, electric, non- identified, etc) achieve half the performance of DSL for each country: [DSL performance] = [others performance]*0.5. This respects country differences and aims at representing an average between un-identified narrowband and wireless broadband solutions.

During the '90s, the typical rates for downstream/upstream for DSL were 128/64 [Kbps] (DSL Forum, 2008), and starting with the introduction of ADSL in 1998, rates of 256/64 [Kbps] were offered (Baudry & Bismut, 2006; Anttalainen, 2003; Horak, 2007). As far as cable modems go, the rates in those first years varied between 1 and 3 [Mbps] for the downstream, and between 0.5 and 2.5 [Mbps] for the upstream, although many network operators limited the speed to 256/64 [Kbps] (Perlman, 2002). Regarding "other" technologies, it is assumed that they had the same rates as dial-up up until 1997. Then, rates of 128 [kbps] downstream and 64 [kbps] upstream were utilized. By 2001, these "other" technologies had rates similar to those of the more common solutions of the time (i.e. ISDN BRI and DSL). This data is

[46] This assumption is disputable, since other studies find different gaps between advertised and actual speed. The National Telecommunications Commission of Thailand found that customers can download at 71 percent of the advertised broadband speeds and upload at only 10 percent (TelecomPapers, 2011). FCC (2011) reports that actual "fiber" connections exceed advertised speed on average. More research is needed to better understand this issue.

considered until 2001, and we consider the years 2002-2006 with a constant growth rate for each country. The results are reported in
Table D-44.

Table D-44: Simple average rates by region for FTTH/B, DSL, and Cable modem, DL/UL, in [kbps].

FTTH/B		2001- 2006	2007	2008	2009	2010
Africa	DL	-	-	5,200	5,125	7,725
	UL	-	-	1,000	1,400	1,700
Latin America and the Caribbean	DL	-	5,200	5,433	6,425	10,872
	UL	-	1,000	1,133	1,738	2,767
North America (USA/Canada)	DL	5,000	5,200	7,000	10,625	16,250
	UL	1,667	1,733	2,333	3,542	4,667
Asia (without Japan and South Korea)	DL	5,000	5,160	6,164	9,370	12,375
	UL	1,000	1,040	2,448	3,107	4,634
Japan	DL	17,783	22,043	29,987	26,024	23,150
	UL	8,196	9,261	13,524	12,080	15,631
South Korea	DL	27,844	35,458	45,817	41,605	44,806
	UL	1,312	1,416	2,353	2,902	3,703
Europe	DL	5,010	5,368	7,982	11,656	17,989
	UL	1,841	2,016	3,368	4,663	7,474
Pacific Ocean	DL	-	5,200	6,000	6,350	12,615
	UL	-	624	1,320	1,650	3,344

DSL simple average of countries		1996-1997	1998-2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Africa	DL	128	256	268	285	307	333	366	453	772	1,225	1,641
	UL	64	64	73	83	96	113	133	160	298	493	870
Latin America and the Caribbean	DL	128	256	359	504	706	991	1,390	1,949	2,555	3,339	6,163
	UL	64	64	78	94	116	142	176	218	341	423	567
North America (USA/Canada)	DL	128	256	358	502	704	988	1,387	1,949	2,555	3,339	6,163
	UL	64	64	91	128	181	257	363	515	748	1,064	1,349
Asia	DL	128	256	302	364	447	559	712	900	1,303	1,773	2,495
	UL	64	64	81	105	139	188	261	351	474	618	930
Europe	DL	128	256	362	517	745	1,084	1,589	2,282	3,517	5,220	7,055
	UL	64	64	94	140	213	328	513	806	1,299	1,813	2,668
Pacific Ocean	DL	128	256	332	433	569	751	999	1,335	1,909	2,488	2,779
	UL	64	64	80	100	127	162	207	265	465	581	858

Cable modem simple average of countries		1997-2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Africa	DL	256	328	425	559	743	999	1,360	2,316	3,674	4,923
	UL	64	78	96	119	150	188	240	449	728	1,272
America Latina and the Caribbean	DL	256	355	496	700	998	1,437	2,087	3,132	3,874	5,049
	UL	64	83	108	142	186	246	327	512	635	851
North America (USA/Canada)	DL	256	430	724	1,220	2,055	3,465	5,848	7,666	10,017	18,490
	UL	64	97	147	222	336	509	772	1,122	1,596	2,023
Asia	DL	256	363	525	774	1,164	1,780	2,699	3,908	5,320	7,485
	UL	64	87	120	170	247	366	529	752	990	1,490
Europe	DL	256	435	746	1,291	2,254	3,970	6,845	10,550	15,661	21,164
	UL	64	101	160	260	429	719	1,189	1,917	2,720	4,002
Pacific Ocean	DL	256	398	624	985	1,563	2,495	4,004	5,728	7,463	9,616
	UL	64	85	115	156	212	290	398	698	871	1,340

Source: Authors' own elaboration, based on NetIndex (Ookla, 2010) and (ITU, 2010). Note: Averages are simple and divided by the number of countries (not weighted by population). Averages only include countries that are reported by the source.

D.7.5 Compression of Content

The compression factors utilized are mostly the same as the ones used with hard disk drives. In the case of WWW traffic, we consider the same compression factors used for servers and for P2P and DDL traffic, those of PC (see Appendix D, Table D-49). There exist two special cases: VoIP/Skype traffic and media streaming, which use the compression factors reported in Table D-45.

Table D-45: Compression factors for different types of content

	Content	1986	1993	2000	2007	"Optimal"
Media Streaming	Video	1.0	1.0	27.0	60.0	60.0
	Audio	1.0	1.0	16.8	11.0	24.0
VoIP/Skype	Voice	1.0	1.0	7.9	8.3	8.3

Source: Authors' own elaboration, based on Appendix A.

The identification of the distribution of content traffic over the Internet is a complicated issue for, at least, three reasons: (i) Most studies about traffic only register the quantity of traffic, and do not analyze the type of content being sent; or they report the amount of minutes dedicated to different applications, and there is no way to translate minutes to the quantity of bits transmitted during said times; (ii) the distribution of the volumes of traffic per connected terminal is very assymetric, which makes it difficult to speak of a “typical user” (it is estimated that about 10 % of hosts contribute to about 99 % of the total traffic) (Sen & Wang, 2004); and (iii) content distribution is also highly skewed at the worldwide level (it is dependent on the bandwidth connection and socio-demographic characteristics of the user). This being said, out approach is twofold: we first estimate the usage of different protocols over the Internet, which is a more reliable statistic: C-mail, FTP, WWW, *streaming*, instant messaging, NNTP, P2P, VoIP, DDL and tunnel/encryption (Table D-46) (Ipoque, 2007)[47]; and then estimate the distribution of content for each protocol (text, images, videos, audio).

Table D-46: Protocol/Applications considered in the study.

Protocol	Description
Email	The transmission of C-mail using protocols such as SMTP (Simple Mail Transfer Protocol) o POP (Post Office Protocol).
FTP	File transfers using the protocol of the same name (File Transfer Protocol), generally utilized by users who connect to a server.
WWW	Encapsulated traffic using the HTTP protocol (HyperText Transfer Protocol), which is the typical deployment of Internet web sites, which also include video and audio (like YouTube).
Media Streaming (incl. gaming)	Specialized traffic devoted to viewing multimedia files on line, through protocols such as RTP (Real-Time Protocol) or RTSP (Real Time Streaming Protocol), including gaming.
IM	Traffic from instant messaging application (such as Windows Live Messenger, Yahoo Messenger, among others).
NNTP	Transfers of information over the protocol named (Network News Transfer Protocol).
P2P	Traffic associated with Peer-to-Peer software, which allows users to share files using applications like Kazaa, Emule, eDonkey, BitTorrent, and others.
VoIP/Skype	Traffic from voice conversations over Skype or by VoIP (Voice Over IP) protocols.
DDL	Just as the acronym implies (Direct Download Links), this is traffic that comes from download links, generally from Web-Hosting sites (like Rapidshare, for example).
Tunnel/Encryption	Traffic devoted to confidential information, such as private networks or VPN’s (Virtual Private Networks), or related to security and network control or routing of traffic.

[47] Protocol is the name given to different standards which lay down methods for communicating or sending data over telecommunications networks.

Unknown/Others	Traffic that cannot be classified in the above categories.

Source: Authors' own elaboration, based on various sources (see text).

For our purposes, we used "Internet Study 2007"[48] (Ipoque, 2007), "P2P Survey" (Ipoque, 2006) and Sandvine (2008), which describe the composition of Internet traffic for different relevant geographic zones (Europe and the Middle East in Ipoque and North America, Latin America and Europe/Middle East/Africa in Sandvine), along with a specification of P2P (peer-to-peer[49]) content traffic. Sandvine (2008) shows significant differences between downstream and upstream. While downstream is dominated by web traffic, upstream is dominated by P2P. P2P has grown decisively. Before the year 2000, P2P content was mostly pushed by music sharing (for example Audiogalaxy (1998); Napster (1999)), and then mostly by video sharing (eDonkey2000, BitTorrent, Gnutella and Freenet en 2000) (Ipoque, 2006). Something similar applies to streaming applications pre- and post-1997 (Acharya & Smith, 1998). After studying these reports, we decided to establish two traffic profiles: one for OECD countries (developed countries), which is based on the content statistics of North America and Europe; and another for non-OECD countries (developing countries), based on the statistics from Latin America, Middle East and Africa (Table D-47).

Most protocols carry different kinds of content. For instance, an E-mail or a web site may have just as many images as it has text. We use the information in Table D-47 to form an estimate, which is based on several sources that consider a wide ranging number of users scattered around the globe. Once we know the distribution for each of the four categories of content (text, image, audio and video) for each of the protocols and applications considered in this study, we may then determine the distribution of such content for both regions (Table D-48).

[48]"The measurements took place during August and September 2007. Ipoque's PRX Traffic Managers installed in-line at the customers' Internet access and peering links generated the raw statistics data in real-time based on the traversing network traffic. Eighteen monitoring sites in five regions of the world contributed data to this study. Thirteen measurements sites were located at ISPs and five at universities. The regions are Australia, Eastern Europe, Germany, the Middle East and Southern Europe."

[49] P2P is an acronym for "peer to peer", a denomination given to applications that run not on server networks, but over connections that are established between different nodes or users of the system. This interaction between users is generally made over the Internet.

Table D-47: Percentage distributions of Internet traffic by protocol and application for two traffic profiles, downstream and upstream.

OECD (developed) DOWNSTREAM	**1986-1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Email	5.0	5.0	5.0	5.0	5.3	6.1	7.2	5.0	4.0	4.0	3.00	3.00	1.00	2.00	1.70	1.70	1.00	0.88	0.75
FTP	54.4	54.4	54.4	54.4	41.4	33.0	23.7	9.0	5.0	6.5	6.00	3.00	1.00	2.00	0.50	0.50	0.50	0.50	0.50
www	0.0	0.0	0.4	0.8	1.5	11.3	24.1	46.2	60.1	60.5	60.22	59.94	59.67	59.39	59.11	58.83	58.56	58.28	58.00
Streaming&gaming	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.2	1.8	2.4	2.41	2.42	2.43	2.44	2.46	2.47	2.48	2.49	2.50
IM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.10	0.10	0.20	0.20	0.20	0.20	0.30	0.18	0.05
NNTP	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.10	2.00	3.00	4.00	4.50	5.00	5.00	4.88	4.75
P2P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.00	10.00	12.00	14.00	16.00	18.00	19.00	21.00	22.50
VoIP/Skype	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.20	0.30	0.40	0.50	0.60	1.00	1.00	1.38	1.75
DirectDownLink	-	-	-	-	-	-	4.3	4.3	4.3	4.3	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30
Tunnel/Encryption	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.30	1.00	1.50	2.00	2.00	3.00	3.00	3.50	4.00
Unknown/others	40.2	40.2	39.8	39.4	51.4	49.2	39.7	33.9	24.3	21.7	17.37	13.93	14.50	9.17	8.63	5.00	4.87	2.63	0.90

Non-OECD (developing) DOWNSTREAM	**1986-1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Email	5.0	5.0	5.0	5.0	11.3	13.0	15.4	10.7	8.5	8.5	6.4	6.4	2.1	4.3	3.6	3.6	2.2	1.5	0.8
FTP	61.1	61.1	58.7	56.2	51.3	40.9	29.4	11.2	6.2	8.1	7.4	3.7	1.2	2.5	0.6	0.6	0.6	0.6	0.6
www	0.0	0.0	2.4	4.9	9.8	19.6	33.0	55.6	70.1	71.1	70.1	69.1	68.1	67.0	66.0	65.0	64.0	63.0	62.0
Streaming&gaming	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-	0.1	0.1	0.3	0.5	0.6	0.7	0.8
IM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3
NNTP	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.5	1.0	2.5	3.0	3.0	3.5	3.8	4.0
P2P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	10.0	11.6	13.1	14.7	16.3	17.9	19.4	21.0
VoIP/Skype	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.6	0.6
DirectDownLink	-	-	-	-	-	-	8.7	8.7	8.7	8.7	8.7	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Tunnel/Encryption	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	2.5	2.8	3.0
Unknown/others	32.0	32.0	32.0	32.0	25.7	24.6	11.6	11.9	4.6	1.5	1.1	2.3	8.0	2.3	3.6	2.7	2.0	1.5	1.0

OECD(developed) UPSTREAM	1986-1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Email	5.0	5.0	5.0	5.0	5.3	6.1	7.2	5.0	4.0	4.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.63	2.25
FTP	54.4	54.4	54.4	54.4	41.4	33.0	23.7	9.0	5.0	6.50	6.00	3.00	1.00	2.00	0.50	0.50	0.50	0.50	0.50
www	0.0	0.0	0.4	0.8	1.5	11.3	24.1	46.2	60.1	60.50	51.80	49.20	39.60	39.50	33.30	26.70	18.70	17.40	16.10
Streaming&gaming	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.2	1.8	1.00	1.00	1.00	1.00	1.00	1.50	2.00	2.00	2.04	2.08
IM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.10	0.10	0.10	0.20	0.20	0.20	0.20	0.30	0.30	0.30
NNTP	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.25	0.40
P2P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	6.00	20.00	40.00	42.50	51.00	58.00	63.20	63.51	63.82
VoIP/Skype	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.20	0.30	0.40	0.50	0.60	0.60	0.70	2.60	4.50
DirectDownLink	-	-	-	-	-	-	4.3	4.3	4.3	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	3.65	3.00
Tunnel/Encryption	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.30	1.00	2.00	2.00	3.00	3.00	4.00	4.00	5.00	6.00
Unknown/others	40.2	40.2	39.8	39.4	51.4	49.2	39.7	33.9	24.3	23.10	26.50	17.00	8.40	3.90	2.50	0.60	3.20	2.13	1.05

Non-OECD (developing) UPSTREAM	1986-1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Email	5.0	5.0	5.0	5.0	11.3	13.0	15.4	10.7	8.5	8.50	6.40	6.40	2.10	4.30	3.60	3.60	3.60	3.68	3.75
FTP	61.1	61.1	58.7	56.2	51.3	40.9	29.4	11.2	6.2	8.10	7.40	3.70	1.20	2.50	0.60	0.60	0.60	0.60	0.60
www	0.0	0.0	2.4	4.9	9.8	19.6	33.0	55.6	70.1	71.10	63.10	61.00	52.00	48.70	47.00	40.90	33.50	29.80	26.10
Streaming&gaming	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-	-	-	-	0.10	0.10	0.30	0.40	0.50
IM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.10	0.10	0.10	0.10	0.20	0.20	0.20	0.20	0.20
NNTP	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.30	0.40
P2P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	4.20	14.10	28.30	30.10	36.10	41.00	44.70	51.43	58.16
VoIP/Skype	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.10	0.20	0.20	0.30	0.30	0.40	1.00	2.00	3.00
DirectDownLink	-	-	-	-	-	-	8.7	8.7	8.7	8.70	8.70	7.00	6.00	5.00	5.00	4.00	3.50	2.75	2.00
Tunnel/Encryption	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.70	1.70	2.00	3.00	4.00	4.00	5.00	5.00	5.00	5.00
Unknown/others	32.0	32.0	32.0	32.0	25.7	24.6	11.6	11.9	4.6	1.50	8.10	5.30	6.90	4.80	2.90	4.00	7.40	3.85	0.29

Source: Authors' own elaboration, based on (Sandvine, 2008; Ipoque, 2007; MacKiC-Mason & Varian, 1994; Cano, 2001; Leinen, 2001; Leibowitz, et al. 2002; Fraleigh, 2003; Karagiannis, 2004; Ipoque, 2006; Bartlett, 2007; Cisco, 2008). Note: between 1986 and 1989 we will assume that the distribution remained the same at the time, since the main change was the introduction of the web in 1989.

Table D-48: Distribution percentages of internet traffic content for different protocols and applications

Web [bytes]	**1986-1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Text	100	85.8	71.6	57.3	43.1	28.9	24.9	24.5	22.8	28.3	33.7	43.5	53.4	53.0	52.7	52.4	46.6	40.7	34.9
Image	0.0	0.0	14.2	28.3	42.5	56.7	56.8	55.2	47.6	47.3	47.1	40.2	33.4	30.4	27.5	26.0	28.1	30.2	32.3
Sound	0.0	0.0	0.0	0.0	2.2	4.3	3.0	3.2	3.9	4.0	4.2	3.6	3.1	2.8	2.5	2.2	2.2	2.2	2.2
Video	0.0	0.0	0.0	0.0	2.8	5.5	8.4	13.1	19.9	14.7	9.6	8.0	6.3	10.1	13.9	17.7	21.5	25.3	29.1
N/A compressed	0.0	14.2	14.3	14.3	9.4	4.6	6.8	4.0	5.8	5.6	5.5	4.7	3.9	3.6	3.4	1.7	1.7	1.6	1.6
FTP [bytes]	**86- 89**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Text	46.7	42.6	38.6	34.5	30.5	26.4	22.4	18.3	14.3	10.3	6.2	2.2	4.3	6.5	8.7	10.9	13.0	16.8	10.9
Image	8.0	7.3	6.7	6.0	5.3	4.6	4.0	3.3	2.6	1.9	1.3	0.6	1.2	1.8	2.4	3.0	3.6	0.6	1.9
Sound	0.0	0.0	0.0	0.0	10.9	21.9	32.8	43.8	54.7	65.6	76.6	87.5	75.0	62.5	48.6	30.0	11.3	8.3	10.4
Video	0.0	0.0	0.0	0.0	1.1	2.1	3.2	4.2	5.3	6.3	7.4	8.4	16.8	25.2	27.0	44.2	61.4	69.4	72.4
N/A compressed	45.3	50.1	54.8	59.5	52.2	45.0	37.7	30.4	23.1	15.9	8.6	1.3	2.7	4.0	13.3	12.0	10.6	4.9	4.3
Email [bytes]	**86- 89**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Text	100	97.7	95.5	93.2	90.9	88.7	86.4	84.1	81.9	79.6	77.3	75.1	72.8	70.5	68.3	66.0	63.7	61.5	59.2
Image	0.0	1.9	3.7	5.6	7.4	9.3	11.1	13.0	14.9	16.7	18.6	20.4	22.3	24.1	26.0	27.8	29.7	31.6	33.4
Sound	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Video	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N/A compressed	0.0	0.4	0.8	1.2	1.6	2.1	2.5	2.9	3.3	3.7	4.1	4.5	4.9	5.3	5.7	6.2	6.6	7.0	7.4
Streaming Media	**86- 89**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Sound	0.0	0.0	0.0	0.0	0.0	0.0	100	100	100	90.6	81.1	71.7	62.2	52.8	43.3	33.9	24.4	15.0	5.6
Video	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.4	18.9	28.3	37.8	47.2	56.7	66.1	75.6	85.0	94.4
P2P	**86- 89**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Text	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	4.3	6.5	8.7	10.9	13.0	16.8	10.9

Image	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.2	1.8	2.4	3.0	3.6	0.6	1.9
Sound	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	87.5	75.0	62.5	48.6	30.0	11.3	8.3	10.4
Video	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.4	16.8	25.2	27.0	44.2	61.4	69.4	72.4
N/A compressed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.7	4.0	13.3	12.0	10.6	4.9	4.3
DDL	**86- 89**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Text	0.0	0.0	0.0	0.0	0.0	0.0	22.4	18.3	14.3	10.3	6.2	2.2	4.3	6.5	8.7	10.9	13.0	16.8	10.9
Image	0.0	0.0	0.0	0.0	0.0	0.0	4.0	3.3	2.6	1.9	1.3	0.6	1.2	1.8	2.4	3.0	3.6	0.6	1.9
Sound	0.0	0.0	0.0	0.0	0.0	0.0	32.8	43.8	54.7	65.6	76.6	87.5	75.0	62.5	48.6	30.0	11.3	8.3	10.4
Video	0.0	0.0	0.0	0.0	0.0	0.0	3.2	4.2	5.3	6.3	7.4	8.4	16.8	25.2	27.0	44.2	61.4	69.4	72.4
N/A compressed	0.0	0.0	0.0	0.0	0.0	0.0	37.7	30.4	23.1	15.9	8.6	1.3	2.7	4.0	13.3	12.0	10.6	4.9	4.3
NNTP	**86- 89**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Text	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
VoIP/Skype	**86- 89**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Voice/audio	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Tunnel/Encryp.	**86- 89**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Text	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Unknown	**86- 89**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Text	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Source: Authors' own elaboration, based on: (Nagamalai, 2008); FTP: (Ewing, et al. 1992); World Wide Web: (Cunha, 1995), (Arlitt & Williamson, 1996, 1997), (Abdulla, 1997), (Arlitt et al., 1999), (Mahanti, 1999), (Pallis et al., 2003), (Wang et al., 2002), (Lacort et al., 2004), (Williams et al., 2005); Media Streaming: (Guo, 2005); P2P: (OECD, 2005), (Cachelogic, 2005), (Ipoque, 2006) and (Ipoque, 2007).

For the period beyond 2007, we had to recur to different sources. We estimate the Internet content for the year 2010 on basis of Cisco Systems (2011b). This source unfortunately does not distinguish between upstream and downstream, so we merely work with the average for the total of both. The actual content of applications like Internet video, video calling and VoIP is obvious, for the rest we use the content distributions from 2007 (for the content of business we refer to the findings from Martino Neuroimaging Center and Center for Climate Change Study at MIT, Madnick et al., 2009). We use the same compression rates as for 2007, weighted by the weights of Table D-49 and Table D-50.

Table D-49: Applications of Internet traffic 2010

	Developed	Developing
File sharing	23%	40%
Internet video	28%	29%
Web, email, and data	17%	10%
Video calling	2%	2%
Online gaming	0%	0%
Voice over IP (VoIP)	1%	1%
Business	28%	18%
	100%	100%

Source: Authors' own elaboration, based on Cisco Systems, 2011b

Table D-50: Content of Internet applications 2010

	File sharing	Web, Email, data	Gaming & streaming	Business
Text	11%	35%	0%	67%
Image	2%	32%	0%	33%
Sound	10%	2%	6%	0%
Video	72%	29%	94%	0%
Compressed	4%	2%	0%	0%
	100%	100%	100%	100%

Source: Authors' own elaboration, based on Cisco Systems, 2011b

D.7.6 Effective use

To estimate the actual use of internet one must make a separation between what we call "actual gross usage" (how much time people have reported "using" the Internet), and the "actual net usage" (how much time the user actually uses the available bandwidth to send/receive information).

ITU (2010) provides the number of minutes per year in which the dial-up connections are used per country. We calculate the (subscription) weighted average. The data for 1986 is based on the year 1993, supposing that the amount of minutes per subscription did not change during those years (during this time the Internet was not yet commercial, but was mostly used in universities in countries in the OECD). Given that all subscriptions in 1986 had the same performance and were dial-up (with 9.6 [kbps] upstream and downstream), it turns out that for 1986 gross use equals net use.

For the years 1993, 2000 and 2007, gross and net use begins diverging. Additionally to the dial-up minutes reported by the ITU (2010), we collect the gross usage reported by broadband users in hours per week (Table D-51). However, we know that even though users report "being" on the Internet for that much time, they are not actually using their available bandwidth every second. In fact, just as with cell phones, if all devices should use this capacity at the same time, the network would collapse (an effect that we refer to as the "midnight on New Year's Eve effect"). Normally, a user will download an email, and then dedicate in a few minutes to reading, or one streams a video, and even though the full video is already accumulated in the buffer, time passes while the entire video is watched. The question is: how much of this "gross use" accounts for the "net use" of the effective net communication of the user?

Table D-51: Gross use: Average number of hours per week that a subscriber uses the Internet.

Gross	Broadband				Dial-up			
	1986	1993	2000	2007	1986	1993	2000	2007
OECD	-	5.2	6.9	12.1	1.0	1.0	2.3	1.7
non-OECD	-	4.0	5.3	9.3	-	0.7	1.5	0.5

Source: Authors own elaboration based on (Dutton & Helsper, 2007; Ewing & Thomas, 2009; Fábián et al., 2007; Findahl, 2001, 2008; Godoy, 2009; Grupo Radar, 2007; ITU, 2010; Koenan et al., 2003; Lebo, 2002; Liang, 2005, 2007; Mediascope Europe, 2008; Mikami, et al., 2005; Peters, 2005; Pitkow & Recker, 1995; Reitze & Ridder, 2005; Salamon, 1998; Smahel & Lupac, 2008; University of Southern California [USC]. Wauters, 2009; WIP-Japan, 2000; WIP-Mexico, 2008; Zamaria & Fletcher, 2008)

To form a clearer idea, we look to statistics which estimate the capacity of internet based the relevant backbone networks. One of the most consistent and persistent sources is the The Minnesota Internet Traffic Studies (MINTS) (Odlyzko, 2010). These reports estimate a worldwide traffic of between 3000-5000 PB/a month for 2007, but do not include non-Internet IP traffic like "corporate IP WAN traffic, IP transport of TV/VoD". Clearly we include this class of traffic, given that is competes with broadband (i.e. during 2007) and is also counted as information received by the user. Another estimate provided by Cisco Systems (2008a, 2008b) estimates 4,675 TB/a month for IP traffic, plus 1,966 for non-IP traffic, giving a total of 6,641 TB/a month for 2007. Using this data, we would have to divide our gross use of broadband in 2007 by a factor of 10.3. This means that of the 104 minutes a person from the OECD uses the Internet on average per day, only during 10.4 minutes the user effectively takes advantage of the entire bandwidth available. The same estimate is made for the years 2000 and 1993, based on the data from Odlyzko (2010), which results in the fact that in 2000 the gross broadband use must be divided by a factor of 2.1 and in 1993 by 3.3 (it should be remembered that there is no need to adjust the actual use of dial-up, given that it is measured in minutes of actual traffic). Table D-52 shows the result. It is interesting to note that the net use increased up to 2000 (in which time there was a world high demand for bandwidth) and that later the demand began to fall (when the supply of bandwidth increased with so-called "broadband").

Table D-52: Net use: Average number of hours per week in which a subscriber effectively uses the available bandwidth.

NET	**Broadband**				**Dial-up (gross=net)**			
	1986	**1993**	**2000**	**2007**	**1986**	**1993**	**2000**	**2007**
OECD	-	1.6	3.3	1.2	*1.0*	*1.0*	2.3	1.7
non-OECD	-	1.2	2.6	0.9	-	0.7	*1.5*	0.5

Source: Authors' own elaboration based on (Dutton & Helsper, 2007; Ewing & Thomas, 2009; Fábián et al., 2007; Findahl, 2001, 2008; Godoy, 2009; Grupo Radar, 2007; ITU, 2010; Koenan et al., 2003; Lebo, 2002; Liang, 2005, 2007; Mediascope Europe, 2008; Mikami, 2005; Peters, 2005; Pitkow & Recker, 1995; Reitze & Ridder, 2005; Salamon, 1998; Smahel & Lupac, 2008; University of Southern California [USC]. Wauters, 2009; WIP-Japan, 2000; WIP-Mexico, 2008; Zamaria & Fletcher, 2008; Odlyzko, 2010; Cisco Systems, 2008a, 2008b).

D.8 Personal Navigation Device (GPS)

Personal navigation devices are linked to the GPS system (Global Positioning System), which is a global navigation system provided by satellite (GNSS) that allows one to find the position of an object, person, vehicle or ship anywhere in the world. GPS works through a network of 32 satellites (28 operational and 4 used as back up).

D.8.1 Personal Navigation Device: Quantity

The amount of different GPS devices is presented in Table D-53. A three year shelf life is assumed for devices that are integrated in mobile telephones, like for the phones themselves. We expect a useful lifetime of 5 years for standalone GPS units.

Table D-53: Shipments of different types of GPS (In millions of devices).

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
PND	-	-	-	-	-	-	-	-	-	1.5	5.0	15.0	25.0
Professional	0.4	0.9	1.3	1.7	2.1	3.0	4.5	7.2	7.8	9.5	11.0	13.0	14.0
Automated dashboard	0.4	0.9	1.3	1.7	2.1	3.0	5.5	6.5	7.5	9.1	10.0	22.0	30.0
Low cost low power	0.0	0.0	0.0	0.1	0.1	0.1	0.2	1.5	3.5	8.9	19.0	35.0	53.0
Mobile phone	0.0	0.0	0.0	0.1	0.1	0.1	0.3	2.0	3.0	4.0	30.0	80.0	164.0
SUM	0.9	1.8	2.7	3.5	4.4	6.2	10.5	17.2	21.8	33.0	75.0	165.0	286.0

Source: (Future Horizons, 2010). Note: The years before 2000 are estimated in a linear fashion, considering that the GPS system was launched in December 1993.

D.8.2 Personal Navigation Device: Performance

Originally, each device was limited to monitoring five or six satellites, but over time, this number grew progressively. In 2007, receivers typically monitored between 12 and 20 satellites. Each GPS satellite continually transmits a navigation message at the rate of 50 bits per second (Weston, 1999). We assume that up to the year 2000, each device had a performance of five satellites (5*50bits/s = 250 bits/s), and in 2007 about twenty (20*50bits/s = 1.0 [kbps]), with a linear approximation for the years in between.

D.8.3 Personal Navigation Device: Compression of content

Forward Error Correction (FEC) is used with a 1/2 convolution code rate, resulting in a message of 25 bits/s, while the respective signal is of 50 bits/s ("GPS signals”, 2010). It is assumed that these 25 bits are at the optimal level of compression.

D.8.4 Effective use

Personal navigation devices are mainly used in the United States and Europe, representing 87.5% of the world market in 2007 (Chandrasekar, 2008). In the United States, an average person spends around 43 minutes a day using some form of transport (Bureau of Labor Statistics, 2008), and Power and Associates (2008) reports that half of GPS users use the devices on a regular basis. So, for lack of better statistics, we assume that half of GPS device owners use their device for 43 minutes per day.

D.9 References

21st-satellite (2010). *Digital TV basics*. Retrieved November 2010, from: http://www.c.com/digital_tv.php

3G Americas (2006). *Mobile broadband: EDGE, HSPA & LTE*. Retrieved November 2008, from: http://www.3gamericas.org/PDFs/white_papers/Rysavy_EDGE_HSPA_LTE_2006.pdf

3G Americas. (2008). Global UMTS and HSPA operator status. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20080414100657/http://www.3gamericas.org/pdfs/Global_3G_Status_Update.pdf

Abdulla, G.; E. A. Fox, M. Abrams & S. Williams (1997). *WWW Proxy Traffic Characterization with Application to Caching* [TR-97-03]. Retrieved November 2010, from Computer Science Department at Virginia Tech Website: http://eprints.cs.vt.edu/archive/00000460/

Acharya, S., & Smith, B. (1998). An experiment to characterize videos stored on the Web. *Proceedings of S&T/SPIE Conference on Multimedia Computing and Networking (MMCN)*.

Advanced Television System Committee (ATSC). (2006). *Recommended practice: Guide to the use of the ATSC television standard*. Retrieved November 2010, from: http://www.atsc.org/standards/a_54a_with_corr_1.pdf

Anderson, J. B., & Johnnesson, R. (2006). *Understanding information transmission*. Hoboken, New Jersey: Wiley-IEEE.

Anttalainen, T. (2003). *Introduction to telecommunications network engineering*. Norwood, MA: Artech House.

Arab Advisors Group (2006, July 2006). Terrestrial TV is still going strong in Morocco. *Arab Advisors News Release*. Retrieved November 2010, from: http://www.arabadvisors.com/Pressers/presser-100706.htm

Arbitron (2006). *Puerto Rico: La radio hoy. Cómo Puerto Rico escucha radio*. Retrieved November 2010, from: http://www.arbitron.com/downloads/PuertoRicoLaRadioHoy06.pdf

ARC Electronics (n.d.). *Modems*. Retrieved November 2010, from: http://www.arcelect.com/modem_dial_lease_line_2-4_wire_multi-drop_multi-point.htm

Arlitt, M., & Williamson, C. (1996). *Web Server Workload Characterization: The Search for Invariants (extended version)*. Proceedings of the ACM SIGMETRICS Conference on the Measurement and Modeling of Computer Systems, 126-137. doi:10.1145/233013.233034

Arlitt, M., & Williamson, C. (1997). Internet Web servers: Workload characterization and performance implications. *IEEE/ACM Transactions on Networking 5*(5), 631-645. doi:10.1109/90.649565

Arlitt, M., Friedrich, R., & Jin, T. (1999). Workload characterization of a web proxy in a cable modem environment. *ACM SIGMETRICS Performance Evaluation Review 27*(2), 25-36. doi:10.1145/332944.332951

Arnold, J., Frater, M. R., & Pickering, M. (2007). *Digital television: technology and standards*. Hoboken, New Jersey: Wiley-Interscience.

Arredondo, P. (2007). *Acceso y usos de Internet en el occidente de México: el caso Jalisco*. Universidad de Guadalajara. Retrieved November 2010, from: http://www.publicaciones.cucsh.udg.mx/pperiod/comsoc/pdf/cys8_2007/cys_n8_2.pdf

Association of Regulatory Authorities (ALM). (2005). *Digitisation 2005: Digital television and analoguC-digital switchover*. Retrieved November 2010, from: http://www.alm.de/fileadmin/Download/Digitisation_2005.pdf

Association of Regulatory Authorities (ALM). (2008). *Digitisation 2008: The question of the digital added value*. Retrieved November 2010, from: http://www.alm.de/fileadmin/forschungsprojekte/GSDZ/digitisation_2008.pdf

ASTRA (2008). *ASTRA reach 2008: Czech Republic, Hungary, Slovakia*. Retrieved November 2010, from: http://www.ses-astra.com/business/en/support/document-library/market-research/index.php

Australian Communications and Media Authority (ACMA). (2008, April 9). Majority of households still to turn to digital freC-to-air television. *ACMA Media Release 33*. Retrieved November 2010, from: http://www.acma.gov.au/WEB/STANDARD/pc=PC_311091

Autoridade Nacional de Comunicações (ANACOM). (2009). *Situaçao das Comunicaçoes 008 – Portugal*. Retrieved November 2010, from: http://www.anacom.pt/

Autoridade Nacional de Comunicações (ANACOM). (2008). *Situaçao das comunicaçoes 007 – Portugal*. Retrieved November 2010, from: http://www.anacom.pt/

Bartlett, G., Heidenmann, J., Papadopoulos, C., & Pepin, J. (2007). *Estimating Traffic Volume at USC*. USC/Information Sciences Institute, 2007. Retrieved November 2010, from: http://www.isi.edu/~johnh/PAPERS/Bartlett07c.pdf

Batra, R. (1999). *The new direct marketing: how to implement a profit-driven database marketing strategy* (3rd ed.). New York, NY: McGraw-Hill.

Baudry, M., & Bismut, S. (2006). *The world telecom services market – Geographical markets*. IDATE.

Bauer, S., Clark, D., & Lehr, W. (2010, October). *Understanding Broadband Speed Measurements*. 38th Research Conference on Communication, Information, and Internet Policy (TPRC), GMU, Arlington, Virginia,.

BDA (2009, June 18). Cable TV in China: Has great potencial & always will? [AN 090618-29]. *BDA Analyst Notes* Retrieved November 2010, from: http://www.bda.com/WebUI/Notes.aspx

Beal, V. (2005). Cable vs. DSL. In *Webopedia*. Retrieved November 2010, from: http://www.webopedia.com/DidYouKnow/Internet/2005/cable_vs_dsl.asp

Bellamy, J. (2000). *Digital telephony* (3rd ed.). Hoboken, New Jersey: Wiley-Interscience.

Benoit, H. (2002). *Digital television: MPEG-1, MPEG-2 and principles of the DVB system* (2nd ed.). Oxford, UK: Focal.

Berni, G. (2007, September 20). *Latest trends and issues in regulation and roll-out of DTT in Europe: Two case studies*. IT Media Consulting, DTT Forum Conference, Sarajevo. Retrieved November 2010, from: http://www.dtt.ba/prezentacije/prezentacije_maj08/Berni_DTT%20in%20Europe.pdf

Bienaimé, J. (2007, June). *3G/UMTS/HSPA deployments worldwide and evolution: Perspectives for Central & Eastern Europe (CEE)*. UMTS Forum Workshop. Retrieved November 2010, from: http://www.umts-forum.org/

Bigelow, S. J., Carr, J. J., & Winder, S. (2001). *Understanding telephone electronics*. Woburn, MA: Newnes.

Bingham, J. A. C. (2000). *ADSL, VDSL, and multicarrier modulation*. Hoboken, New Jersey: John Wiley & Sons.

Bodecek, K., & Novotny, V. (2005). *From Standard Definition to High Definition Migration in Current Digital Video Broadcasting*. IEEE Proceedings of International Multi-Conference on Computing in Global Information Technology (ICCGI '07).

Bodic, G. L. (2003). *Multimedia messaging service: an engineering approach to MMS*. Hoboken, New Jersey: John Wiley & Sons

Bohn, R., & Short, J. (2009). *How much information? 2009 Report on American consumers*. Retrieved November 2010, from San Diego: Global Information Industry Center at the University of California: http://hmi.ucsd.edu/howmuchinfo_research_report_consum.php

Bolea de Anta, Adelaida (2009). *La radio que viene, ¿hay alguien ahí?* Retrieved November 2010, from Asociación Española de Investigación de la Comunicación (AC-IC) Website: http://www.aeic2010malaga.org/upload/ok/216.pdf

Briel, R. (2008, April 3). Satellite drives digital in Austria. *Broadband TV News*. Retrieved November 2010, from: http://www.broadbandtvnews.com/2008/04/03/satellitC-drives-digital-in-austria/

Broersma, M. (2000, July 7). GPRS: A timeline. Retrieved November 2010, from ZDNet UK News: http://www.zdnet.co.uk/news/desktop-hardware/

Bureau of Labor Statistics (2004). *TimC-use survey – Firsts results announced by BLS*. Retrieved November 2010, from: http://www.bls.gov/news.release/archives/atus_09142004.pdf

Bureau of Labor Statistics (2010). Economic News Release. Retrieved November 2010, from: http://www.bls.gov/news.release/atus.t01.htm

Bureau of Labor Statistics. (2008). *American time use survey*. Retrieved November 2010, from: http://www.bls.gov/tus/tables/a1_2007.pdf

Business Wire (1999, March 15). Nokia to deliver Asia's first GPRS network to KG Telecom, Taiwan. Retrieved November 2010, from CBS Business Network (BNET): http://findarticles.com/

Business Wire (2006, March 27). SES ASTRA increases penetration to reach over 16 million satellite households in Germany. Retrieved November 2010, from CBS Business Network (BNET): http://findarticles.com/

Business Wire (2008, November 4). Learn about the China cable television market assessment and forecast to 2012. November 4, 2008. Retrieved November 2010, from All Business Website: http://www.allbusiness.com/

Cable Europe (2009). *Cable in Europe: Delivering the future today*. Retrieved November 2010, from: http://ec.europa.eu/information_society/eeurope/i2010/docs/post_i2010/additional_contributions/solon_cable_europe.pdf

Cable televisión. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/CATV

CableLabs (2006). Digital cable makes debut in India. *Specs News & Technology from CableLabs® 18(5)*. Retrieved November 2010, from: http://www.cablelabs.com/news/newsletter/SPECS/NovDec_2006/story7.html

Cachelogic. (2005). *P2P in 2005*. Cachelogic, 2005.

Calem, R. E. (2004, September 1). *Retroscope: The rise & fall of Dial-up*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20061020012048/http://www.firstglimpsemag.com/editorial/article.asp?article=articles/2004/e0209/30e09/30e09.asp&guid=

Canadian Radio-Television and Telecommunications Commission (CRTC). (2009). *Communications monitoring report 2009*. Retrieved November 2010, from: http://www.crtc.gc.ca/eng/publications/reports/policymonitoring/2009/2009MonitoringReportFinalEn.pdf

Cano, M., Malgosa-Sanahuja, J., Cerdan, F., & Garcia-Haro, J. (2001), *Internet Measurements and Data Study Over the Regional Network Ciez@net*. IEEE Pacific Rim Conference on Communications, Computers and Signal Processing, 2001, 393-396. doi:10.1109/PACRIM.2001.953652

Castelli, M. J. (2003). DSL and cable modem networks. In *Network Sales and Services Handbook*. Cisco Press. Available at: http://www.ciscopress.com/articles/

CDMA Development Group (CDG). (2008). CDMA2000: Market facts. Retrieved November 2008, from: http://www.cdg.org/technology/3g/resource/CDMA2000%20Market%20Facts.pdf

CDMA Development Group (CDG). (2008). *4Q 2007 subscribers statistics*. Retrieved November 2010, from: http://www.cdg.org/worldwide/archives/cdma_world_subscriber074Q.asp

CDMA Development Group. (CDG). (2008). *2Q 2008 Subscribers Statistics*. Retrieved November 2010, from: http://www.cdg.org/worldwide/archives/cdma_world_subscriber_082Q.asp

CDMA Development Group (CDG). (2011). Market facts. Retrieved October 2011, from: http://www.cdg.org

Celular Online. (n.d.). The history of GSM. Retrieved November 2010, from: http://www.cellular.co.za/gsmhistory.htm

Centro de Investigaciones de las Telecomunicaciones (CINTEL). (2008). Serie servicios: Televisión. *Interactic, Documentos Sectoriales 6*(1). Retrieved November 2010, from: http://www.interactic.com.co/dmdocuments/tv_2008.pdf

Chahdi, L. (2001). Radio listening maintains its audience, fall 2000. *Culture Statistics Program 13*(2), Statistics Canada. Retrieved November 2010, from: http://www.statcan.gc.ca/pub/87-004-x/87-004-x2001002-eng.pdf

Chandrasekar, P. (2008). *Navigation market update: PND still the most dominant market segment globally*. Frost & Sullivan. Retrieved November 2010, from: http://www.frost.com/prod/servlet/market-insight-top.pag?docid=127289673

Chen, J., & Thyssen, J. (2008). Analisys by synthesis speech coding. In J. Benesty, M. Sondhi & Y. Huang (Eds.), *Springer handbook of speech processing*. Berlin: Springer.

Cheng, S. (2008, April 24). *The development of FTTH in CHT*. Broadband Network Laboratory, Telecommunication Laboratories, CHT. Retrieved November 2010, from: http://wocc2008.aoetek.com/PDF/O34.pdf

Chew, A. (2003). FTTH, Market drivers and innovations in fiber optic communications. OFS. Retrieved November 2010, from: http://www.spc.tc-ieee.org/OFSchew.PDF

China Cablecom (2008, August). *China's emerging cable operator*. Retrieved November 2010, from: http://www.bloobble.com/broadband-presentations/presentations?itemid=1473

Cisco Systems. (2008). *Global IP traffic forecast and methodology, 2006-2011*. Retrieved November 2010, from: http://www.hbtf.org/files/cisco_IPforecast.pdf

Cisco Systems. (2008). *The exabyte era*. Retrieved November 2010, from: http://www.hbtf.org/files/cisco_ExabyteEra.pdf

Cisco Systems. (2011a). Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2010–2015, Retrieved October 2011, from: http://www.cisco.marcom/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.pdf

Cisco Systems. (2011b). Cisco Visual Networking Index: Forecast and Methodology, 2010–2015, Retrieved October 2011, from: http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-481360.pdf

Comisión Interamericana de Telecomunicaciones (CITEL). (2007, Enero). *Boletín electrónico 31*. Retrieved November 2010, from: http://www.citel.oas.org/newsletter/2007/enero/gsm_e.asp

Comisión Nacional de Defensa de la Competencia (CNDC). (2007, Febrero). *Problemas de competencia en el sector de distribución de programas de televisión en la Argentina*. Retrieved November 2010, from: http://www.mecon.gov.ar/cndc/comp_television_castell.pdf

Comisión Nacional de Televisión (CNTV-Colombia). (2009). I*nforme sectorial de televisión 2009*. Retrieved November 2010, from: http://www.cntv.org.co/cntv_bop/estudios/segundo_informe_sectorial.pdf

Computer Hope. (n.d.). *Computer History, 1990 – 2000*. Retrieved November 2010, from: http://www.computerhope.com/history/19902000.htm

Continued growth in mobile phone sales. (2000, October 7). Helsingin Sanomat, Business & Finance – International Edition. Retrieved November 2010, from: http://www2.hs.fi/english/archive/

Convergence Korea (2009, February 27). The number of digital cable subscribers exceeds 2 million. *Industry News*. Retrieved November 2010, from: http://www.convergencekorea.org/

Correa, D. (2007, June). Speed matters: Assessing broadband in America. *The FTTH Prism 4*(3). Retrieved November 2010, from: http://mysite.verizon.net/vzetw22d/fibertoday/nwsltr/FTTH_Prism_Ver4_Vol3.pdf

Correos de Chile. (2010). *Calcule el costo de su envío*. Retrieved November 2010, from: http://www.correos.cl/calcular/index.php

Correos de España (2010). *Cartas y documentos*. Retrieved November 2010, from: http://www.correos.es/contenido/01P-EnviarDoc/01-CPostales/01P01-CPostales.asp

Couch, L. W. (1997). *Digital and analog communication Systems* (5th ed.). New Jersey: Prentice Hall

Countries using DAB/DMB. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Regional_implementations_of_DAB

Cunha, C., Bestavros, A., & Crovella, M. (1995). *Characteristics of WWW client-based traces* [BU-CS-95-101]. Retrieved November 2010, from Department of Computer Sciense at Boston University: http://www.cs.bu.edu/techreports/pdf/1995-010-www-client-traces.pdf

Datamonitor (2007). *European and US digital TV, 2006 – 2012 (Review Report): Boosting competitive advantage in the digital TV sector*. Retrieved November 2010, from: http://www.scribd.com/doc/6417536/European-and-US-digital-TV

Datamonitor (2008, July). *Tracking digital television households adoption across broadcast platforms*. Retrieved November 2010, from Scribd Website: http://www.scribd.com/doc/6417537/European-and-US-Digital-TV

Dataxis (2006). *Digital television data – EU market for digital television*. Report prepared for the European Commission Information Society and Media DirectoratC-General. Retrieved November 2010, from: http://ec.europa.eu/information_society/policy/ecomm/doc/library/ext_studies/digital_tv_final_report_cec.pdf

Davies, C., & Delaney, J. (2005, July). IPTV & VoD Market Analysis. OVUM. Retrieved November 2010, from: http://www.ictregulationtoolkit.org/en/Document.2949.pdf

Davies, S. (2005). *FTTH: A necessary future*. Retrieved November 2010, from: http://members.westnet.com.au/wizard/FTTH,%20a%20neccessary%20future.pdf

Department of Communications, Information Technology and the Arts (DCITA). (2007). The Three Essential Elements. In *Broadband Blueprint*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20080731024206/http://archive.dcita.gov.au/2007/12/broadband_blueprint/broadband_blueprint_html_version/chapter_five_broadbandthe_three_essential_elements

Digital audio broadcasting. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Digital_Audio_Broadcasting

Digital Broadcasting Expert Group (DiBEG). (2007). *ISDB-T: Digital terrestrial television broadcasting system*. Retrieved November 2010, from: http://www.dibeg.org/techp/isdb/isdbt.htm

Digital Radio. (n.d.). *Coverage (in Germany)*. Retrieved November 2010, from: http://www.digitalradio.de/en/digital-radio/coverage/

Digital Video Broadcasting (DVB). (2001). *DVB-RCT: Return channel terrestrial*. Retrieved November 2010, from: http://www.dvb.org/technology/dvbrcs/index.xml

Digital Video Broadcasting (DVB). (2010). *DTT deployment data* [data file]. Retrieved November 2010, from: http://www.dvb.org/about_dvb/dvb_worldwide/

Digitalisierungsbericht (2008, September 2). Germany – Digital cable TV in more households than DTT. *Digital TV Business, Technology & Market Research News*. Retrieved November 2010, from: http://www.digitaltvnews.net/content/?p=3785

Digitalisierungsbericht. (2008, September 9). *3.9 Million DTT Households in Germany*. Retrieved November 2010, from DVB Website: http://www.dvb.org/about_dvb/dvb_worldwide/germany/index.xml

Directorate General of Press and Information (2010, June). *Radio and television in Turkey*. Retrieved November 2010, from: http://www.byegm.gov.tr/db/dosyalar/webicerik31.pdf

Ditech Network (2008, December). *VQA benefits for iDEN networks*. Retrieved November 2010, from: http://ditechnetworks.com/learningcenter/whitepapers/VQA_benefits_for_iDEN.pdf

Domain-b.com (2008, December 16). *Broadcom to provide satellite STP technology for Airtel's DTH service*. Retrieved November 2010, from: http://www.domain-b.com/companies/companies_b/Bharti_Enterprises/20081216_broadcom.html

DSL Forum (n.d.). *History of DSL*. Retrieved November 2008, from: www.dslforum.org/about/history.shtml

DSL Reports. (2008). *Speed problem: Monitor your download speeds*. Retrieved November 2010, from: http://www.dslreports.com/

DTV Status (2007, Diciembre). *ATSC, DVB-T e ISDB-T*. Retrieved November 2010, from: http://es.dtvstatus.net/ATSC_DVB-T_ISDB-T_es_archivo122007.html

Dutton, W. H., & Helsper, E. J. (2007). The Internet in Britain 2007. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/OxIS%20Report%202007.pdf

Equipo TIC-ISUC (2001, September). *Tecnologías, redes, sujetos: Una propuesta de exploración en torno a los usos de las TIC en la Sociedad de la Información. El* *caso de Chile. El caso de las nuevas generaciones*. Retrieved November 2010, from: http://web.mit.edu/crisgh/www/Observatorio%20TIC-ISUC.pdf

Ethernet in the First Mile Alliance (EFMA). (2004, June). EFM Copper (EFMC) Tutorial. Revision 4. Retrieved November 2010, from: http://www.nsgate.ru/doc/EFMC_Tutor_V4.pdf

European Commission Information Society (2008). *Russia*. Retrieved November 2010, from: http://ec.europa.eu/information_society/activities/internationalrel/docs/pi_study_rus_ukr_arm_azerb_bel_geor_kaz_mold/2_russia.pdf

European Communities Trade Mark Association (ECTA). (2007). *Broadband scorecard Q3 – 2007: European competitive telecommunications association*. Retrieved November 2010, from: http://www.ectaportal.com/en/REPORTS/Broadband-Scorecards/Broadband-Scorecard-2007/

European Regulators Group (ERG). (2005). *Broadband market competition report, Annex A – Country report*. Retrieved November 2010, from: http://www.erg.eu.int/doc/publications/erg_05_23_broadbd_mrkt_comp_annex_a_p.pdf

European Standard Telecommunications Institute (ETSI). (1997). *Digital Video Broadcasting (DVB): Multipoint video distribution system (mvds) at 10 ghz and above* [ETSI EN 300 748 V1.1.2 EBU-UER. Retrieved November 2010, from: http://broadcasting.ru/pdf-standard-specifications/transmission/

European Standard Telecommunications Institute (ETSI). (1997). *Digital Video Broadcasting (DVB): Microwave Multipoint Distribution Systems (MMDS) below 10 GHz* [ETSI EN 300 749 V1.1.2]. EBU-UER. Retrieved November 2010, from: http://broadcasting.ru/pdf-standard-specifications/transmission/

European Standard Telecommunications Institute (ETSI). (2004). Digital Video Broadcasting (DVB): Framing structure, channel coding and modulation for digital terrestrial television (ETSI EN 300 744 V1.5.1). EBU-UER. Retrieved November 2010, from: http://broadcasting.ru/pdf-standard-specifications/transmission/

Ewing D., Hall R., & Schwartz M. (1992). *A measurement study of Internet file transfer traffic* [CU-CS-571-92]. Retrieved November 2010, from University of Colorado Website: http://www.cs.colorado.edu/department/publications/reports/docs/CU-CS-571-92.pdf

Ewing, S. & Thomas, J. (2008). *CCi Digital Futures Report: The Internet in Australia*. Retrieved November 2010, from the World Internet Project Website:

http://www.worldinternetproject.net/_files/_Published/_oldis/AuDigitalFutures2008.pdf

Fábián, Z., Galácz, A., Gerhardt, E., Kollanyi, B., Júlia, K., … Székely, L. (2007). *The map of the digital future: Hungarian society and the Internet 2007*. Retrieved November 2010, from ITHAKA Website: http://www.ithaka.hu/Letoltheto

Fachhochschule für Technik Esslingen (FHTE). (2001). *The FHTE web history of telecommunications*. Retrieved November 2010, from: http://www2.hs-esslingen.de/telehistory/1975-.html

FCC (Federal Communications Commission). (2011). *Measuring Broadband America: A Report on Consumer Wireline Broadband Performance in the U.S*. Washington: FCC's Office of Engineering and Technology and Consumer and Governmental Affairs Bureau. Retrieved from http://transition.fcc.gov/Daily_Releases/Daily_Business/2011/db0802/DOC-308828A1.pdf

Fiber to the premises by country. (n.d.) In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Fiber_to_the_premises_by_country

Findahl, O. (2001). *Swedes and the Internet, year 2000*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/Sweden_Internet2000.pdf

Findahl, O. (2008). *The Internet in Sweden*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/wii-rapport-internet_in_sweden_2007.pdf

FM broadcasting. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/FM_radio

Forrester, C. (2008, May). Insight: Russia- The wild east of DTV? *SatMagazine – Commercial Satellite Imagery*. Retrieved November 2010, from: http://www.satmagazine.com/

Foster, S. G. (2008). *Overview of current european experiencie in FTTH and current installation techniques*. FTTH Council Asia-Pacific. Retrieved November 2010, from: http://duct.cpami.gov.tw/intro/Conference/10/M10-7.pdf

Fraleigh, C., Moon, S., Lyles, B., Cotton, C., Khan, M., … & Diot, S. C. (2003). *Packet-level traffic Measurements from the Sprint IP Backbone*. IEEE Network 17(6), 6-16. doi: 10.1109/MNET.2003.1248656

Freeman, R. L. (2005). *Fundamentals of telecommunications* (2nd ed.). Hoboken, New Jersey: John Wiley & Sons.

FTTH Council (2010). *Rural Utilities Services Workshop - FTTH Deployment Status Update*. October 2010, Retrieved November 2011, from http://www.ftthcouncil.org/en/content/ftth-council-presentations-to-rural-utilities-service-workshop-october-2010; http://s.ftthcouncil.org/files/rus_workshop_-_ftth_status.pdf

Future Horizons (2010). *Semiconductor Applications Market Report - 2008 Edition*. Retrieved November 2010, from http://www.futurehorizons.com/

Godoy, S. (2004). *Principales resultados WIP Chile 2004*. Retrieved November 2010, from: http://www.estrategiadigital.gob.cl/files/INFORME%20WIP%20CHILE%202004.pdf

Godoy, S. (2009). *Los internautas chilenos y sus símiles en el resto del mundo: Resultados del estudio WIP-Chile 2008*. Retrieved November 2010, from Camara de Comercio de Santiago (CCS) Website: http://www.ccs.cl/html/eventos/2009/doc/0326_WIP_informe.pdf

Gorman, T. (1996, January). *Television: Glorious past, uncertain future*. Statistics Canada. Retrieved November 2010, from: http://www.statcan.gc.ca/pub/63f0002x/63f0002x1995006-eng.pdf

GPS signals. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/GPS_signals#CNAV_Navigation_message

Grande, J. C. (2007, December). El consumo de medios masivos en el área metropolitana de San Salvador. *Minerva Revista en Línea CIC-UES 1* Retrieved November 2010, from: http://www.cic.ues.edu.sv/REVISTA%20CIC-UES%20MINERVA/articulos/Humanidades/Consumo%20Cultural.pdf

Gruber, H. (2005). *The economics of mobile telecommunications*. Cambridge, UK: Cambridge University Press.

Grupo Radar (2007). *El Perfil del Internauta Uruguayo* (5th ed.). Retrieved November 2010, from InnovaAge.com Website: http://www.innovaportal.com/innovaportal/file/86/1/Internet_en_Uruguay_2007.pdf

GSM World (2008). *3GSM platform: Number of connections WCDMA*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20080405111504/http://www.gsmworld.com/technology/3g/statistics.shtml

GSM World (2008b). *GPRS class type*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20080805030515/http://www.gsmworld.com/technology/gprs/class.shtml

GSM World (2008d). *GSM subscriber statistics (2002 – 2004)*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20070125062057/http://www.gsmworld.com/news/statistics/pdf/gsma_stats_q4_05.pdf

GSM World. (2010). *Growth of the global digital mobile market (1992 – 2004)*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20070421095452/http://www.gsmworld.com/news/statistics/pdf/gsma_stats_q4_04.pdf

GSM World. (2010). *GSM facts and figures*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20061111081421/http://www.gsmworld.com/news/statistics/

Guo L., Tan E., Chen S., Xiao Z., Spatscheck O., & Zhang X. (2006). *Delving into Internet streaming media delivery: A quality and resource utilization perspective*. Proceedings of the 6th ACM SIGCOMM Internet Measurement Conference (IMC'06), 217-230. doi: 10.1145/1177080.1177108

Guzmán C., C. (1997). *Las nuevas síntesis urbanas de una ciudad cultural (la ciudad como objeto de consumo cultural)*. Retrieved November 2010, from: http://www.redinterlocal.org/IMG/ciudadania_cultural.pdf

Hahn, F. E., Davis, T., Killian, B., & Magill, K. (2003). *Do-it-yourself advertising and promotion: how to produce great ads, brochures, catalogs, direct mail, web sites, and more!* (3rd ed.). Hoboken, New Jersey: John Wiley & Sons

Hana Institute of Finance (2007). A *review on CATV's potencial growth based on digitization*. Retrieved November 2010, from: http://mibbeuda.tistory.com/attachment/jk71.pdf

Harrison, K., & Cantor, J. (1997). The relationship between media consumption and eating disorders. *Journal of Communication 47*(1), 40-67. doi: 10.1111/j.1460-2466.1997.tb02692.x

Hilbert, M., & López, P. (2011). The World's Technological Capacity to Store, Communicate, and Compute Information. Science, 332(6025), 60 -65. doi:10.1126/science.1200970

Hoeg, W., & Lauterbach, T. (2003). *Digital audio broadcasting: principles and applications of digital radio* (2nd ed.). West Sussex, UK: Wiley-Interscience.

Home Chinese Forum Blog HR Market (2010, June 04). Global FTTH/B market grows to almost 41 million subscribers. *News Release*. Retrieved November 2010, from: http://www.cn-c114.net/577/a513510.html

Horak, R. (2007). *Telecommunications and data communications handbook*. Hoboken, New Jersey: Wiley-Interscience.

Hornik, J., & Schlinger, M. J. (1981). Allocation of time to the mass media. *The Jornal of Consumer Research 7*(4), *Special Issue on Consumption of Time*, 343 – 355.

Hppy bthdy txt! (2002, December 3). *BBC News, World Edition*. Retrieved November 2010, from: http://news.bbc.co.uk/2/hi/uk_news/2538083.stm

Hutcheson, L. (2009, February 11). *FTTH/FTTB in Asia-Pacific*. Ovum. Retrieved November 2010, from: http://www.slideshare.net/ceobroadband/ftth-conferencC-2009-ftth-in-asia-pacific

Ibarra, D. J. & Arabito, J. (2005). *La contrucción del público radiofónico. Oyentes modelos y oyentes empiricos en radios de Olavaria*. IX Jornadas Nacionales de Investigadores en Comunicación. . Retrieved November 2010, from: http://www.redcomunicacion.org/memorias/pdf/2005aribarra-arabito.pdf

Ibrahim, K. F. (2007). *Newnes Guide to Television and Video Technology* (4th ed.). Amsterdam: Elsevier.

IDATE (2000, December). *Development of digital TV in Europe, 2000 report: Austria*. Prepared by Slazburg Research Forschungsgesellschaft mbH, Retrieved November 2010, from: http://ec.europa.eu/archives/ISPO/infosoc/telecompolicy/en/dtv_au2000v4.pdf

IDATE (2000, December). *Development of digital TV in Europe, 2000 report: Italy*. Prepared by Databank Consulting. Retrieved November 2010, from: http://ec.europa.eu/archives/ISPO/infosoc/telecompolicy/en/dtv_it2000v4.pdf

Informa Media Group. (2004). *Latin American TV* (8th ed.). Retrieved November 2010, from: http://www.proexport.com.co/vbecontent/library/documents/DocNewsNo5732DocumentNo4953.PDF

Informa Telecoms & Media (2009, June 16). TV International. *Analysis for the Global Television Content and Delivery Industry 17*(11). Retrieved November 2010, from: http://www.informatm.com/pdf/Feb-2006/22/bt021006_14.3.pdf

Instituto Nacional de Estadisticas (INE Chile). (2009, Mayo). *Enfoque estadístico: ¿Cómo distribuyen el tiempo hombres y mujeres?* Retrieved November 2010, from: http://www.ine.cl/canales/chile_estadistico/estadisticas_sociales_culturales/encuesta_tiempo_libre/pdf/enfoque_eut_pag.pdf

International Paper Knowledge Center. (n.d.). Format selection. In *Learn about Printing: Direct mail – Planning and design*. Retrieved November 2010, from: http://glossary.ippaper.com/default.asp?req=knowledge/article/448&catitemid=56

International Telecommunications Union (ITU). (1988). *G.711: Pulse Code Modulation (PCM) of Voice Frequencies. Telecommunication Standardization Sector of ITU*. ITU-T Recommendation G.711. Retrieved November 2010, from: http://www.itu.int/rec/T-REC-G.711-198811-I/en

International Telecommunications Union (ITU). (2008). About Mobile Technology and IMT-2000. Retrieved November 2010, from: http://www.itu.int/osg/spu/imt-2000/

International Telecommunications Union (ITU). (2009). *ITU world telecommunications ICT indicators 2009* [data file].

International Telecommunications Union (ITU). (2010). *ITU World Telecommunication ICT Indicators 2010* [data file].

International Telecommunications Union (ITU). (2011). *ITU World Telecommunication ICT Indicators 2011* [data file].

International Telecommunications Union (ITU). (n.d.). *Data communication over the telephone network*. Retrieved November 2010, from: http://www.itu.int/rec/T-REC-V/en

IP-Network (2007). *Television 2007 international key facts*. Retrieved November 2010, from: http://www.ip-network.com/tvkeyfacts/Tables/CableAndSatpdf.pdf

IP-Network (2008). *Television 2008 international key facts*. Retrieved November 2010, from: http://www.ip-network.com/tvkeyfacts/Tables/Cable&sat08.pdf

IP-Network (2009). *Television 2009 international key facts*. Retrieved November 2010, from:http://www.ip-network.com/tvkeyfacts/Tables/Cable&sat09.pdf

Ipoque. (2006). *P2P survey 2006*. Retrieved November 2010, from: http://www.ipoque.com/resources.

Ipoque. (2007). *Internet study 2007*. Retrieved November 2010, from: http://www.ipoque.com/resources.

Ishiyama, K. (2003). *The start of digital terrestrial broadcasting in Japan and the transition from analog broadcasting to digital broadcasting*. Japan Broadcasting Corporation (NHK). Retrieved November 2010, from Broadcast Papers Website: http://www.broadcastpapers.com/

Jack, K. (2005). *Video demystified: a handbook for the digital engineer* (4th ed.). Oxford, UK: Newnes/Elsevier.

Jack, K. & Tsatsulin, V. (2002). *Dictionary of video and television technology*. Woburn, MA: Elsevier Science

Jorge, J. E. (2008, December). Actitudes hacia la política y la democracia, capital social y uso de medios en la región del Gran La Plata: Resultados de la encuesta comunicación y cultura política 2008. *Revista Question 20*.

Jung, B. (2001). Media consumption and leisure in Poland in the 1990s: Some quantitative aspects of consumer behavior. *International Journal on Media Managements, 3*(2), 88-90. doi: 10.1080/14241270109389951

JWM Direct Marketing (n.d.). *Direct Mail 101*. Retrieved November 2010, from: http://www.jwmdirect.com/direct-mail.asp

Kalden, R. A. (2004). *Mobile Internet traffic measurement and Modeling based on data from commercial GPRS networks* (Doctoral dissertation, University of Twente). Retrieved November 2010, from: http://doc.utwente.nl/48238/1/thesis_kalden.pdf

Karagiannis, T., Broido, A. Brownlee, Claffy, K., C., & Floutsos, M. (2004). *Is P2P dying or just hiding?* IEEE Global Telecommunications Conference 3, 1532-1538. doi:10.1109/GLOCOM.2004.1378239

King, B. (1999, December 6). *Broadcasting system details*. Retrieved November 2010, from University of Surrey Website: http://www.ee.surrey.ac.uk/Contrib/WorldTV/broadcast.html

Koenan, A., Konert, B., & Groebel, J. (2003). *Germany and the digital world*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/WIP%20Report%20Germany%202002.pdf

Koren, Hillel (2010, March 10). HOT losses money, customers in cable TV. *Globes Israel's business arena News*. Retrieved November 2010, from: http://www.globes.co.il/serveen/globes/nodeview.asp?fid=1725

Korpela, J. K. (2006). Unicode explained. Sebastopol, CA: O'Reilly.

KPMG (2009, September). *Comunicaciones en Argentina* [PowerPoint Slides]. Septiembre, 2009. Retrieved November 2010, from Slide Share Website: http://www.slideshare.net/cxocommunity/kpmg-comunicaciones-en-argentina

Kunigonis, M. (2004, February). *International broadband and FTTH deployments: Lessons learned around the globe applied to India*. SuperComm India. Retrieved November 2010, from: http://www.corning.com/WorkArea/downloadasset.aspx?id=8003

Kunigonis, M. (2004, March 18). Fiber to the home: Myths versus realities. Corning. Retrieved November 2010, from: http://networks.jcbroadband.com/downloads/FTTHMythsAndRealities.pdf

Kunigonis, M. (2005, January 14). *FTTH deployments in China and Asia: Market drivers, politics and technology choices*. Corning. ChinaTel Summit 2005. Retrieved November 2010, from: http://www.corning.com/docs/opticalfiber/cm6317.pdf

Kurachi, Mitsuo (1986, July). Present trends in high-speed and broadband communication services in Japan. *IEEE Journal on Selected Areas in Communications SAC-4*(4), 438 – 443.

Laboratorio de Industrias Culturales (2008, Marzo). Televisión por cable en Argentina. *Click 3*(12) (Boletín informativo LIC). Retrieved November 2010, from: http://lic.cultura.gov.ar/investigaciones/click/CLICK3-12-tv_por_cable.pdf

Lacort, J. A., Pont, A., Gil, J. A., & Sahuquillo, J. (2004). *A comprehensive web workload characterization*. Retrieved November 2010, from: Department of Computer Engineering, Polytechnic University of Valencia: http://www.comp.brad.ac.uk/het-net/HET-NETs04/CameraPapers/P67.pdf

Laplante, P. A. (1999). *Electrical engineering dictionary*. Boca Raton: CRC Press LLC.

Lathi, B. P. (1998). *Modern digital and analog communication systems* (3rd ed.). Oxford, UK: Oxford University Press.

Lebo, H. (2002). *The UCLA Internet report 2001: Surveying the digital future, year two*. Retrieved November 2010, from Center for the Digital Future, USC Annenberg School: http://www.digitalcenter.org/pdf/InternetReportYearTwo.pdf

Leibowitz, N., Bergman, A., Ben-Shaul, R., & Shavit, A. (2002). *Are file swapping networks cacheable? Characterizing P2P traffic*. Procedures of Web Content Caching and Distribution (WCW) International Workshop.

Leinen, S. (2001). *Flow-based traffic analysis at SWITCH*. Poster at Passive and Active Measurements (PAM) Workshop, 2001.

Liang, G. (2005). Surveying Internet usage and impact in five chinese cities. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/China%20Report%202005.pdf

Liang, G. (2007). *Surveying Internet usage and its impact in seven chinese cities*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/_China%20Internet%20Project%20Survey%20Report%202007.pdf

LinowSat. (n.d.). DVB service information and bitrate database. Retrieved November 2010, from: http://www.linowsat.de/

List of device bit rates. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/List_of_device_bandwidths

López, P., & Hilbert, M. (2011). Supporting Online Material: The World's Technological Capacity to Store, Communicate, and Compute Information. Science, 332(6025), 60 -65. doi:10.1126/science.1200970

MacKiC-Mason, J., & Varian, H. (1994), Economic FAQs about the Internet. *The Journal of Economic Publishing* 2(1). doi:10.3998/3336451.0002.102

Madnick, S., Smith, M., & Clopeck, K. (June 2009). How much information? Case studies on scientific research at MIT. *HMI? Case Studies*, Global Information Industry Center at the School of International Relations and Pacific Studies, University of California. Retrieved November 2010, from: http://hmi.ucsd.edu/

Mahanti, Anirban (1999). *Web Proxy Workload Characterization and Modelling* (Master Thesis, University of Saskatchewan, Canada). Retrieved November 2010, from: http://www.comsoc.org/ni/private/2000/may/pdf/Mahanti.pdf

Mallick, M. (2003). *Mobile and wireless design essentials*. Hoboken, New Jersey: John Wiley & Sons.

Marcus, J. S. (1999). *Designing wide area networks and internetworks: a practical guide*. Reading, MA: Addison-Wesley.

Marples, G. (2004). The History of Satellite TV. Retrieved November 2010, from TheHistoryOf Website: http://thehistoryof.net/history-of-satellitC-tv.html

Marshall, D. (2001). Implications of sample rate and bit size. Retrieved November 2010, from Cardiff School of Computer Science & Informatics Website: http://www.cs.cf.ac.uk/Dave/Multimedia/node150.html

MAVISE. (n.d.). *MAVISE database*. Retrieved November 2010, from: http://mavise.obs.coe.int/welcome

Mayer, W. G. (1993). Poll trends: Trends in media usage. *The Public Opinion Quarterly 57*(4), 593–611.

Mazumdar, S. (n.d.). *India-content: Distribution market and digitalization*. Retrieved November 2010, from India Digital Website: http://www.indigital.co.in/pdf/IndiamktIMCL&PESHIL.PDF

Meattle, J. (2007, November 29). *Total time spent online is up 24.3%* [Web log post]. Retrieved November 2010, from: http://blog.compete.com/2007/11/29/total-timC-spent-onlinC-is-up-243/

Media InfoCenter. (n.d.). *Hours spent listening to the radio per week*. Retrieved November 2010, from: http://www.mediainfocenter.org/music/radio_audience/hours_perweek.asp

Media Partners Asia Ltd. (MPA). (2005). *Asia Pacific cable & satellite markets 2005*. Retrieved November 2010, from: http://www.exchange4media.com/e4m/media_matter/matter_280405.asp

Media Statistics: Television viewing (most recent) by country. (n.d.). In *Nation Master*. Retrieved November 2010, from: http://www.nationmaster.com/graph/med_tel_viC-media-television-viewing

Mediascope Europe (2008). *Tendencias 2008*. Retrieved November 2010, from the Diputación de Salamanca Website: http://www.dipsanet.es/cipsa/docs/2008%20Estudio%20Mediascope%20Europe.pdf

Mediatica (2006, Enero). *Emociones y radioescuchas*. Retrieved November 2010, from Asociación de Radiodifusores de Chile (ARCHI): http://www.archi.cl/nuevo/images/estudios/1_ESTUDIO_LA_RADIO_Y_LAS_EMOCIONES.pdf

Mikami, S., Kubota, F., Hashimoto, Y., Hiroaki, Y., Endo, K., …Kitamura, S. (2005). *Internet usage trends in Japan: Survey report 2005*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/Japan_Report_2005.pdf

Mikami, S., Kubota, F., Hashimoto, Y., Hiroaki, Y., Endo, K., & Ishii, E. (2002). *Internet usage trends in Japan: Survey report 2001*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/Japan_Report_2001.pdf

Ministry of Internal Affairs and Communications (MIC). (2009, June 12). State of cable television penetration. *MIC Press Release*. Retrieved November 2010, from:

http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Statistics/pdf/090612_1.pdf

Mitchell, B. (2009). *DSL vs. cable modem comparison both offer advantages to the home and small business customer*. Retrieved November 2010, from About.com Guide: http://compnetworking.about.com/od/dslvscablemodem/a/dslcablecompare.htm

MK Marketing+Ventas (2004, December). *¿Qué medios prefieren los europeos?* Retrieved November 2010, from: http://pdfs.wke.es/9/6/8/1/pd0000019681.pdf

Montagne, R. (2008, June 18). *From today broadband to FTTx: Strategies – French case*. IDATE, Warsaw. Retrieved November 2010, from: http://www.uke.gov.pl/_gAllery/11/67/11670/prezentacja_IDATE.pdf

Montagne, R. (2008, November 12). FTTH *Worldwide status – French case and business model issues*. IP Cities 2008, IDATE. Paris. Retrieved November 2010, from: http://www.localret.cat/jornades-i-actes/materials/jornades2008/ipcities/idate.pdf

Motorola (2000). *iDEN: Technical overview*. Retrieved November 2010, from: http://webaugur.com/matt/files/nextel/techover.pdf

Motorola (n.d.). iDEN mobile devices. Retrieved May 2008, from: http://idenphones.motorola.com/iden/

Motorola Media Center (2002). Motorola sets another broadband-industry milestone with landmark 10 millionth cable modem shipment. *Press Release*. Retrieved May 2008, from: http://www.motorola.com/mediacenter/news/detail.jsp?globalObjectId=2178_1767_23&page=archive

Moulton, P. (2001). *Telecommunication Survival Guide*. New Jersey: Prentice Hall PTR.

Multiplex (TV). (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Multiplex_(TV)

Nagamalai, D., Dhinakaran, B. C., & Lee, J. K. (2008). An in-depth analysis of spam and spammers. *International Journal of Security and its Applications 2*(2), 9-22. Retrieved November 2010, from: http://www.sersc.org/journals/IJSIA/vol2_no2_2008/2.pdf

National Cable & Telecommunications Association (NCTA). (2009). *Operating Metrics (as March 2009)*. Retrieved November 2010, from:http://www.ncta.com/Search.aspx?t=statistics

National Cable & Telecommunications Association (NCTA). (2010). *Digital video customers 1998 – 2009*. Retrieved November 2010, from:http://www.ncta.com/Stats/CableAvailableHomes.aspx

Navarro Briones, Javier (2005). Las Encuestas de Jóvenes en Iberoamérica. Un recuento de experiencias recientes. *Revista de Estudios sobre Juventud 9*(23), 148-209. Retrieved November 2010, from: http://prejal.oit.org.pe/prejal/docs/bib/200711220015_4_2_0.pdf

Newman, J., & Willis, D. (1996, May 16). *What ISDN Is: BRI and PRI*. Retrieved November 2010, from Network Computing for IT by IT Website: http://www.networkcomputing.com/netdesign/isdnf.html

NHK (2006). *NHK and convergence* [PowerPoint Slides]. Retrieved November 2010, from: http://www.psb-review.org.hk/eng/documents/2-(NHK)HK060613V1.0Convergence.ppt

Nielsen (2007, October 1). Media consumption in Malaysia remains strong: Adex expected to register another year of positive growth. *Nielsen News*. Retrieved November 2010, from: http://my.nielsen.com/site/20071001.shtml

NielsenWire (2009, September 2). *Three screen report: Media consumption and multi-tasking continue to increase across TV, Internet and Mobile* [Web log post]. Retrieved November 2010, from: http://blog.nielsen.com/nielsenwire/media_entertainment/threC-screen-report-media-consumption-and-multi-tasking-continuC-to-increase

Nikkei Business Publications Inc. (2000, July). Telstra first to initiate GPRS network. Retrieved November 2010, from: http://techon.nikkeibp.co.jp/NEA/archive/200007/106445/

Nippon Network Television Corporation (NTV). (2006). *Basic knowledge about television in Japan*. Retrieved November 2010, from: http://www.ntv.co.jp/english/ir/images/ar/2006-05.pdf

Nique, M., Ramahandry, T., & Salanave, J. (2007). *The world telecommunications equipment market: Market overview*. IDATE.

Nyquist, H. (2002). Certain topics in telegraph transmission theory. *Proceedings of the IEEE*, *90*(2), 280-305. doi: citeulikC-articlC-id:966439

O2. (n.d.). *GPRS countries*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20080617044102/http://www.o2.co.uk/services/messaging/mediamessaging/gprscountriesO2 (2008). GPRS Countries. http://travelabroad.o2-uktech.com/gprsnetworks.php?location=services

Odlyzko, A. (2010). *Minnesota Internet Traffic Studies (MINTS)*. Retrieved November 2010, from: http://www.dtc.umn.edu/mints/

Ofcom (2003). *ITC multichannel quarterly – Q4 2002*. Retrieved November 2010, from: http://www.ofcom.org.uk/static/archive/itc/research/multichannel_q4_2002.pdf

Ofcom (2004). *Digital television uptake Q4 2003*. Retrieved November 2010, from: http://stakeholders.ofcom.org.uk/market-data-research/tv-research/dtv/dtv2003q4/uptake

Ofcom (2005). *Digital television update Q4 2004.* Retrieved November 2010, from: http://stakeholders.ofcom.org.uk/binaries/research/tv-research/q4_2004.pdf

Ofcom (2007, December 18). Summary profiles of pay TV in France, Germany, Italy, Spain, Sweden and United States. *Annex 9 to Pay TV Market Investigation Consultation*. Retrieved November 2010, from: http://stakeholders.ofcom.org.uk/binaries/consultations/market_invest_paytv/annexes/annex9.pdf

OfCom (2007). *Digital television update – 2007 Q1*. Retrieved November 2010, from: http://stakeholders.ofcom.org.uk/market-data-research/tv-research/dtv/dtu_2007_q1/

Ofcom (2007). *The communications market: Digital progress report, Digital TV, Q4 2006*. Retrieved November 2010, from: http://stakeholders.ofcom.org.uk/binaries/research/tv-research/dtu_2006_q4.pdf

OfCom (2008). *Digital television update – 2008 Q2*. Retrieved November 2010, from: http://stakeholders.ofcom.org.uk/market-data-research/tv-research/dtv/dtu_2008_q2/

Ofcom (2008). *The communications market: Digital progress report, Digital TV, Q4 2007*. Retrieved November 2010, from: http://stakeholders.ofcom.org.uk/binaries/research/tv-research/dtvq407.pdf

Ofcom (2009). *International communications market 2009 charts*. Retrieved November 2010, from DocStoc Website: http://www.docstoc.com/docs/22331657/ICMR-2009-charts

Ofcom (2009). *International communications market report 2008*. Retrieved November 2010, from Slide Share Website: http://www.slideshare.net/comment.ofcom/international-communications-market-2008-presentation

Ofcom (2009). *The communications market: Digital progress report, Digital TV, Q4 2008*. Retrieved November 2010, from: http://stakeholders.ofcom.org.uk/binaries/research/tv-research/q42008.pdf

Ofcom. (2008). The communications market: Digital progress report digital TV, Q4 2008. Retrieved November 2010, from: http://stakeholders.ofcom.org.uk/binaries/research/tv-research/q42008.pdf

Ofcom (2010). *Ofcom research reveals increase in UK's average actual broadband speed – But consumers still not achieving advertised speeds*. Retrieved November 2011, from http://media.ofcom.org.uk/2010/07/27/ofcom-research-reveals-increase-in-uk%E2%80%99s-average-actual-broadband-speed-but-consumers-still-not-achieving-advertised-speeds/

Ojala, P., Toukomaa, H., Moriya, T., & Kunz, O. (1998). Report on the MPEG-4 speech codec verification tests *ISO/IEC JTC1/SC29/WG11, MPEG98/N2424*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/*/http://sound.media.mit.edu/mpeg4/audio/public/w2424.pdf

Ookla. (2011). *NetIndex source data* [Downstream and Upstream speed-test results]. Retrieved November 2011, from: http://www.netindex.com/source-data/

Organisation for Economic Co-Operation and Development (OECD). (2001). *OECD communications outlook 2001 – Information society*. Retrieved November 2010, from: http://213.253.134.43/oecd/pdfs/browseit/9301021E.PDF

Organisation for Economic Co-Operation and Development (OECD). (2005). *OECD communications outlook 2005 – Information* and *communications technologies*. Retrieved November 2010, from: http://213.253.134.43/oecd/pdfs/browseit/9305011E.PDF

Organisation for Economic Co-Operation and Development (OECD). (2007). *OECD communications outlook 2007 – Information* and *communications technologies*. Retrieved November 2010, from: http://213.253.134.43/oecd/pdfs/browseit/9307021E.PDF

Organisation for Economic Co-operation and Development (OECD). (2009). *OECD Communications Outlook 2009 – Information and Communications Technologies*. Retrieved November 2010, from: http://213.253.134.43/oecd/pdfs/browseit/9307021E.PDF

Organisation for Economic Co-Operation and Development (OECD). (2011). *OECD communications outlook 2011 – Information* and *communications technologies*. Retrieved November 2011, from: http://213.253.134.43/oecd/pdfs/browseit/9305011E.PDF

Oyamada, K., Kurakake, T., & Miyazawa, H. (2001). *ISDB-C: Cable television transmission for digital broadcasting in Japan*. NHK (Japan Broadcasting Corporation). Retrieved November 2010, from: http://www.nhk.or.jp/strl/publica/bt/en/pa0007.html

Pallis, G., Vakali, A., Angelis, L., & Said Hacid, M. (2003). *A study on workload characterization for a web proxy server*. Proceedings of the 21st International Multi-Conference on Applied Informatics.

Patiño, D. (2007). El nivel ético de los medios de comunicación en Ecuador: Nortvisión, Radio Máster y Semanario La Prensa de la ciudad de Tulcán. Universidad Técnica Particular de Loja. Retrieved November 2010, from: http://repositorio.utpl.edu.ec/bitstream/123456789/3272/1/170X363.pdf

Paul Budde Communication Pty Ltd (2010, April 4). *Global: Broadband & FttH – Key statistics & trends*. Report Synopsis. Retrieved November 2010, from: http://www.budde.com.au/Research/Global-Broadband-FttH-Key-Statistics-and-Trends.html

Perlman, R. (2002). *Internet Access via Cable TV* [PowerPoint Slides]. Central and Eastern European Networking Association (CEENET). Retrieved November 2010, from: http://www.ceenet.org/workshops/lectures2002/Richard_Perlman/Cable%20Modems-2002.ppt

Personal digital cellular. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Personal_Digital_Cellular

Peter Fleming Consulting (2006). *Status of DAB around the world*. Retrieved November 2010, from the Canadian Association of Broadcasters (CAB) Website: http://www.cab-acr.ca/english/research/06/sub_mar1506_app_g.pdf

Peters, M. (2005, February 25). Lyra Research PMA 2005 Digital Camera Forecast. Let's Go Digital Online Magazine. Retrieved November 2010, from: http://www.letsgodigital.org/en/news/articles/story_2680.html

Pierce, J. (1980). An introduction to Information Theory: Symbols, signals and noise (2nd rev. ed.). New York, NY: Dover Publications.

Pineda, Salvador (2003). Los medios de comunicación social salvadoreño y su afinidad ideológica política, como herramienta para incidir en la población durante periodos eleccionarios. Retrieved November 2010, from Biblioteca de la Universidad Tecnológica de El Salvador Website: http://biblioteca.utec.edu.sv/siab/virtual/auprides/17176/capitulo%202.pdf

Pitkow, J., & Recker, M. (1995). Using the Web as a survey tool: results from the second WWW user survey. *Journal of Computer Networks and ISDN* *systems*(27), 809-822. Retrieved November 2010, from College of Computing, Georgia Institute of Technology: http://www.cc.gatech.edu/gvu/user_surveys/survey-09-1994/html-paper/survey_2_paper.html

Power and Associates. (2008). Portable navigation device usage and satisfaction study. Retrieved November 2010, from: http://www.jdpower.com/electronics/articles/2008-PortablC-Navigation-DevicC-UsagC-and-Satisfaction-Study/

PR Newswire. (1990, September 11). *Integrated Network Corporation to unveil high speed "bandwidth on demand" ISDN unit at TCA*. Retrieved November 2010, from HighBeam Reasearch Website: http://www.highbeam.com/doc/1G1-8829300.html

Pronovost, G. (1996). *Medios de comunicación social y prácticas culturales: Una misma perspectiva de análisis*. Retrieved November 2010, from: http://www.consultas-cursos-dC-psicoanalisis.com/cultura2dsociologia2dantropologia/una_misma_perspectiva_de_analisis2d_gilles_pronovost.pdf

Quinde, I., & Borja, A. (2006, Marzo). *Estudio y análisis de la tecnología para difusión de televisión vía satélite: DBS (Directs Broadcast System Satellite), su aplicación DTH (Direct to Home) y sus futuras perspectivas*. Retrieved November 2010, from Biblioteca de la Escuela Politécnica Nacional: http://bibdigital.epn.edu.ec/bitstream/15000/692/1/CD-1641(2008-07-28-11-27-53).pdf

Rairhurst, G. (2001). MPEG-2. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20070101073921/http://erg.abdn.ac.uk/research/future-net/digital-video/mpeg2.html

Rämö, A., & Toukomaa, H. (2005). *On comparing speech quality of various narrow- and wideband speech codecs*. Paper presented at the Proceedings of the Eighth International Signal Processing and Its Applications. doi: 10.1109/ISSPA.2005.1581010

Regulatel (2005). *Comparison of monthly charges for broadband internet access in Regulatel member countries – Anexo 8*. Retrieved November 2010, from: http://www.regulatel.org/

Regulatory Authority for Broadcasting and Telecommunications (RTR). (2005). *Communications report 2005*. Retrieved November 2010, from: http://www.rtr.at/en/komp/KBericht2005/CommReport_2005_E.PDF

Regulatory Authority for Broadcasting and Telecommunications (RTR). (2007). *Communications report 2007*. Retrieved November 2010, from: http://www.rtr.at/en/komp/KBericht2007/C-Report_2007.pdf

Regulatory Authority for Broadcasting and Telecommunications (RTR). (2008). *Communications report 2008*. Retrieved November 2010, from: http://www.rtr.at/en/komp/KBericht2006/C-Report2006.pdf

Regulatory Authority for Broadcasting and Telecommunications (RTR). (2009). *Communications report 2009*. Retrieved November 2010, from: http://www.rtr.at/en/komp/KBericht2009/C-Report_2009.pdf

Reina Schement, J. (2002). *Encyclopedia of communication and information*. New York, NY: Macmillan Reference USA.

Reinfeld, G. (n.d.). *Finding the right direct-mail format*. Retrieved November 2010, from Directory M Articles Website: http://articles.directorym.net/

Reitze, H., & Ridder, C. (2005). Eine Langzeitstudie zur Mediennutzung und Medienbewertung 1964-2005. Retrieved November 2010, from: http://www.media-perspektiven.de/

Render, M. (2010). *North American FTTH/FTTP status*. FTTH Council North America. Retrieved November 2010, from Slide Share Website: http://www.slideshare.net/ceobroadband/michael-render

Research In China (2009, July 13). *China digital TV market operation report, 2008-2009*. Retrieved November 2010, from DocStock Website: http://www.docstoc.com/docs/14604310/CablC-Tv-In-China

ResearchInChina (2010). *China digital TV operation report, 2009-2010*. Retrieved November 2010, from: http://www.researchinchina.com/htmls/report/2010/5858.html

Reyes, M. & Vorher, V. (2003). Fundamentos conceptuales para el diseño de un noticiario en radio para niños y bases para su producción. Retrieved November 2010, from Universidad de las Américas Website: http://catarina.udlap.mx/u_dl_a/tales/documentos/lco/reyes_v_m/capitulo3.pdf

Ricciato, F., Hasenleithner, E., & Pilz, R. (2006). *Composition of GPRS/UMTS traffic: Snapshots from a live network*. 4th International Workshop on Internet Performance, Simulation, Monitoring and Measurement, Salzburg. Retrieved November 2010, from: http://userver.ftw.at/~ricciato/darwin/svoboda-IPSMOMC-1.4.pdf

Ricker, T. (2006, January 1). Digital television, part II: Global status. *Engadget News*. Retrieved November 2010, from: http://www.engadget.com/2006/01/18/digital-television-part-ii-global-status/

Rideout, V., Foehr, U., & Roberts, D. (2010). *Generation M^2: Media in the lives of 8- to 18-year-olds*. Retrieved November 2010, from Kaiser Family Foundation: http://www.kff.org/entmedia/upload/8010.pdf

Riley, R. W., & Robinson, S. P. (1994, October). TV viewing and parental guidance. *Education Consumer Guide, No. 10*. Retrieved November 2010, from: http://www2.ed.gov/pubs/OR/ConsumerGuides/tv.html

Rock.com.ar (1996). *Soda Stereo*. Retrieved November 2010, from: http://www.rock.com.ar/artistas/soda-stereo

Romano, F. (2007, June 27). *Direct mail formats*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20080720013019/http://creativepro.paperspecs.com/resources/tips/20076732165.htm

Rudinei, J. (n.d.). Evolução da TV brasilera. Retrieved November 2010, from Eletrônica Quartz Website: http://www.equartz.com.br/quartz/html/modules/xt_conteudo/index.php?id=5

Saito, T., Hashimoto, A., Minematsu, F., Nomoto, T., & Matsumura, H., (2000). *ISDB-S: Satellite transmission system for advanced multimedia services provided by Integrated Services Digital Broadcasting*. NHK (Japan Broadcast Corporation). Retrieved November 2010, from: http://www.nhk.or.jp/strl/publica/bt/en/pa0005.html

Salamon, A. (1998). *Internet statistics*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20080702030001/http://www.dns.net/andras/stats.html#weekly

Salomon, D. (2007). *Data Compression: The Complete Reference* (4th ed.). Berlin, Germany: Springer-Verlag.

Sanchez-Klein, J. (1998, December 10). Europe's first ADSL service launches. *IDG News Service*. Retrieved November 2010, from Cable News Networks (CNN) Website: http://www.cnn.com/TECH/computing/9812/10/euradsl.idg/

Sandvine (2008). *2008 Global broadband phenomena*. Retrieved November 2010, from: http://www.sandvine.com/news/global_broadband_trends.asp

Satellite television. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Satellite_television

Sato, K. (2007, November 14). *Telecommunications market in Japan and NTT's strategy for FTTH*. DigiWorld 2007 Summit Executive Seminar "Who should pay for FTTx?". Retrieved November 2010, from Bloobble Website: http://www.bloobble.com/broadband-presentations/presentations?itemid=972

Savage, J. (2009, September). Fiber to the home: A global success, a national imperative. *The FTTH Prism 6*(4). Retrieved November 2010, from: http://www.chaffeefiberoptics.com/nwsltr/ftthprismvol6no4.pdf

Schmid, G. (2003). *Two scenarios of future mail volumes 2003-2017*. Retrieved November 2010, from President's Commission on the United States Postal Service (US Department of the Treasure) Website: http://www.ustreas.gov/offices/domestic-finance/usps/pdf/mail-volumC-scenarios-5-20.pdf

Secretaria Nacional de Ciencia, Tecnología e Innovación (SENACYT). (2006). Indicadores de percepción socia de la ciencia y la tecnología en Panamá 2006. Retrieved November 2010, from: http://www.senacyt.gob.pa/media/documentosDireccionGestion/indicadoresPercepcionSocial2006.pdf

Secretaria Nacional de Ciencia, Tecnología e Innovación (SENACYT). (2008). Indicadores de percepción socia de la ciencia y la tecnología en Panamá 2008. Retrieved November 2010, from: http://www.senacyt.gob.pa/media/documentosDireccionGestion/indicadoresPercepcionSocial2008.pdf

Sen, S & Wang, J. (2004). Analyzing peer-to-peer traffic across large networks. *Transaction on Networking, IEEE/ACM 12*(2), 219-232. doi: 10.1109/TNET.2004.826277

Sharpe, A- (2008, January 27). *Self mailers in B2B direct mail: Advantages and disadvantages*. Retrieved November 2010, from the Popular Articles Website: http://www.populararticles.com/article4592.html

Sharpe, A. (2005, July 5). *Direct mail formats: How to choose the right one for your next mailing*. Retrieved November 2010, from Ezine Articles: http://ezinearticles.com/?expert=Alan_Sharpe

Shepherd, B. (2009). *Media consumption in AU – Fascinating: Nielsen Australian Internet and technology report 2007* [Web log post]. Retrieved November 2010, from: http://talkingdigital.wordpress.com/2009/03/13/media-consumption-in-au-fascinating/

Shinohara, H. (2005). Broadband access in Japan: Rapidly growing FTTH market. *IEEE Communications Magazine, Topics in Emerging Technologies Magazine 43*, 72 - 78. doi: 10.1109/MCOM.2005.1509970

Sklar, B. (2001). *Digital communications: fundamentals and applications* (2nd ed.). New Nork, NY: PrenticC-Hall PTR.

Smahel, D., & Lupac, P. (2008). *The Internet in the Czech Republic 2008: Four years of WIP in the Czech Republic*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/Czech_Republic_2008_Four%20Years.pdf

Smith, S. W. (1997). *The scientist and engineer's guide to digital signal processing*. CA: California Technical Publishing. Available at: http://www.dspguide.com/pdfbook.htm

South Dakota Official State Government. (2005). Accounting Records – Useful Life Table. Retrieved November 2010, from: http://www.state.sd.us/legislativeaudit/Counties/Accounting_Manual/County_Section_4/County_Section%204_Useful_Life_Table.pdf

Sportcal Media Communications (2010). *Global sports Media Yearbook 2010: Brazil*. Retrieved November 2010, from: http://www.sportcal.com/pdf/GSMediaYearbook/GSMediaYearbook2010_Brazil.pdf

Starr, T. J. J. (1993). *Application of high bit-rate digital subscriber line (HDSL) technology*. The X International Symposium on Subscriber Loops and Services, 283 – 288. doi: 10.1109/ISSLS.1993.763717

Statistics Canada (2005, October 12). Cable and satellite television 2004. *The Daily*. Retrieved November 2010, from: http://www.statcan.gc.ca/daily-quotidien/051012/dq051012c-eng.htm

Statistics New Zealand (1999). *Time use – Time for culture*. Retrieved November 2010, from: http://www.stats.govt.nz/browse_for_stats/people_and_communities/time_use/timC-usC-timC-for-culture.aspx

Statistics Norway (2002). *Time use for different leisure activities among persons 16-74 years, all and by sex*. Retrieved November 2010, from: http://www.ssb.no/tidsbruk_en/tab-2002-05-13-10-en.html

Steele, R.; Lee, C. & Gould, M. (2001). GSM, cdmaOne and 3G systems. Hoboken New Jersey: John Wiley & Sons.

Strasser, R. (2003, January 8). Briefing for the President's Commisson on the United States Postal Service. *US Department of the Treasure Press Release Report*. Retrieved November 2010, from: http://www.ustreas.gov/press/releases/reports/strasser1803.pdf

Subsecretaría de Telecomunicaciones (SUBTEL-Chile). (2010, Agosto 23). *Series suscriptores television de pago* [data file]. Retrieved November 2010, from: http://www.subtel.cl/prontus_subtel/site/artic/20100608/asocfile/20100608122246/1_series_servicios_limitados_tv_jun10_230810_v1.xls

Summerfield, P. (2006, October 10). *SRG: The future of TV is on-demand; the que question is how*. Retrieved November 2010, from Media in Canada Website: http://www.mediaincanada.com/articles/mic/20061010/srg.html

Swapcom (2005). *The challenges of GPRS for value added services in Africa*. Retrieved November 2010, from: http://www.swapcom.net/pdf/solutions-2006/ppt/Workshop_west_africa.pdf

Tam, A. (2001, March). *TV goes digital, Japan yawns: CS and BS satellite, digital terrestrial and cable broadcasting – Is it all just a load of BS?* Retrieved November 2010, from: http://www.japaninc.com/article.php?articleID=145

TelecomPaper. (2011). Thai customers baffled by ISP use of "up to" in speed claims. TelecomPaper News, (Thursday 10 February 2011 | 12:57 CET).

Television Bureau of Advertising (2008). *Media trends track: TV basics, time spent viewing – persons*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20080616225108/http://www.tvb.org/rcentral/MediaTrendsTrack/tvbasics/09_TimeViewingPersons.asp

Television History (2001). *Television facts and statistics – 1939 to 2000*. Retrieved November 2010, from: http://www.tvhistory.tv/Color_Households_64-78.JPG

Televisión Nacional de Chile (TVN). (n.d.). *Historia*. Retrieved November 2010, from: http://www.tvn.cl/corporativo/historia.aspx

The cable and television revolution in Europe. (n.d.). Retrieved November 2010, from Study World Website: http://www.studyworld.com/newsite/ReportEssay/History/European%5CThe_Cable_and_Television_Revolution_In_EuropC-341454.htm

Thomas, P. & Nain, Z. (2004). *Who owns the Media? Global trends and local resistances*. Penang, Malaysia: Zed Books.

Timeline of the introduction of color television in countries. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Timeline_of_the_introduction_of_color_television_in_countries

Timeline of the introduction of television in countries. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from:

http://en.wikipedia.org/wiki/Timeline_of_the_introduction_of_television_in_countries

TNT. (2007). Regulatory environment: Postal regulation and concession. In *2006 Annual Report and Form 20-F*. Retrieved November 2010, from: http://group.tnt.com/investors/reports/index.aspx

Turner, S. D. (2005). *Broadband reality check – The FCC ignores America's digital divide*. FreePress. Available at: http://www.freepress.net/files/broadband_report.pdf

TV History (n.d.). *Cable television statistics 1960 – 1978*. Retrieved November 2010, from: http://www.tvhistory.tv/Cable_TV_60-78.JPG

TV-Free America (2000). Television statistics and sources. Retrieved November 2010, from: http://www.catholiceducation.org/articles/parenting/pa0025.html

TV3 (Malaysia). (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/TV3_(Malaysia)

U. S. Census Bureau. (n.d.). *Statistical abstracts*. Retrieved November 2010, from: http://www.census.gov/prod/www/abs/statab.html

UltTex Speed Tester (2006). *3100 speed test results for 2005-2006 by type of technology*. Retrieved November 2010, from: http://ult-tex.net/speed/results.pl?view_usa=All

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2007). *Trends in audiovisual markets: China, Mongolia & South Korea*. Retrieved November 2010, from: http://ec.europa.eu/culture/media/programme/docs/pa/links/asia/china.pdf

United States Postal Service (USPS). (2007). *The household diary study: Mail use & attitudes in FY 2007*. Retrieved November 2010, from: http://www.usps.com/householddiary/welcome.htm

United States Postal Service (USPS). (2010). *Prices*. Retrieved November 2010, from: http://www.usps.com/prices/

Universal Postal Union (UPU). (2007). *Postal statistics: Technical notes*. Retrieved November 2010, from: http://www.upu.int/en/resources/postal-statistics/query-thC-database.html

Universal Postal Union (UPU). (2010). *Postal statistics – Query the database: Data by country*. Retrieved November 2010, from: http://www.upu.int/en/resources/postal-statistics/query-thC-database/data-by-country.html

Universidad de Palermo (2009). *Resumen de Noticial Nº 18*. Centro de Investigación de Entretenimiento y Medios. Retrieved November 2010, from: http://www.palermo.edu/economicas/PDF_2009/Boletines/Boletin18_v1.pdf

University of Southern California (USC). (2008). *Annual Internet survey by the Center for the Digital Future finds shiftingtTrends among adults about the benefit and consequences of children going online*. Retrieved November 2010, from Center for the Digital Future, USC Annenberg School: http://www.digitalcenter.org/pdf/2008-Digital-Future-Report-Final-Release.pdf

Vector sum excited linear prediction. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Vector_sum_excited_linear_prediction

Vergara Leyton, E. (2007). El Desarrollo de la televisión por cable en Chile y su impacto en la oferta y el comsumo televisivos. *Revista de Economía Política de las Tecnologías de la Información y Comunicación IX*(2). Retrieved November 2010, from Economia Política de las Tecnologías de la Información de la Comunicación (EPTIC) Website: http://www.eptic.com.br/arquivos/Revistas/v.%20IX,n.%202,2007/AEnriqueLeyton.pdf

Vergeer, M., Coenders, M., & Scheepers, P. (2009). *Time spent on television in european countries: Cross-national comparisons and explanations*. Retrieved November 2010, from: http://dare.ubn.kun.nl/bitstream/2066/74681/1/74681.pdf

Verkasalo, H. T. (2007). Handset-based measurement of smartphone service evolution in Finland. *Journal of Targeting and Analysis for Marketing 16*, 7 – 25. doi:10.1057/palgrave.jt.5750060

Vioque J., Torres A., & Quiles J. (2000). *Time spent watching television, sleep duration and obesity in adults living in Valencia, Spain*. Retrieved November 2010, from: http://www.ncbi.nlm.nih.gov/pubmed/11126224

Voice Age. (n.d.). *QCELP-13 (IS-733)*. Retrieved November 2010, from: http://www.voiceage.com/prodqcelp13.php

Wang Q., Makaroff, D. Edwards, H. K., & Thompson, R. (2003). *Workload characterization for an C-commerce web site*. Proceedings of the 2003 conference of the Centre for Advanced Studies on Collaborative research, 313-327.

Wauters, R. (2009, December 23). *The rumors are true: We spend more and more time online*. Retrieved November 2010, from TechCrunch.com http://techcrunch.com/2009/12/23/harris-interactivC-poll/

Wenger, S.; Hannuksela, M.; Stockhammer, T.; Westerlund, M. & Singer, D. (2005). *RTP payload format for H.264 Video*. Network Working Group. Retrieved November 2010, from: http://tools.ietf.org/html/rfc3984#ref-9

Werner, O., Iedel, A., & Wirtz S. (2004, October). *Switchover – the German approach*. EBU Technical Review. Retrieved November 2010, from: http://www.ebu.ch/fr/technical/trev/trev_300-werner.pdf

Westelcom's Online Help Desk (2009). *V.90 Standard*. Retrieved November 2010, from: http://help.westelcom.com/articles/v90.htm

Weston, E. (1999). *GPS navigation satellite message format and protocol details*. Retrieved November 2010, from: http://gpsinformation.net/gpssignal.htm

Wilkinson, S. (2007, January). *What can US telecommunications operators learn from Japan's FTTH build-out?* The FTTH Prism 4 (1). Retrieved November 2010, from: http://www.chaffeefiberoptics.com/nwsltr/FTTH_Prism-Vol4_no1.pdf

Williams, A., Arlitt, M., Williamson, C., & Barker, K. (2005). *Web workload characterization: Ten years later*. Web Content Delivery 2. Retrieved November 2010, from: http://en.scientificcommons.org/42448602

WIP Japan (2000). *Internet usage trends in Japan: Survey report 2000*. Retrieved May 2008, from the World Internet Project Website: http://www.worldinternetproject.net/publishedarchive/Japan_Report_2000.pdf (offline).

WIP-Mexico (2008). Estudio 2008 de hábitos y percepciones de los mexicanos sobre Internet y diversas tecnologías asociadas Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/wipmx_0112_2008.ppt

Wootton, C. (2005). *A practical guide to video and audio compression: from sprockets and rasters to macroblocks*. Burligton, MA Oxford, UK: Focal/Elsevier.

World DMB [Digital Multimedia Broadcasting] (2007, October). *Latest news: Country profiles*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20071020034343/http://www.worlddab.org/country_profile.php

Writer Services. (n.d.). *Word count to page: How to match page sizes*. Retrieved November 2010, from: http://www.writersservices.com/wps/p_word_count.htm

Yamamoto, N. (2004). *Strategies for next-generation fixed service in Japan* (Master's thesis, MIT Sloan School of Management). Retrieved November 2010, from: http://dspace.mit.edu/handle/1721.1/17888

Yes. (2009). *DBS satellite services 1998*. Retrieved November 2010, from: http://service.yes.co.il/YesAbout_English.aspx

Youngquist, Rober J. (1978). Sampling frequency considerations. *Journal of Audio Engineering Society 26(1/2)*. Retrieved November 2010, from: http://www.aes.org/aeshc/docs/aeshist/standards.hist/digital.standards/jaes26-1.pdf

Zackon, R. (2009). *Ground breaking study of video viewing finds younger boomers consume more video media than any other group*. Retrieved November 2010, from: http://www.researchexcellence.com/news/032609_vcm.php

Zakon, R. H. (2006). *Hobbes' Internet timeline*. Retrieved November 2010, from: http://www.zakon.org/robert/internet/timeline/

Zamaria, C., & Fletcher, F. (2008). *Canada Online! - The Internet, media and emerging technologies: Uses, attitudes, trends and internacional comparisons 2007*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/CIP07_CANADA_ONLINC-REPORT-FINAL.pdf

E Computation

E.1 General concepts

E.1.1 General-purpose and application-specific computer

We distinguish between two broad groups of computers. The first group includes all computers that are directly guided by their human users. The user can change the purpose of the computational power. We call this group “general-purpose computer”. The second group carries out automated computations that are incidental to the primary computing task. The key characteristic is being dedicated to handle a particular task. While the user may have a range of predefined choices regarding its functionality, the user cannot change the automated logic of these systems. These supportive computations include the translation of analog to digital signals, interfaces that convert signals into sounds or images, and controller for some electronic system (like household appliances, entertainment electronics, and transport and office machines). We call this group “application-specific computer”.

In the first group we focus on the capacity provided by the microprocessors of personal computers (incl. laptops), servers and mainframes, supercomputers, videogame consoles, electronic calculators and mobile phones and personal digital assistants (PDA). In the second group we focus on digital signal processors (DSP), Graphic Processing Units (GPU) and Microcontroller (MCU). While general purpose computers are also equipped with application-specific parts from the second group (mobile phones come with digital signal processors and PCs have microcontroller, etc.), we only focus on the capacity of humanly guidable microprocessors in the inventory of the first group. It is important to notice that our inventory of application-specific computers is not complete. There is a significant number of other semiconductor and logic circuit units which we have not included in the inventory of application-specific computer.

E.1.2 MIPS as an indicator of hardware performance

Measuring the computational power of digital devices in not an easy task, chiefly because their characteristics are multidimensional (Lilja, 2000; Norhaus, 2006; McCallum, 2002). The final choice of our unit of measurement was determined principally by the availability of relevant and consistent statistics, more than their robustness.

E.1.3 The selection of Dhrystone MIPS 1.1

Despite the disadvantages that this metric possesses, which makes it seem like one of the weakest (Lilja, 2000), we utilized VAX MIPS as a unit of measure.ment This permitted us to use the extensive databases reported by R. Longbottom (2010), J. McCallum (2003), and W. Nordhaus (2006). Nordhaus's statistics generate a “timeline” of performance from 1850 to 2006 – starting with manual calculation with an abacus– based on work by McCallum and the analytical methods of Knight and Moravec. McCallum and Nordhaus normalize performance values to the DEC VAX 11/780 machine (1 MIPS with the Dhrystone 1.1 benchmark) (York, 2002). We opted to continue the same line of work. This implies that the performance of other devices must be in the same units and, in case they are in other units, we must use a transformation to VAX MIPS. If the performance were obtained using the Dhrystone MIPS 2.1 benchmark, we multiply the value with 0.943, which makes it comparable with the Dhrystone 1.1[50].

E.1.3.1 From SPEC to Dhrystone MIPS 1.1

With the end of standardizing one unit of measurement, various computational system manufacturers form the *Standard Performance Evaluation Cooperative* (SPEC) (SPEC89, SPEC92, SPEC95, SPEC2000, and SPEC2006) (Hennessy et al., 2007). When reported in SPEC, we utilize the benchmark SPEC CPU2000 (i.e. CINT2000 “base”), because it has performance measures for computer systems between 2000–2006[51].

The conversion to VAX MIPS is given by a series of relationships between distinct benchmarks found in the literature. In the first place (Ashmanskas et al., 2001), determined that the ratio between SPECint2000 and SPECint92 is equal to 4.5; later, given that SPECint92 and SPECint89 use the same machine as a frame of reference (also the VAX 11/780), Munafo (2010) defines that the results of both tests are comparable. Therefore it can be said that the ratio between SPECint2000 and SPECint89 is equal to 4.5. On the other hand, Kaynaga et al. (1991) found that the results of SPECint89 and Dhrystone 2.1 are related by a factor equal to 1.5. Thus, given the relationship between Dhrystone 2.1 and Dhrystone 101 previously mentioned, the relationship between SPECint2000 and Dhrystone 1.1 is arrived at in the following manner: [1 Dhrystone MIPS 1.1] = 4.5 x [SPEC2000 / 1.4143].

50This is obtained from the ratio of DIPS achieved by the VAX 11/780 with both benchmarks, that is: [MIPS Dhrystone 1.1] / [MIPS Dhrystone 2.1] = [1657 DIPS] / [1758 DIPS] = 0.943

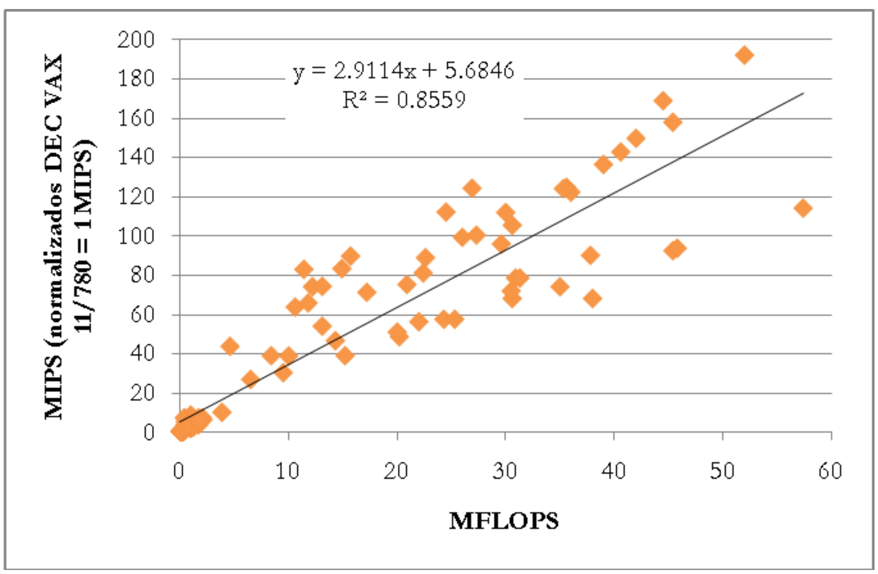
51 This utilizes, as a reference machine, a Sun Ultra 5-10 with a 300 [Mhz] SPARC processor and 256 MB of memory (RAM), whose benchmark execution time is assigned a score of 100 and, based on this, we assign the value of the measurement of other machines.

E.1.3.2 From FLOPS to Dhrystone MIPS 1.1

Supercomputer performance is measured in MFLOPS *(Millions of Floating Points Operations Per Second*), that is to say, the number of floating point operations that the program executes – which can be derived from the size of the matrix representing the system of equations that the device must resolve in order to measure its performance (Weicker, 1990). Lamentably, a ready to use formula does not exist for the conversion between FLOPS and MIPS. The two types of metrics measure complementary computations. However, for our investigation, we strive for having one single metric.

McCallum (2003) supposes that each floating point operation requires that the processor executes (approximately) 6.5 instructions (1 MFLOPS = 6.5 MIPS). This conversion rate is based on a single datum, that of the VAX 11/780 from 1977, that achieves 0.14 MFLOPS and 0.91 MIPS. Following this logic and extending to the 97 machines from 1981-1995 for which Giladi (1996) reports MFLOPS and MIPS, we observe that over the years the relationship between MFLOPS and MIPS is close to 1:3 (as shown in Figure E-1). This implies a constant conversion rate of 3 MIPS for each MFLOPS, even for the post-1995 period. In short: 1 MFLOPS = 3 MIPS).

Figure E-1: Relationship between MFLOS and MIPS, 1981-1995 (n=97).



Source: Authors' own elaboration, based on (Giladi, 1996).

E.1.4 Speculations on the contributions of faster algorithms[52]

Theoretically, the world's computational capacity depends on three factors:

- infrastructure: the amount of computational devices;
- hardware: the hardware capacity of computational devices (measured in MIPS or any other hardware indicator);
- software: the speed of the applied algorithms.

Conceptually, the logic is similar to what we argue for information storage and communication, which depends on the installed infrastructure, its performance (or bandwidth), and on the level of compression of the respective content. The compression of content allows effectively storing and communicating more information with the same amount of hardware. As we have seen, compression algorithms came a long way during the past two decades and it does make a difference. As evidenced by the appendixes C, D and E, the specification of the contributions of compression gave us a lot of headache, but we finally came up with what we consider to be reasonable approximations. Translating this logic to the case of computation, we also know that more efficient algorithms allow the realization of more computations with the same amount of hardware. For example, an algorithms that runs in polynomial time, such as a discrete Fourier transformation used for the compression of lossy images and sound compression, which runs in $O(N^2)$, is much slower than a fast Fourier transformation, which runs in $O(N \log N)$ (for more on algorithms and O-notation, see Cormen, Leisserson, Rivest and Stein, 2003). Running both on the same amount of hardware makes a significant difference. If we would have a measure on these advancements, we could (similar to what we did with storage and communication) argue that computer hardware has contributed X % to technological progress in computation, while better software has contributed Y % during recent decades. Nevertheless, we did not execute this same logic for the case of computation. Why not? The reasons are both theoretical and practical in nature.

Our main theoretical doubt is that the theoretical basis for performance measurements for computers is much less solid than the theoretical basis for information storage and communication. For the latter, Shannon (1948) gave us an ultimate measure with the bit, which is defined as a received symbol that reduces a given probability space in half (i.e. using entropic coding, which approximates the entropy of the message). This definition is independent from the specific task or content and thus allows us, for example, to compare information in the form of text (which reduces uncertainty with regards to possible letters from a natural language alphabet), with information in the form of images (which reduces uncertainty in form of colored pixels, from a given color scale). We can then say things like "a 6 cm^2

[52] We would like to thank Len Adleman, from the University of Southern California, for his inspiring words and ideas for this section.

newspaper image is worth a 1000 words", because we need the same amount of yes/no decisions to produce both (we reduce the same amount of uncertainty, in a strict probabilistic sense). In this sense, what is it that "one computation" achieves? What is the final ultimate goal of computation? If we would have two computations, both in their fastest available algorithmic speed (normalized on what is defined to be the "fastest in 2007"), but focusing on two different tasks, would those two be comparable? We are not aware of a theoretical framework that would allow us to unambiguously reconcile these questions.

Even if we would go ahead and add some kind of normalization on "what is considered to be the fastest possible computation for a specific task in 2007", we would be confronted with several practical hurdles. We would need:

(a) statistics on the performance and running speed of a particular class of algorithms dedicated at a specific kind of task at a given point in time;
(b) statistics on the most commonly used algorithms on different kinds of equipment;
(c) statistics on how frequently which kind of task is executed on which kind of computer.

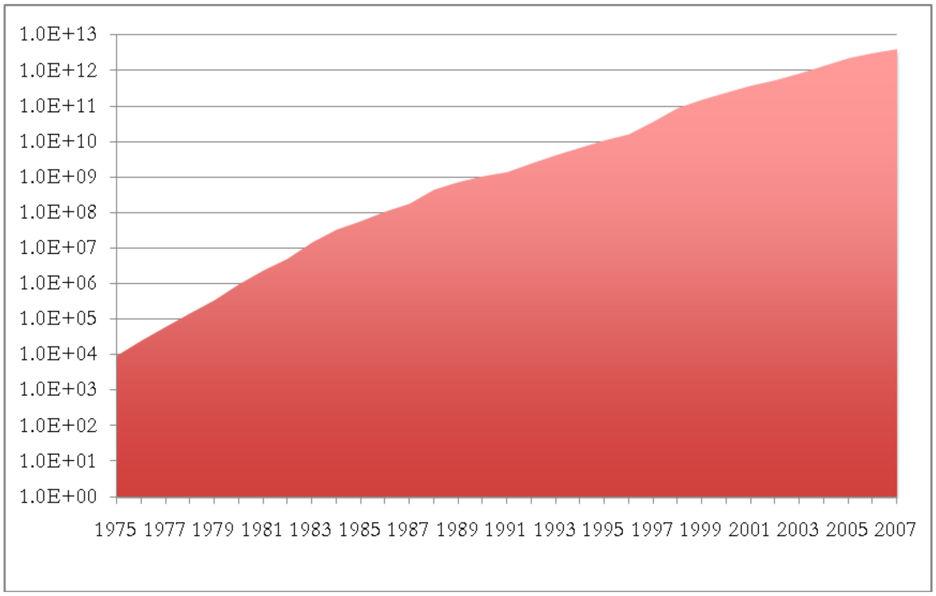
With the sufficient resources, we are confident that one could come up with an estimate for (a), i.e. running time in O-notation. We know that algorithms have improved significantly over the past couple of decades, even though it seems like the largest leap have been made before the period of our study (Dongarra & Sullivan, 2000). Regarding statistics on (b) and (c), it would maybe be possible to justify some estimate on which kinds of computer use are capable of which kind of algorithms, but it would be highly speculative to estimate the actual execution of them. Let us do some speculation. From our estimates we know that roughly 20 % of the world's computational power is dedicated to assisting communication and storage devices in the encoding and decoding of digital information. We could track the speed improvements of the leading compression algorithms to estimate technological progress for these tasks. Besides, we know that videogame consoles heavily focus on image transformation, and mainframes and supercomputers execute some kind of simulation or optimization tasks. Servers will probably be dedicated to some kind of routing or sorting (for example through search engines). This would leave us with some broad groups (compression algorithms, image and sound transformation, simulation, optimization, sorting, etc). However, while personal computers (which by far represent the bulk of global computational power) are universal computers capable of executing quite sophisticated algorithms, they are usually used for very uneventful tasks, such as typing or the reproduction of some media. How many seconds is the typical personal computer used for which kind of computational task? How long does it "sort"? How long does it reproduce media? What are the most typical algorithms involved in word processing? We would need to have some approximation of this in order to be able to weight the technological progress made by the advancements of algorithms.

Summing up, in order to estimate the contributions of faster algorithms to the world's capacity to compute information one faces both theoretical and practical challenges. Based on a disputable theoretical framework, one would require the necessary resources to create statistics on the actual usage of algorithms (which we do not have at this point). While it would be very interesting and exciting to compare hardware and software contributions to the global computational capacity, we consider it to be highly speculative. We decided not to pursue this task at this point and instead, leave the reader with these speculations, which might inspire future work in this area. This being said, our numbers of computational capacity (in MIPS), merely present the contributions of changes in computational infrastructure and changes in computational hardware performance.

E.2 Personal computers

In this section, we will consider personal computers (PCs, laptops, mini-computers and low-end workstations). We will use the acronym “PC” for this group, independent of the producer (Dell, Apple, etc) and its portability (workstation or notebook/laptop).

Figure E-2: Computational capacity of personal computers (MIPS, semi-logarithmic presentation).



Source: Authors’ own elaboration, based on various sources (see text).

E.2.1 Personal computers: capacity

The total number of personal computers is extracted principally through the International Telecommunications Union [ITU] database (2009).[53] The intervening years were estimated using a constant growth rate.

[53] To complete the series –especially 1975 and 1985 – we utilized reported data referring to the number of computers installed in the United States and the world through eTForecast (2008).

Table E-1: Number of personal computers installed 1985 - 2007.

Year	1985	1986	1987	1988	1989	1990
MIPS	33,000,000	41,191,836	51,701,550	74,910,346	87,744,045	102,517,280
Year	1991	1992	1993	1994	1995	1996
MIPS	115,919,664	133,852,707	151,930,586	177,082,348	209,691,057	245,347,583
Year	1997	1998	1999	2000	2001	2002
MIPS	288,469,875	336,707,817	394,111,836	465,460,671	527,835,914	590,429,449
Year	2003	2004	2005	2006	2007+	
MIPS	666,409,514	754,780,982	848,302,252	945,729,882	1,034,024,833	

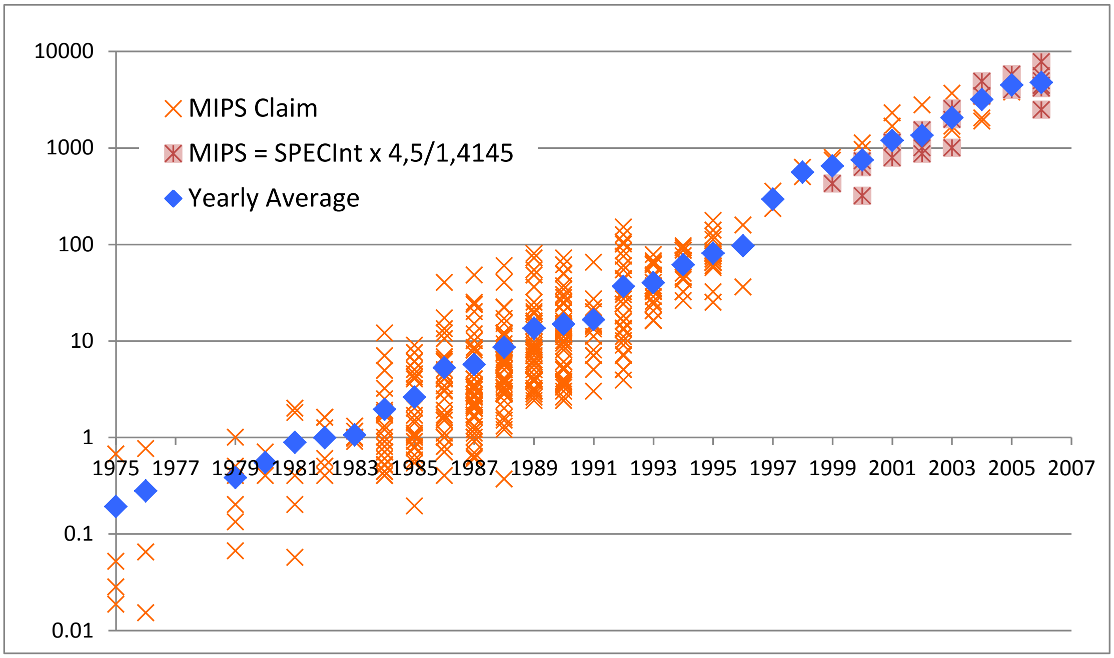
Source: Authors' own elaboration, based on (ITU, 2009).

It is important to note that the ITU reports the quantity of PCs per country, that is to say, it contains all computers accumulated, from those that are sold in a particular year, as well as those that have been sold in previous years. In order to allocate the respective performance of those computers, we need to disaggregate the total. For this, we orient ourselves at the useful lifetime of hard disks (see Appendix D, chapter D.8), which is equal to 10 years for 1976-1986, 7 years from 1987-1989, and 5 years from 1990-2007 (various sources point to an actual lifespan of between 3 and 7 years; Gov. Of South Australia, 2008; J. Gold Associates, 2009; Goss, 2010; Jorgenson & Vu, 2005; Northwestern University, 2007). Each computer is multiplied by their corresponding capacity based on year of production and remains constant during the specified number of years. In the year after the last year of useful life, the computing performance is upgraded to the newest technology, which is equivalent to saying that all machines which have completed their useful life are replaced by new computers.

E.2.2 Personal computers: performance

The principal sources from which we extract the processing levels are Longbottom (2010a, 2010b), MCCallum (2003), and SPEC (2008a, 2008b). From these, we aggregate the performance of 499 computers distributed from the period of 1975-2006 (of which 133 are PCs, 282 mini-computers, and 84 low end-work stations). The performance of various equipment from 1999-2006 are measured in SPEC and we applied the conversion MIPS = SPECInt*(4.5/1.4145), with a linear extension of the computing power for 2007 (which is in accord with the general tendency detected in Figure E-3).

Figure E-3: Personal computer performance 1954 – 2006 (n=499), en MIPS.



Sources: Authors' own elaboration, based on (Longbottom, 2010a, 2010b; McCallum, 2003; SPEC, 2008a, 2008b; Aburto, 2010).

Table E-2 summarizes the average performance of PCs for the period 1975-2007.

Table E-2: Personal computer performance 1975 - 2007 [in MIPS].

Year	1975	1976	1977	1978	1979	1980	1981
MIPS	0.19	0.28	0.31	0.35	0.38	0.55	0.89
Year	1982	1983	1984	1985	1986	1987	1988
MIPS	0.99	1.06	1.95	2.62	5.28	6.32	8.59
Year	1989	1990	1991	1992	1993	1994	1995
MIPS	13.6	14.9	16.6	36.7	40.2	61.4	81.3
Year	1996	1997	1998	1999	2000	2001	2002
MIPS	97	294	561	651	749	1,197	1,351
Year	2003	2004	2005	2006	2007+		
MIPS	2,056	3,177	4,495	4,756	5,017		

Source: Authors' own elaboration, based on various sources, i.e. Longbottom (2010), McCallum (2003), y SPEC (2008). +: Linear estimation.

E.2.3 Personal computers: effective use

We usually report the number of maximally possible computations (supposing that all machines run 24 hours a day). However, to put things into perspective, we also make estimations on effective usage. We use global Internet usage statistics to approximate PC use. The reported data represent the "gross" use value; that is to say, we approximate how many hours a week the user is interacting with the computer, not how much time the computer is running at maximum capacity.

Table E-3: Average gross use of computers/Internet

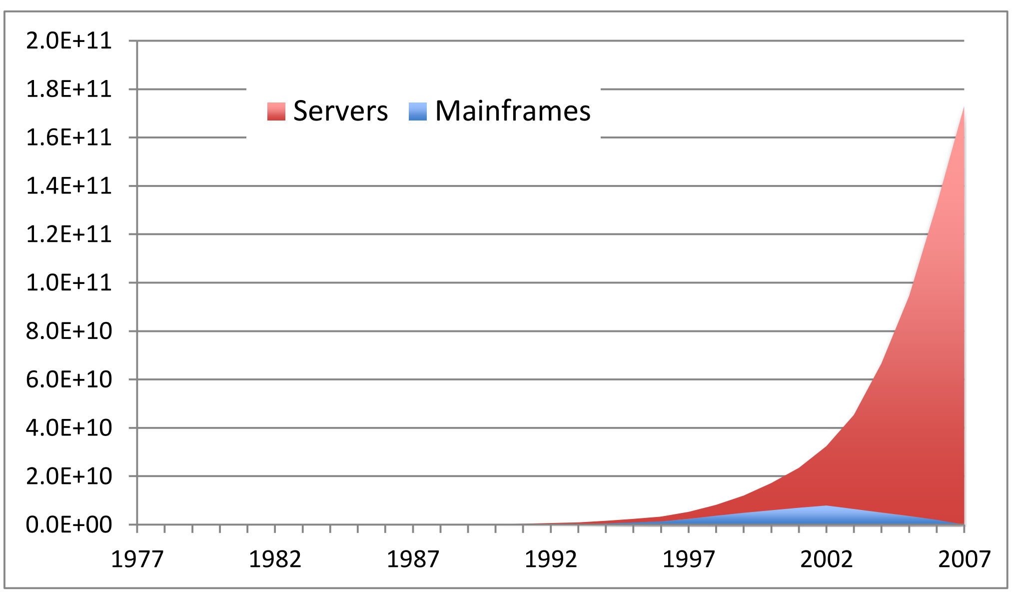
		1986	1993	2000	2007
Hours per week	OECD	1.0	5.2	6.9	12.1
	Non-OECD	*0.7*	*4.0*	*5.3*	9.3
Weighting for number of computers	OECD	100%	87%	80%	67%
	Non-OECD	0%	13%	20%	33%
Average	Global	1	5	6.6	11.2

Source: Authors' own elaboration based on (Dutton & Helsper, 2007; Ewing & Thomas, 2008; Fábián et al., 2007; Findahl, 2001, 2008; Godoy, 2009; Grupo Radar, 2007; Koenan et al., 2003; Lebo, 2002; Liang, 2005, 2008; Mediascope Europe, 2008; Mikami et al., 2005; Peters, 2002; Pitkow & Recker, 1995; Reitze & Ridder, 2005; Salamon, 1998; Smahel & Lupac, 2008; University of Southern California [USC], 2008; Wauters, 2009; WIP-Japan, 2000; WIP-Mexico, 2008; Zamaria & Fletcher, 2008)

E.3 Professional computers

In this section, we consider professional computers (mainframes, servers, and mid-/high-end workstations).

Figure E-4: Computational capacity of professional computers (MIPS).



Source: Authors' own elaboration

E.3.1 Professional computers: quantity

Due to the lack of a better historical record, we estimate the number of mainframes based on the number of hard disks that were sent to mainframe and server manufacturers (Porter, 1980 – 1999). Mainframes are not recorded after 2002, because of their rapidly decreasing numbers and their subsequent integration into the statistics on "mid-range and high-end enterprise servers". With the last officially recognized mainframes shipped in 2002, their installed number reaches zero in 2007 (after a five years lifespan). For this calculation we assume that each mainframe contains only one hard disk (though this disk may be very large).

Table E-4: Quantity of hard disks shipped for mainframes in thousands (= quantity of mainframes).

Year	# equipment	Year	# equipment	Year	# equipment
1978	57	1988+	441	1998	*2,339*
1979	72	1989	446	1999+	*1,875*
1980	92	1990	610	2000	*1,280*
1981	106	1991+	676	2001+	*1,091*
1982	165	1992+	823	2002	*960*
1983+	275	1993	868	2003+	-
1984+	385	1994+	1,106	2004+	-
1985	345	1995+	1,331	2005+	-
1986	327	1996	1,463	2006+	-
1987	389	1997+	1,962	2007+	-

Source: Unmarked: Estimation based on (Porter 1980-1999), +: Linear Estimation.

The quantity of servers from 1996-2007 is based on data for volume servers, mid-range enterprise servers, and high-end servers from IDC (Koomey, 2007). For the years pre-1996, we use the number of hard disks in servers, just as for mainframes. However, according to the technical specification reports on hard disk arrays presented in Porter (1980 – 1999), the number of drives per array is extremely variable. Therefore, we calculated the quantity of disks per server for 1996 (which turns out to be 5), and estimated a constant growth rate for the number of disk per sever for the period since 1980 (for which we assume 1 disk per server) (see Table E-5).

Table E-5: Quantity of servers shipped in thousands.

Year	# equipment	Year	# equipment	Year	# equipment
1981	195	1990	1,770	1999+	3,589
1982	138	1991	1,607	2000+	4,222
1983	291	1992	1,637	2001+	4,197
1984	545	1993	1,405	2002+	4,397

1985	723	1994	1,619	2003+	5,237
1986	823	1995	1,762	2004+	6,276
1987	881	1996+	1,751	2005+	7,017
1988	934	1997+	2,256	2006+	7,473
1989	897	1998+	2,862	2007+	7,974

Source: Unmarked: Estimation (Porter, 1980 – 1999), +: (Koomey, 2007; IDC, 2008).

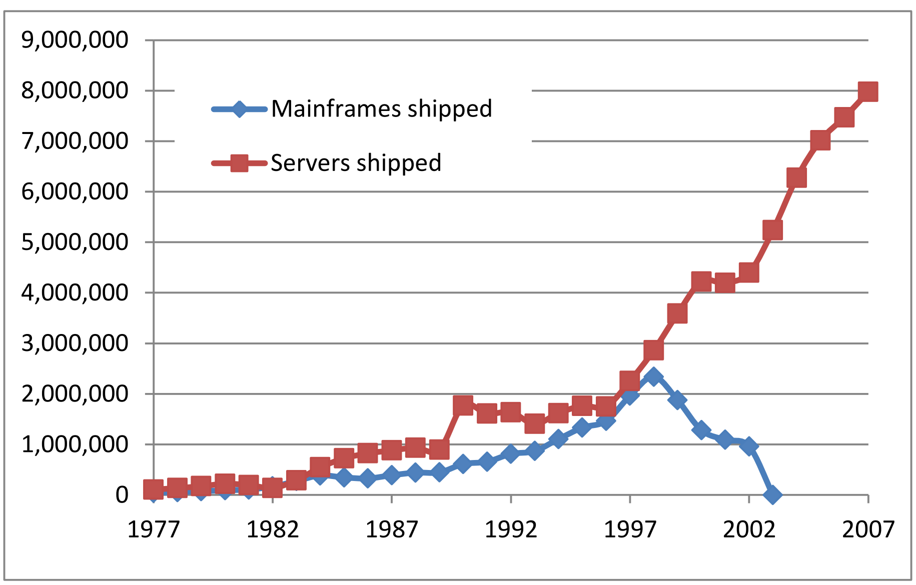
Table E-6: Quantity of hard disks per server.

Year	Disks per server	Year	Disks per server	Year	Disks per server
1980+	1.00	1989+	2.47	1998	5.74
1981+	1.11	1990+	2.73	1999	4.52
1982+	1.22	1991+	3.02	2000	3.84
1983+	1.35	1992+	3.34	2001	5.24
1984+	1.50	1993+	3.70	2002	6.75
1985+	1.65	1994+	4.09	2003	5.44
1986+	1.83	1995+	4.52	2004	5.00
1987+	2.02	1996	5.00	2005	5.07
1988+	2.24	1997	5.69	2006	5.57
				2007	5.73

Sources: + on (Porter, 1980 – 1999), rest: (Koomey, 2007; IDC, 2008).

The results for both mainframes and servers can be appraised in Figure E-5. What is clear is that, in recent years, servers have replaced mainframes.

Figure E-5: Quantity of servers and mainframes shipped.



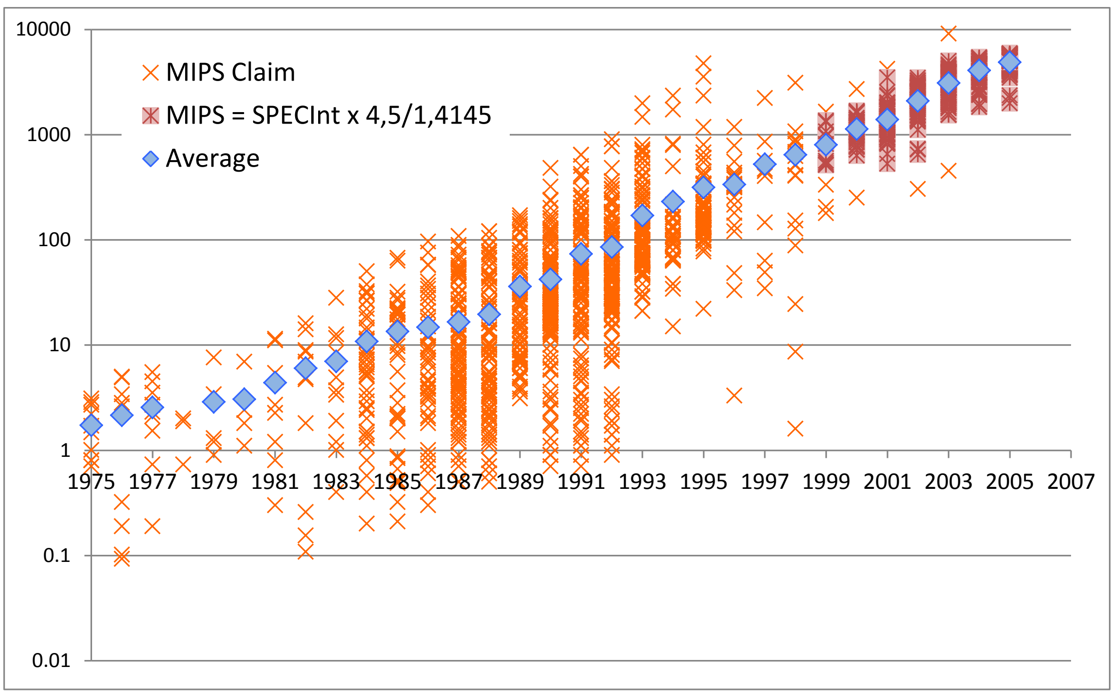
Source: Authors' own elaboration, based on Disk Trend and IDC.

With respect to the useful lifetime of mainframes and servers, we follow the same assumptions made for PCs and HDDs. That is to say, 10 years lifespan for the period 1980-1986, 7 years for 1987-1989 and 5 years for 1990-2007. The last assumption is reconfirmed by the relationship between the numbers of shipped and installed servers reported for the period 1997-2006 by IDC (Koomey, 2007).

E.3.2 Professional computers: performance

The same sources as for PCs are utilized (Longbottom, 2010; MCCallum, 2003; SPEC, 2008). Combined we were able to obtain the performance for 2433 computers for the period 1975-2007[54], of which 582 are mainframes, 1454 servers, and 396 mid-/high-level workstations. Various machines from 1999-2007 give their measurement of performance in SPEC, for which we utilized the conversion formula MIPS = SPECInt*(4.5/1.4145) (see Figure E-6).

Figure E-6: Professional computer performance 1975 - 2007, MIPS (n=2433).



Sources: Authors' own elaboration, based on (Longbottom, 2010a, 2010b; McCallum, 2003; SPEC, 2008a, 2008b; Aburto, 2010).

In Table E-7 we represent the performance summary of professional computers.

54 The fact that the number in the sample of mainframes and servers is so much larger than for personal computers most likely comes from the simple fact that the industry tends to measure the performance of mainframes and servers much more frequently than for personal computers, as this indicator has more relevance for the advanced use of computers.

Table E-7: Professional computer performance 1975 – 2007 (MIPS).

Year	1975	1976	1977	1978	1979	1980	1981
MIPS	1.73	2.15	2.56	2.72	2.88	3.05	4.39
Year	1982	1983	1984	1985	1986	1987	1988
MIPS	6.0	7.0	10.9	13.5	14.8	16.6	19.6
Year	1989	1990	1991	1992	1993	1994	1995
MIPS	36	42	74	86	170	231	316
Year	1996	1997	1998	1999	2000	2001	2002
MIPS	336	524	643	802	1,130	1,391	2,096
Year	2003	2004	2005	2006	2007		
MIPS	3,091	4,086	4,865	6,029	6,532		

Sources: Authors' own elaboration, based on (Longbottom, 2010a, 2010b; McCallum, 2003; SPEC, 2008a, 2008b; Aburto, 2010).

E.3.3 Professional computers: effective use

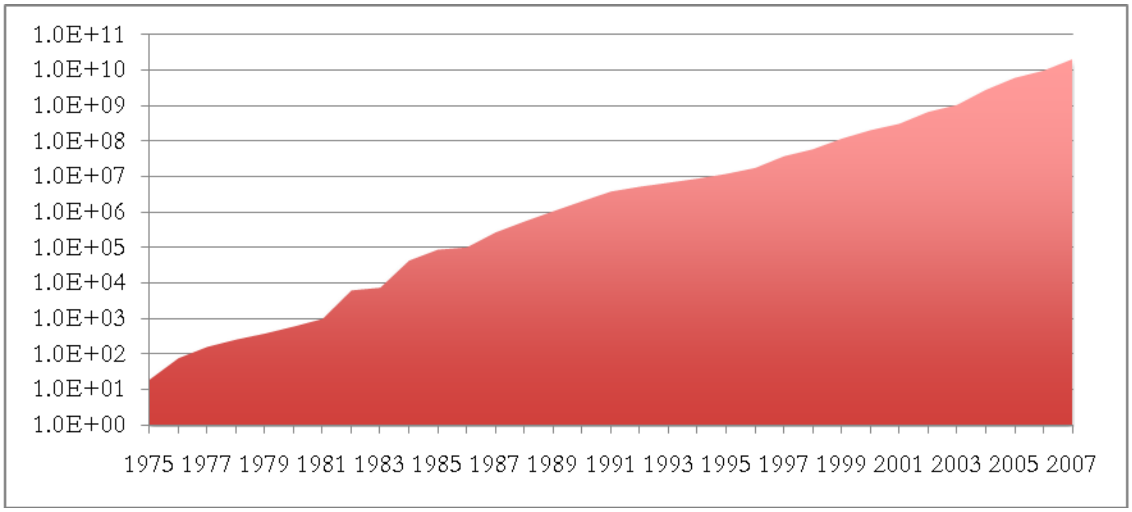
Due to a lack of more detailed information, we assume that mainframe computers run 8 hours during the work week (5 days a week), and that servers run 8 hours a day, 7 days a week.

E.4 Supercomputers

The term supercomputer refers to computational systems, which provide the best achievable performance in solving challenging computational problems (Graham, Snir & Patterson, 2005; Morris, 1996). In general, supercomputers are classified into three categories: parallel, vector, and cluster. The first type utilizes multiple CPUs for resolving problems and is therefore able to perform more than one instruction simultaneously. The second type's functionality is based on a *pipeline* architecture, which connects a set of data processing elements serially. For their part, clusters are a group of computers connected to a local area network to function as a single computer. This type of supercomputer is more cost-effective than a single supercomputer of another type of comparable speed and capacity (Baker, 2000). The first clusters were introduced in 1996 and, by 2007 they represent 79% of the 500 fastest supercomputers in the world.55

55 For example, Sun's TSUBAME Grid Cluster, which was the ninth fastest computer in the world in 2006, consists of 648 Sun Fire™ X4600 servers with a total of 11,088 AMD Opteron™ processor cores (Top500 Tsubame, 2006).

Figure E-7: Total computational capacity of supercomputers (MIPS, semi-logaríthmic presentation).

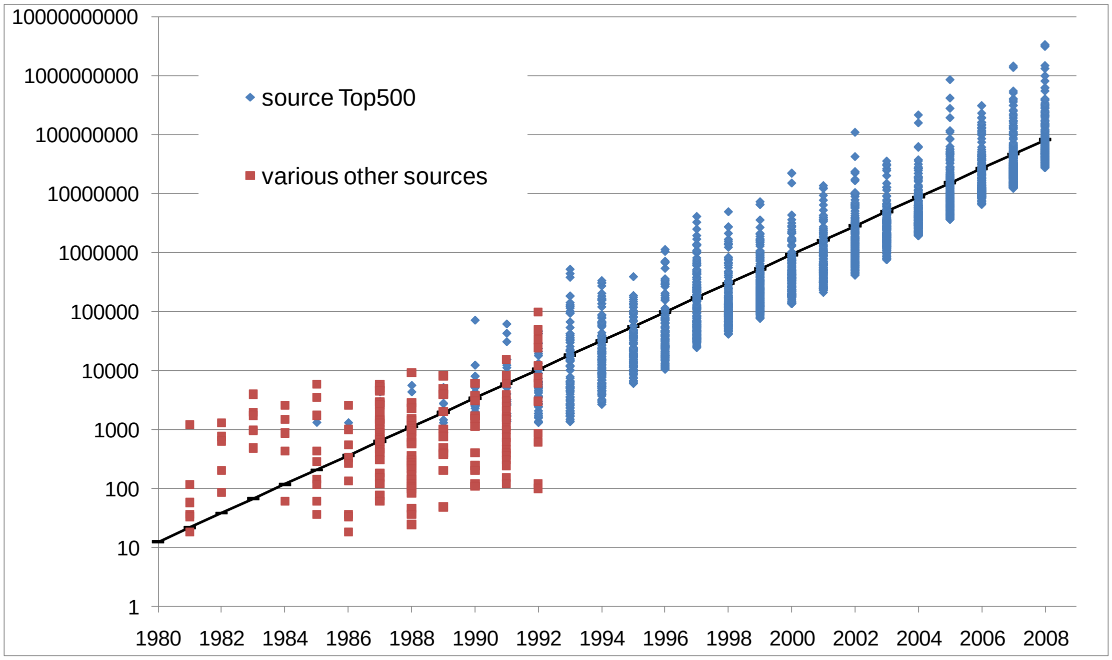


Source: Authors' own elaboration, based on various sources (see text).

E.4.1 Supercomputers: performance

Top500 (2010), Longbottom (2008), McCallum (2003) and Nordhaus (2006) and report the performance of almost four thousand supercomputers in MFLOPS. After the conversion to MIPS (utilizing the conversion of 3 MIPS for each MFLOPS), we applied an exponential trend line to locate the "representative computing power" for each year (Table E-8).

Figure E-8: Supercomputer Performance 1980 - 2008 (n=3805).



Sources: (Banks, 1999: Computer Museum, 2010a, 2010b, 2010c, 2010d, 2010e; Corda, 1996; Cray-Cyber Team, 2010; Dongarra & Duff, 1989; Longbottom, 2010a, 2010b; McCallum, 2003; Nordhaus, 2006; Oyanagi, 2006; TOP500, 2010).

Table E-8: Average supercomputer performance from 1975 to 2007, (MIPS).

Year	1975	1976+	1977+	1978+	1979+	1980	1981
MIPS	1.73	*3.8*	*5.9*	*8.1*	*10.2*	12.3	21.5
Year	1982	1983	1984	1985	1986	1987	1988
MIPS	38	66	116	203	355	622	1,090
Year	1989	1990	1991	1992	1993	1994	1995
MIPS	1,910	3,347	5,865	10,276	18,007	31,553	55,288
Year	1996	1997	1998	1999	2000	2001	2002
MIPS	96,878	169,755	297,453	521,211	913,291	1,600,314	2,804,148
Year	2003	2004	2005	2006	2007		
MIPS	4,913,564	8,609,787	15,086,489	26,435,283	46,321,193		

Sources: Authors' own elaboration, based on (Banks, 1999: Computer Museum, 2010a, 2010b, 2010c, 2010d, 2010e; Corda, 1996; Cray-Cyber Team, 2010; Dongarra & Duff, 1989; Longbottom, 2010a, 2010b; McCallum, 2003; Nordhaus, 2006; Oyanagi, 2006; TOP500, 2010).

To estimate the capacity in the period before 1991, the total number of new computers is multiplied by their respective capacity shown in the previous table. In contrast, from 1992 onwards, due to the fact that the computing power of each supercomputer was included in the TOP500 list, a simple sum of these values (converted to MIPS from MFLOPS) gives us the total capacity, which is even more precise.

E.4.2 Supercomputers: quantity

For the years 1976-1988, we base the estimation on an inventory done in 1988 (Goodman, 1988, Oak Ridge National Laboratory [ORNL], 1999). For the period 1992-2007, we extract the number of new supercomputers listed in the TOP500 (2010) for each year. This list does not include the total number of machines installed worldwide – only the 500 fastest. After consulting with TOP500 about their estimate of the total number of supercomputers (electronic correspondence 2008), we assume that for each supercomputer included, there exists another that is not. These remainders are multiplied by the computing power (performance) of the least powerful supercomputer considered for the TOP500. We consider an accumulation effect of 14 years, supposing that supercomputers are reutilized for other functions after their principal use (it turns out that the performance of a supercomputer is about equal the performance of a PC 14 years later, e.g. 1987/8 - 2000/1) (Table E-9).

Table E-9: Estimated total number of supercomputers worldwide 1975 – 2007.

Year	1975	1976	1977	1978	1979	1980	1981
MIPS	11	26	40	52	64	82	100
Year	1982	1983	1984	1985	1986	1987	1988
MIPS	241	259	573	796	836	1,109	1,368
Year	1989+	1990+	1991+	1992	1993	1994	1995
MIPS	1,634	1,915	2,215	2,535	2,807	3,043	3,325
Year	1996	1997	1998	1999	2000	2001	2002
MIPS	3,436	3,832	3,788	3,957	4,299	4,308	4,411
Year	2003	2004	2005	2006	2007		
MIPS	4,463	4,724	4,848	4,864	5,188		

Source: Authors' own elaboration based on (Goodman, 1988; ORNL, 1999; TOP500, 2010; +: Linear Estimation).

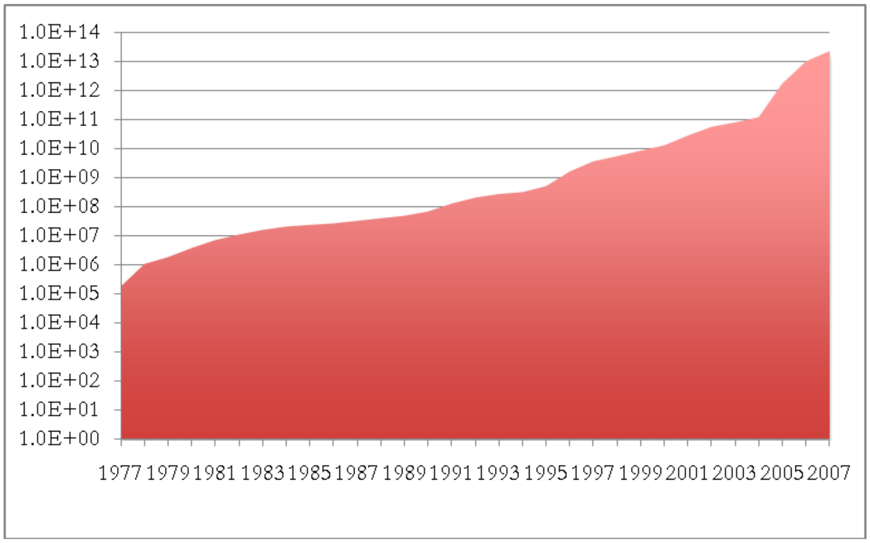
E.4.3 Supercomputers: effective use

Due to a lack of more detailed information, we suppose that a supercomputer runs 24 hours a day, 365.2422 days a year.

E.5 Game consoles

We consider the 29 most popular models of video-game consoles. Each of these models has sold more than a million units (see Table E-11).

Figure E-9: Computational capacity of video-game consoles (MIPS, semi-logarithmic presentation).



Source: Authors' own elaboration, based on various sources (see text).

E.5.1 Game consoles: performance

Table E-10 contains the computing power for each console utilized in the estimation.

Table E-10: Computing power of video-game consoles.

Console	MIPS	Console	MIPS	Console	MIPS
Wii	*2,800.0*	Dreamcast	360.0	TurboExpress	*1.5*
PlayStation 3	81,920.0	Neo Geo Pocket	*17.2*	GB & GB Color	1.5
Xbox 360	19,200.0	Nintendo 64	125.0	Sega Genesis	1.0
Nintendo DS	114.0	Nomad	*26.6*	TurboGrafx-16	1.5
PSP	*114.0*	PlayStation	30.0	Master System	*0.7*
N-Gage	*18.0*	Saturn	50.0	NES	*0.7*
GBA	*18.0*	Panasonic 3DO	10.6	ColecoVision	*0.7*
Xbox	1,980.0	Sega-CD	*1.5*	Intellivision	*0.7*
GameCube	1,125.0	SNES	4.8	Atari 2600	*0.7*
PlayStation 2	450.0	Game Gear	*1.5*		

Sources: Authors' own elaboration, based on ("Console", 2010; Diot, 2006; IGN Staff, 2003; "Instructions per second", 2010; "Intel MSC-48", 2010; Porobic, 2002; SegaSaturn.co.uk, 2010). Italics: estimate based on similar console.

E.5.2 Game consoles: quantity

We counted the number of consoles sold per year of 17 models (PlayStation, PlayStation 2, PlayStation 3, PSP, Nintedo Wii, Nintendo DS, GameCube, Nintendo 64, SNES, NES, GameBoy, GameBoy Advance, Xbox, Xbox 360, Sega Dreamcast, Sega

Genesis y Sega Master System) (Mazel, 2009; Nintendo, 2010; PCV Forum, 2005; Pettus 2002; Sony Computer Entertainment Inc. [SCEI], 2010a, 2010b, 2010c, 2010d); for the rest was estimated on basis of trend of the total sales from 1977 to 2007. The distribution of products sold per year in this group was estimated to behave like other consoles from the same period of production, both in their functionality and applications (Table E-11).

Table E-11: Total sales of different videogame consoles (in millions until the end of 2007).

Console Model	Units sold	Console Model	Units sold	Console Model	Units sold
Wii	50.4	Dreamcast	10.6	TurboExpress	1.5
PlayStation 3	12.6	Neo Geo Pocket	2.0	GB & GB Color	118.5
Xbox 360	17.7	Nintendo 64	32.9	Sega Genesis	30.9
Nintendo DS	122.4	Nomad	1.0	TurboGrafx-16	10.0
PSP	40.5	PlayStation	102.5	Master System	13.4
N-Gage	3.0	Saturn	17.0	NES	61.9
GBA	81.1	Panasonic 3DO	2.0	ColecoVision	6.0
Xbox	24.2	Sega-CD	6.0	Intellivision	3.0
GameCube	21.7	SNES	49.6	Atari 2600	30.0
PlayStation 2	129.9	Game Gear	11.0		

Source: (“3DO Interactive…”, 2010; “Atari 2600”, 2010; Classic Gaming Museum, 2010; Carroll, 2005; “Intellivision”, 2010; Mazel, 2009; “Mega Drive”, 2010; “Mega-CD”, 2010; “Neo Geo…”, 2010; Nintendo, 2010; “N-Gage”, 2010; PCV Forum, 2010; Pettus 2002; SCEI, 2010; “Sega Game…”, 2010; “Sega Master…”, 2010; “Sega Nomad”, 2010; “Sega Saturn”, 2010; Snow, 2007a, 2007b; “TurboExpress”, 2010; “TurboGrafx-16”, 2010)

Finally, we have opted to consider a useful lifespan of 5 years, equal to that of a computer, which is in accord with product cycles (generations) that main product manufacturers, for example: Playstation1 (1995); Playstation2 (2000); Playstation3 (2006) (“Video game console”, 2010).

E.5.3 Game consoles: effective use

Similar to PCs, the effective use data on videogame consoles refers to “gross” use, that is to say, the approximate number of hours per week the user is interacting with the console, not how long the computer runs at maximum capacity.

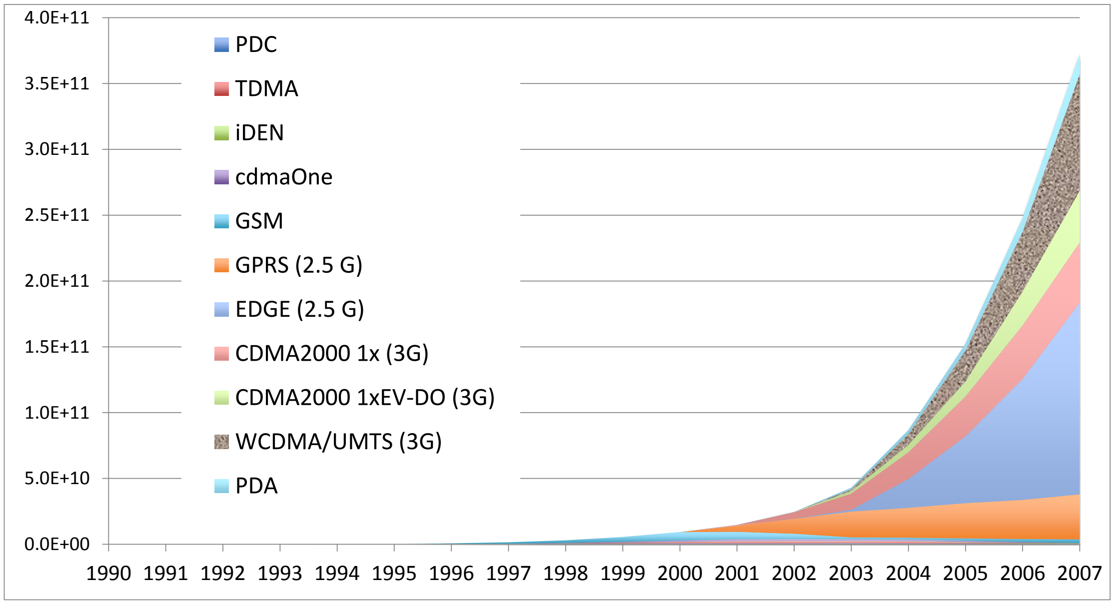
Table E-12: Simple average use of videogame consoles, hours per week.

Year	1986	1993	2000	2007
Average hours/week	0.4	2.6	6.1	11.5

Source: Authors’ own elaboration based on (American Alliance for Health, Physical Education, Recreation and Dance [AAHPERD], 2009; Armentrout, 2008; Cheng, 2007; Godoy y Herrera, 2003; LaRose & Eastin, 2007; Looms, 2002; Nielsen, 2005, 2007, 2008, 2009; Olson, et al., 2007; Rideout, et al., 2010).

E.6 Mobile phones and PDAs

Figure E-10: Computational capacity of mobile phones and PDAs (MIPS).



Source: Authors' own elaboration, based on various sources (see text).

E.6.1 Mobile phones, PDAs, and handheld PCs: performance

The performance of mobile phone processors is extracted from (Belk, 2007), and converted to Dhrystone MIPS 1.1 from 2.1.

Table E-13: Cellular phone processing levels (MIPS Dhrystone 1.1).

	GSM	cdmaOne	PDC	GPRS	EDGE	CDMA2000 1x	WCDMA (UMTS)	CDMA2000 1xEV-DO
Generation	2G	2G	2G	2.5G	2.5G	3G	3G	3G
MIPS	14	14	14	22	151	151	467	467

Sources: Authors' own elaboration, based on (Belk, 2007)

The estimation for the period 1995-2002 is based on the annual average performance of 23 models of PDAs with Motorola-Dragonball processors (Freescale Semiconductors, 1995; Motorola, 2001a, 2001b). For 2004 we consider the computing power of the *Tungten T5* and for 2005 of the *LifeDrive*, these being equal to 170 MIPS and 174 MIPS (in Dhrystone 2.1), respectively. Given the convergence between PDA and smart phones (which is reconfirmed by the fact that their performance is becoming very similar at the time of 2.5G mobile phones), we suppose that for the years 2006 and 2007 the computational capacity is the same as 3G phones (Table E-14.)

Table E-14: Processing levels of PDAs (MIPS).

Año	1990-1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
MIPS	2.6	3.1	3.1	5.1	5.1	*83*	161	164	467	*467*

Sources: (Belk, 2007; Freescale Semiconductors, 1995; Motorola, 2001a, 2001b); estimates in italics.

E.6.2 Mobile phones, PDAs, and handheld PCs: quantity

We follow the same methodology as described in the Appendix E, chapter E.6. eTForecasts (2006) reports data regarding the number of PDAs[56] and handheld PCs sold . We suppose each of these devices has a useful life of three years ("Continued growth…", 2000), equal to cellular phones.

Table E-15: Quantity of PDAs sold worldwide (millions of units).

	1992	1993	1994	1995	1996	1997	1998	1999
PDA	0.06	0.05	0.10	0.17	0.39	0.92	2.12	4.93
	2000	2001	2002	2003	2004	2005	2006	2007
PDA	11.43	11.85	12.29	12.75	13.12	13.51	13.88	14.34
Handheld PC					0.00	0.01	0.08	0.22

Source: Authors' own elaboration, based on various sources (see text).

E.6.3 Mobile phones, PDAs, and handheld PCs: effective use

The gross effective use is estimated basis of mobile voice and mobile Internet usage.

Table E-16: Number of hours per week mobile phone is used for voice and Internet services per subscriber.

		2000	2007
Hours per week	OECD	18.85	34.42
	Non-OECD	14.10	22.41
Weighting for number of mobile phones	OECD	82 %	71 %
	Non-OECD	18 %	29 %

[56] Includes PDAs with operative systems from Palm, Pocket PCs (Windows CE) or any other operating system.

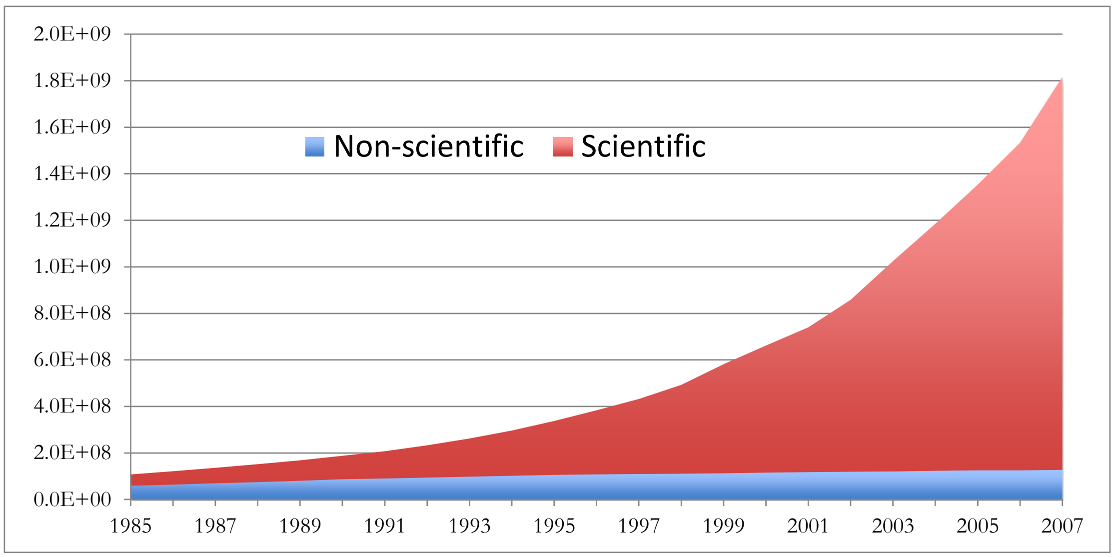
Weighted global average (hours per week)	Mundial	18.0	31.0

Source: Authors' own elaboration, based on (Mandelli & Bossi, 2002; Mikami et al., 2005; NielsenWire, 2009; Rideout et al., 2010; WIP-Japan, 2000; Zackon, 2009; Zamaria & Fletcher, 2008)

E.7 Electronic calculators

In this section we distinguish between two types of calculators: non-scientific electronic and scientific electronic.

Figure E-11: Computational capacity of calculators (MIPS).



Source: Authors' own elaboration, based on various sources (see text).

E.7.1 Calculators: Quantity

Due to the lack of statistics on total worldwide calculator use in different years, we turned to statistical information on the number of households and students as an approximation (ITU, 2009). For non-scientific calculators, we suppose that each household in OECD member states possesses one simple electronic calculator in 1980 and two from 1990 onwards (linear interpolation). In non-OECD countries, we suppose that no households had any calculators until 1975 and that, in 1995 onwards, there exists one calculator per household (linear interpolation between 1975 and 1995).

The number of scientific calculators is approximated on basis of the number of secondary and university students from data provided from 1970 by the UNESCO database (2004, 2010). The same distinction is made between OECD and non-OECD nations (with the same transition between 1975 and 1995 for non-OECD nations) and we suppose an academic career of 4 years for each student. Each new student acquires a scientific calculator upon entering university education and keeps it for four years after matriculation before discarding it. We assume that each tertiary student that has graduated in a field in which calculators are essential (science, engineering, manufacturing, construction, architecture, which corresponds to around 10% of all tertiary students) maintains possession of a calculator throughout their professional lives (40 years) and that they replace them with a new calculator every five years (J. Woerner; personal communication, October 10, 2010).

The result of this estimation assumes that there have been some 5.5 billion calculators produced since the 1970s. We know that Cisco has produced 1 billion calculators since 1972 (J. Woerner; personal communication, October 10, 2010). Combining those two numbers would result in a historical market share by Cisco of 18%. This seems reasonable, knowing that Cisco is one of the largest manufacturers, but that their competitors, such as Texas Instruments and Hewlett-Packard, maintain a larger market share than Cisco.

E.7.2 Calculators: performance

In the case of non-scientific calculators, we consider the computing power of the Intel 4004 processor, which was constructed in 1971 for a Japanese company which aimed to make a pocket calculator (0.06 MIPS, Byte.com, 1995). We suppose that this level of performance has remained constant, given that this type of calculator has not notably improved in its functionality since its market introduction.

Scientific calculators have evolved from allowing (limited) programming to even the power to graph functions on a monitor. The Hewlitt-Packard Museum (Museum of HP Calculators [MoHPC], 2007) reports the performance of various HP calculators from 1968 to 2003. Lamentably this performance is not measured in MIPS, but it is deducible that the computing power in 1981 was around double that of 1971; in 1991 the performance was again doubled and between 1991 and 2001 it quadrupled. Based in this rate of technological progress for calculators, one begins with 0.06 MIPS in 1971 (Byte.com, 1995), calculate for the years 1981, 1991, and 2001, and extrapolate with a constant growth rate for the intervening years, applying the rate of 2000-2001 for the years 2002-2007 (Table E-17).

Table E-17: Estimated computational power of scientific calculators 1971-2007 (MIPS).

Year	Non-scientific	Scientific	1971	1972	1973	1974	1975	1976
MIPS	0.060		0.060	0.064	0.069	0.074	0.079	0.085
Year	1977	1978	1979	1980	1981	1982	1983	1984
MIPS	0.091	0.097	0.104	0.112	0.120	0.129	0.138	0.148
Year	1985	1986	1987	1988	1989	1990	1991	1992
MIPS	0.158	0.170	0.182	0.195	0.209	0.224	0.240	0.276

Year	1993	1994	1995	1996	1997	1998	1999	2000
MIPS	0.317	0.364	0.418	0.480	0.551	0.633	0.728	0.836
Year	2001	2002	2003	2004	2005	2006	2007	
MIPS	0.960	1.103	1.267	1.455	1.671	1.920	2.206	

Source: Authors' own elaboration, based on Hewlett-Packard's growth rate (MoHPC, 2007).

E.7.3 Calculators: effective use

Due to a lack for more exact information, we suppose that, for all calculators, scientific calculators are used (gross use) for 3 hours per week (class work and homework that use calculators in a school or university, for example), and non-scientific calculators are used 0.5 hours per week.

E.8 Digital Signal Processors (DSP)

A digital signal processor (DSP) is a specialized microprocessor with an optimized architecture for the fast operational needs of measuring, filtering and/or compressing continuous real-world analog signals (e.g. audio, speech, sonar, radar, sensor array, spectral, image and biometric, etc.).

E.8.1 DSP: performance

We include 13 families of technologies into this part of the inventory (see

Table E-18). The result is based on a sample of 52 different DSP solutions. Missing years where estimated on basis of the general requirement of the technology and the technological process made by the performance of PC. The resulting average performance rates in MIPS are in agreement with expert assessments of the general evolution of DSP over the past decades (Bier, 1997). It is important to notice that some of the technologies included here also count with a small microprocessor, which we do not consider at this point.

Table E-18: Performance of 13 technological families that use DSP (in MIPS).

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Fixed phone	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Dial-up modem	*11*	*12*	*14*	*15*	16	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*	*16*
CD device	*3*	*3*	*5*	*7*	*8*	*24*	*46*	*54*	*54*	54	*54*	*54*	*54*	*54*	*54*	*54*
Digital radio					79	79	79	79	79	79	79	79	79	79	79	79
Printer & Fax	*15*	*17*	*25*	*34*	40	40	*50*	61	*111*	162	*162*	*162*	*162*	*162*	*162*	*162*
Broadband modem & setup boxes	*12*	*14*	*21*	*27*	*33*	*99*	189	*189*	189	*189*	*189*	*189*	*189*	*189*	*189*	*189*
DVD device and PVR					*45*	*135*	*258*	300	300	300	300	300	300	300	300	300
Laser printer	*22*	*24*	*37*	*49*	*58*	*176*	*337*	*391*	450	450	450	450	450	450	450	450
Digital cameras & camcorder	*13*	*14*	*21*	*21*	*21*	*21*	41	40	80	*85*	91	100	316	389	500	*527*
Portable Media Player							*58*	*63*	*90*	*108*	*119*	*163*	*332*	*441*	*511*	*539*
Personal navigation (GPS)			*8*	*11*	*13*	*39*	*75*	*87*	100	*131*	*148*	*225*	*348*	*493*	*521*	550
Mobile phones	*11*	*18*	20	25	30	*34*	38	*44*	50	*63*	*75*	*88*	100	*133*	*167*	200
Avg. DSP performance	11	12	16	20	31	63	106	134	148	158	161	175	213	244	258	265

Source: Authors' own elaboration, based on PMP: Austex Software, 2010; Freescale Semiconductors, 2005; NVIDIA, 2010; Portalplayer, 2007, 2010; Quirk. Modems: AMCC, 2006; Business Wire, 2000; Conexant, 2002; Daxal Communications, 2000; EDGE Publishing, 1999; Marsh & Kempainen, 1998; PairGain Technologies, 1998; PR Newswire Europe, 2010; ST Microelectronics, 2001; TDC, 2005; The Gale Group, 2002; TI Algotron, 2010; Wipro, 2003. Setup boxes: Advanced Software, 2010; Best Market, 2010; Cirrus Logic, 2010; Conexant Systems, 2010; Ku Satellite, 2010a, 2010b; Parabolic Communications, 2005; Dreambox Shop, 2010; Motorola Media Center, 2003; Opticum, 2009; M2 Presswire, 2001; MAYORTEC, 2006, Scientific Atlanta, 2006; Sony Passage, 2002; Triax, 2007, 2010; Digital cameras and camcorders: Arakawa et al., 2006; Hitachi, 1997, 2002; National Semiconductor Corporation, 2002a, 2002b; Renesas Technology, 2005; Takahashi et al., 2004; Takezaki, 1997; Texas Instruments, 2005, 2010; Vision Components, 2009. Digital radio: Uchiyama, et.al., 2001; Martin, 2002. Digital fixed-line phone: Adaptive Digital Technologies, 2010. GPS: Ferzli, 2005; Söderholm et al., 2008; Fastrax, 2008; King, 2003. CD: Atherton, 1993; Butler, 2005; Gadegast, 1993; Nuntius, 2010; Texas Instruments, 2002; Uchiyama et al., 2001. DVD: Martin,2002. PVR Atherton, 1993; Butler, 2005; Gadegast, 1993; Martin 2002; Nuntius, 2010; Texas Instruments, 2002; Uchiyama et al., 2001. Printer and fax: Datasheet Archive, 1994, 1996; Weiss, 1994; Hitachi, 1997, 2001; Cantata Technology, 2006; Mainpine, 2007; Uchiyama et al., 2001; Texas Instruments, 2001. Laser printer: Ferzli, 2005, ARM, 2010. Mobiles: Chen and Thyssen, 2008. Note: italic are estimates.

E.8.2 DSP: quantity

We distinguish between the different types of technologies, because we suppose different lifetimes for several of them. The sum of the 13 technologies in our sample matches quite well with the numbers of total DSP produced in 2000 and 2004, showing that our sample is quite complete. McIlvaine (2001) reports that 918 million DSP were produced in 2000 and our sample sums up to 787 million in 2000 and 863 million newly installed DSP in 2001. Research and Markets (2005) reports that 1,500 million were shipped in 2004, while our sample sums up to 1,366 million for the same year.

E.8.2.1 Portable Media Player (PMP)

The number of MP3 players since 1998 is based on U.S Securities and Exchange Commission, 2007; Morgan Stanley, 2006; and Ethier, 2007, 2008 (see Table E-19). We decided to separate iPods from other MP3 players, since they have a higher performance than MP3 players, and have organized the number of units sold since its inception in 2001 (Apple, 2002-2008). We obtained the number of units sold in 2005-2006 (Gilroy, 2007) and (Ethier, 2007; 2008). We suppose a useful lifetime of 3 years for this technology (equal to that of mobile phones).

Table E-19: Global number of portable entertainment devices manufactured.

Nº units globally [millions]			
	MP4	MP3 (except iPod)	iPod
1998	0	0.8	0
1999	0	3.7	0
2000	0	6.6	0
2001	0	9.4	0.1
2002	0.2	11.9	0.5
2003	0.5	14.2	1.1
2004	3.4	26.7	8.3
2005	5.5	96.7	32.0
2006	9.8	172.2	46.4
2007	10.8	189.2	52.7

Sources: based on (U.S Securities and Exchange Commission, 2007;, Diamond Multimedia's, 2007; Morgan Stanley, 2006; Apple, 2002-2008; Gilroy, 2007)

E.8.2.2 Modems and set-up boxes

In this category, we group equipment whose computational power points to the transformation of signals, for the Internet (as with dial up modems, IDSN, DSL, Cable and other modems), and for televisions (set-top boxes) (Table E-20). Set-top boxes (STB) are responsible for receiving and, optionally, decoding analog or digital television (DTV) signals, and then displaying then on a display device.

The number of units is based on the distribution of subscribers to the various Internet access technologies (dial-up, ISDN, DSL, Cable Modem, FTTH, and Others) according to ITU (2011), the assumption being that each Internet connection is established by a subscriber using a modem. The number of set-top-boxes is reported by (Cadden, 2006; In-Stat, 2008). We assume a useful life of five years, equal to that of computers.

Table E-20: Shipments of Set-top-boxes (thousands), 2000 - 2007.

2000	2001	2002	2003	2004	2005	2006	2007
21,722	24,563	26,667	29,705	38,332	43,611	63,925	78,803

Source: (Morgan Stanley, 2006; In-Stat, 2008)

E.8.2.3 Digital Cameras and camcorders

For the number of units worldwide, we turned to different sources (Computer Industry Report, 1997; Drapkin & DiMarco, 2000; Infotrends, 2001, 2002; Nisselson, 2004; Palta 2008; Peters, 2005; Rabadi et al., 2000; Rebelo, 2007). From 1991 to 1996 we extrapolated, using a constant growth rate (supposing 1990 as year digital cameras were introduced). In accord with various sources, we suppose an average useful life of 5 years (Chen, 2005; Northwestern University, 2007; South Dakota Official Website, 2002). Digital camcorders are reported in Morgan Stanley (2006).

Table E-21: Quantity of digital cameras and camcorders shipped worldwide (in millions of units).

	1991	1992	1993	1994	1995	1996	1997	1998	1999
Cameras	0.15	0.24	0.38	0.61	0.99	1.6	2.2	3.8	5.5
Camcorders	0.09	0.14	0.22	0.36	0.58	0.94	0.80	1.75	3.44
	2000	2001	2002	2003	2004	2005	2006	2007	
Cameras	11	18	24	47	63	81	106	131	
Camcorders	6.88	9.45	12.30	14.85	15.75	21.00	27.00	33.37	

Source: Authors' own elaboration based on various sources (Computer Industry Report, 1997; Drapkin & DiMarco, 2000; Infotrends, 2001, 2002; Nisselson, 2004; Palta 2008; Peters, 2005; Rabadi et al., 2000; Rebelo, 2007; Morgan Stanley (2006)

E.8.2.4 Radio digital

Same assumption as for digital radio for communication (see Appendix E, chapter E.3).

E.8.2.5 Digital fixed-line telephony

Same statistics as in Appendix E, chapter E.5.

E.8.2.6 Personal Navigation Device (GPS)

Same assumption as in Appendix E, chapter E.8.

E.8.2.7 CD, DVD, Personal video recorder (PVR)

Morgan Stanley (2006) reports the shipment of DVD players and recorders until 2006, as well as CD (and Minidisks) players and recorders for 2000-2006. We estimate the rest of the years on basis of the growth rates of optical DVDs and CDs units (see Storage, E). The number of PVR devices is reported by (In-Stat, 2003, 2005, 2006, 2008; Paxton, 2006). As with TV sets, we assume an average lifetime of 10 years (South Dakota Official State Government, 2005).

Table E-22: Shipments of equipment CD, DVD and PVR (millions).

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1983
CD & Minidisk	0.02	0.44	1.2	2.2	3.7	5.5	7.4	9.87	12	16	23	39	0.02

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
CD & Minidisk	49	60	76	90	98	117	117	123	129	136	143	146	118
DVD		0.06	0.71	2.95	9.70	21	35	22	39	86	102	123	156
PVR					0.13	0.46	0.80	1.50	4.6	11.4	19.0	19.8	19.6

Source: Authors' own elaboration based on (In-Stat, 2003, 2005, 2006, 2008 Morgan Stanley, 2006; Paxton, 2006).

E.8.2.8 Printers and Facsimile

Morgan Stanley (2006) reports the shipment of inkjet and laser printers for 2003-2006. We estimate the remaining years of basis of the PC growth rate, considering that 1985 was the first year for high resolution and high-speed printing for electro-photographic printers and we estimate that in 1994 there were 66 million printers (until 1994 HP sold 30 million printers with 45 % of market share (Business Wire, 1995)). Gartner (2008) reports the amount of facsimile sold in the U.S. We assume the same ration of [U.S. / rest of world] as for PC (76% in 1986, 46 % in 1994; 35 % in 2000 and 24 % in 2007). We suppose a useful lifetime of 5 years.

E.9 Microcontroller (MCU)

Microcontrollers are omnipresent since the 1970s and are typically found in automatically controlled products, including household appliances, entertainment electronics, and transport and office machines. Since the mid-1990s, some 30 of them are included in a medium priced car and they assist us on a daily basis through watches, kitchen tools, washing machines, garage door openers, remote controls and toys. Technically speaking, microcontrollers (MCU) are integrated circuits that contain many of the same items that a desktop computer has, such as a central processing unit (CPU), memory, etc. (Parallax, 1999). Microcontrollers are designed for machine control applications and human users cannot intervene in the logic of their functionality.

E.9.1 MCU: performance

Microcontrollers are typically produced in three forms: 8-bit, 16-bit and 32-bit. We took a sample of 18 modern MCUs of 8-bit (ST Microelectronics, 2010; Silicon Labs; Ubicom, 2010); 18 modern MCU of 16-bits (Texas Instruments, 2010; Analog Devices, 2010; Fujitsu, 2010); and 56 modern MCUs of 32-bits (Texas Instruments, 2010; Renesas, 2010; Freescale, 2010); which result in 32 MIPS, 50 MIPS and 269 MIPS respectively. We take this as the performances for 2007. ST Microelectronics (2009) presents some average values of 9 MIPS (8-bit), 32 MIPS (16-bit) and 171 MIPS (32-bit), which we take for 2002, and ICE (1998) reports that Toshiba's MCU had roughly 0.5 MIPS (8-bit), 8 MIPS (16-bit) and 12 MIPS (32-bit) in 1996. We interpolate linearly and assume that during the years pre-1996, technological progress was at the same rate as for PC's microprocessor performance MIPS.

E.9.2 MCU: quantity

We take the values of

Table E-23 and consider a useful lifespan of 5 years.

Table E-23: Shipments of Microcontrollers of 8-bit, 16 bit and 32-bit (in million).

units	1982*	1983*	1984*	1985*	1986*	1987*	1988*	1989*	1990*	1991	1992	1993	1994
8-bit	*227*	*262*	*301*	*347*	*399*	*460*	*530*	*610*	*702*	808	895	1,043	1,091
16-bit	*232*	*267*	*308*	*354*	*408*	*470*	*541*	*623*	*717*	826	914	1,066	1,383
32-bit	*10*	*11*	*13*	*15*	*17*	*20*	*23*	*26*	*30*	34	38	67	106
units	1995	1996	1997	1998*	1999*	2000*	2001*	2002*	2003*	2004	2005	2006	2007
8-bit	1,073	1,070	1,120	*1,246*	*1,384*	*1,537*	*1,705*	*1,891*	*2,095*	2,344	2,756	3,180	3,889
16-bit	1,686	1,863	2,240	*2,398*	*2,566*	*2,746*	*2,939*	*3,144*	*3,364*	3,229	3,218	3,099	3,095
32-bit	184	311	320	*389*	*467*	*554*	*653*	*764*	*889*	1,227	1,693	2,220	3,016

Sources: Authors' own elaboration, based on ICE (1998); and ST Microelectronics (2009). Note: * estimations based on constant growth rates.

E.10 Graphic Processing Units (GPU)

A graphics processing unit (GPU) is a specialized microprocessor that offloads and accelerates graphics. We include dedicated graphics cards and integrated graphics solutions.

E.10.1 GPU: quantity

Jon Peddie Research (2010) has specialized in tracking this market. We obtained the total values for 1982-2007. For the years 2001-2007 we also obtained the separation among discrete desktop video cards, integrated desktop solutions, discrete notebook video cards and integrated notebook solutions. We estimate the previous years on basis of constant growth rates, considering the year 1990 as the starting year for notebooks. The numbers are consistent with the data from the Telecommunications Union [ITU] database (2009) on the installments of PCs.

Table E-24: Shipments of Graphic Processing units (in million).

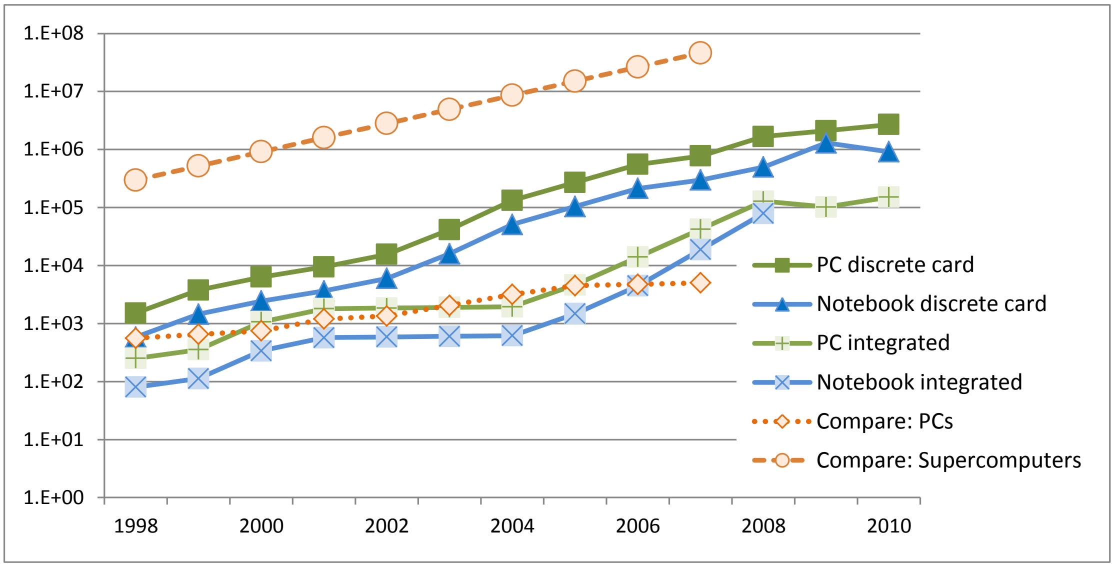
	1982	1983	1984	1985	1986	1987	1988	1989	1990
Total GPU	2	4	6	8	10	15	20	25	30
	1991	1992	1993	1994	1995	1996	1997	1998	1999
Total GPU	35	40	45	55	80	105	120	130	140
	2000*	2001	2002	2003	2004	2005	2006	2007	
Desktop discrete	63	76	89	80	84	83	80	98	
Desktop integrated	73	125	150	180	111	122	145	147	
Notebook discrete	6	8	9	13	22	20	21	25	
Notebook integrated	13	17	21	27	23	45	69	85	

Sources: Authors' own elaboration, based on Jon Peddie Research (2010). Note: * estimations based on constant growth rates.

E.10.2 GPU: performance

Graphic accelerators calculate floating point operations (FLOPS), which we translate to MIPS through our translation 1 FLOPS = 3 MIPS. We create a sample of 117 GPUs from the period between 1996 and 2007 (B&R automation, 2009; Comparison of NVIDIA…; Comparison of ATI…). As can be seen the following Figure, the resulting tendency is quite similar to the technological process of supercomputers. This should not be surprising, as both specialize in floating point operations (FLOPS). It is generally known that the gap between the performance trajectories of GPUs and PCs has been widening over recent years (see Figure, also Green, 2006). We therefore estimate the performance of GPU for the years pre-1998 on basis of the technological progress of the average supercomputer.

Figure E-12: Average performance of GPU, in comparison with supercomputers and PCs (MIPS) (semi-log plot).



Sources: Authors' own elaboration, based on B&R automation, 2009; Comparison of NVIDIA…; Comparison of ATI… .

E.11 References

3DO Interactive Multiplayer (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/3DO_Interactive_Multiplayer

Aburto, A. (n.d.). PDS: The performance database server – Dhrystone. Retrieved November 2010, from: http://performance.netlib.org/performance/html/dhrystone.data.col0.html

Adaptive Digital Technologies. (n.d.). Vocoder algorithms: G.711, G.711 waveform coder appendix 1 & G.711 appendix 2. Retrieved November 2010, from: http://www.adaptivedigital.com/product/vocoders/g711.htm

Advanced Software. (n.d.). *Grabación digital de video – DVR-2460*. Retrieved November 2010, from: http://www.advancedsoft.net/pdf/cam/CamDVR2460.pdf

AMCC (2006). *PowerPC 405EP embedded processor*. Retrieved November 2010, from: https://www.amcc.com/MyAMCC/retrieveDocument/PowerPC/405EP/PPC405EP_PB2004.pdf

American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD). (2009). *Appropriate use of instructional technology in physical education*. Retrieved November 2010, from: http://www.aahperd.org/naspe/standards/upload/Appropriate-Use-of-Instructional-Technology-in-PE-2009-2.pdf

Analog Devices. (2010). Products. Retrieved November 2010, http://www.analog.com

Apple (2002, January 16). Apple reports first quarter profit of $38 Million. Apple Press Release Library. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2003, October 15).Apple Reports Fourth Quarter Results: Revenue Increases 19 percent. Apple Press Release Library. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2004, April 14).Apple Reports Second Quarter Results: Earning per Share Triples Apple Press Release Library. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2004, January 14). Apple Reports First Quarter Results: Revenue Increases 36 percent Year-over-Year. Apple Press Release Library. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2004, July 14).Apple Reports Third Quarter Results: Revenue Increases 30 percent and Profits Triples Year-over-Year. Apple Press Release Library. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2004).Apple Reports Forth Quarter Results: Revenue Increases 37 percent Year-over-Year, iPod Shipments Top 2 million. Apple Press Release Library. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2005, April 13). Apple Reports Second Quarter Results: Revenue Increases 70 percent and Net Income Increases over 500 percent Year-over-Year. Apple Press Release Library. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2005, January 12). Apple Reports First Quarter Results: Quarterly Revenue & Net Income Highest in Apple's History. Apple Press Release Library. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2005, July 13).Apple Reports Third Quarter Results: Apple Delivers Record Revenue & Earnings. Apple Press Release Library. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2005, October 11).Apple Reports Fourth Quarter Results: Apple Concludes Best Quarter & Best Year in Compañny History. Apple Press Release Library. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2006, April 13).Apple Reports Second Quarter Results: Revenue Grows 34 percent percent Year-over-Year and Earnings 41 percent. Apple Press Release Library. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2006, January 18). Apple Reports First Quarter Results: Apple Delivers Record Revenue & Earnings. Apple Press Release Library. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2006, July 19).Apple Reports Third Quarter Results: Post Second Highest Quarterly Revenue and Earning in Company's History. Apple Press Release Library. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2006, October 18).Apple Reports Preliminary Fourth Quarter Results: Ships Record 1.61 Million Macs. Apple Press Release Library. Retrieved November 2010, from: http://www.apple.com/pr/library/

Apple (2008, January 22). Apple reports first quarter results: Best quarterly revenue & earnings in Apple History; Mac, iPod & iPhones sales break previous records. Apple Press Release Library. Retrieved November 2010, from: http://www.apple.com/pr/library/

Arakawa, F., Yamada, T., Okada, T., Ishikawa, M.,Kondo, Y., … Yoshioka, S. (2006). Development of processor cores for digital consumer appliances. *Systems and Computers in Japan 37*(3), 10-19. doi: 10.1002/scj.20450

ARM, (2010). ARM946 Processor for the HP Deskjet 5940 Photo Printer. Retrieved November 2010, from http://www.arm.com/markets/enterprise/hp-deskjet-5940.php.

Armentrout, J. (2008, January). *Introduction to video and electronic games*. Presented to the Hall-Dale Elementary School District PTO. Retrieved November 2010, from: http://www.halldale.org/images/uploads/VideoGamingPresentation.pdf

Arredondo, P. (2007). *Acceso y usos de Internet en el occidente de México: el caso Jalisco*. Universidad de Guadalajara. Retrieved November 2010, from: http://www.publicaciones.cucsh.udg.mx/pperiod/comsoc/pdf/cys8_2007/cys_n8_2.pdf

Ashmanskas, B., Belforte, S., Hughes, R., Keener, P. T., Kreymer, A., … Würthewein, F. (2001). *Report on benchmarking CDF CAF review, Fall 2001*. Retrieved November 2010, from CDF Central Analysis Facility Website: http://www-cdf.fnal.gov/upgrades/computing/projects/central/CAF_benchmarking.ps

Atari 2600 (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Atari_2600

Atherton, P. (1993). Consumer audio DSP and Motorola's DSP56004 microprocessor. *IEE Colloquium on Audio DSP – Circuits and Systems (Digest No 1993/219),* 1-8.

Austex Software. (n.d.). *Nueron – Processor Comparison*. Retrieved November 2010, from: http://ieee.uwaterloo.ca/sca/www.austexsoftware.com/nueronprocessor.html

B&R automation. (2009). Benchmark test industrial PC, 12 march 2009, Retrieved November 2010, from http://www.br-automation.com/downloads_br_productcatalogue/BRP44400000000000000100403/BenchmarkingtestsIndustriePC_E_V2_4.pdf

Baker, M. (2000). *Cluster computing white paper*. IEEE Task Force on Cluster Computing. Retrieved November 2010, from Cornell University Library: http://arxiv.org/pdf/cs/0004014v2

Banks, P. R. (1999). *The full Acorn machine list*. Retrieved November 2010, from: http://www.khantazi.org/Archives/MachineLst.html

Belk, J. K. (2007). *CDMA2000: Insight into the Future of 3G Devices and Services* [CDG Webcast]. Retrieved November 2010, from: http://www.cdg.org/news/events/webcast/070228_webcast/Qualcomm.pdf

Best Market. (n.d.). *KVR-1000 PLUS*. Retrieved November 2010, from: http://www.bestmarket.gr/hotshop/files/products/KVR-1000%20PLUS%20-%20Specifications.pdf

Bier, Jeff (1997). The Evolution of DSP Processors. CS152, University of California at Berkeley November 14, 1997. Retrieved November 2010, from: http://www.cs.berkeley.edu/~pattrsn/152F97/slides/slides.evolution.ps

Bohn, R., & Short, J. (2009). How much information? 2009 Report on American consumers. Retrieved November 2010, from San Diego: Global Information Industry Center at the University of California: http://hmi.ucsd.edu/howmuchinfo_research_report_consum.php

Bolea de Anta, Adelaida (2009). *La radio que viene, ¿hay alguien ahí?* Retrieved November 2010, from Asociación Española de Investigación de la Comunicación (AE-IC) Website: http://www.aeic2010malaga.org/upload/ok/216.pdf

Bureau of Labor Statistics (2004). *Time-use survey – Firsts results announced by BLS*. Retrieved November 2010, from: http://www.bls.gov/news.release/archives/atus_09142004.pdf

Bureau of Labor Statistics (2010). Economic News Release. Retrieved November 2010, from: http://www.bls.gov/news.release/atus.t01.htm

Business Wire (1995, May 30). *HP discontinues its last pen plotter; inkjet technology drives extinction of pen plotters*. Retrieved November 2010, from CBS Business Network (BNET): http://findarticles.com/

Business Wire (2000, September 19). Broadcom adds VoIP telephony and home networking technology to industry-leading DOCSIS cable modem chip. Retrieved November 2010, from the Free Library Website: http://www.thefreelibrary.com/

Butler, W., Crowgey, S., Heineman, W., & Gourley, S. (2005). *Personal electronics for law enforcement solid state recorders and body wires* [U.S. Department of Justice, Document No.: 210488]. Retrieved November 2010, from: http://www.ncjrs.gov/pdffiles1/nij/grants/210488.pdf

Byte.com (1995, September). *Most important chips*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20080401091547/http://www.byte.com/art/9509/sec7/art9.htm

Cadden, C. (2006, January 17). Digital cable set top box unit shipments post second consecutive year of growth according to In-Stat. *In-Stat Press Release*. Retrieved November 2010, from: http://www.instat.com/press.asp?Sku=IN0502144ME&ID=1541

Cantata Technology (2006). *Enterprise performance at small business value, Brooktrout Trufax*. Retrieved November 2010, from: http://www.communica.se/cantata/brkt_trufax.pdf

Carroll, R. (2005, September 6). *Good enough: Why graphics aren't the number one*. Retrieved November 2010, from Game Tunnel Website: http://www.gametunnel.com/good-enough-why-graphics-arent-number-one-article.php

Chen, J., & Thyssen, J. (2008). Analisys by synthesis speech coding. In J. Benesty, M. Sondhi & Y. Huang (Eds.), Springer handbook of speech processing. Berlin: Springer.

Chen, L. (2005). 2005 Digital camera buyer's guide. Retrieved November 2010, from Photography Review Website: http://www.photographyreview.com/digitalcamerabuyerguidecrx.aspx

Cheng, J. (2007, March 5). *Console gaming growing in popularity among all ages*. Retrieved November 2010, fromArs Technica Website: http://arstechnica.com/gaming/news/2007/03/console-gaming-growing-in-popularity-among-all-ages.ars

Cirrus Logic. (n.d.). *New highly-integrated processors for tomorrow's DVD players and DVD receivers available today, CS9820 Product Bulletin*. Retrieved November 2010, from: http://www.chipsinfo.com/Doc/71575842A83762EC9018335C5D5B3536.pdf

Classic Gaming Museum. (n.d.). *ColecoVision – 1982-1984 (Also known as de Personal Arcade)*. Retrieved November 2010, from: http://classicgaming.gamespy.com/View.php?view=ConsoleMuseum.Detail&id=24&game=8

Comisión Nacional de Televisión – Colombia (2006). *Informe sectorial de televisión*. Retrieved November 2010, from: http://www.cntv.org.co/cntv_bop/estudios/in_sectorial.pdf

Comparison of ATI Graphics Processing Units. (2010). Wikipedia. Retrieved November 2010, from http://en.wikipedia.org/wiki/Comparison_of_ATI_Graphics_Processing_Units

Comparison of NVIDIA Graphics Processing Units. (2010). Wikipedia. Retrieved November 2010, from http://en.wikipedia.org/wiki/Comparison_of_NVIDIA_Graphics_Processing_Units

Computer Industry Report. (1997, July 15). Digital camera market size. Retrieved November 2010, from CBS Business Network (BNET): http://findarticles.com/

Computer Museum. (n.d.). *Historical Computers in Japan, Supercomputers: [NEC] SX-3 Series*. Retrieved November 2010, from: http://museum.ipsj.or.jp/en/computer/super/0011.html

Computer Museum. (n.d.). *Historical Computers in Japan, Supercomputers: [Hitachi] HITAC S-280*. Retrieved November 2010, from: http://museum.ipsj.or.jp/en/computer/super/0009.html

Computer Museum. (n.d.). *Historical Computers in Japan, Supercomputers: [Fujitsu] Fujitsu VP2000 Series*. Retrieved November 2010, from: http://museum.ipsj.or.jp/en/computer/super/0010.html

Computer Museum. (n.d.). *Historical Computers in Japan, Supercomputers: [Fujitsu] FACOM VP-100 Series*. Retrieved November 2010, from: http://museum.ipsj.or.jp/en/computer/super/0005.html

Computer Museum. (n.d.). Historical *Computers in Japan, Supercomputers: [Hitachi] HITAC M1-180IAP*. Retrieved November 2010, from: http://museum.ipsj.or.jp/en/computer/super/0004.html

Conexant Systems. (n.d.). *(CX24152/CX24155) Single-chip satellite system solution*. Retrieved November 2010, from: http://www.datasheet4u.com/html/C/X/2/CX24152_ConexantSystems.pdf.html

Conexant. (2002). Single-chip cable modem solution, DOCSIS™ 2.9-Based – CX24951. Retrieved May 2008, from: http://solution.eccn.com/\pdf\Conexant_063211j.pdf

Console. (n.d.). Retrieved November 2010, from PVC Website: http://www.pcvsconsole.com/features/consoles/

Continued growth in mobile phone sales. (2000, October 7). Helsingin Sanomat, Business & Finance – International Edition. Retrieved November 2010, from: http://www2.hs.fi/english/archive/

Corda, A. J. (1996). *This old SGI – Professional IRIS Series (4D/50-85)*. Retrieved November 2010, from Martnet.com Website: http://www.martnet.com/~bobd/sgi/4dfaq.html#profiris

Cormen, T., Leiserson, C., Rivest, R., & Stein, C. (2003). *Introduction to algorithms* (2nd ed.). Massachusetts, USA: McGraw-Hill Science/Engineering/Math.

Cray-Cyber Team (2010). *Cray-Cyber Timeline*. http://www.cray-cyber.org/craycyber/history.php

Datasheet (1994). *Datasheet Archive: IBM PowerPC 403*. Retrieved November 2010, from: http://www.datasheetarchive.com/403GC-datasheet.html

Datasheet (1996). *Datasheet Archive: IBM PowerPC 401*. Retrieved November 2010, from: http://www.datasheetarchive.com/401GF-datasheet.html

Daxal Communications. (2000). *Modem timeline and breakdown*. Retrieved November 2010, from: http://www.surfthe.us/reference/modem-timeline.html

Diot, J. (n.d.). *Atari Web Site*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20061109041825/http://john.diot.free.fr/atari/

Dongarra, J., & Duff, I. S. (1989). *Advanced Architecture Computers* [UT-CS-89-90]. University of Tennesse, Knoxville, USA.

Dongarra, J., & Sullivan, F. (2000). Guest editors' introduction: The top 10 algorithms. *Computing in Science & Engineering 2*(1), 22-23. doi:10.1109/MCISE.2000.814652

Drapkin, A.,& DiMarco, S. (2000). Photokina 2000. The Digital Journalist. Retrieved November 2010, from: http://www.digitaljournalist.org/issue0011/camera_frameset.html

Dreambox Shop. (n.d.). Dreambox 800 DM800 HD PVR Satellite Receiver. Retrieved November 2010, from: http://www.dreamboxshop.org/dreambox-800-dm800-hd-dm800-hd-pvr-satellite-receiver-p-42.html

Dutton, W. H., & Helsper, E. J. (2007). The Internet in Britain 2007. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/OxIS%20Report%202007.pdf

EDGE Publishing. (1999, June 21). *Broadband: General instrument interactive digital platform now deployed by more than 100 broadband network operators. comcast cable communications becomes the recipient of gi's four-millionth digital set-top terminal*. Retrieved November 2010, from CBS Business Network (BNET): http://findarticles.com/

Equipo TIC-ISUC (2001, September). *Tecnologías, redes, sujetos: Una propuesta de exploración en torno a los usos de las TIC en la Sociedad de la Información. El caso de Chile. El caso de las nuevas generaciones*. Retrieved November 2010, from: http://web.mit.edu/crisgh/www/Observatorio%20TIC-ISUC.pdf

etForecast. (2008). Worldwide PC market. *eTForecasts, Executive Summary*. Retrieved November 2010, from: http://www.etforecasts.com/products/ES_pcww1203.htm

eTForecasts. (2006). Worldwide PDA & smartphone forecast. eTForecasts, Executive Summary. Retrieved November 2010, from: http://www.etforecasts.com/products/ES_pdas2003.htm

Ethier, S. (2007, August). Worldwide demand remains strong for MP3 and Portable Media Players. In-Stat Report Summary. Retrieved November 2010, from: http://www.instat.com/

Ethier, S. (2008, December). The worldwide PMP/MP3 player market: Shipment growth to slow considerably. In-Stat Report Abstract. Retrieved November 2010, from: http://www.instat.com/

Ewing, S. & Thomas, J. (2008). *CCi Digital Futures Report: The Internet in Australia*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/AuDigitalFutures2008.pdf

Fábián, Z., Galácz, A., Gerhardt, E., Kollanyi, B., Júlia, K., … Székely, L. (2007). *The map of the digital future: Hungarian society and the Internet 2007*. Retrieved November 2010, from ITHAKA Website: http://www.ithaka.hu/Letoltheto

Fastrax. (2008, May 13). Fastrax introduces pure software GPS solution. Brings low cost positioning in high volume consumer devices. *Fastrax Press Release*. Retrieved November 2010, from: http://www.fastraxgps.com/news/

Ferzli, R. (2005). *Procesamiento digital parte 2: aplicaciones* [PowerPoint Slides]. *Técnicas Digitales III, Digital Signal Processing Lab*. Retrieved November 2010, from Facultad Regional San Nicolás, Universidad Tecnológica Nacional, Argentina: http://www.frsn.utn.edu.ar/tecnicas3/presentaciones/Procesamiento%20digital%20parte%202%20-%20aplicaciones.ppt

Findahl, O. (2001). *Swedes and the Internet, year 2000*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/Sweden_Internet2000.pdf

Findahl, O. (2008). *The Internet in Sweden*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/wii-rapport-internet_in_sweden_2007.pdf

Freescale Semiconductor Inc. (1995). *Product brief: Integrated portable system processor – DragonBallTM*. Retrieved November 2010, from Datasheet Catalog Website: http://www.datasheetcatalog.org/datasheets2/19/199744_1.pdf

Freescale Semiconductors (2005). *SCF5250: Integrated ColdFire version 2 microprocessor*. Retrieved November 2010, from: http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=SCF5250&nodeId=0162468rH3YTLC00M91752

Freescale. (2010). Products. Retrieved November 2010, from http://www.freescale.com

Fujitsu. (2010). Products. Retrieved November 2010, from http://www.fujitsu.com

Gadegast, F. (1996, June 02). MPEG-FAQ: multimedia compression, version: v 4.1. Retrieved November 2010, from FAQs.org: http://www.faqs.org/faqs/mpeg-faq/part2/

Gartner. (2008). *Dataquest facsimile and multifunction products, North America program*. Retrieved November 2010, from: http://www.gartner.com/it/products/research/dataquest.jsp

Giladi, R. (1996). Evaluating the MFLOPS measure. *IEEE Micro, 16*(4), 69-75. doi: 10.1109/40.526927

Gilroy, A. (2007, June 5). iSuppli: Flash Memory wins 65% of PMP market. Retrieved November 2010, from This Week In Consumer Electronics (TWICE) Website: http://www.twice.com/article/CA6449227.html

Godoy, S. (2004). *Principales resultados WIP Chile 2004*. Retrieved November 2010, from: http://www.estrategiadigital.gob.cl/files/INFORME%20WIP%20CHILE%202004.pdf

Godoy, S. (2007, July). *WIP Chile 2003-2006: Uso e impacto de Internet*. Cuadernos de Información No. 20. Retrieved November 2010, from: http://www.accionaudiovisual.uc.cl/prontus_fcom/site/artic/20080418/asocfile/20080418230431/articulo_wip_2006_cuadernos_jul_07_en_pdf.pdf

Godoy, S. (2009). *Los internautas chilenos y sus símiles en el resto del mundo: Resultados del estudio WIP-Chile 2008*. Retrieved November 2010, from Camara de Comercio de Santiago (CCS) Website: http://www.ccs.cl/html/eventos/2009/doc/0326_WIP_informe.pdf

Godoy, S., & Herrera, S. (2003). Qué ocurre cuando se usa (y no se usa) Internet: Resultados del World Internet Project-Chile. *Cuadernos de Información 16-17*, 71-84.

Goodman, S. E. (1988). *Global trends in computer technology and their impact on export control*. Washington, DC: National Academy Press.

Gorman, T. (1996, January). *Television: Glorious past, uncertain future*. Statistics Canada. Retrieved November 2010, from: http://www.statcan.gc.ca/pub/63f0002x/63f0002x1995006-eng.pdf

Goss, S. (n.d.). *Depreciation – Useful life, or economic life*. Retrieved November 2010, from: http://www.sgafc.co.za/depreciation-useful-life-or-economic-life/

Government of South Australia (2008). *Useful life of non current assets*. Retrieved November 2010, from: http://decs.sa.gov.au/goldbook/pages/financial/assetlives/?reFlag=1

Graham, S. L., Snir, M., & Patterson, C. A. (2005). *Getting up to speed: the future of supercomputing*. Washington, DC: National Academies Press.

Grande, J. C. (2007, December). El consumo de medios masivos en el área metropolitana de San Salvador. *Minerva Revista en Línea CIC-UES 1* Retrieved November 2010, from: http://www.cic.ues.edu.sv/REVISTA%20CIC-UES%20MINERVA/articulos/Humanidades/Consumo%20Cultural.pdf

Green, Simon. (2006). GPU Physics, NVIDIA Developer Technology. Retrieved November 2010, from http://developer.download.nvidia.com/presentations/2006/cedec/2006-cedec-gpu-physics.pdf

Grupo Radar (2007). El Perfil del Internauta Uruguayo (5th ed.). Retrieved November 2010, from InnovaAge.com Website: http://www.innovaportal.com/innovaportal/file/86/1/Internet_en_Uruguay_2007.pdf

Guzmán C., C. (1997). *Las nuevas síntesis urbanas de una ciudad cultural (la ciudad como objeto de consumo cultural)*. Retrieved November 2010, from: http://www.redinterlocal.org/IMG/ciudadania_cultural.pdf

Harrison, K., & Cantor, J. (1997). The relationship between media consumption and eating disorders. *Journal of Communication 47*(1), 40-67. doi: 10.1111/j.1460-2466.1997.tb02692.x

Hayes, J., Handley, S., Kridner, J., & Nadeski, M. (1999). A programmable DSP solution to a solid state audio player. *IEEE Transactions on Consumer Electronics 45*(1), 975-979. doi: 10.1109/30.793660

Hennessy, J. L., Patterson, D. A., & Arpaci-Dusseau, A. C. (2007). *Computer architecture: a quantitative approach* (4th ed.). San Francisco, CA: Morgan Kaufmann.

Hidalgo, J. (2006, November 13), La revolución del iTunes. Del fenómeno del iPod a la construcción de una iconósfera podcastera [Web log post]. Retrieved November 2010, from: http://www.blogs.catholic.net/radiocatolica/2006/11/la_revolucion_del_itunes_del_f.html

Hitachi (1997, November 25). Hitachi realeases SH7612 SH-DSP with on-chip cache memory for multimedia equipment. *Hitachi News Release*. Retrieved November 2010, from: http://www.hitachi.com/New/cnews/E/1997/971125B.html

Hitachi (2001, December 17). Hitachi releases 65 MIPS SuperHTM single-chip microcontrollers with 256-Kbyte on-chip 3.3V single-power-supply flash memory. *Hitachi News Release*. Retrieved November 2010, from: http://www.hitachi.com/New/cnews/E/2001/1217/index.html

Hitachi (2002, June 27). New 3G applications processor with on-board camera. *Hitachi News Release*. Retrieved November 2010, from: http://www.3g.co.uk/PR/June2002/3622.htm

Hornik, J., & Schlinger, M. J. (1981). Allocation of time to the mass media. *The Jornal of Consumer Research 7*(4), *Special Issue on Consumption of Time*, 343 – 355.

ICE (Integrated Circuit Engineering). (1998). Status 1998: MOS Microcomponent Market Trends, http://smithsonianchips.si.edu/ice/cd/STATUS98/SEC06.PDF

IGN Staff (2003, July 30). *PSP specs revealed: Processing speed, polygon rate and lots more*. Retrieved November 2010, from: http://gameboy.ign.com/articles/430/430939p1.html

In- Stat. (2005, May 25). Consumer Demand for PVRs Drives Record Unit Shipments. . *In-Stat Press Release*. Retrieved November 2010, from: http://www.instat.com/pr_all.asp

In-Stat. (2003, March 24). Consumer electronics manufacturers shifting gears to boots PVR sales. *In-Stat Press Release*. Retrieved November 2010, from: http://www.instat.com/pr_all.asp

In-Stat. (2006, June 5). Just Seven Years After their Introduction, PVRs Become Mainstream Products. *In-Stat Press Release*. Retrieved November 2010, from: http://www.instat.com/pr_all.asp

In-Stat. (2008, April 30). Cable set top box market looking strong after record growth in 2007. *In-Stat Market Alert*. Retrieved November 2010, from: http://www.instat.com/newmk.asp?ID=2300

In-Stat. (2008, January 14). Long-Term Prospects Bright for Maturing PVR Market. *In-Stat Press Release*. Retrieved November 2010, from: http://www.instat.com/pr_all.asp

INE Chile (2009, Mayo). *Enfoque estadístico: ¿Cómo distribuyen el tiempo hombres y mujeres?* Retrieved November 2010, from: http://www.ine.cl/canales/chile_estadistico/estadisticas_sociales_culturales/encuesta_tiempo_libre/pdf/enfoque_eut_pag.pdf

InfoTrends, (2002). Revenue from worldwide digital camera sales to reach $11.8 billion in 2007", Infotrends Press Release. Retrieved November 2010, from: http://www.infotrends-rgi.com/

InfoTrends. (2001, September 25). Digital camera sales capture 21% of worldwide digital camera market in 2001. Infotrends Press Release. Retrieved November 2010, from: http://www.infotrends-rgi.com/

Instructions per second. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Million_instructions_per_second

Intel MSC-48. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Intel_8048

Intellivision (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Intellivision

International Telecommunications Union (ITU). (2009). *ITU world telecommunications ICT indicators 2009* [data file].

J. Gold Associates. (2009, April 23). Keeping notebooks past their prime: A study of failures and costs. *J. Gold Associates Press Release*. Retrieved November 2010, from: http://www.jgoldassociates.com/Press_Releases/Keeping_Notebooks_Past_Their_Prime_Press_Release.pdf

Jon Peddie Research. (2010). JPR Market Watch. Retrieved November 2010, from http://jonpeddie.com

Jorge, J. E. (2008, December). Actitudes hacia la política y la democracia, capital social y uso de medios en la región del Gran La Plata: Resultados de la encuesta comunicación y cultura política 2008. *Revista Question 20*.

Jorgenson, D. W., & Vu, K. (2005). Information technology and the World economy. *Scandinavian Hournal of Economics 107*(4), 631-650. doi:10.1111/j.1467-9442.2005.00430.x. Retrieved November 2010, from Department of Economics at Hardvard University: http://www.economics.harvard.edu/files/faculty/34_03_sjoe430.pdf

Jung, B. (2001). Media consumption and leisure in Poland in the 1990s: Some quantitative aspects of consumer behavior. *International Journal on Media Managements, 3*(2), 88-90. doi: 10.1080/14241270109389951

Kaynaga, M.; Yamada, K., & Inayoshi, H. (1991). *Analysis of SPEC benchmark programs*. Proceedings 8 on TRON Project Symposium, 208 – 215. doi: 10.1109/TRON.1991.213102

King, T. M. (2003). *US Patent No. 09/791343: Memory reduction method for a DSP-based GPS*. Schaumburg, IL. Retrieved November 2010, from: http://www.freepatentsonline.com/6583758.html

Koenan, A., Konert, B., & Groebel, J. (2003). *Germany and the digital world*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/WIP%20Report%20Germany%202002.pdf

Koomey, J. (2007). *Estimating regional power consumption by servers: A technical note*. Oakland, CA: Analytics Press. Retrieved November 2010, from: http://ccsl.iccip.net/koomey_estimating_technicalnote.pdf

Ku Satellite. (n.d.). *CoolSat 7000 PVR*. Retrieved May 2008, from: http://www.kusat.com/gofta.php?path=/mpeg2/coolsat7000.php

Ku Satellite. (n.d.). *Viewsat MaxHD*. Retrieved May 2008, from: http://www.kusat.com/gofta.php?path=/mpeg2/viewsatmaxhd.php

LaRose, R., & Eastin, M. S. (2007). A social cognitive theory of Internet uses and gratifications: toward a new model of media attendance. *Journal of Broadcasting & Electronic Media*.Retrieved November 2010, from the University of New Mexico Website: http://www.unm.edu/~werder/Documents/561readings/Lee%202007.pdf

Lebo, H. (2002). *The UCLA Internet report 2001: Surveying the digital future, year two*. Retrieved November 2010, from Center for the Digital Future, USC Annenberg School: http://www.digitalcenter.org/pdf/InternetReportYearTwo.pdf

Liang, G. (2005). Surveying Internet usage and impact in five chinese cities. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/China%20Report%202005.pdf

Liang, G. (2007). *Surveying Internet usage and its impact in seven chinese cities*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/_China%20Internet%20Project%20Survey%20Report%202007.pdf

Lilja, D. J. (2000). *Measuring computer performance: A practitioner's guide*. Cambridge, UK: Cambridge University Press.

Link, M. W. (2009, October 29). *How U.S. adults use radio and other forms of audio*. The Nielsen Company. Retrieved November 2010, from: http://www.rab.com/public/reports/VCM_Radio-Audio_Report_FINAL_29Oct09.pdf

Longbottom, R. (n.d.). *Computer speed claims 1980 to 1996*. Retrieved November 2010, from: http://www.roylongbottom.org.uk/mips.htm

Longbottom, R. (n.d.). *Whetstone benchmark history and results*. Retrieved

November 2010, from: http://www.roylongbottom.org.uk/whetstone.htm

Looms, P. O. (2002). Sailing into uncharted waters – the impact of new media use on education. In A. Williamson, C. Gunn, A. Young, T. Clear (Eds.). *Proceedings from the 19th annual conference of the Australisian society for Computers in learning in tertiary education (ASCILITE) 1*, 5-16. Retrieved November 2010, from: http://www.ascilite.org.au/conferences/auckland02/proceedings/papers/key_looms.pdf

M2 Presswire. (2001, October 16). *SandCraft delivers world's highest performance MIPS processor; new SR71000 sampling with 600 MHz and 500 MHz speed grades; 800 MHz speed grade imminent*. Retrieved November 2010, from HighBeam Research Website: http://www.highbeam.com/doc/1G1-79173079.html

Mainpine (2007). *What type of Fax Board do I need?* Retrieved November 2010, from: http://www.mainpine.com/whattypeofboard.html

Mandelli, A., & Bossi, V. (2002). *World Internet Project – Italy 2002*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/wip2002-rel-15-luglio.pdf

Marsh, D., & Kempainen, S. (1998, August 3). ADSL trims with G.lite. *EDN Magazine*. Retrieved November 2010, from: http://www.edn.com/archives/1998/080398/16ecs.htm

Martin, D. (2002). DSP Applications. In V. Oklobdzija (Ed.), The computer engineering handbook. Boca Raton: CRC Press.

Mayer, W. G. (1993). Poll trends: Trends in media usage. *The Public Opinion Quarterly 57*(4), 593–611.

MAYORTEC. (n.d.). FTA MAYORTEC MT-6100 Private USB 2.0 PVR MP3 MPEG. Retrieved November 2010, from: http://hermosillo.olx.com.mx/fta-mayortec-mt-6100-private-usD-2-0-pvr-mp3-mpeg-iid-18346096

Mazel, J. (2009, February 24). *Big four videogame hardware and software shipments from 1983 to 2009… and beyond*. Retrieved November 2010, from VGChartz Website: http://news.vgchartz.com/news.php?id=3035

McCallum, J. C. (2002). Price-performance of computer technology. In V. G. Oklobdzija (Ed.), *The computer engineering handbook*. Boca Raton: CRC Press.

McCallum, J. C. (2003). *Chart of CPU performance over time*. Retrieved November 2010, from: http://www.jcmit.com/cpu-performance.htm

McIlvaine, Bill. (2001). Market Focus: DSP makers' forward spin on the market. EETimes, Design and Resue. Retrieved November 2010, from: http://www.design-reuse.com/articles/2320/market-focus-dsp-makers-forward-spin-on-the-market.html

Meattle, J. (2007, November 29). *Total time spent online is up 24.3%* [Web log post]. Retrieved November 2010, from: http://blog.compete.com/2007/11/29/total-time-spent-online-is-up-243/

Media Statistics: Television viewing (most recent) by country. (n.d.). In *Nation Master*. Retrieved November 2010, from: http://www.nationmaster.com/graph/med_tel_vie-media-television-viewing

Mediascope Europe (2008). *Tendencias 2008*. Retrieved November 2010, from the Diputación de Salamanca Website: http://www.dipsanet.es/cipsa/docs/2008%20Estudio%20Mediascope%20Europe.pdf

Mega Drive. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Mega_Drive

Mega-CD. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Mega_cd

Mikami, S., Kubota, F., Hashimoto, Y., Hiroaki, Y., Endo, K., …Kitamura, S. (2005). *Internet usage trends in Japan: Survey report 2005*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/Japan_Report_2005.pdf

MK Marketing+Ventas (2004, December). *¿Qué medios prefieren los europeos?* Retrieved November 2010, from: http://pdfs.wke.es/9/6/8/1/pd0000019681.pdf

Morgan Stanley. (2006, March 3). Q1 2006 Global technology data book. Retrieved November 2010, from: http://www.morganstanley.com/institutional/techresearch/pdfs/global_techdatabook0306.pdf

Morris, C. G. (1996). *Academic Press dictionary of science and technology*. San Diego, CA: Academic Press.

Motorola (2001a). *Product brief: MC68EZ328 (DragonBall™ EZ) Integrated portable system processor*. Retrieved November 2010, from: http://ic.laogu.com/datasheet/31/MC68EZ328_MOTOROLA_105738.pdf

Motorola (2001b). *Product brief: MC68VZ328 (DragonBall™ VZ) Integrated portable system processor*. Retrieved November 2010, from: http://www.freescale.com/files/32bit/doc/prod_brief/MC68VZ328P.pdf

Motorola Media Center. (2003). *Motorola broadband unveils enhanced digital cable HDTV/PVR set-top family – the DCT6000 series*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20071012111706rn_1/www.motorola.com/mediacenter/news/detail.jsp?globalObjectId=2732_2217_23

Munafo, R. (2006). *The SPEC benchmarks*. Retrieved November 2010, from: http://www.mrob.com/pub/comp/benchmarks/spec.html

Museum of HP Calculators, The (MoHPC). (n.d.). *Benchmark results*. Retrieved November 2010, from: http://www.hpmuseum.org/speed.htm

N-Gage. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/N-Gage

National Semiconductor Corporation (2002, November). LM9701 digital image processor with integrated pre-processor. Retrieved November 2010, from: http://www.datasheet4u.com/download.php?id=662632

National Semiconductor Corportaion (2002, October). *LM9704 real time digital image processor*. Retrieved November 2010, from: http://media.digikey.com/pdf/Data%20Sheets/National%20Semiconductor%20PDFs/LM9704.pdf

Navarro Briones, Javier (2005). Las Encuestas de Jóvenes en Iberoamérica. Un recuento de experiencias recientes. *Revista de Estudios sobre Juventud 9*(23), 148-209. Retrieved November 2010, from: http://prejal.oit.org.pe/prejal/docs/bib/200711220015_4_2_0.pdf

Neo Geo Pocket. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Neo_Geo_Pocket

Nielsen Interactive Entertainment. (2005). *Video-games in Europe 2005*. Prepared for the Interactive Software Federation of Europe. Retrieved November 2010, from: http://www.worldcybergames.it/docs/ISFE05_ConsumerStudy.pdf

Nielsen Wireless and Interactive Services. (2007). *The state of the console: Video game console usage, Fourth quarter 2006*. Retrieved November 2010, from: http://dataforbreakfast.com/wp-content/uploads/2007/08/nielsen_report_state_console_03507.pdf

Nielsen. (2008, May). GamePlay metrics. *Nielson Consumer Insight Magazine*.

Nielsen. (2009, September). *Cómo los adolescentes utilizan los medios de comunicación*. Retrieved November 2010, from: http://www.nielsencompass.com/reportes/091109rep13/091109-NC12.pdf

NielsenWire (2009, September 2). *Three screen report: Media consumption and multi-tasking continue to increase across TV, Internet and Mobile* [Web log post]. Retrieved November 2010, from: http://blog.nielsen.com/nielsenwire/media_entertainment/three-screen-report-media-consumption-and-multi-tasking-continue-to-increase

Nintendo Homepage (2010). *Consolidated sales transition by region*. Retrieved November 2010, from: http://www.nintendo.co.jp/ir/library/historical_data/pdf/consolidated_sales_e0912.pdf

Nintius. (n.d.). *Multimedia streaming audio codecs: MPEG-2 advanced audio coding (AAC)*. Retrieved November 2010, from: http://nuntius.com/solutions31.html#top

Nisselson, E. (2004). Will more than 100 billion images be captured worldwide in 2005. The Digital Journalist. Retrieved November 2010, from: http://www.digitaljournalist.org/issue0403/nisselson.html

Nordhaus, W. D. (2006). Two centuries of productivity growth in computing. *Journal of Economic History 67*(1), 128-159. Retrieved November 2010, from Department of Economics at Yale University: http://nordhaus.econ.yale.edu/nordhaus_computers_jeh_2007.pdf

Northwestern University. (2007). Useful lives table. Retrieved November 2010, from: http://www.northwestern.edu/equipment-inventory/propertycodes.html

NVIDIA. (n.d.). *PP5024: Digital media Management system-on-chip*. Retrieved November 2010, from: http://www.nvidia.com/page/pp_5024.html

Oak Ridge National Laboratory (ORLN). (1999). *History of Supercomputing*. Retrieved November 2010, from: http://www.csm.ornl.gov/ssi-expo/

Olson, C., Kutner, L., & Beresin, E. (2007), Children and video games: How much do we know? *Psychiatric Times 24*(12). Retrieved November 2010, from: http://www.psychiatrictimes.com/

Opticum (2009). Opticum 7300L 2CX PVR. Retrieved November 2010, from: http://opticum.tv/?cmd=select&subcmd=1229002517936386

Organisation for Economic Co-operation and Development (OECD) (2007). *OECD Communications Outlook 2007 – Information and Communications Technologies*. Retrieved November 2010, from: http://213.253.134.43/oecd/pdfs/browseit/9307021E.PDF

Organisation for Economic Co-operation and Development (OECD). (2009). *OECD Communications Outlook 2009 – Information and Communications Technologies*. Retrieved November 2010, from: http://213.253.134.43/oecd/pdfs/browseit/9307021E.PDF

Oyanagi, Y. (2006). *Supercomping in Japan*. Presentation at the 3rd BG/L Systems Software and Applications Workshops. Retrieved November 2010, from: http://www.cbrc.jp/symposium/bg2006/PDF/Oyanagi.pdf

PairGain Technologies Inc. (1998). *Megabit modem 768: Installation manual*. Retrieved November 2010, from: http://www.adc.com/

Palta, T. (2008, May 4). IDC forecast growth for the digital camera. Digital Camera Info News. Retrieved November 2010, from: http://www.digitalcamerainfo.com/

Parabolic Communications. (2005). *Echostar PVR-5020 / 80 G HDD twin tuner receiver*. Retrieved November 2010, from: http://www.parabolic.co.uk/catalog/product_info.php?products_id=231

Parallax. (1999). What's a Microcontroller? Student Guide for Experiments #1 through #6, Version 1.9. Retrieved November 2010, from http://www.parallax.com/dl/docs/prod/sic/WaM1_9.pdf

Patiño, D. (2007). El nivel ético de los medios de comunicación en Ecuador: Nortvisión, Radio Máster y Semanario La Prensa de la ciudad de Tulcán. Universidad Técnica Particular de Loja. Retrieved November 2010, from: http://repositorio.utpl.edu.ec/bitstream/123456789/3272/1/170X363.pdf

Paxton, M. (2006, December). In-dustry update: PVR update: Year-end 2006. *In-Stat Report's Abstract: Multimedia Entertainment Equipment*. Retrieved November 2010, from: http://www.instat.com/

PCV Forum. (2005, February 6). Xbox hardware and software sales [Msg #1]. Message posted to PVC Forum. Retrieved November 2010, from: http://forum.pcvsconsole.com/

Peters, K. (2002, December 13). *Worldwide Internet users grow their time spent online*. Retrieved November 2010, from the Internet Retailer Website: http://www.internetretailer.com/2002/12/13/worldwide-internet-users-grow-their-time-spent-online

Peters, M. (2005, February 25). Lyra Research PMA 2005 Digital Camera Forecast. Let's Go Digital Online Magazine. Retrieved November 2010, from: http://www.letsgodigital.org/en/news/articles/story_2680.html

Pettus, S. (2002). *SegaBase: Volume 7 – Dreamcast. Death of the Dream, Part I, II and III*. Retrieved Nobember 2010, from SegaBase© Website: http://www.segacd.org/segabase/index-segadchistory1.html

Pitkow, J., & Recker, M. (1995). Using the Web as a survey tool: results from the second WWW user survey. *Journal of Computer Networks and ISDN systems*(27), 809-822. Retrieved November 2010, from College of Computing, Georgia Institute of Technology: http://www.cc.gatech.edu/gvu/user_surveys/survey-09-1994/html-paper/survey_2_paper.html

Porobic, A. (2002, May). *Devoted to fifth generation computing project 1982-1992, established 20 years ahead of its time*. Retrieved November 2010, from: http://research.microsoft.com/en-us/um/people/gray/talks/AdiProbicWhatNextRevealed.pdf

PortalPlayer. (2007). *PP5020: Digital media Management system-on-chip*. Retrieved November 2010, from: http://microblog.routed.net/wp-content/uploads/2007/11/pp5020e.pdf

PortalPlayer. (n.d.). *PP5022: Digital media Management system-on-chip*. Retrieved November 2010, from: http://www.eefocus.com/data/06-12/111_1165987864/File/1166002400.pdf

Porter, J. N. (1981). Rigid disk drives 1981. Disk Trend Report.

Porter, J. N. (1982). Rigid disk drives 1982. Disk Trend Report.

Porter, J. N. (1984). Rigid disk drives 1984. Disk Trend Report.

Porter, J. N. (1985). Rigid disk drives 1985. Disk Trend Report.

Porter, J. N. (1986). Rigid disk drives 1986. Disk Trend Report.

Porter, J. N. (1987). Rigid disk drives 1987. Disk Trend Report.

Porter, J. N. (1989). Rigid disk drives 1989. Disk Trend Report.

Porter, J. N. (1990). Rigid disk drives 1990. Disk Trend Report.

Porter, J. N. (1991). Rigid disk drives 1991. Disk Trend Report.

Porter, J. N. (1994). Rigid disk drives 1994. Disk Trend Report.

Porter, J. N. (1997). Rigid disk drives 1997. Disk Trend Report.

Porter, J. N. (1999). Disk Drives Evolution. 100th Anniversary Conference: Magnetic recording and information storage, Santa Clara University. Retrieved November 2010, from: http://www.disktrend.com/

PR Newswire Europe Ltd. (2010). *Imedia Semiconductor leads industry with launch of new cable modem processor*. Retrieved November 2010, from: http://www.prnewswire.co.uk/cgi/news/release?id=82750

Pronovost, G. (1996). *Medios de comunicación social y prácticas culturales: Una misma perspectiva de análisis*. Retrieved November 2010, from: http://www.consultas-cursos-de-psicoanalisis.com/cultura2dsociologia2dantropologia/una_misma_perspectiva_de_analisis2d_gilles_pronovost.pdf

Quirk, G. A. (2006, January 30). Find out what's really inside the iPod. *EE Times Design Article*. Retrieved November 2010, from: http://www.eetimes.com/design/audio-design/4015931/Find-out-what-s-really-inside-the-iPod

Rabadi, W., Talluri, T., Illgner, K., Liang, J., & Yoo, Y. (2000). Programmable DSP platform for digital cameras. Texas Instruments (Application Report). Retrieved November 2010, from: http://focus.ti.com/lit/an/spra651/spra651.pdf

Rebelo, A.. (2007, January 10). Digital camera worldwide shipments will exceed 130 Million by 2010. Lyra Research Press Room. Retrieved November 2010, from: http://www.lyra.com/

Reitze, H., & Ridder, C. (2005). *Eine Langzeitstudie zur Mediennutzung und Medienbewertung 1964-2005*. Retrieved November 2010, from: http://www.media-perspektiven.de/1196.html?&tx_mppublications_pi1[showUid]=803&cHash=0cb7656858

Renesas Technology (2005, February 8). Renesas Technology releases SH-Mobile3A application processor for mobile phones with support for terrestrial digital TV broadcast and 5-megapixel camera modules. *Renesas News Release*. Retrieved November 2010, from: http://www.renesas.com/media/company_info/news_and_events/press_releases/2005/0208/20050208e.pdf

Renesas. (2010). Products. Retrieved November 2010, from http://am.renesas.com

Research and Markets. (2005). DSP Demand in Applications 2004-2009. Retrieved November 2010, from: http://www.researchandmarkets.com/reports/310570/dsp_demand_in_applications_2004_2009

Rideout, V., Foehr, U., & Roberts, D. (2010). *Generation M^2: Media in the lives of 8- to 18-year-olds*. Retrieved November 2010, from Kaiser Family Foundation: http://www.kff.org/entmedia/upload/8010.pdf

Riley, R. W., & Robinson, S. P. (1994, October). TV viewing and parental guidance. *Education Consumer Guide, No. 10*. Retrieved November 2010, from: http://www2.ed.gov/pubs/OR/ConsumerGuides/tv.html

Rodríguez, C. (2008, September 26). Los jóvenes chilenos escuchan 4 horas diarias de música. *El Mercurio*. Retrieved November 2010, from: http://www.emol.com/magazine/

Salamon, A. (1998). *Internet statistics*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20080702030001/http://www.dns.net/andras/stats.html#weekly

Scientific Atlanta. (2006). *Digital video and DVR in an IPTV world*. Retrieved November 2010, from: http://www.saeurope.com/solutions/Downloads/brochure_DigitalVideoDvrIPTV_G1603.pdf

Secretaria Nacional de Ciencia, Tecnología e Innovación (SENACYT). (2006). Indicadores de percepción socia de la ciencia y la tecnología en Panamá 2006. Retrieved November 2010, from: http://www.senacyt.gob.pa/media/documentosDireccionGestion/indicadoresPercepcionSocial2006.pdf

Secretaria Nacional de Ciencia, Tecnología e Innovación (SENACYT). (2008). Indicadores de percepción socia de la ciencia y la tecnología en Panamá 2008. Retrieved November 2010, from: http://www.senacyt.gob.pa/media/documentosDireccionGestion/indicadoresPercepcionSocial2008.pdf

Sega Game Gear. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Game_gear

Sega Master System. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Master_system

Sega Nomad. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Sega_Nomad

Sega Saturn. (nn.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Sega_saturn

SegaSaturn.co.uk. (n.d.). *About Sega Saturn*. Retrieved November 2010, from: http://www.segasaturn.co.uk/about_sega_saturn.html

Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal, 27*, 379-423. doi:citeulike-article-id:1584479

Shepherd, B. (2009). *Media consumption in AU – Fascinating: Nielsen Australian Internet and technology report 2007* [Web log post]. Retrieved November 2010, from: http://talkingdigital.wordpress.com/2009/03/13/media-consumption-in-au-fascinating/

Silicon Labs. (2010). Products. Retrieved November 2010, from http://www.silabs.com

Smahel, D., & Lupac, P. (2008). *The Internet in the Czech Republic 2008: Four years of WIP in the Czech Republic*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/Czech_Republic_2008_Four%20Years.pdf

Snow, B. (2007, July 30). The 10 Worst-Selling Handhelds of All Time. *GamePro Magazine*. Retrieved November 2010, from: http://www.gamepro.com/article/features/125748/the-10-worst-selling-handhelds-of-all-time/

Snow, B. (2007, May 4). The 10 Worst-Selling Consoles of All Time. *GamePro Magazine*. Retrieved November 2010, from: http://www.gamepro.com/article/features/111822/the-10-worst-selling-consoles-of-all-time/

Söderholm, S., Jokitalo, T., Kaisti, K., Kuusniemi, H., & Naukkarinen, H. (2008). *Smart positioning with Fastrax's software GPS receiver Solution*. ION GNSS 2008 conference and exhibition, Savannah, Georgia, USA. Retrieved November 2010, from: http://www.fastraxgps.com/

Sony Computer Entertainment Inc. (SCEI). (2010a). *PlayStation®3 worldwide hardware unit sales*. Retrieved November 2010, from: http://www.scei.co.jp/corporate/data/bizdataps3_sale_e.html

Sony Computer Entertainment Inc. (SCEI). (2010b). *PlayStation®2 worldwide hardware unit sales*. Retrieved November 2010, from: http://www.scei.co.jp/corporate/data/bizdataps2_sale_e.html

Sony Computer Entertainment Inc. (SCEI). (2010c). *PSP® (PlayStation®Portable) worldwide hardware unit sales*. Retrieved November 2010, from: http://www.scei.co.jp/corporate/data/bizdatapsp_sale_e.html

Sony Computer Entertainment Inc. (SCEI). (2010d). *PlayStation® cumulative production shipments of hardware*. Retrieved November 2010, from: http://www.scei.co.jp/corporate/data/bizdataps_e.html

Sony Passage. (2002). *Sony announces cable ready HD PVR*. Retrieved November 2010, from: http://www.milwaukeehdtv.org/forums/archive/index.php/t-709.html

South Dakota Official State Government Website. (2002). Section IV- Accounting records: Useful life table. Retrieved November 2010, from: http://www.state.sd.us/legislativeaudit/Counties/Accounting_Manual/County_Section_4/County_Section%204_Useful_Life_Table.pdf

South Dakota Official State Government. (2005). Accounting Records – Useful Life Table. Retrieved November 2010, from: http://www.state.sd.us/legislativeaudit/Counties/Accounting_Manual/County_Section_4/County_Section%204_Useful_Life_Table.pdf

SPEC (2008a). *All SPEC CINT2000 results published by SPEC*. Retrieved November 2010, from: http://www.spec.org/cpu2000/results/cint2000.html

SPEC (2008b). All SPEC CFP2000 results published by SPEC. Retrieved November 2010, from: http://www.spec.org/cpu2000/results/cfp2000.html

ST Microelectronics (2001, January 22). STMicroelectronics announces development platform for ST120 digital signal processor core. *ST Microelectronics News Release*. Retrieved November 2010, from: http://www.st.com/stonline/press/news/year2001/t838d.htm

ST Microelectronics. (2009). ST7 Microcontroller Training, Application Lab Team, Micro Power Analog Group. Retrieved November 2010, from http://www.st.com/internet/com/TECHNICAL_RESOURCES/TECHNICAL_TRAINING/TECH_TRAINING_PRESENTATION/1143448609.pdf

ST Microelectronics. (2010). Products. Retrieved November 2010, from http://www.st.com/internet/com/home/home.jsp

Statistics New Zealand (1999). *Time use – Time for culture*. Retrieved November 2010, from: http://www.stats.govt.nz/browse_for_stats/people_and_communities/time_use/time-use-time-for-culture.aspx

Takahashi, H., Toyonoh, Y., Tanaka, T., Kojima, M., Abiko, S. … Nitta, H. (2004). A 1.5 V, 200 MHz, 188 uA/MHz and 1.2 V, 300 MHz, 600 MIPS, 169 uA/MHz Digital Signal Processor Core for 3G Wireless Applications (Low-Power System LSI, IP and Related Technologies. *IEICE Transaction on Electronics E87-C*(4), 491–501. Retrieved November 2010, from: http://ci.nii.ac.jp/naid/110003214882/

Takezaki, N. (1997, March). *Made-in-Japan microprocessors*. Retrieved November 2010, from: http://www.japaninc.com/cpj/magazine/issues/1997/may97/0597made.html

TDC Ltd. (2005). *CX82100 home network processor*. Retrieved November 2010, from: http://www.tdc.co.uk/home_networking/home_networking_conexant1.htm

Television Bureau of Advertising (2008). *Media trends track: TV basics, time spent viewing – persons*. Retrieved November 2010, from the Internet Archive Website: http://web.archive.org/web/20080616225108/http://www.tvb.org/rcentral/MediaTrendsTrack/tvbasics/09_TimeViewingPersons.asp

Texas Instruments (2001). *TI DSP firsts*. Retrieved November 2010, from: http://www.ti.com/corp/docs/investor/dsp/firsts.htm

Texas Instruments (2002). *Audio solutions guide. analog and digital amplifiers, audio converters, digital signal processors. Power management, USB.* Retrieved November 2010, from: http://focus.ti.com/download/vf/audio/audiosolutionsguide1.pdf

Texas Instruments (2005*). TMS320DSC21 – A high performance, programmable, single chip digital signal processing solution to digital still cameras*. Retrieved November 2010, from: http://focus.tij.co.jp/jp/lit/wp/spry086/spry086.pdf

Texas Instruments. (2010). Products. Retrieved November 2010, from www.ti.com

Texas Instruments (n.d.). Suggested devices for digital still camera. Retrieved November 2010, from: http://focus.ti.com/

The Gale Group. (2002, January 01). Conexant launches world's fastest single-chip cable modem. *Goliath Business News*. Retrieved November 2010, from: http://goliath.ecnext.com/coms2/gi_0199-1312340/CONEXANT-LAUNCHES-WORLD-S-FASTEST.html

TI Algotron. (n.d.). Data Pump Implementation Summary. Retrieved November 2010, from: http://www.algotron.com/pages/modsummary.html

TOP500 (2006). *TSUBAME Grid Cluster*. Retrieved November 2010, from: http://www.top500.org/system/8216

TOP500 (2010). *TOP500 list releases*. Retrieved November 2010, from: http://www.top500.org/lists

Triax. (2007). *Triax TR 307 (305307) set top box*. Retrieved November 2010, from: http://www.triax.ro/triax-tr-307-305307.html

Triax. (n.d.). *TRIAX CR317 – Digital set top box for CATV applications: PVR with 160 GB HDD.* Retrieved November 2010, from: http://www.triax.fi/upload/produktblad_cr317.doc

TurboExpress. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Turbo_Express

TurboGrafx-16. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/TurboGrafx-16

TV-Free America (2000). Television statistics and sources. Retrieved November 2010, from: http://www.catholiceducation.org/articles/parenting/pa0025.html

U.S. Securities and Exchange Commission. (1998, December 31). Annual report pursuant to section 13 or 15 (d) of Securities Exchange Act of 1934. Retrieved November 2010, from: http://www.sec.gov/Archives/

Ubicom. (2010). Products. Retrieved November 2010, from http://www.ubicom.com

Uchiyama, K., Mukai, H., Kawasaki, I., & Tachiuchi T. (2001). CPU technologies for networks and multimedia. *Hitachi Review 50*(2), 40-44. Retrieved November 2010, from: http://www.hitachi.com/rev/archive/2001/__icsFiles/afieldfile/2004/06/08/r2001_02_104.pdf.

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2004). *World development indicators*. International Bank for Reconstruction and Development/THE WORLD BANK. Retrieved November 2010, from: http://stats.uis.unesco.org/unesco

United Nations Educational, Scientific and Cultural Organization (UNESCO). (n.d.). *Statistics Database: Education and literacy*. Retrieved November 2010, from: http://www.uis.unesco.org/pagesen/ed.htm

University of Southern California (USC). (2008). *Annual Internet survey by the Center for the Digital Future finds shiftingtTrends among adults about the benefit and consequences of children going online*. Retrieved November 2010, from Center for the Digital Future, USC Annenberg School: http://www.digitalcenter.org/pdf/2008-Digital-Future-Report-Final-Release.pdf

Velázquez, A. (2007, April 17). *Evolución de consolas de videojuegos* [Msg #1]. Retrieved November 2010, from ForosWebGratis.com: http://www.foroswebgratis.com/

Video game console (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved November 2010, from: http://en.wikipedia.org/wiki/Video_game_console

Vision Components (2009, January 23). Revised camera uses 1-GHz processor. Retrieved November 2010, from: http://www.vision-systems.com/display_article/350860/19/none/none/PRODD/Revised-camera-uses-1-GHz-processor

Wauters, R. (2009, December 23). *The rumors are true: We spend more and more time online*. Retrieved November 2010, from TechCrunch.com http://techcrunch.com/2009/12/23/harris-interactive-poll/

Weicker, R. P. (1990). An overview of common benchmarks. *Computer 23*(12), 65-75. doi: 10.1109/2.62094

Weiss, R. (1994). *Oak DSP core delivers 40-MIPS, 16-bit performance*. EDN. Retrieved November 2010, from HighBeam Research Website: http://www.highbeam.com/doc/1G1-15377840.html

WIP Japan (2000). *Internet usage trends in Japan: Survey report 2000*. Retrieved May 2008, from the World Internet Project Website: http://www.worldinternetproject.net/publishedarchive/Japan_Report_2000.pdf (offline).

WIP-Mexico (2008). Estudio 2008 de hábitos y percepciones de los mexicanos sobre Internet y diversas tecnologías asociadas Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/wipmx_0112_2008.ppt

Wipro (2003, February). *Wipro home gateway software solution*. Retrieved November 2010, from: http://www.wipro.com/pdf_files/Home-Gateway_presentation.pdf

York, R. (2002). *Benchmarking in context: Dhrystone*. Retrieved November 2010, from the Internet Archive: http://web.archive.org/web/20070413150512/http://www.arm.com/pdfs/Dhrystone.pdf

Zackon, R. (2009). *Ground breaking study of video viewing finds younger boomers consume more video media than any other group*. Retrieved November 2010, from: http://www.researchexcellence.com/news/032609_vcm.php

Zamaria, C., & Fletcher, F. (2008). *Canada Online! - The Internet, media and emerging technologies: Uses, attitudes, trends and internacional comparisons 2007*. Retrieved November 2010, from the World Internet Project Website: http://www.worldinternetproject.net/_files/_Published/_oldis/CIP07_CANADA_ONLINE-REPORT-FINAL.pdf