Trends – Download an HD Movie in 5 Minutes!

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May 5, 2003

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In 1964, an engineer named Gordon Moore, who would later co-found Intel, observed that the amount of data that can be stored in silicon circuits doubles every year[1]. Moore's Law held until the late 70s at which point the doubling slowed to every 18-24 months. This high-tech industry trend plays itself out year after year in areas other than that to which Moore first applied it.

Some critics of the MPAA, Inc. et al. position in the broadcast flag rulemaking[2] base their threat analyses on anecdotal "evidence" gathered using today's systems while completely ignoring Moore's Law and other well-established relevant industry trends.

The question has been posed: does copyrighted audio-visual digital content require protection from unauthorized redistribution due to the current and increasing availability of faster and faster transport systems? Or does the large file size and the resulting difficulty of digital distribution via internet and stored media a priori eliminate any threat?

Even today using current art compression techniques and commonly available broadband speeds, one could download a typical half-hour TV show almost in real-time.

Taking historical industry trends into account, there is a high likelihood that…

… in 1 year, it will take less time to download a standard definition movie than to watch it, and

… in 3-4 years, it will take less time to download a high definition movie than to watch it!

Additionally…

… in 3 years, a single removable disk will be able to store 50 high definition movies,

… in 7 years, a single removable disk will be able to store 700 high definition movies,

… or alternatively, 17000 standard definition sitcoms.

Illegal redistribution occurs now and the trends show that the problem will grow exponentially. Before two more Olympics have been held, unless steps are taken to protect them, movies and television shows could be illegally redistributed electronically in a few brief minutes. The annual movie production for the entire motion picture industry could be stored on a single disk. A movie studio's entire vault of films could be placed on a few disks.

The following tables and graphs will provide details. These trends have been found to be historically accurate if observed from a multi-year point of view.

[1] See ftp://download.intel.com/research/silicon/moorespaper.pdf for original paper published the following year.
[2] MB Docket No. 02-230.

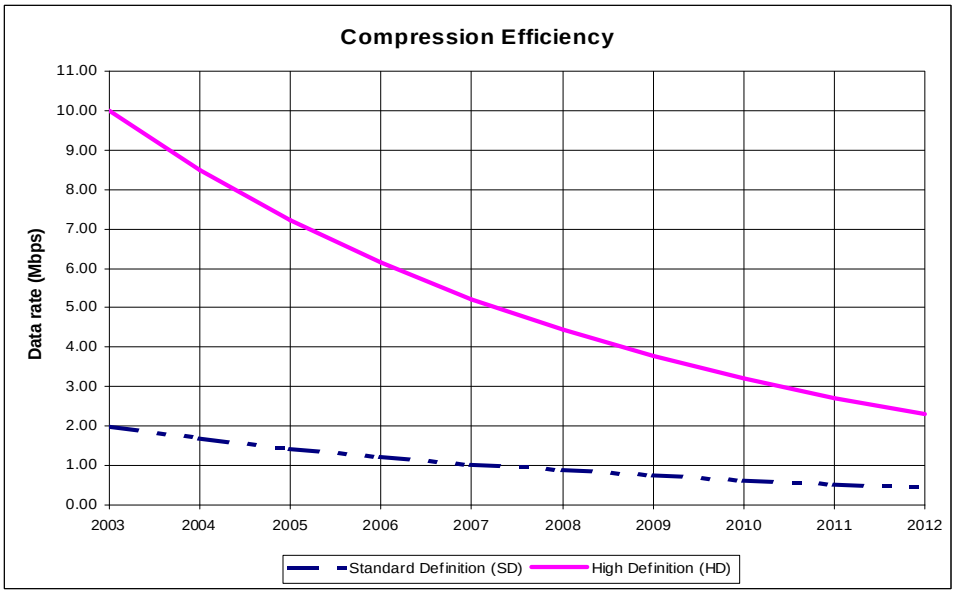
Compression Efficiency

In April 2003, Ken McCann of Zetacast, documented trends in compression efficiency in a presentation to DVB World in Dublin, Ireland.[3] "McCann's Law" observes that "the bit-rate required to achieve a given audio or video quality reduces by an average of 15% per year." The improvement results from a gradual improvement in encoding processes combined with periodic jumps due to introduction of new compression algorithms. This improvement is not as dramatic as Moore's Law but it is indirectly related because compression algorithms are usually designed with certain implementation cost targets. These implementation costs are tied to memory size, processor speed and silicon density, which are, in turn, tied to Moore's Law.

The 15% rate applies to new systems or to systems that can be reprogrammed to use new algorithms. Software algorithms that are seeking optimal compression for an internet transmission or archival application will typically be able to use the best available algorithm.

The following table and chart use McCann's Law to forecast the required bit-rate for compression of both standard definition (SD) and high definition (HD) content. The starting point was selected as 2 Mbps for SD and 10 Mbps for HD. Some companies have already demonstrated MPEG-4 Part 10 solutions better than these levels. Also, proprietary solutions in this range are available. To be clear, this table points out that if current trends hold, the quality level that can be achieved with MPEG-4 Part 10 today using 2.0 Mbps will be able to be achieved with the best available algorithm in 2007 using only about 1.0 Mbps.

Compression efficiency	15%	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
Standard Definition (SD)		2.00	1.70	1.45	1.23	1.04	0.89	0.75	0.64	0.54	0.46	Mbps
High Definition (HD)		10.00	8.50	7.23	6.14	5.22	4.44	3.77	3.21	2.72	2.32	Mbps



[3] To review McCann's presentation, see http://www.zetacast.com/Assets/DVB%20World%202003.pps.

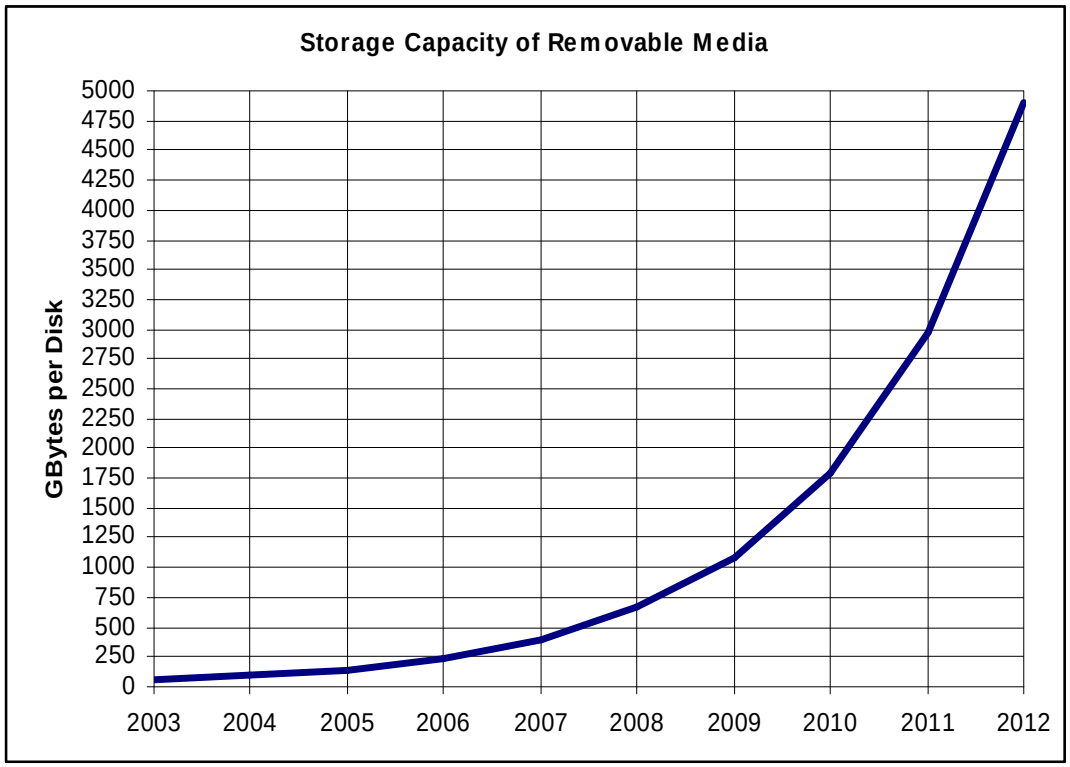
Removable Media (e.g., DVDs) Storage Capacity

Optical storage capacity has had an accelerating growth rate for several years. In 1983, the CD was introduced for audio with a 650 MB capacity. While it took about 10 years for the capacity to double to 1.3 GB in 1993, it doubled again every two years until about 1999-2000 when 10.4 GB media was defined[4]. This represents a 41% annual growth rate from 1993-1999.

The near-term projected improvement trend in storage capacity for removable media is about 65% per year. This rate is based on the current state-of-the-art represented by Blu-ray recordable optical disks, the expected availability of holographic technology in 2005 and the expected availability of 2nd generation holographic technology in 2007[5].

While the growth trend has been accelerating in the past ten years, the following table holds the rate steady for the next ten years[6].

Storage capacity		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
Optical/Holographic	65%	54	89	147	243	400	660	1090	1798	2967	4895	Gbytes
Maxell's roadmap		54		200		400						per disk



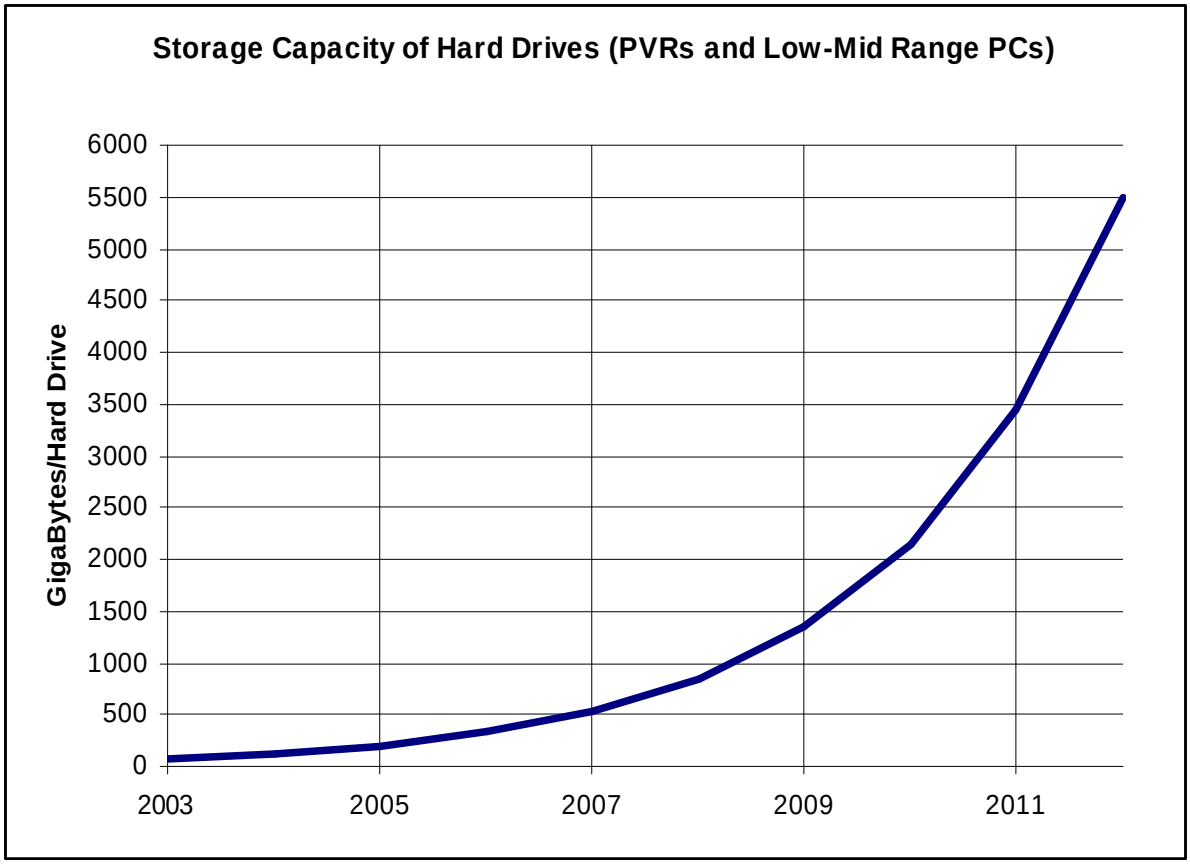
[4] See paper by Optical Storage Technology Association at http://www.osta.org/technology/pdf/benefits.pdf.
[5] This growth path was described by Maxell at their exhibit at the National Association of Broadcasters convention, April 2003.
[6] It takes a significant amount of time from introduction of a new storage technology until it achieves market significance since hardware replacement is required.

Fixed Hard Disk Drive Storage Capacity

For fixed hard disk drives, the historical growth rate for storage capacity was 25% until early 90s; 60% until about 2000[7]; then 100% until present[8]. For this paper, an annualized rate of 60%, instead of the current 100%, has been chosen to track the longer historical trend. This could be overly conservative because we could be at a new sustained knee of the curve as we were in the early 90s.

The starting point has been set at 80 GB for 2003 since this is the size drive being used in new personal video recorders (PVRs) and in low to mid-range PCs.

		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
Hard Drive capacity	60%	80	128	205	328	524	839	1342	2147	3436	5498	Gbytes



[7] Theodore Johnson of AT&T Research describes historic growth trends on page 5 of his presentation on storage trends. See http://www.dcs.napier.ac.uk/~vldb99/IndustrialSpeakerSlides/johnson.pdf.
[8] Seagate reports that storage capacity is driven by areal density, which is currently doubling every year. See http://www.seagate.com/newsinfo/technology/storage/index.html.

Growth Trend for Speed of Home Connections

The total performance of an internet download is a function of the source of the data, the transmission path and the home connection.

For home connections, upload speeds are typically lower than download speeds, though there are some technologies and Internet Service Providers (ISPs) who will provide high speed upload capabilities. If business or university facilities are used for upload, then the source of the data will not be the limiting factor in end-to-end performance.

The current capacity for telecommunications transmission paths is also not a limiting factor since these systems use optical fibers and very high data rates. The following examples provide a glimpse of the future for long-range fiber communications. In 2000, a research team from Siemens reported that they were able to achieve a 7 terabit per second (Tbps) transmission over a distance of 50 kilometers[9]. Similarly, a team from Alcatel achieved a 5.12 Tbps transmission over a distance of 300 kilometers[10]. The Siemens system would be able to transmit 111 HD movies every second in a single fiber.

The key limiting factor for the speed of home connections is the "last mile", or "last few hundred feet" connection to the home combined with the headend systems provided by that home connection provider and the ISP. Fortunately for consumers there is heavy competition between telephone companies with Digital Subscriber Lines (DSL) and cable providers with cable modems. Cable modems are theoretically capable of achieving about 30 Mbps download speed on a single cable channel. Current DSL modems are capable of achieving about 5-10 Mbps with new technology announced that could achieve up to 50 Mbps[11]. There is significant room for improvement between what people currently achieve in their homes and what the telephone and cable companies may be able to provide without relying on a communications technology advance. After the home connection providers extract every bit of capability that they can from the existing twisted pair telephone lines and coaxial television cables, there is always wireless or fiber to provide further opportunities to continue competing and progressing.

Home connection speeds are documented daily by Broadbandreports.com by measuring the speed of 176 ISPs. A broadband customer today who selects their ISP wisely might be represented by the 75th percentile ISP from that report. On 4/15/03, the 75th percentile ISP provided a 1.3 Mbps download capability to their customers. Actually, this level is achieved by many ISPs today and has been selected as representative of today's capability for the purposes of this paper.

In 1998, Jakob Nielsen documented the growth trend for speed of home connections (Nielsen's Law of Internet Bandwidth)[12]. Nielsen showed that from 1983 (300 baud modem) until 1998, the internet connection bandwidth increased at an annualized rate of

[9] Farbert et al: "7 Tbit/s (175 x 40 Gb/s) WDM transmission experiment with 50 GHz channel spacing", ECOC 2000, post-deadline paper 1.3.
[10] Bigo and Idler: "Multi-terabit/s transmission over Alcatel TeraLight™ fiber", Alcatel Telecommunications Review – 4th Quarter 2000.
[11] See http://www.centillium.com/news/press/this_release.cfm?ID=75.
[12] Nielsen's Law of Internet Bandwidth. See http://www.useit.com/alertbox/980405.html.

50%. Nielsen's 1998 prediction for the 2003 connection speed was just over 1 Mbps – very accurate when compared with the 75th percentile ISP service level of 1.3 Mbps.

This 50% per year improvement is more than supported by the infrastructure as shown by Dr. Lawrence G. Roberts who observed the following trends[13]:

- Communications cost improvement – bits/dollar is 100% per year
- Internet traffic growth – 300% per year
- Internet router/switch maximum speed improvement – 300% per year

		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
Home connection speed	50%	1.3	2.0	2.9	4.4	6.6	9.9	14.8	22.2	33.3	50.0	Mbps

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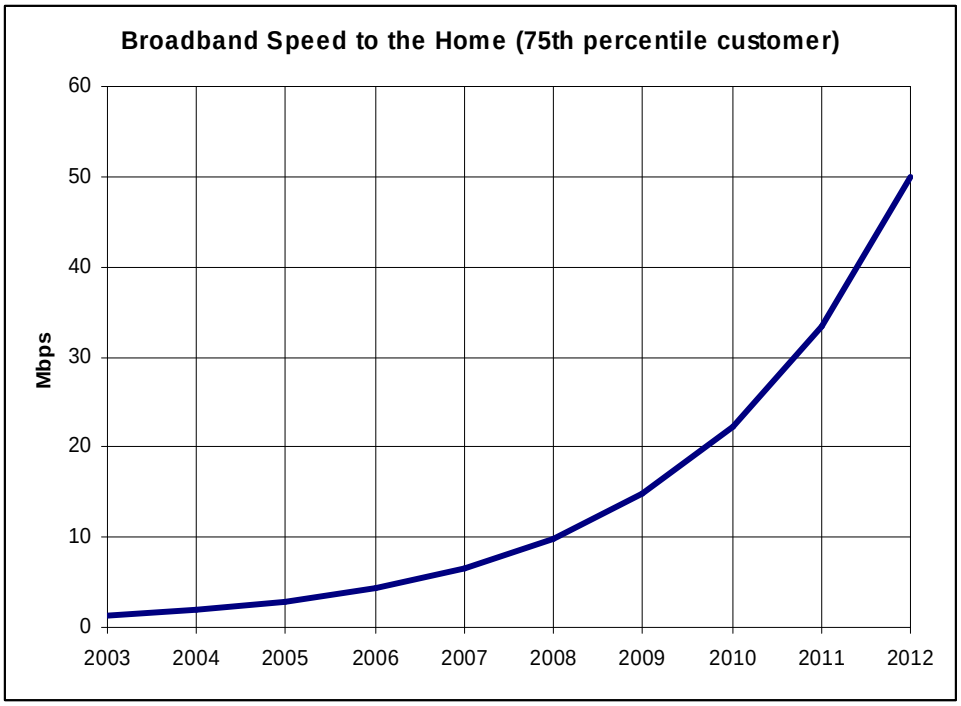
One ISP in the United States is actually providing better than 2007 level services to their customers by using a neighborhood fiber network[14]. Broadbandreports.com reports that they achieve about 7 Mbps for both download and upload for their customers.



Anecdotally, just in case some may think these numbers look high, Caltech issued a press release[15] on March 18, 2003 announcing, "Caltech computer scientists have developed a new data transfer protocol for the Internet fast enough to download a full-length DVD movie in less than five seconds." They achieved 8,609 Mbps over a 10,000 km distance averaged over an entire hour.

[13] See http://www.packet.cc/files/InternetTrends.htm.
[14] See http://www.surewestbroadband.com/wf/.
[15] See press release from CalTech at http://atcaltech.caltech.edu/tech-today/subpage.tcl?story_id=8322.

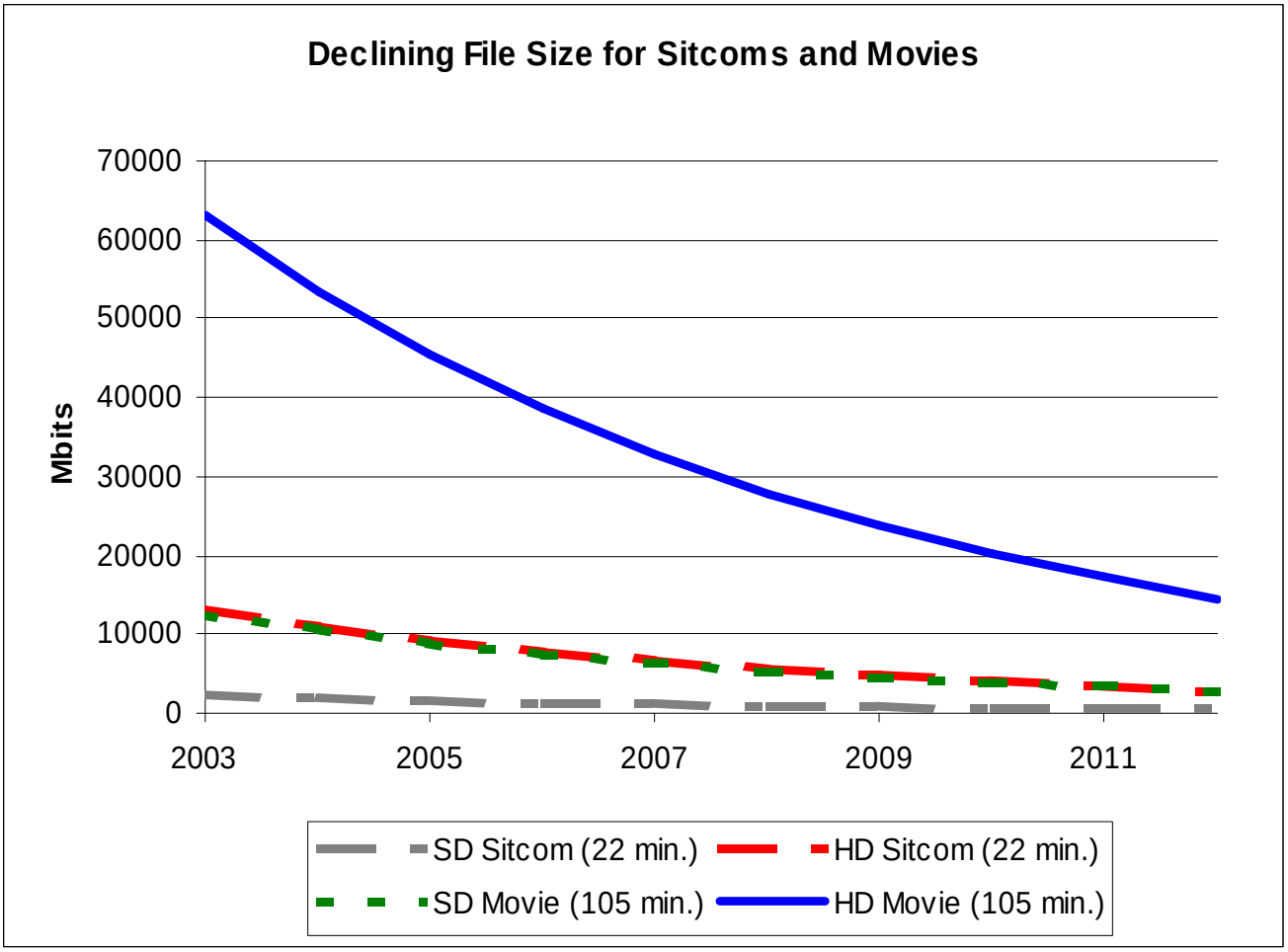
Declining File Size for Television Shows and Movies

Due to the 15% per year improvement in compression established through McCann's Law, the file size of a television situation comedy (sitcom) or a movie shrinks year after year.

The following table shows trends for four different types of shows:

- 22-minute sitcom[16] in standard definition (SD)
- 22-minute sitcom in high definition (HD)
- 105-minute movie in SD
- 105-minute movie in HD.

Show File Size	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
SD Sitcom (22 min.)	2640	2244	1907	1621	1378	1171	996	846	719	611	Mbits
HD Sitcom (22 min.)	13200	11220	9537	8106	6890	5857	4978	4232	3597	3057	Mbits
SD Movie (105 min.)	12600	10710	9104	7738	6577	5591	4752	4039	3433	2918	Mbits
HD Movie (105 min.)	63000	53550	45518	38690	32886	27953	23760	20196	17167	14592	Mbits



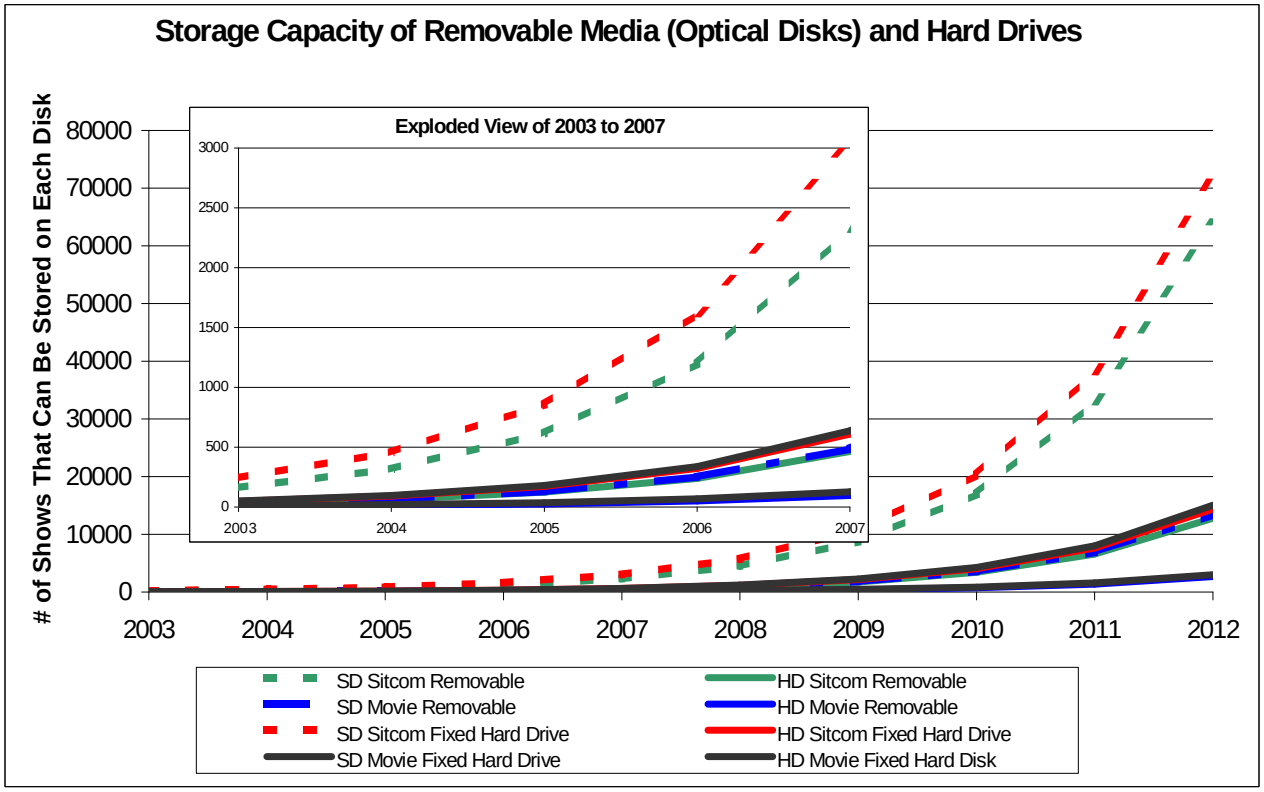
[16] Note that a 22-minute show expands to 30 minutes with commercials.

Explosion of Number of Television Shows and Movies that can be Stored

The decline in size of a compressed show and the simultaneous increase in capacity of storage media are leading to a future in which entire libraries or archives could be stored on one or a few disks. An entire year's production of movies for the entire motion picture industry will be able to be placed on a single piece of high-density media in less than 10 years.

#of Shows/Removable Disk	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
SD Sitcom (22 min.)	164	318	617	1197	2323	4510	8755	16996	32991	64042	Shows/Disk
HD Sitcom (22 min.)	33	64	123	239	465	902	1751	3399	6598	12808	Shows/Disk
SD Movie (105 min.)	34	67	129	251	487	945	1834	3561	6912	13418	Shows/Disk
HD Movie (105 min.)	7	13	26	50	97	189	367	712	1382	2684	Shows/Disk

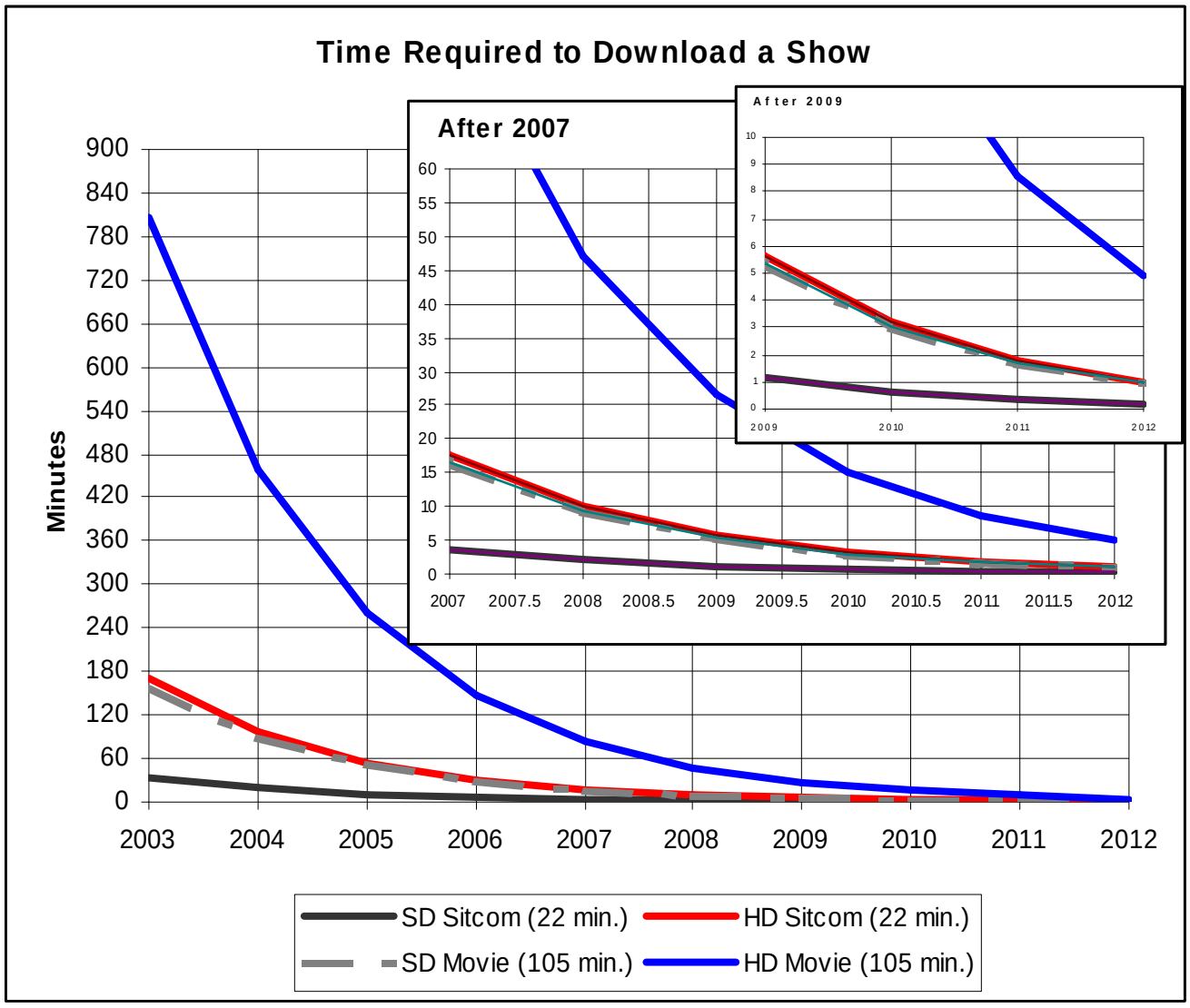
# of Shows/Hard Drive	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
SD Sitcom (22 min.)	242	456	859	1617	3044	5729	10784	20299	38211	71926	Shows/Disk
HD Sitcom (22 min.)	48	91	172	323	609	1146	2157	4060	7642	14385	Shows/Disk
SD Movie (105 min.)	51	96	180	339	638	1200	2260	4253	8006	15070	Shows/Disk
HD Movie (105 min.)	10	19	36	68	128	240	452	851	1601	3014	Shows/Disk



Declining Time Required to Download a Television Show or Movie

The declining size of the compressed file of a show and the increasing home broadband connection speeds are leading to a future in which one could download an HDTV movie in less than 5 minutes and an SD sitcom in about 12 seconds[17].

Time to Download Show	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
SD Sitcom (22 min.)	33.8	19.2	10.9	6.2	3.5	2.0	1.1	0.6	0.4	0.2	Minutes
HD Sitcom (22 min.)	169.2	95.9	54.3	30.8	17.4	9.9	5.6	3.2	1.8	1.0	Minutes
SD Movie (105 min.)	161.5	91.5	51.9	29.4	16.7	9.4	5.3	3.0	1.7	1.0	Minutes
HD Movie (105 min.)	807.7	457.7	259.4	147.0	83.3	47.2	26.7	15.2	8.6	4.9	Minutes



[17] The initial compression rates and download speed selected for 2003 are conservative and account for any inefficiencies due to system and network overhead.

Conclusion

This paper illustrates, through the use of publicly available data gathered from third party resources unaffiliated with the MPAA, Inc. that it will soon be possible for an individual to quickly move and easily store a huge amount of high-quality entertainment content.

Historical trends have shown that compression algorithms available for redistribution improve at an average rate of 15% per year and that home connection speeds improve at an average rate of 50% per year. Taking these trends into account, there is a high likelihood that…

… in 1 year, it will take less time to download a standard definition movie than to watch it, and

… in 3-4 years, it will take less time to download a high definition movie than to watch it.

The creators, distributors, and customers of entertainment content will always favor the best source material and compression algorithms available. Past trends and future projections from neutral parties reasonably suggest that the technical barriers to the movement and storage of massive amounts of high-quality entertainment will disappear in the very near future. Decision makers should take this analysis into account.