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I. Introduction

Over the last decade, the consumer Internet experience has grown from a set of simple, text-heavy pages to a personalized, rich multimedia experience. First rich graphics and images, then music, animation, and gaming – each of these have posed delivery challenges, but technology vendors have been able to surmount them all.

Supporting highly scaleable, high-quality streamed video has always been the greatest challenge for Internet technology. Now, with growing broadband penetration and a greater willingness from content owners to experiment with new distribution channels, it seems the time is ripe for Internet video. Recent success stories from iTunes and YouTube demonstrate that demand for such services exists.

Figure 1.1: Online Video Streams per Month

![Figure 1.1: Online Video Streams per Month](source)

However, delivering high-quality video to TV-scale mass audiences will require greater bandwidth, scalability and control than the existing Internet infrastructure is capable of delivering.

This paper reviews broad trends in the evolution of the Internet as a distribution channel for multimedia content and the corresponding infrastructure requirements, with a focus on content delivery networks (CDNs). For the purpose of grouping stages of the Internet's multimedia development, we have organized the study into three phases. For each phase, we discuss the main trends in multimedia content and the corresponding requirements from CDNs.
II. Phase I: 1997-2004
From Global Notice Board to Glossy Magazine

While the Internet developed steadily from the early Arpanet experiments, it only became a consumer application in the mid 90s. The look and feel of the Internet initially was most similar to a global notice-board. It was mostly text-heavy and information-rich content. Primary uses remained data collation and communication as most consumers had only a 28.8 kbit/s connection.

Over time, the Internet began to model itself more on newspapers. The online experience was still very text-heavy, but professionals were starting to get involved in laying it out. As the online consumer base began to swell, an increasing number of corporate entities began to recognize the Internet's marketing potential. They also saw that Websites would be reflections of their brands and companies, and were keen to ensure the sites reflected their identity effectively. They developed better-funded Websites, and agencies and graphic designers with a Web orientation began to emerge. By the late 90s, Websites with slick graphics, rich images, and even animation were widely available. Some sites even had embedded video. The Internet was transforming itself from a text-heavy newspaper to a visually rich, glossy magazine-like medium.

2.1 Advertising & E-commerce

Over time, advertisers began to take notice of this new medium, recognizing that it was a single point of access for millions of customers around the world. Dollars began to flow to the Internet, and e-commerce became a buzzword. The ebb and flow of ad revenues is shown in Figure 2.1.

![Figure 2.1: U.S. Internet Advertising Revenues](source: PriceWaterhouseCoopers, 2006)

The ability to use the Internet to actually transact business dramatically altered perceptions of the medium. Advertisers began to experiment with new advertising models, and new technologies for ad-serving and tracking developed rapidly. Advertisers, e-commerce sites, and online media companies such as AOL, Lycos, and Yahoo! also began to recognize the importance of a rich media experience, including video.

2.2 Accelerating the Web: The Birth of CDNs

Just as corporate entities recognized the need for visual richness in their Websites, they began to concern themselves more with the consumer experience. Loading a Web page with rich media elements could take a substantial amount of time and was a major source of aggravation for con-
sumers. With the vast majority of visitors on dial-up connections, the visual richness of the site could substantially lengthen the download times for the Web page.

E-commerce sites were particularly concerned about the effect of delays: The longer a consumer was required to wait, the more likely they were to walk away from the transaction. Download delays thus immediately and significantly damaged their bottom line. Similarly, online media sites became concerned about retaining visitors who grew frustrated by long download times.

The same held true for advertisers, who worried that their ads didn't download fast enough and were often missed by visitors. Rich media ads in particular, were likely to suffer from delays. Yet, advertisers knew that rich media advertising can be extremely effective. For example, online video ads are seen as highly effective in driving sales, according to the Online Publishers Association. A recent study found that of the 80 percent of viewers who had watched an online video ad, just over half had taken some sort of action. Nearly a third had visited the Website, while 22 percent had searched for more information, 15 percent had gone into a store, and 12 percent had actually made a purchase. Naturally, delaying consumer access to the ad would only frustrate viewers and limit the success of this new ad format.

The global nature of the Web also played a role in this problem. In order to deliver a Web page, the Web server must send the information through a series of packets. The server must ask for, and receive, confirmation that each packet or set of packets has been delivered correctly, and thus doesn't need to be resent.

Unfortunately, this requires back-and-forth communication between the client and server, and depending on the distance and number of connections required from one end to another, this can take a substantial amount of time. When servers and clients are geographically very distant, the delivery of rich media content can become extremely slow. One company reported that it took up to 200-240 milliseconds to get each packet from the U.S. to the Far East, with 40 to 100 round trips per page. The page could thus take as long as 40 seconds to load – five times the assumed "patience threshold" for the average visitor.

This led to the development of CDNs. In its most basic form, the CDN is a set of servers placed at various locations around the world. These servers were often housed at the premises of the Internet service provider and connected to the Internet backbone. CDN servers cached content from their customers' Web pages, and because they were closer to the client, they could accelerate delivery of the content directly.

Over time, the CDN became an intelligent network, with the ability to route content based on the optimal path to the end user, taking into account not only geographic distance, but also network congestion. The CDN has been an effective tool for this purpose, substantially speeding up downloads and ensuring a high-quality experience for the end user.
III. Phase II: 2004-2007
The Bubble Years... & Beyond

The Internet bubble of 1999-2000 has been well documented. A bevy of very well-funded startups had been confidently predicting that the Internet would be the distribution channel for all media. Traditional media companies, terrified by the prospect of missing out on this opportunity, followed with their own dot-com properties.

Websites offering radio and TV shows, independent videos, and other types of multimedia content proliferated. Most of them were free to the consumer, with the expectation that as they gathered eyeballs, they could sell advertising. In the meantime, however, companies were spending heavily on production costs, and revenue was slow in coming.

Investment in the dot-coms rose to more than $10 billion in 1999, with $5 billion invested in the third quarter of that year alone. The Nasdaq index of technology companies rose to a record-breaking 5,048.64 in May 2000. Meanwhile, Wall Street was severely punishing companies that lacked an Internet-related strategy.

3.1 The Bursting of the Bubble

Then came the nuclear winter for telecom and media technology. The bubble burst and investment in the sector dried up almost completely as scores of Internet media companies went under. It was only in 2004 that the technology industry began to stir. Much had changed in the interim: Investors were certainly more cautious, and the owners of content were even more wary of supporting online distribution of their content.

3.2 After the Burst: The Recovery

At the same time, other factors had lined up to encourage a fresh look at the Internet.

Broadband penetration had grown to 13 percent of U.S. homes, and was rapidly growing in other parts of the world as well. Service providers were offering higher bandwidth speeds, going from 256 kbit/s to 1.5 Mbit/s and then 3 Mbit/s. New video compression formats such as VC1 and MPEG-4 offered more bandwidth-efficient solutions for delivery video content without compromising quality. Online advertising had reversed its downturn, generating $7.2 billion in 2003, and e-commerce had become an established business model.

Gaming had emerged as an legitimate content genre, comparable to video and music. Massively multiplayer online role-playing games (MMORPGs) such as Everquest and World of Warcraft gained massive global followings. As of March 2007, World of Warcraft had 8.5 million registered users, and Second Life had 5 million registered "residents." Several MMORPGs require high-resolution graphics and are low-latency games — meaning that the response time for players could affect whether they win or lose, thus making connection speed an important consideration.

The Internet had developed into a potent medium for the distribution of music, despite the dogged opposition of the record labels. Initially started by file-sharing sites such as Napster, an entire generation of consumers was downloading music from the Internet using the MP3 format, rather than going to retail outlets and buying CDs. The record labels have since been successful in shutting down some illegal file sharing sites, and continue to pursue legal action against several students, but have also had to recognize that the future of music is online. CD sales fell again in the first quarter of 2007, a staggering 20 percent below the comparable quarter in the preceding year.

The launch of iTunes and the success of the iPod demonstrated the first effective Internet-based business model for music distribution. As of January 2007, the iTunes store had sold more than 2
billion songs, accounting for more than 80 percent of worldwide online digital music sales. Meanwhile, 100 million iPods have been sold, making it the fastest-growing audio device in history.

Consequently, Apple's foray into video in October 2005 was a momentous event. By signing up Disney and licensing ABC shows for download, Apple opened the floodgates for online video distribution deals. Over the last 18 months, hardly a week has passed without an announcement about some kind of Internet video deal. New providers such as Babelgum, Joost, and Veoh have launched, and content owners such as MTV, NBC, the BBC, and the U.K.'s Channel 4 are posting their shows online.

"Long tail" content has proven to be more attractive online than at video stores, where traditionally the top 20 percent (typically new releases) generate 80 percent of revenues. This ratio does not hold true on the Internet: For example, the average Blockbuster outlet carries fewer than 3,000 DVDs, yet a fifth of Netflix rentals are outside its top 3,000 titles. This is largely due to the fact that Netflix can carry titles that no retail store would find it economical to keep. In addition, Netflix's recommendation engine and interactive interface allows consumers to more effectively identify titles of interest, which has a marked effect on rentals. This means that larger libraries of less popular content can help drive usage and revenues for online video distributors.

A new genre of video entertainment has also been born and is seeing phenomenal growth: user-generated content (UGC). YouTube, the poster child of UGC video, is eclipsing the bandwidth requirements of any other Website in history. About 100 million clips are viewed daily on YouTube, with 65,000 new videos uploaded every 24 hours; 42 percent of online U.S. adults say they have watched a video on YouTube, and 14 percent say they visit the site regularly. YouTube has almost 20 million visitors each month, according to Nielsen//NetRatings. Figure 3.1 shows YouTube's rise in popularity since the beginning of 2006. The lines at the bottom of the chart are the page views of competing video sharing sites Photobucket, Dailymotion, and Metacafé. YouTube's dominance is apparent.

![Figure 3.1: YouTube Page Views as a Percentage of Global Web Page Views](source: Alexa)

A related – and perhaps causative – trend is that of social networking. Led by pioneer MySpace, users are posting their likes, dislikes, personal profiles, and digital photos on social networking Websites. The media on these sites increasingly includes embedded videos. According to Nielsen//NetRatings, five of the top ten fastest-growing Websites are social networking sites.
Social networking and Internet communication tools such as instant messaging can also act as recommendation engines. Information travels incredibly quickly in an online community or social network, sometimes driving massive numbers of visitors to a particular site – and bringing it down. This online phenomenon – where a large global audience, driven by rapid information flow within digital communities, rushes to a particular site or piece of content – is called a "flash crowd."

### 3.3 CDNs Grow Up: Multimedia Drives New Support Requirements

The proliferation of multimedia content online, coupled with rapid growth in broadband adoption, has created new performance requirements for CDNs. The distribution of video, in particular, has raised the bar on delivery. For high-quality video delivery, it is even more important to reduce distances between the client and the server, making edge caching an important requirement. The CDN's ability to route content intelligently is also an important attribute, as avoiding congestion on the network has an even greater positive effect on the delivery of video files.

Rapidly growing scalability requirements also have important economic implications. Savvy content owners are looking at various ways to optimize both their CDN investments and the consumer experience in a cost-effective manner. They are looking at a mix of solutions, some based on technology and others based on business rules.

For example, driving traffic to off-peak hours using variable pricing or other promotional tools can help decrease peak-time traffic and reduce the support requirements at the high end of the usage spectrum. Similarly, encouraging video downloads for non-time-sensitive content types reduces bandwidth and caching requirements, as content can be delivered at a lower bit rate to reside on the viewer's PC. Streamed video has a considerably more stringent set of support requirements to insure a high-quality experience for the viewer.

In addition, peer-to-peer (P2P) technologies are also emerging as a lower-cost solution for online video distribution. Pure P2P delivery of large numbers of videos is less costly, but quality is an issue. Due to their uncontrolled nature, pure P2P networks cannot match the quality and reliability offered by CDNs.

As usage of Internet video grows, content owners are required to balance the need for high-quality video delivery with the cost of serving a growing number of streams.
IV. Phase III: 2007 Onwards
Prime Time for Internet Video

We are now entering a new phase in the evolution of the Internet – one in which the consumption of online video has become a mainstream activity. A recent study by the Online Publishers Association, shown in Figure 4.1, found that 5 percent of Internet users view online video daily, 24 percent view online video once a week, and 46 percent view online video once a month.

Figure 4.1: Frequency of Online Video Viewing Among U.S. Internet Users

A Nielsen Media Research study estimated 81 million people, or 63% of the 129 million people who access the Internet over broadband in the U.S., watch broadband video at home or at work. This number increased from 70 million in September 2006 to 81 million in March 2007, a jump of 16% in just six months.

Online video usage times have also been growing, as Figure 4.2 illustrates. According to comScore, the average online video usage per viewer grew from 80 minutes in October 2005 to 100 minutes in March 2006.

Figure 4.2: Average Online Video Usage per Viewer, in Minutes

Source: Online Publishers Association, 2006
Source: comScore, 2006
Driving this trend is the steady growth of broadband Internet. Approximately 50 percent of U.S. homes now have a broadband connection, as shown in Figure 4.3. Additionally, a great deal of Internet video consumption takes place in the office, where broadband connections are the norm.

Figure 4.3: Broadband Penetration Is Growing Steadily

![Broadband Penetration Chart]

Source: Federal Communications Commission, 2006

Average connection speeds are also growing, with major providers such as Comcast now offering 8 Mbit/s downstream. New fiber deployments, most notably Verizon's FiOS, offer 16 Mbit/s downstream, with plans to go even higher. Verizon, in planning for the expected upsurge in Internet video and other high-bandwidth services, is already designing its network to offer consumers up to 100 Mbit/s of bandwidth. Cable operators across the US are preparing for this competition by leveraging higher throughput technologies of their own, such as DOCSIS 3.0 and channel bonding. Other telcos using copper-based xDSL solutions for the last mile are also looking to loop bonding techniques to drive faster speeds for customers.

This trend has profound implications for the number of bits that are delivered, as well as the requirements for delivering them. Owners of video content will need to ensure that their audiences are not disappointed by the quality of their experience. And there are several additional challenges for Internet video distribution:

**Flash crowds will grow exponentially.** As social networking and Internet video consumption proliferate, the bandwidth demands of flash crowds will reach a massive scale. Supporting sudden delivery requirements for million of streams will not be possible with today's Internet infrastructure.

**In-home PC-to-TV connectivity will develop.** One of the major factors constraining Internet video adoption today is that there is no cost-effective, simple way to get the video to the TV set. TVs are strongly preferred by consumers as the viewing device of choice. But this distinction is gradually becoming less meaningful: New wireless networking technologies, including standardized technologies such as 802.11n and proprietary solutions from companies such as Ruckus Wireless, are emerging to enable in-home video distribution.

Meanwhile, various device manufacturers are creating media-extender devices to transfer video from the PC to the TV. For example, the Xbox Live service allows Xbox owners to download movies and TV shows for viewing on the TV. Several of the titles offered are in high definition. Simi-
larly, set-top boxes from TiVo and Akimbo deliver Internet video to the TV, and service providers are increasingly integrating these capabilities into their set-top boxes. Perhaps the most widely noted news in this space came from Apple, whose Apple TV product is designed to link iTunes video content on the PC to the TV for large-screen viewing.

**Portable and mobile video consumption will grow.** The Consumer Electronics Association study "The Future of Portable Entertainment Devices," conducted in early April 2007, found that approximately one in three online adults, or 54.1 million people, owns a portable digital media device. In terms of content, 78 percent of portable digital media device owners reference their existing libraries of audio and video content, although 51 percent have downloaded content from online sources. The study found 41% of owners connect their portable digital media device to a PC, and 25% connect the device to their home A/V receiver. While the primary form of content for these devices is still audio, increased familiarity with audio downloads and portable consumption is driving experimentation with video. In parallel, an increasing number of wireless service providers are exploring mobile video services to the cellphone.

Nielsen Media Research, the dominant TV viewership measurement organization, has responded to this trend by adding a new module to their reporting, called "Anytime, Anywhere" measurement. This module tracks consumer viewing of video outside the home, acknowledging that it is a growing trend.

**HDTV has arrived.** More than two out of every five homes in the U.S. will have an HDTV display at the end of 2007, as shown in Figure 4.4.

![Figure 4.4: HDTV Is a Growing Phenomenon](image)

Source: Heavy Reading Estimates, 2007

However, consumers are generally dissatisfied with the amount of HD content available on TV. Also, more than a third of HD households are not receiving HD signals. One of the reasons for this is that analog cable subscribers need to upgrade to digital cable to be eligible for HD, and they also need to get an HD set-top box, at an additional charge. As a result, their cable bill would go from about $45 to $65 – an approximately 45 percent increase. For this reason, HD services are significantly lagging adoption of HD displays.

This would suggest that there is a real opportunity for content owners to offer HD video over the Internet. However, the delivery requirements for HD video streams are substantially higher than
for standard-definition video. Still, ABC has announced that it will be streaming HD video of its shows online, though it will be delivered at 2 Mbps which is a considerably lower bitrate than HD services from pay TV operators.

HD is a growing phenomenon, and it raises the bar for Internet video. As consumers get used to the quality and resolution of HD from cable or satellite, they will look for it from the Internet, as well. Despite the massive bandwidth and processing requirements this creates, sooner or later HD must be supported.

**Personal network storage will grow.** The success of social networking sites and the increasing technological awareness of consumers is driving more emphasis on network-based storage of content. Instead of emailing their photos to a short list of immediate contacts, consumers can now post them online and share them with a substantially larger audience. For example, Yahoo! today offers unlimited storage to its Webmail users, up from 1 GB a few months ago – which in turn was exponentially more than what was offered just a few years ago.

As consumers' digital libraries grow, UGC, including home movies and other forms of UGC video, will increasingly be stored and accessed via the Internet. This will be accelerated by growing consumer demand to access their content anywhere, at any time. As a result, the requirements for a high-quality experience for consumers are set to dramatically increase.

### 4.1 New Content Delivery Requirements: Taking the Next Step

Growing demand for high-bandwidth, high-quality services will drive evolution from the existing support ecosystem. Online content distributors will require solutions that can handle a significantly larger user base, longer sessions, and higher-resolution streams. Some of the key issues they should keep in mind are:

- **Addressing higher peak usage levels while managing costs:** Increased popularity will drive higher demand. Content distributors should find solutions that can address peak demand in a cost-effective manner, particularly for live or scheduled events that draw TV-sized crowds. These could include technologies that combine P2P techniques with CDNs that are well connected to the broadband aggregation points. P2P could be used to distribute the most popular titles, unless quality declines significantly. An intelligent agent application at the client site could identify the decline of video quality below a mandated threshold and switch to a CDN feed only if required. This approach could prove more economical for certain types of content delivery and still maintain a high-quality consumer experience.

- **Maximizing benefits from variable delivery times:** Video content that is not time-sensitive could leverage distribution models that do not require the rigid high-performance standards of streaming. Trickle download services that leverage off-peak network hours could reduce the burden on more expensive peak-bandwidth hours. Similarly, progressive download technologies that can take advantage of burst downloads to initiate a viewing session, and then leverage flow control as the non-time sensitive parts of the video are delivered smooth out peak-bandwidth usage.

- **Leveraging business rules to balance network demands:** Variable pricing models could also be used to encourage downloads over streaming during peak times. So could variable pricing during different times of day. Pricing may be increased to lower volumes at certain times of day, and then lowered at off-peak hours.

- **Identifying vendors that can scale quickly to meet traffic growth:** YouTube has demonstrated that demand for a site could scale both significantly and rapidly. As the market for Web video grows, the quality of the user experience will become an even more impor-
tant requirement for retaining audiences. CDNs, in particular, should provide connectivity to last-mile providers. They should also offer solutions leveraging a combination of different technologies such as on-demand, live streaming and progressive downloads to support rapid – but also efficient and rational – growth approaches. Technology solutions should also be selected based on their ability to leverage broader industry-scale economies, so that online content distributors’ costs also decline with time.

- **Maximizing infrastructural flexibility to drive emerging advertising approaches:** Content providers need to leverage the unique capabilities of the Internet as a one-to-one communications platform. They should implement technologies that allow flexible approaches to advertising insertion, based on the relevance of a user or household to specific advertisers’ campaigns. They should also use CDN and P2P technologies, integrated with major advertising networks and capable of delivering audience information, both in aggregate and individually.

- **Optimizing multiplatform video distribution:** Online content is increasingly consumed on a variety of devices. Content will need to be provided in multiple formats destined for multiple platforms, which adds another layer of technological complexity for online content distributors. Transcoding and asset management will become critical requirements, as video quality should be optimized for each viewing platform, keeping bandwidth requirements especially in mind. Solutions that simplify the workflow of going from a single master source of video and support delivery in all relevant device formats will improve the quality of digital assets and reduce the chance of introducing errors in the encoding and library-management process. Online video distributors will also need rights management and consolidated reporting across devices. Royalty obligations for each asset will need to be tracked, reported, and settled with all rightsholders.
V. Conclusion

As Internet video evolves into a mass-market application, scaleability and quality-assurance requirements will grow exponentially. For example, YouTube alone is responsible for 2% of all Internet traffic today, according to analysis from Ellacoya Networks. To put this metric in context, YouTube was founded in February 2005, just about two and a half years ago. It was an unknown startup, enabling a new service. More competitors will certainly emerge for this particular niche, and will expand the overall market. And established content aggregators and distributors, observing YouTube’s success, are already developing their own online distribution models. As a result, video traffic will scale dramatically.

The average Internet video viewer spent 100 minutes viewing Internet video in March 2006, according to comScore. But this figure was up more than 15% from six months previously. If we assume that average viewing duration of Internet video will grow at the same percentage over the next five years, we will see video traffic volumes almost treble on that basis alone.

In addition, as video quality becomes more important for content distributors, average bit rates are also on the rise. Video streams at 500 kbit/s are not going to be an acceptable standard for established distributors, who must protect consumer perceptions of their brands. ABC.com, for example, is delivering SD video at 1.5 Mbit/s and HD at 2 Mbit/s. Even if we assume that average bitrates will only double over the next five years, we will see a doubling of video traffic. Couple this growth with the viewing duration increases discussed earlier, and it is clear that expectations of total network traffic growth cannot be measured in percentage terms. Online content distributors will need to architect for rapid, exponential traffic growth over the next five years.

To add to the challenges from growing traffic volume, video content will need to be delivered using a variety of consumer devices, download and streaming approaches, and revenue models. Online content distributors will need a CDN that is scaleable and flexible in the face of unpredictable demand and evolving business models.

This will be critical to their success in the next five years, as a mass market audience develops for Internet video.