Peer-to-Peer Filesharing Systems for Digital Media

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INTRODUCTION

In 1999, exchanges of digital media objects, especially files of music, came to constitute a significant portion of Internet traffic thanks to a new set of technologies known as peer-to-peer (P2P) file-sharing systems. The networks created by software applications such as Napster and Kazaa have made it possible for millions of users to gain access to an extraordinary range of multimedia files, which, by virtue of their purely digital form, have the desirable characteristics of portability and replicability, which pose great challenges for businesses that have in the past controlled images and sound recordings.

Peer-to-peer is a type of network architecture in which various nodes have the capability of communicating directly with other nodes without having to pass messages through any central controlling node (Whinston, Parameswaran, & Susarla, 2001). The basic infrastructure of the Internet relies on this principle for fault tolerance; if any single node ceases to operate, messages can still reach their destination by rerouting through other still-functioning nodes. The Internet today consists of a complex mixture of peer-to-peer and client-server relationships, but P2P file-sharing systems operate as overlay networks (Gummadi, Saroiu, & Gribble, 2002) upon that basic Internet structure.

P2P file-sharing systems are software applications that allow direct communications between nodes in the network. They share this definition with other systems used for purposes other than file sharing, such as instant messaging, distributed computing, and media streaming. What these P2P technologies have in common is the ability to leverage the combined power of many machines in a network to achieve results that are difficult or impossible for single machines to accomplish. However, such networks also open up possibilities for pooling the interests and actions of the users so that effects emerge that were not necessarily anticipated when the network technology was originally created (Castells, 2000).

TECHNICAL FOUNDATIONS

In order for P2P file-sharing systems to function, several digital technologies had to come together (see Table 1).

Digital media files are large, and until both low-cost broadband connections and effective compression technologies became available, the distribution of digital media objects such as popular songs was not practical. Today, with relatively affordable broadband Internet access widely available in much of the world, anyone who wishes to use a P2P file-sharing application can do so.

The first digital format for a consumer product was the music CD (compact disc), introduced in the early 1980s. This format, known as Redbook Audio, encoded stereo sound files using a sample rate of 44.1 kHz and a sample bit depth of 16 bits. In Redbook Audio, a song 4 minutes long requires 42 Mb of storage. A music CD, with roughly 700 Mb of storage, can thus hold a little over an hour of music. Even at broadband speeds, downloading files of this size is impractical for many users, so the next necessary component of file sharing is effective compression.

The breakthrough for file sharing came from the MPEG specification for digital video via the Fraunhofer Institute in Erlangen, Germany, which examined the MPEG-1 Layer 3 specification and developed the first stand-alone encoding algorithms for MP3 files. Layer 3 deals with the audio tracks of

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Table 1. Enabling technologies for P2P file-sharing systems

Broadband Internet access	T1 and T3 digital transmission lines, DSL, cable modems, satellite
Encoding for digital media	Music: MP3 (MPEG [Motion Picture Experts Group] 1 Layer 3), Advanced Audio Coding (AAC), Windows Media Audio (WMA) Movies and video: Digital Video Express (DivX) (MPEG 4)
Multimedia players	Software: Winamp, MusicMatch, RealPlayer Hardware: iPod, Rio
P2P overlay networks	Napster, Kazaa, BitTorrent, Grokster, Limewire

a video recording. The MP3 encoding algorithm makes use of a psychoacoustic phenomenon known as masking to discard portions of the sound spectrum that are unlikely to be heard during playback, yielding a compression ratio for standard MP3 files of 11:1 from the original Redbook file. Standard MP3 encoding uses a bit-stream rate of 128 Kb per second, although MP3 encoding tools now allow variable rates. With a single song of 4 minutes in length available in relatively high-quality form in a digital file *only* 4 Mb large, the stage was set for the emergence of P2P file-sharing applications. The killer app for MP3 users was Winamp, a free software application able to decode and play MP3 files. The widespread adoption of the MP3 format has made it necessary for developers of other media applications such as Windows Media Player and RealPlayer to add MP3 playback capabilities to their media platforms. P2P applications can make any file type at all available; while MP3s are the most popular for music, many other file types also appear, including .wav (for audio), .exe (computer programs), .zip (compressed files), and many different formats for video and images.

In order to get an MP3 file for one's Winamp, it is necessary to either make it oneself from a CD (ripping), or find it on a file-sharing network. Applications such as Napster and Kazaa use metadata to allow keyword searches. In the original Napster, keywords went to a central server that stored an index of all files in the system, and then gave the file seeker the IP (Internet protocol) address of a machine, the servant, which contained a file whose metadata matched the query. This system thus used centralized index and distributed storage. The Gnutella engine, which is the basis for P2P systems such as Kazaa, Limewire, and others, uses a more purely peer-to-peer architecture in which no central index is required (Vaucher, Babin, Kropf, & Jouve, 2002). A Gnutella query enters the P2P network looking for keyword matches on individual computers rather than in a central index. This architectural difference means that a Kazaa search may be less complete than a Napster search because Gnutella queries include a "time-to-live" (TTL) attribute that terminates the query after it crosses seven network nodes.

Once a desired file is discovered, the P2P application establishes a direct link between the two machines so the file can be downloaded. For Napster, Kazaa, and many other P2P systems, this involves a single continuous download from a single IP address. In order to handle multiple requests, queues are set up. Users may share all, none, or some of the files on their hard drives. Sharing no files at all, a behavior known as free riding (Adar & Huberman, 2000), can degrade the performance of the network, but the effect is surprisingly small until a large majority of users are free riding. For individual song downloads, using one-to-one download protocols works well, but for very large files, such as those used for digital movie files, the download can take hours and may fail entirely if the servant leaves the network before transfer is complete. To solve this problem, the P2P tool BitTorrent allows the user to download a single file from many users at once, thus leveraging not only the storage but also the bandwidth of the machines on the network. A similar

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