Availability of titles on peer-to-peer file sharing networks

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File sharing, typically involving video or audio material in which copyright may persist and using peer-to-peer (P2P) networks like BitTorrent, has been reported to make up the bulk of Internet traffic (Pouwelse et al., 2008; Kryczka et al., 2011). The free-riding problem appears in this “digital gift economy” but its users exhibit rational behaviour (Becker and Clement, 2006), subject to the characteristics of the particular network (Feldman et al., 2006). The high demand for the Internet as a delivery channel for entertainment (Alleman and Rappoport, 2009) underlines the importance of understanding the dynamics of this market, especially when considering possible business models for future pricing or licensing regimes (Gervais, 2004) and for the provisioning of network capacity to support future services. The availability of specific titles on file sharing networks is the focus of this paper, with a special emphasis on the P2P protocol BitTorrent. The paper compares the incentives provided in BitTorrent to those in other file-sharing communities, including file hosting, and discusses the number of titles available in the community at any given time, with an emphasis on popular video items with ambiguous legal status (Watters et al., 2011).

Introduction

The main object of this research is to understand how incentives operate in the world of (mainly anonymous) file sharing, to produce a spectrum of available content. The mechanism for sharing will clearly influence the amount of content available to any specific individual seeking such content online. After all, the proliferation of the technology for home audio and video taping in the 1970s and 1980s created an environment in which any individual had easy access to all material under the control of their conventional social peers but not more. The legal controversy (Lessig, 2004) of then and now is however not the main topic of this work.

The Internet, together with digital multimedia formats, has enabled media sharing (like many other things) to take place between complete strangers all over the globe and with lossless transmission of the content. The use of file-sharing networks for distributing unauthorised copies of copyrighted material is of concern to the media and publications industries (Holsapple et al., 2008) and one reaction has been attempts by authorities in many countries to either block file-sharing traffic or to ban access to websites indexing such content, recently in Italy and reportedly even more stringently in the United Kingdom (Arthur, 2010). Given the high percentage of Internet traffic involving file sharing (Gummadi et al., 2003; Menasche et al., 2009; Plissonneau et al., 2005; Pouwelse et al., 2008) this is of particular concern also in the debate around network neutrality.

The high demand for the Internet as a de-
livery channel for audio-visual entertainment (Alleman and Rappoport, 2009) underlines the importance of understanding the dynamics of this market, especially when considering possible business models for future pricing or licensing regimes (Gervais, 2004) and for the provisioning of network capacity to support future services. This is of particular interest when it becomes a matter of public policy, for instance where tax-funded investment in new generation networks (NGNs) are being considered.

The availability of specific titles on file sharing networks is the focus of this paper, with a special emphasis on the peer-to-peer (P2P) protocol BitTorrent. An overview of the operation of the network will be given and we shall consider the model proposed by Menasche et al. (2009) for content availability in BitTorrent swarms. Alternatives to P2P are briefly considered and finally some factors determining the availability of titles are discussed, together with data illustrating users’ behaviour on the network.

**Altruism in file-sharing**

File sharing communities on the Internet are characterised by a high degree of anonymity, especially in light of the (somewhat remote) possibility of prosecution or (more likely) threatening letters from Internet service providers (ISPs). Indeed, these communities are responding to attacks from copyright holders by evolving more sophisticated mechanisms for maintaining anonymity. Unlike the taping and mix-taping of earlier decades, where the sharing communities presumably coincided with ordinary social networks, file sharing requires a degree of altruism that is not backed up by an implicit offline social quid-pro-quo convention. Nevertheless, a lot of file sharing between strangers evidently does take place. The rôle of altruism in these networks has been studied by many people, e.g. Feldman et al. (2006). Basically, small costs can be imposed for free-riding. Furthermore, there are closed networks where this is not a problem and users exhibit rational behaviour within this digital gift economy (Becker and Clement, 2006) subject to the characteristics of the particular network (Feldman et al., 2006).

The principle of P2P networking is illustrated by the following toy example. Suppose that a single publisher of some specific content appears on the network where a single potential recipient is waiting. If the recipient (or, leecher) is not prepared to donate anything to others on the network, and the publisher (or, seeder) is prepared to donate only one copy, the net effect will be that the leecher downloads a single copy and the publisher donates one copy. Further leechers arriving on the network and seeking a copy will not be serviced. However, should leechers be prepared to act as peers, i.e. to let other download from them, then a large number of copies can be distributed from a single seeder. Suppose n leechers appear simultaneously, while the original seeder is available, and each leecher is prepared to donate only the equivalent of \( \frac{n-1}{n} \) copies of the file. Then, it becomes possible for each of the leechers to obtain the entire file in the following way.

1. Let the \( k \)-th leecher download the \( k \)-th part of the file, of size \( \frac{1}{n} \), so that the seeder will have donated only a total of one full copy of the file.
2. Now, let each leecher donate his/her fraction \( \frac{1}{n} \) of the desired file to each of the \( n-1 \) other leechers.

At this point each leecher will have obtained a full copy of the file but will have uploaded less than a full copy of the content.

It is easy to see how some free-riding can be accommodated within the system. Suppose there were, as above, \( n \) peers and one seed but also a single leecher not willing or able to upload any content. If each of the \( n \) original peers is prepared to donate a full copy of the content, only step 2 above need be modified to enable the free-riding leecher to also obtain a full copy of the content. Obvi-

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1Here *publisher* signifies any entity or individual making a file available to others, and not necessarily the copyright owner or offline publisher.
ously many more free-riding leechers could be serviced, should sufficiently many peers be prepared to make available even more than a single multiple of the content. Equally obviously, the ability of leechers to download desired content is entirely dependent on the willingness of peers to make the content available to others.

The toy example is simplistic and does not even incorporate the influence of accidental sharing by leechers. In the case of very popular content, most P2P clients will automatically share chunks of content already downloaded while not yet in possession of the complete file and will continue seeding the content once the download has been completed until either

- a prescribed share ratio (number of full copy equivalents shared to others) has been reached, or
- the client or torrent is stopped manually by the user.

In the case of popular content just after publication, many leechers will unintentionally act in a very altruistic way since they will, while waiting for a download to complete, facilitate many uploads of the same material to others, also since the demand is high at these times. Such unintentional peering probably contributes significantly to the availability of titles shortly after release, for example popular television shows in the days after which they have been broadcast or otherwise leaked to the public. Even though the preceding illustrates that free-riding can be accommodated in a file sharing community, the presence of a community of BitTorrent publishers with a financial incentive has been hypothesized (Cuevas et al., 2010).

Consider the (perhaps rather unscientific) statistics published by the website KickAssTorrents.com in Table 1 harvested from the BitTorrent tracker PublicBT.com for episodes from Season 6 of the series Desperate Housewives published through the highly regarded and prolific EZTV. Availability of Episode 1 seems good even after several months although the amount of leeching going on at a specific time is not very high at all, the number of downloaders being just over 1% of the number observed less than 48 hours after episode 20 of the show was shown on ABC broadcast television in the United States. Clearly the amount of free-riding or miserly sharing is much higher early in the life of the swarm.

### The BitTorrent network

The BitTorrent protocol enjoys widespread use and has been implemented on many platforms. It is also the primary protocol supported by the famous PirateBay portal for online content and subject of frequent legal action. However, BitTorrent (BT) is also used for distributing software such as installation discs for new Linux distributions and for scientific data (Langille and Eisen, 2010). The main reason for the success of BT is that it scales very well when demand increases. As outlined cursorily above, a P2P distribution system can easily accommodate a very high demand for a certain large file of collection of files without a specifically high degree of investment at any specific node (Izal et al., 2004). In fact, free-riding appears to be the only problem other than unavailability of content. It will be helpful for the discussion below to describe briefly the operation of a BT network, from the user’s point of view.

A prospective user of general content will typically visit a torrent index site such as PirateBay or AnimeSuki where the potential downloader will click on a file with the .torrent file extension (or, of the number observed less than 48 hours after episode 20 of the show was shown on ABC broadcast television in the United States. Clearly the amount of free-riding or miserly sharing is much higher early in the life of the swarm.

### Table 1

**Availability on PublicBT.com for two selected episodes of Desperate Housewives**

| File name | Date       | Seeders | Leechers |
|-----------|------------|---------|----------|
| ...S06E20... | 27 April 2010 | 10113   | 3863     |
| ...S06E01... | 27 April 2010 | 334     | 48       |

2 A single title can be available in many swarms (Vinkó et al., 2012). The statistics in Table 1 are for a single swarm.

3 Invented by Bram Cohen.

4 [http://thepiratebay.org/](http://thepiratebay.org/)

5 [http://www.animesuki.com/](http://www.animesuki.com/)
more recently, a .magnet file). This torrent file will contain references to specific torrent tracking servers and might well be opened automatically by BT client software[6] on the user’s computer so that the user will not necessarily even be aware of the torrent file per se. The BT will start querying the trackers listed in the torrent file as part of the process of joining a swarm. The tracker servers will provide information about actual peers already in the swarm and the new peer will start requesting, and eventually offerings, parts of the file to be downloaded. The download time experienced by the user depends very much on the conditions in the swarm [Chiu and Eun, 2008].

The BT swarm as $M/G/\infty$ queue

Menasche et al. (2009) describe a BT swarm as an $M/G/\infty$ queue (Browne and Steele, 1993). That is, the swarm is supposed to consist of publishers which appear at irregular intervals and peers with Poisson arrivals. The queuing system is busy as long as the title remains available from peers that are online. They deduce estimates for the expected length of a busy period under various assumptions w.r.t. peer behaviour. For example, if all peers are selfish and leave as soon as completing their download has been completed, the expected length of a busy period is

$$B = \frac{e^{(r+\lambda)/\mu} - 1}{r + \lambda}$$

where $s$ is the size of the file, $\mu$ is the mean download rate of peers, $r$ the arrival rate of publishers and $\lambda$ the arrival rate of peers. It is further assumed that peers who arrive when the content is not available, immediately leave. Publishers are assumed to stay online only for a time $s/\mu$, i.e. long enough to serve one copy of the content. The reader will be able to confirm, at a glance, that $B$ behaves as common sense would suggest when $\mu \to \infty$ and $\lambda \to \infty$. One can also observe that doubling the size of the file from $s$ to $2s$ would increase the size of $B$ by a factor of

$$\frac{e^{2s(r+\lambda)/\mu} - 1}{e^{s(r+\lambda)/\mu} - 1}$$

which is very substantial. The busy periods will generally be much longer in a swarm with file size $2s$ than the sum of the expected busy times of two separate swarms with file size $s$. Menasche et al. (2009) obtain much more precise mathematical estimates of the advantage in terms of availability in large swarms and could thereby present a convincing explanation of content bundling[7].

Predictions by the model of Menasche et al. (2009) are consistent with a vast amount of data on real networks investigated in their study. The data in their work showed 80% of swarms as unavailable at least 80% of the time. Nevertheless, their model might be inappropriate for the large amount of BT activity that consists of the distribution of material within the first few weeks (or days) after it appears. If this initial burst of activity is take into account, the arrival rate of publishers and peers is certainly far from constant, as one can clearly see in Table 2 where it seems clear that activity peaked about 36 hours after the swarm was constituted and the declined rather rapidly. The $M/G/\infty$ queue also has no room for incorporating individual behaviour or system-wide constraints such as the total amount of available storage and bandwidth and possibly limited demand for audio-visual content.

A fluid model

Qiu and Srikant (2004) use partial differential equations to describe a fluid model for BT swarms. As on the model of Menasche et al (2009) the parameters like peer arrival are assumed to be con-

[6]For example, Vuze or BitTornado.

[7]Content bundling is the phenomenon where individual books or episodes of a television series are not available as single files but only in a bundled torrent consisting, for example, of hundreds of e-books on a particular topic, or of all of a specific season of a television series.
Table 2
Torrent activity for Desperate Housewives S06E20
during the week after its first broadcast, from kick-
asstorrents.com, reported for tracker:publicbt.com
and a swarm formed on 26 April 2010 with purpo-
sive sampling.

| Date and time          | Seeding | Leeching |
|------------------------|---------|----------|
| 27 April 2010, 15:32:30| 10 113  | 3 863    |
| 27 April 2010, 19:15:01| 11 187  | 5 132    |
| 27 April 2010, 21:19:10| 11 000  | 4 872    |
| 27 April 2010, 22:31:42| 9 664   | 4 468    |
| 28 April 2010, 22:16:10| 7 701   | 2 445    |
| 29 April 2010, 05:20:27| 4 640   | 1 078    |
| 29 April 2010, 21:32:32| 6 825   | 1 887    |
| 30 April 2010, 07:35:36| 4 416   | 840      |

Anonymous file hosting

Anonymous file hosting is another way of shar-
ing content when the publisher does not neces-
sarily want to do so openly, possibly out of fear of
political persecution, harrassment or of prosecu-
tion for possibly copyright violations. An anony-
mous file host allows users to upload a file to
an Internet web page with a generic name8 that
gives no indication of the content of the file stored
there. The uploader might place a link to the web
page in an Internet forum or circulate it in another
way. Registration is not required of casual users
but the business model of these providers of one-
click hosting evidently includes enticing users to
take out a subscription which allows downloading
files without the waiting time imposed on casual
users of the free service. Subscribers also enjoy
faster download speeds and file hosting offers a far
greater degree of anonymity than P2P distribution
(Blond et al. 2010a,b) i.a. since both publishers
and peers are exposed for only as long as it takes to
transfer the file from/to the hosting site. It is quite
clear that one-click hosting has created a revenue
model for content sharing, whether legal or possi-
bly illegal, and Antoniades et al. (2009) observe
that of a list of 100 unpopular film titles, more are
available on RapidShare than on BitTorrent.

Title availability

In this section, we consider the characteristics
of an ideal and fairly complete model of title avail-
ability. First, consider the salient features of the
networked digital multi-media world.

Hollywood universality Antoniades et al. (2009)
found 100% availability on PirateBay for the
top 50 US DVD rental titles for the week
under investigation but only 76% availabil-
ity for Amazon’s top 25 German films of all
time. Anecdotal evidence suggests that pop-
ular US television series become available
within a few hours of airing and are nearly
universally available because of the ease of
digital home recording.

Ease of copy The cost of copying a computer file
is nearly zero and does not degrade the
original copy. Hence, even compared to
relatively inexpensive media such as CD
or DVD discs, the marginal cost of re-
production is exceptionally low for com-
puter copies. Further, digital rights man-
agement (DRM) is not particularly efficient9
and there is no limit to the number of copies
of a particular item a consumer can make.
As more consumers source their entertain-
ment from unencrypted digital sources, the
smaller the impact of DRM will become.

Storage efficiency Digital media can be quite ef-
efficiently stored. A single portable computer
hard disk can store hundreds or thousands of
films in a space no greater than that of a sin-
gle DVD box.

8http://rapidshare.com/files/16433818/ for example.
9Not least of all because of the analog hole.
Open borders There are no customs inspections on the Internet and with relatively inexpensive bandwidth in many places, the cost of transmitting digital content is low. Storage capacity of offline media has not increased sufficiently quickly in order to make the physical transport of media files an efficient proposition.

In view of the German film example, we suppose only that almost all English-language content produced for US television or cinema audiences, is available in digital format on some computer which is connected to the Internet. Such material would, for many, constitute a perfectly acceptable source of entertainment, perhaps to the extent that they would need no other. It is not quite the case yet but one might also assume that each potential consumer has sufficient storage space available to archive a full copy of this corpus. The corpus grows only slowly and perhaps slowly enough that a typical residential user in the US could download the entire accrual each day.

Assume, for argument’s sake, that Hollywood is somehow wiped out and that the corpus stops growing. In this case, it would be of benefit to each user to download the entire corpus and this would be possible, in principle, using P2P if each user is only prepared to contribute approximately as much as they download. This would be a real socialist utopia, but for the problem of enforcing cooperation and punishing free-riding. Since even BT is subject to opportunistic strategic manipulation (Levin et al., 2008) the availability of titles is still very much subject to constraints on storage, network use and the problem of free-riding. However, many tests have shown BT to be an efficient allocator of resources and P2P could very well be one of the mechanisms that would assist in a fair allocation of network resources on the Internet, a network not initially designed for commercial use.

In the discussion above, it has been taken for granted that consumers of content have a fixed preference in terms of quality. That is, given a specific unit of artistic content (an episode of Desperate Housewives, for example) corresponds to a specific chunk of data with associated storage and transmission costs. However, the proliferation of high-definition display devices means that consumers now increasingly prefer high-definition content. High-definition video requires file sizes that are several times those of standard definition content and anecdotal evidence suggest that the spectrum of content available in high-definition formats (1080p or 720p) is still far below that of the old standard television resolution.

Conclusion

Protocol design creates incentives that determine, among other things, the range of titles available on a given platform. Online sharing involves relatively high costs (e.g. the decrypting, copying and recoding or “ripping” of a commercial DVD in a compressed and unencrypted digital format) incurred by publishers of material and much smaller costs for those who simply share files which they have already downloaded. The world of online file-sharing is not simply a free-for-all of illegal material but rather an almost organic self-organising economy which manages to allocate scarce resources and supply consumer demand. It has even been suggested that digital downloads often help to increase sales offline (Peitz and Waelbroeck, 2006). The modelling of P2P networking presents a fascinating opportunity for network economists and applied mathematicians, with much to be done to formulate a realistic model that properly incorporates the dynamics of the system. Observing the spread of high-definition content will provide further data but will also require a model of consumers’ preference for high-quality content.

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