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High-definition content and file sharing networks

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High-definition content and file sharing networks

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Abstract

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 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 the effect of a presumed increasing preference for high-definition content on the availability of specific titles on file sharing networks is the focus of this paper, with a special emphasis on the P2P protocol BitTorrent which has very wide application and is the subject of ongoing skirmishes between the file sharing community and copyright enforcers. Protocol design creates incentives that determine, among other things, the range of titles available on a given platform. 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) and consider how a preference for higher definition content could impact on the spectrum of available content and whether content providers could use a preference for the quality of content to obviate possible revenue losses through file sharing. It will be important to consider the difference between the case of audio and of video content and the different challenges in the two markets.

1 Introduction

The music market was disrupted in the late 1990s with the appearance of Napster and other tools for downloading and sharing music files (Becker and Clement, 2006; Gervais, 2004). This development was made possible by the adoption of algorithms for creating compressed

music files (MP3 mainly), the widespread availability of computers that could create the compressed files from the then dominant medium, the compact disc (through the process of “ripping” and encoding), and the ability of networks to support the traffic generated by the exchange of these music files. Since then, the market has shifted towards new retail models, including subscription services (offering all the music one wants “in the cloud” on the basis of a monthly fee), retailing online through iTunes (a mixed model that actually also supports consumers’ use of downloaded or casually exchanged digital material) and a shift to earning revenue in other ways such as through live performance and the sale of other branded goods and even the option of explicitly authorising peer-to-peer and other free distribution channels (Netanel, 2003).

Although legal disputes regarding the exchange of copyrighted materials continue, as time passes it seems likely that a generation will grow up who will regard it as natural just as earlier generations did with the making of audio cassette tapes and establishing a regime for the strict punishment of violations seems increasingly less likely (Pouwelse et al., 2008). The number of very active users required (for the original placing of the material) and the protocol designs support a large number of quasi-inactive users (or want-to-be free riders) and are so far quite stable (Vinkó et al., 2012) despite the sometime efforts to disrupt sharing through the provision of fake material and prosecutions (Becker and Clement, 2006; Cuevas et al., 2010).

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 exchange of video material is still considerably more costly than audio. Whereas the generation of a good quality compressed audio file (encoding) typically takes much less time than playing it, this is still not true of video and the same applies to downloading because of the file sizes. A typical episode of a television series in standard definition (around 350 MB) is roughly 100 times the size of a typical song in MP3 format (3 to 4 MB). The introduction of high-definition broadcasting has increased this gap even further, by a factor of roughly five. The purpose of this work is to interrogate the possible effect of large high-definition video files on the ecology and incentives in file-sharing networks.

2 Overview of peer-to-peer networking

The principle of P2P networking is illustrated by the following toy example. Suppose that a single publisher¹ 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

¹Here *publisher* signifies any entity or individual making a file available to others, and not necessarily the copyright owner or offline publisher.

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. Obviously 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. 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).

The BitTorrent protocol² 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 or 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

²Invented by Bram Cohen.

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 PirateBay³ where the potential downloader will click on a file with the .torrent file extension (or, 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 software⁴ on the user's computer so that the user will not necessarily even be aware of the torrent file per se. The BT client 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 download. The download time experienced by the user depends very much on the conditions in the swarm (Chiu and Eun, 2008).

3 File size and availability

Large files which package together a significant chunk of content (an entire season of a television series, for example) are an efficient vehicle for the distribution of material for which the demand is not sufficiently high to support the availability of the individual parts (episodes, for example). This mechanism is well understood (Menasche et al., 2009) but in itself imposes a cost on those wishing to download material in such compendia, unless they specifically know how to download only individual files. These compendia can stay alive for longer than the individual files but this is obviously true only within a certain range. If all available content were aggregated into a single archive, there would probably be no-one who would download (or seed!) this mega file!

The focus on this work is however not on aggregation but specifically on the possible effect of the larger file sizes necessitated by high-definition (HD) video content on the availability of content. Most obviously, HD formats impact in two distinct ways.

1. The cost of having the item available for download is higher. Firstly, preparing and making available of the material in an appropriate digital format (often as an AVI, MP4 or MKV file) requires more processor time than for standard definition material. However, this happens only once and seems to often be attributable to a small and specialised community of users (Le Blond et al., 2010) and this part of the cost will not be considered in detail here. Secondly, and perhaps more importantly, the files takes up considerably more space on the hard disk of the host/seed than the corresponding material in standard definition. This is true for every seeder and can therefore influence the number of seeders from whom a specific title might be available.
2. The cost of the transmission for large files might be considerably higher, either through direct charges (in the case of volumetric pricing) or in opportunity cost where peer-to-peer activity displaces other desirable uses of the available bandwidth such as the streaming of very high definition audio, for example.

Consider the case of the season 4 premier of Modern Family. On 27 September 2012, PirateBay reported 13 632 seeders for the standard definition (SD) version and just 1 217

³<http://thepiratebay.org/>

⁴For example, Vuze or BitTornado.

seeders for the most popular HD version. Since the HD version is obviously better than the SD version, one has to conclude that the cost factors mentioned above dissuade more than 90% of users from opting for the HD file. Naturally, there is positive feedback in the preference for a specific version. The more people join a specific swarm, the more attractive that swarm will be to others.

4 Other platforms for content exchange

Anonymous file hosting is another way of sharing content when the publisher does not necessarily want to do so openly, possibly out of fear of political persecution, harrassment or of prosecution for possibly copyright violations. An anonymous file host allows users to upload a file to an Internet web page with a generic name⁵ 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 (Le Blond et al., 2010; Blond et al., 2010) 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 possibly illegal, and Antoniadis et al. (2009) observe that of a list of 100 unpopular film titles, more are available on RapidShare than on BitTorrent.

The existence of infringing material on file hosting services suggests that there is obviously a subset of material for which the market is most efficiently served in this way. Essentially there is therefore already a digital distribution mechanism different from peer-to-peer networking and that has a specific application. File hosting services can more efficiently publish material but are naturally constrained by the need to avoid legal problems while maintaining their income streams. Nevertheless, they suggest not only that digital distribution can be profitable but that it is possible to compete with peer-to-peer distribution.

5 Efficient distribution networks

Obviously the cost of distribution of material over a network only becomes an issue when non-negligible use of network resources is implied. This can either be specific resources allocated to a user (a wireless channel to the base station, for example, or a copper connection to the telephone exchange) or common resources such as the international capacity purchased by an Internet service provider and made available to its customers. The user will be directly affected by his/her own use of the dedicated resource but might also in general suffer a negative effect from the use of the common resource. For, users are subject (*pace* network neutrality and other considerations and regulations that can be enforced only with considerable difficulty) to throttling and fair use regulations that have, in the end, the effect of guaranteeing availability

⁵<http://rapidshare.com/files/16433818/> for example.

of the product in the retail market⁶ ().

There exist environments that are not subject to the same constraints, namely local networks on which there is sufficient capacity to allow for the free exchange of entertainment video to the extent that participants require. University dormitories are reportedly frequent offenders in this regard as are wireless community networks. However, the industry explicitly acknowledges that such network environments exist as it markets hardware (AppleTV and other media streaming devices) and software that make it easier for users to share content in an environment in which this is presumed not to amount to a copyright violation. Incidentally, this approach does not seem likely to sensitise users to the desired respect for copyright niceties. After all, an industry selling devices that allow one to share films throughout a multi-user household cannot reasonably object if users feel that they are also entitled to share the same with the neighbours across the road, friends in another city and so on.

Nevertheless, it can also be inefficient to distribute content in a peer-to-peer environment when the network resources required are considerable – as they appear to be for BitTorrent for instance. Broadcasting (in whatever form) has always been able to provide a vast amount of content, not least because it does not require a two-way network. The two-way network does not scale in the same way as a broadcasting network does. Any broadcasting network (wireless or cabled) can be endlessly duplicated and extended locally. For digital content, this process involves absolutely no decline in the quality of the content either. This same is not true for two-way networks where an expansion of the network might require considerable additional capacity elsewhere. Simply put, expanding CNN's availability from the US embassy compound to all of China would require investment only in China but expanding Internet access would have required great investment in Pacific Ocean cables and probably upstream in the US as well in order to accommodate the increase in demand for content.

The next section uses toy examples to demonstrate in the most simple possible way that for sufficiently large files and specific network topologies, peer-to-peer distribution might not be efficient and that a surplus could be realised by an operating providing more central distribution. This is of course completely consistent with that which can be observed – that peer-to-peer distribution co-exists with more centralised forms of distribution. This fact can however be supported by purely economic arguments and does not require resorting to fear of prosecution for any legal transgression.

6 An elementary model

Consider a toy model with four users on a network: A, B, C and D. All traffic between B, D and C transit via A so this is a star-shaped network with A at the centre. Suppose further that B and D each have a file (of the same size) which is desired by all the other users in the network and that the transfer cost is one unit per segment, so that the transfer of a file from B to C would cost 2 units, for example. In order to satisfy the demand for the content in the possession of B and D, one would need to transfer a file from B to A, C and D at a cost of 1, 2 and 2 units respectively and likewise from D for a total cost of 10 units for the transfers. Suppose however that A could host the files. Then A would be able to have the files transferred from B and D respectively (at a cost of 2 units) and then further distribute

⁶For, otherwise consumers would have a very strong incentive to simply share connections – were excessive use not discouraged by the service providers.

the file to the two other users (C and D in the case of the file from B; B and C in the case of the file from D) at a further cost of 4 units, giving a total cost of 6 units.

Clearly, A would have an incentive to mediate an arrangement where it would accrue some of the surplus of 4 units realised in the second instance, where it serves as central distributor. The effect is enhanced if there are more users. Suppose users B_1, B_2, \dots, B_n are all connected to A directly but not to each other and that B_1 has a file that all $n + 1$ users desire. The example in the previous paragraph would be an instance with $n = 3$, for example. Now, the cost of peer-to-peer distribution (in each case via A) would be

$$1 + 2(n - 1)$$

for each file since it costs one unit for a transfer to A and two units for every other transfer. Clearly an arrangement where A hosts the file would cost only

$$1 + (n - 1) = n$$

units and a surplus of $n - 1$ could be shared among the participants in the network. If the unit cost is large, this incentive should be quite strong.

One can therefore conjecture that pure peer-to-peer transmission flourishes only where the unit cost of transmission for each file is sufficiently modest for the incentive to remain small. It should be noted that in the toy model discussed above, the size of the incentive is directly proportional to the amount of traffic or, otherwise, to the number of users. This can be quite large of course and suggests that a large number of peer-to-peer downloaders will imply a substantial opportunity to profit from centralised provisioning. It is also reminiscent of Sarnoff's law of broadcasting – that the value of a broadcasting network is proportional to the number of viewers.

7 High definition (HD) video and file size

The 720p (1280 × 720 resolution) high-definition content provided nowadays by many cable and satellite television providers, gives rise to video file sizes 3 or 4 times greater than standard television programming. Upgrading to the 1080p mode (1920 × 1080 resolution) already supported by many consumer devices will more than double the file sizes involved. Blu-ray discs can already contain 1080p content and one could argue that the continued mere existence of the Blu-ray standard suggests that the pirating of high-definition content has not reached epidemic proportions.

Krogfoss et al. (2011) describe in detail the additional bandwidth required to provide high-definition television to households and the strain it could place on existing networks. Their focus is on live streaming non-infringing content but the bandwidth requirement is no less than for peer-to-peer downloading. However, they argue that significant investment would be required to satisfy household demand for high-definition content. This remains under the assumption that distribution is efficient and does not take into account the problem of choosing an efficient placement of the content on the network, considered above but present an additional constraint to the distribution of high-definition content.

8 Conclusion

Location awareness in peer-to-peer networks is one possible approach to imposing efficient distribution topologies on the public network and Liu et al. (2009) have shown that the performance of the BitTorrent protocol can be improved by introducing a location awareness that favours downloads from nearby sources. It is not however clear whether such a tweaking of the protocol would be able to remove all incentives to distribute material centrally. With a persistent incentive to effect economies through the centralisation of distribution, one can expect that peer-to-peer distribution will never supplant conventional or new distribution channels that can charge for convenience or quality of service. A preference for high definition content will strengthen the incentives that favour commercial distribution.

Consumers' potential preference for high definition material is presumable limited by little except

- (a) the capacity of the human eye to discern higher pixel densities, and
- (b) the ability of the industry to make as displays as large as consumers might want to accommodate at their premises.

In the case of the former, consumer products are claimed to have only just reached⁷ reached that limit on relatively small screens of up to 15 inches. It will clearly take some time for entertainment display devices to reach the practical limit of the resolution discernible to the human eye and at a size which is pleasing to consumers. This resolution and resultant file sizes will be many times more than what is current today.

Namiki et al. (2011) have even warned that the present design of Internet infrastructure might not be able to cope with the transmission of ultra-high definition video and this would be a further factor that could keep the future transmission of video content on traditional broadcasting and distribution media channels and not move the distribution to peer-to-peer networks. As the elementary model presented above shows, apart from potential technical problems, it is always possibly that economic incentives will favour some form of centralised distribution. This implies directly that peer-to-peer networks, although certainly responsible for the transmission of a fair amount of content, do not necessarily represent a mortal threat to the content distribution industry.

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⁷The “retina display” devices by AppleTM appear to be the most important example but the veracity of the claim is being disputed.

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