Economics of BitTorrent Communities

Ian A. Kash
Harvard CRCS
kash@seas.harvard.edu

John K. Lai
Harvard SEAS
jklai@seas.harvard.edu

Haoqi Zhang
Harvard SEAS
hq@eecs.harvard.edu

Aviv Zohar
Microsoft Research SVC
avivz@microsoft.com

ABSTRACT

Private file-sharing communities built on the BitTorrent protocol typically require members to maintain a minimum ratio between uploads and downloads, effectively establishing credit systems, and with them an economy. We report on a half-year-long measurement study of DIME, a community for sharing live concert recordings.

While the download of files is priced only according to the size of the file, we observe significant disparities in the rate of return for seeding new and old files. By consuming and subsequently seeding new files, users can quickly earn credit, while old files offer lesser returns. Factoring in the potential gains from seeding, the *resale value* of files of the same size is not uniform. We provide evidence that users react to these differences in resale value by preferentially consuming older files during a 'free leech' period.

1 Introduction

Interactions among large numbers of agents on the Internet challenge system designers to not only focus on system-level function, but also to account for user incentives. In systems ranging from eBay to BitTorrent, the designs of reputation systems and sharing protocols pay particular attention to the role of economics in computer systems. In BitTorrent, incentivizing users to contribute by uploading while downloading a file leads to an effective form of file-sharing that now accounts for 18% of Internet traffic traffic [1].

Despite BitTorrent's success, there is no incentive for peers to continue uploading a file after it is downloaded. *Private BitTorrent communities* are on solution to this problem. Private communities build on the BitTorrent protocol by developing their own policies and mechanisms for motivating members to share content and contribute resources. Communities tend to be organized around a particular interest—live concert recordings, HD movies, or the newest TV shows—and registered members acquire files of interest in return for sharing files with like-minded users. There are over 800 active private BitTorrent communities [16], each enforcing its own set of rules that are refined over time to fit the community's goals and needs.

Supported by additions to the original BitTorrent protocol, private communities track how much each user downloads and uploads. This allows them to require members to upload a certain fraction of the amount they download. This regulation, known as *share ratio enforcement* (SRE), effectively introduces a currency to the system. Users earn credit by uploading files they download, and spend credit by downloading new files. In accounting for consumption (download) and labor (upload), *private BitTorrent communities evolve from computer systems into economic systems.*

Anecdotal evidence from discussions among members in private communities points to a rich, multi-faceted set of user behaviors that emerge in response to economic forces. Their stories and shared advice suggest that users often make economic decisions and trade-offs, e.g., by joining new torrents as a way to quickly earn credit that can then be spent on downloading older torrents. If properly directed, these economic forces can have great positive effects on the efficiency of the system as they influence individuals to make better use of resources, but if misdirected they can lead to skewed incentives and inefficiency.

Previous studies of BitTorrent communities (e.g. [3, 12]) typically emphasize their characteristics as computer systems and focus on aspects such as the arrival rate of peers to a torrent, the quantity of resources available, and the performance experienced by users. A few recent works study the economics of private communities, using theoretical and simulation approaches to examine how ratio enforcement incentivizes contributions and how issues such as lack of credit flow [8] or potential for collusion [11] can create inefficiencies and manipulation opportunities. While analysis and simulation results from these works provide some insight, gaining a deeper understanding of the economy in private BitTorrent communities require rich datasets from actual communities that can direct our attention to inefficiencies that may arise for economic reasons.

In this paper, we advance the study of private communities as economic systems by reporting on a half-year-long measurement study of the DIME community for sharing live concert recordings. Using extensive traces of activity on different files and daily snapshots of the activity of all users, we observe that users react to the economic aspects of these private communities. We find that:

- There are significant differences between the returns to seeding of new and old files, resulting in higher *resale value* for downloading new files.
- Users preferentially consume older files during a 'free leech' period, which provides evidence that users are aware of and react to the resale value of files.

Based on these observations about resale value, we discuss several economic interventions that have the potential to improve DIME.

1.1 BitTorrent and related terminology

BitTorrent [5] is a protocol designed for sharing files via direct (peer-to-peer) connections between different hosts. A user who wishes to distribute a file to others starts by creating a *torrent* that contains metadata about the file to be distributed, and publishes it (usually by posting it to some web site). The torrent, which is downloaded by other users who wish to gain access to the content, points to a centralized server called a *tracker* that is used to coordinate between various peers who are sharing the designated file. Once a peer learns the address of others who are sharing the same file, it directly connects to them and can download and upload pieces of the file. BitTorrent makes a distinction between *seeders*, who are peers that have a full copy of the file (and thus only upload it to others), and *leechers* who only have a partial copy and engage in both upload and download.

File sharing communities provide a set of services: they host the website on which torrent files are posted, host the trackers used to coordinate the sharing of each file, and keep track of updates that are sent by the various peers about the upload and download that they have performed on each file.

1.2 File sharing communities as economies

By tracking the upload and download of members beyond a single torrent, communities are able to require that members perform some minimal amount of work. DIME for example enforces a *share ratio* of 0.25, which requires members to upload at least a quarter of the amount they download (in bytes). The amount of *credit* or *wealth* each user has on DIME is defined as:

$$\text{Credit} = 4 \times \text{upload} - \text{download}$$

On DIME, users are allowed to have a negative amount of credit (limited to 5GB). This helps new users, who begin with 0 credits, to download their first files. Users who owe more than 5GB are not allowed to download additional files.

It is important to notice that, because DIME requires a share ratio of 0.25, every transfer of data adds credit to the system. If a byte is sent from peer A to peer B, then B loses a unit of credit, but A gains 4 units of credit.

The *price* of a file is the amount of credit deducted from the account of the downloader when the file is acquired, or simply the size of the file (in bytes). Prices per byte are the same across all files on DIME. However, users can seed a file and earn credits after completing the download. As a result, each file downloaded has a *resale value*. This value is realized if the file is later seeded, resulting in a credit gain for the seeder (and possibly some inconvenience cost due to effort associated with seeding for some period). Even if two files have the same price, their resale values can be significantly different due to a difference in the expected returns for seeding. For example, suppose that file A and B have the same size, but file A has few seeders and many leechers while file B has many seeders and few leechers. The costs of the files are equal but the resale value of file A is greater than that of file B. To the extent that users are constrained by their ability to earn credit or simply want to maintain higher ratios, this resale value is important.

Occasionally, DIME has a *free leech* period, during which users do not spend any credits when downloading files. In other words, the prices of all files are fixed to 0 during free leech. However, users still receive credit for uploading files so files retain their resale value.

2 Overview and Methodology

In this section we give an overview of DIME, discuss our methodology, and discuss user contribution and consumption.

2.1 Overview of DIME

DIME (www.dimeadozen.org) is a private BitTorrent community in which users share live concert recordings (bootlegs) in lossless audio format. Sharing concert recordings has a rich history prior to BitTorrent, as music enthusiasts would trade tape and CD recordings of their favorite bands. DIME provides a community in which to continue this tradition of bootleg trading, but with the convenience afforded by its website, forum system, and BitTorrent trackers.

DIME allows open registration, but restricts the maximum number of accounts to approximately 110,000 so as to reduce server load and work for moderators. While the site is typically full, new accounts open up frequently, as existing accounts that are inactive for long periods of time are periodically removed from the system. The minimum share ratio required from users is only 0.25, a figure that is low compared to other private BitTorrent communities.

2.2 Methodology

DIME's servers collect information that is reported periodically by the BitTorrent clients of its members, which it tracks and displays in the form of HTML pages available to all members. We obtained the following information by performing periodic crawls of the website:[1]

- **Account profile snapshots**: We took periodic snapshots of the profile pages of all user accounts in the system. These profile pages included static information such as the user's join date and dynamically updated information such as the user's ratio, and upload / download amounts and rates.[2]
- **Torrent traces**: We recorded traces of torrent detail pages from the time a torrent was posted for a number of torrents. These pages included information about the seeders and leechers on the torrent and their current upload and download amounts for the torrent. We downloaded

[1] Our study is conducted with permission from DIME moderators, and with approval from Harvard's Institutional Review Board.

[2] We performed daily scrapes between April 28, 2010 and September 27, 2010, and multiple scrapes per day between December 23, 2010 and January 21, 2011. Out of 153 possible days between 4/28/10 and 9/27/10, we are missing 32 days due to scrape failures.

the torrent details pages every five minutes for the torrents being tracked.[3]

- **Torrent snapshots**: In late 2010, we also started to take snapshots of all active torrents in the system. For these snapshots we crawled the same pages as the torrent traces, but did not track individual torrents and instead took less frequent snapshots of all torrents.

While most of the statistics we collect are precise, two require some care. One is the maximum upload bandwidth available to a user. DIME tracks the maximum upload bandwidth it has ever observed for a user, but the actual maximum bandwidth of a user varies over time. While at an individual level the reported value may be a noisy signal of how much bandwidth a user can typically provide, in aggregate our results suggest it provides a reasonable signal. For example, on average the upload rate of a peer is roughly linear in this quantity (see Figure 3(a)).

The other statistic is the current upload of a peer when tracking a torrent. We did not perform peer-level measurements, so we only have access to the data that peers reported to the tracker. Though we crawled each tracked torrent every five minutes, empirically we observe that a peer's reported upload updates every 20 to 30 minutes. We can derive upper and lower bounds on the peer's upload during these 20 to 30 minute intervals, but do not have finer grained information. When computing statistics such as upload rates, we assume the upload is distributed equally across these intervals, and aggregate data from many users to mitigate errors due to this assumption.

2.3 User Contribution and Consumption

Having presented our methodology, we turn to examining user contributions and consumption on DIME. Figure 1 shows a snapshot of the historical upload and download amounts of all users on February 20th, 2010. There are 109,891 users in the system at the time of the snapshot, of whom 7.4% have donated money to the site. Note that almost all users who download more than 10GB and are still in the system have a ratio above 0.25 and that many users have a ratio above 1. This shows that many users choose to behave "altruistically" and upload significantly more than they download. In fact, DIME and other private communities encourage this by issuing social rewards to users with high ratio: they may earn special badges for attaining specific levels of activity, are often more respected in the community, and are given additional privileges on the site, inspiring them to upload more than what is necessary to merely maintain their membership status. This suggests that even DIME users with ratios significantly above 0.25 may care about the resale value of a file.

Figure 2 provides a histogram of the share ratios of users in the system. It shows that 50 percent of users have a ratio of at least 0.5 and 30 percent of users have a ratio of at least 1. Of the users with ratios less than 0.25, only 6.5% (or around 2000 users) downloaded more than 20GB, indicating that most user with low ratios are free riders who will either donate or leave the system. The figure shows distinct increases around ratios 0.25 and 1. The spike at 0.25 is consistent with a group of users performing the minimum amount of work required to remain active in the system due to share ratio enforcement. The bump around 1 can be explained by some users attempting to contribute at least as much as they receive from the system.

[3] Our first batch of traces tracked 173 torrents posted after April 29, 2010 until June 26, 2010. Our second batch of traces tracked 176 torrents posted after June 27, 2010 until September 7, 2010.

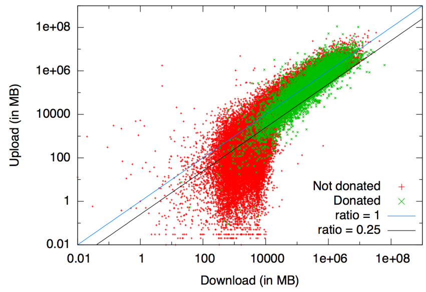


Figure 1: Snapshot showing all users' upload and download amounts. Users marked in green donated money to the site; users marked in red (including those covered by the thick green) did not.

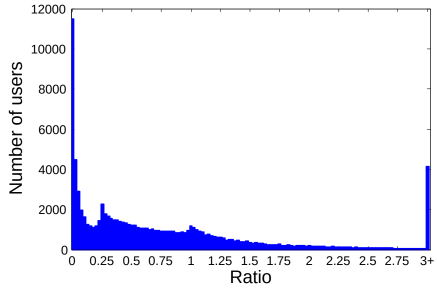


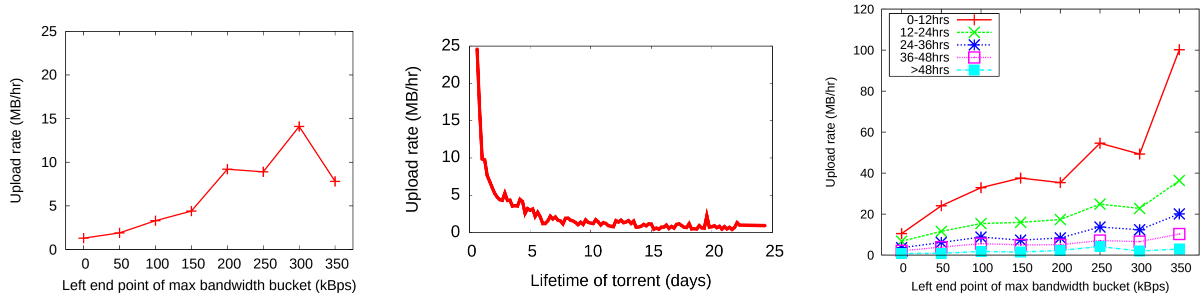
Figure 2: A Histogram of user ratios from a snapshot taken on May 1st, 2010 with bin sizes of 0.025.

3 Resale Value

3.1 Resale Value and Torrent Age

In order to examine the relationship between user behavior and differences in resale value, we consider factors that affect the resale value of torrents. An analysis of our collected data suggests that the rate of return to seeding is highly (negatively) correlated with the age of a torrent, i.e. the time elapsed since the torrent was first posted. This finding leads us to examine torrent age as a key factor for understanding how user behavior correlates with the resale value of torrents.

Note that a priori, it is unclear whether new torrents or old torrents will result in the highest returns to seeding as there are competing effects at play. Early in the life of a torrent there are more leechers who wish to download the file, suggesting a higher return to seeding. However, there are also more seeders around, suggesting that users may face more



(a) Upload rate vs Max bandwidth.

(b) Upload rate vs. Torrent age.

(c) Upload rate vs. Max bandwidth for different torrent age buckets.

Figure 3: Effects on Upload Rate.

competition with other users for upload. By tracking the activity on individual torrents on DIME, we find that *earning potential is significantly higher during the early lifetime of a torrent and decays as the torrent ages*.

We use the first batch of torrent traces (173 torrents) to obtain an aggregate estimate of the upload per period of time seeding over the age of the torrent. For each torrent, we compute an estimate of the upload rate as follows. For each seeder (other than the original uploader of the file) on the torrent, we construct a sequence of (upload, (start time, end time)) pairs which gives an estimate of how much the user uploaded in (start time, end time). We then bucket these observations by time (5 hours), so that for each bucket, we have the total upload as well as the total time spent seeding. From here, we divide total upload by total time to get an estimate of the upload rate in the time bucket. We then take the average of these upload rates across all torrents in our set of traces. Torrents that had no seeding activity in a time bucket are included with a rate of 0.

Figure 3(b) shows that the average upload rate on a torrent is extremely high in the hours immediately following its posting, and that there is a severe drop in rate of return over the course of the first few days. After five days, the decrease in upload rate slows, but continues for the lifetime of the torrent. The slow decline in the tail may be an artifact of torrents dying and our measurements recording a rate of 0 for these torrents that are inactive. The large discrepancy between the returns from seeding early and seeding late shows that when a user downloads the file may be more important than how long the user plans to spend seeding it.

While Figure 3(b) suggests that the upload rate is higher for those seeders who join a torrent early, it could be that the population of seeders who join a torrent early is different than the overall population. For instance, it could be that those who join a torrent early tend to have higher upload bandwidth, accounting for the observed discrepancies in upload rate. (Figure 3(a) shows the effect of bandwidth on upload rate.) To control for the effect of upload bandwidth, we plot in Figure 3(c) the upload rate for users in different bandwidth buckets during the early lifetime of a torrent. We see that higher bandwidth leads to higher upload rates as expected, while earlier join times magnify this effect through changing the slope of the plotted relationship. Figure 3(c) also suggests that an effective way to compensate for connection speed is to join torrents earlier. For example, while we refrain from giving precise numbers due to measurement noise, the figure suggests that joining in the first 0-12 hours as a low bandwidth user (50-150 kbps) may yield higher upload rates than joining in the first 12-24 hours as a higher bandwidth user (150-250 kbps).

A consequence of these observations is that there is a higher resale value for downloading newer torrents. For each unit of time spent seeding, a user can gain more credit on a new torrent than on an old torrent.

3.2 Resale Value and Decision Making

In DIME, users make economic trade-offs when deciding which files to download. Given the difference in resale value between new and old files, we expect users to preferentially download newer files. In general, we think of the resale value of a file as reducing the "effective cost" of that file. Thus, if files were made cheaper, we would expect downloads of older files to increase. Based on a natural experiment that occurred during our study, we are able to test this prediction.

From December 23, 2010 to December 26, 2010, DIME had a free leech period, during which downloading did not count against a user but uploading still provided credit. Figure 4 shows the number of active downloads during a three week period including the free leech. We observe significantly more active downloads during the free leech period than during the days before and after free leech, where the amount of download activity during free leech is 50 to 75% higher than during the days following free leech.[4]

In the days before and after free leech, we observe that the number of active downloads of files uploaded within the last week (new files) is nearly identical to the number of active downloads of files older than a week (old files). However,

[4]Note that prior to the free leech period our data has only a single observation each day, while during and after free leech we have multiple observations per day. The results during the latter period captures some of the daily fluctuations in usage that are typical of private communities [7].

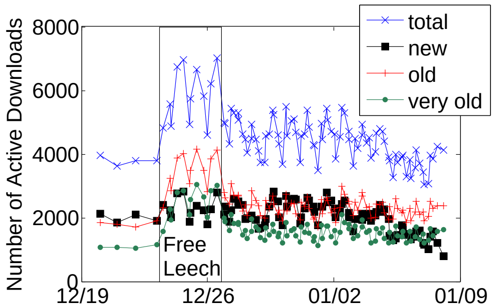


Figure 4: Leeching activity before, during, and after a free leech period.

there are approximately 25 times more old files than new files at any given time. Thus, users are downloading significantly more copies of newer files than older files. Some of this difference may be because old files have already been downloaded by many users. However, we see in Figure 4 that while there is no noticeable increase in demand for new files during the free leech period, demand for old files increased 60 to 70%. Moreover, the demand for files more than sixty days old (very old) nearly doubled during free leech. From an economic perspective, the added incentive to download new files during the free leech is small, because such files have a high resale value and are thus "cheap" even without the price reduction. But for old files that are "expensive" due to low resale value, free leech provides a significant opportunity to acquire these files for free. Thus, the behavior we observe appears to be a rational economic response, where files with the lowest resale value received the greatest additional interest. We hypothesized that users might also download larger files, but the increase in demand appeared relatively uniform across file sizes (not shown).

While there was no particular bonus for seeding during free leech, the increase in download activity allowed a seeder to earn more credit per hour spent seeding. Interestingly, there was essentially no increase in the number of seeders during free leech, either overall or among those with low share ratios. Given the increase in the number of active downloads during free leech, more downloads are supported by the same number of seeders during this period. Assuming that the characteristics of the population of seeders (e.g., their bandwidth distribution) are more or less the same during free leech and at other points in time, this observation suggests that there is an excess supply of available upload bandwidth among active seeders that is not utilized except during free leech. While previous work by Andrade et al. [3] suggests that approximately 75% of torrents are constrained by upload bandwidth, due to their methodology the result only applies to torrents that currently have multiple leechers (i.e., newer files). For the long tail of older files on which there is only one leecher or none at all, our results suggest that seeders of these files have excess upload bandwidth; due to the files' low resale value there is typically not enough demand to use up the available supply. While this finding points to a potential inefficiency of the system, having a supply of seeders with available bandwidth on older torrents does allow these files to remain available to users who choose to download them. It also highlights why the resale value of files is important: there is a pool of users who are willing to seed more but their content may not be of interest to others, so their efforts may be spared or better directed to files that are in greater demand.

4 Discussion

We have presented a study of DIME's complex economy. In it, we have focused on issues related to the cost and resale value of files. We have shown that old files are much harder to upload to others (because of low demand and very high supply) and so they have low resale value, but are equally priced per byte. We have given evidence that suggests that this effect skews the everyday consumption of files toward newer, more popular files — an effect that is reflected in the increased desire to download old files when the price is dropped during 'free leech' days.

Based on this insight there several possible changes that might improve the efficiency of DIME's economy. However, it is important to note that, even without further intervention, DIME's survival despite changing conditions, such as increases in bandwidth and file size and having a dynamic user population, is a tribute to both the community spirit that it maintains, and to the robustness of its economy. Changes should thus be introduced with great care.

Restricting access of new users to older files

Our measurements surprisingly find that new users have an increased tendency to download old files. Figure 5 shows that the median user who registered within the last 0-14 days initiated download 96 hours into the torrent's lifetime, while the median veteran user (who had an account for more than 50 days) tended to join a torrent after only 11.3 hours. This effect may have several causes. First, users who have just joined may find old files appealing (and they were not around to download them when they were new). Second, these users may be less aware of the pitfalls of downloading old files (which can quickly result in them having negative credit). Finally, some users may be joining the site to get a particular file, and may not be interested in staying for the long run. These "free riders" know in advance that they will not need to regain their lost credits and will not upload the file. They therefore place no value on the resale value and may download old files more often.

Newcomers who unwittingly end up with a negative amount of credit may be driven to create new accounts, or may turn to moderators for a temporary suspension of the ratio enforcement (a temporary loan of credits). An approach requiring less manual intervention would be to limit the access of users to older files, e.g., until after they gain some experience on the site, or only when they have enough absolute wealth to cover the entire cost of downloading the old file. This would both help new users avoid the potential mistake of

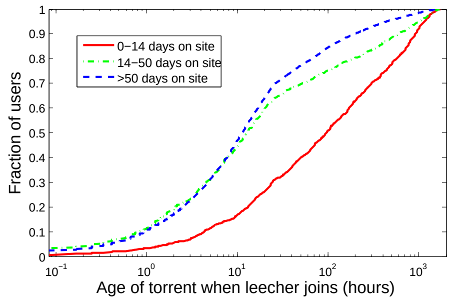


Figure 5: A CDF of times leechers begin to download torrents. Users are grouped by the age of their account.

getting into debt for downloading a file they cannot later upload, and at the same time would also make free-riding less appealing as more effort would be needed to access many files.

A possible pitfall of this approach is that new users may be dissuaded from joining the site since they cannot initially access material they desire. While this is certainly something to be wary of, DIME is currently running at capacity and new users need to wait for accounts to become available. If this is a concern, another alternative would be to use a warning or softer limit based on their current ratio.

Increasing demand for files

In conventional markets, the price of services that have too much supply and too little demand naturally drops. But on DIME, all transfers are credited equally, so prices remain fixed. One can imagine adopting a credit system in which uploads and downloads convert to credit based on the prices of files. In such a system, one can attempt to adjust the price of torrents by slowly lowering the price over time, by making all files beyond a certain age cheaper, or by making the price depend on the seeder to leecher ratio in the torrent. This would attract more reluctant downloaders, and give additional hints to seeders about how to best direct their efforts. Related approaches to helping match supply and demand across torrents are considered in Antfarm [13] and PACE [4].

Price alterations should be done very carefully. If the cost decreases too much, too many users will wait to download files and too few will seed them which will amount to a stagnation in the economy. We also need to be careful not to make it too easy to earn money. Theoretical models [10] show that if it is too easy to earn money, rational users feel “rich” and decrease their willingness to work, leading to a vicious cycle where fewer and fewer users contribute.

5 Related Work

A number of papers empirically study private BitTorrent communities, generally concluding that private communities exhibit higher download speeds and availability. While we also conduct an empirical study that tracks information similar to that of earlier studies, we conduct a series of traces and can examine how user behavior changes over time. Additionally, our torrent level traces allow us to study how activity on individual torrents varies over time, leading to our novel study of resale value.

In a series of papers, Andrade et al. [2, 15, 3] study traces from seven BitTorrent communities, some of which use SRE. They find that peers contribute significantly more, particularly by seeding for longer periods of time, in communities with SRE. They also study the arrival rate of peers to torrents, showing that it is initially high, but rapidly drops and then has a long, slowly-decaying tail. This arrival pattern fits with our observation that the greatest opportunities to gain upload as a seeder are early in the life of a torrent.

Liu et al. [11] study a user snapshot of HDChina, which uses a variable SRE depending on download amount, and show that seeder / leecher ratio is significantly higher in HDChina than in public torrents. The authors also develop a model of incentive mechanisms in BitTorrent communities and show that a ratio mechanism provides good incentives. They argue that collusion is an inherent problem in private communities and propose an entropy-based method for detecting collusion.

Hales et al. [8] report some basic statistics from a seven day trace of a community using SRE at a ratio of 0.67. They show that a majority of the uploading each day is contributed by ten percent of peers, possibly starving others of the opportunity to maintain an acceptable ratio while downloading desired files. Using a theoretical model and simulations, they demonstrate conditions under which this occurs. Rahman et al. [14] build on this through additional modeling and simulations and show how an adaptive policy can help avoid credit crunches by instituting free leech periods when many peers are “stuck” at a low ratio.

Meulpolder et al. [12] study five communities, three of which use SRE. They find that more stringent ratio requirements lead to higher download speeds, longer seeding time, and fewer firewalled peers.

Zhang et al. [16] study the landscape of private BitTorrent communities and estimate that over 800 private communities combine to have approximately the same number of torrents as publicly available trackers and have significantly more active users at any time.

In a pair of papers, Chen et al. [7, 6] study 17 communities, including a 68 day trace of DIME, and note that those that use SRE have significantly greater user activity and seeding. Their study of DIME is more limited and focuses primarily on the characteristics of users. They model the tendency of peers to be starved for opportunities to upload and discuss mechanisms such as free leech periods that communities use to ameliorate the problem.

Huberman and Wu [9] propose an incentive mechanism for p2p exchange that credits servers for seeding files, much like the SRE mechanism for private BitTorrent communities. They conclude that such a mechanism creates an incentive for servers to provision the long tail of files that may not be accessed very often. Indeed, we observe that many older files are still actively seeded.

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