Small Is Not Always Beautiful

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Abstract

Peer-to-peer content distribution systems have been enjoying great popularity, and are now gaining momentum as a means of disseminating video streams over the Internet. In many of these protocols, including the popular BitTorrent, content is split into mostly fixed-size pieces, allowing a client to download data from many peers simultaneously. This makes *piece size* potentially critical for performance. However, previous research efforts have largely overlooked this parameter, opting to focus on others instead.

This paper presents the results of real experiments with varying piece sizes on a controlled BitTorrent testbed. We demonstrate that this parameter is indeed critical, as it determines the degree of parallelism in the system, and we investigate optimal piece sizes for distributing small and large content. We also pinpoint a related design trade-off, and explain how BitTorrent's choice of dividing pieces into subpieces attempts to address it.

1 Introduction

Implementation variations and parameter settings can severely affect the service observed by the clients of a peer-to-peer system. A better understanding of protocol parameters is needed to improve and stabilize service, a particularly important goal for emerging peer-to-peer applications such as streaming video.

BitTorrent is widely regarded as one of the most successful swarming protocols, which divide the content to be distributed into distinct pieces and enable peers to share these pieces efficiently. Previous research efforts have focused on the algorithms believed to be the major factors behind BitTorrent's good performance, such as the piece and peer selection strategies. However, to the best of our knowledge, no studies have looked into the optimal size of content pieces being exchanged among peers. This paper investigates this parameter by running real experiments with varying piece sizes on a controlled testbed, and demonstrates that *piece size is critical for performance*, as it determines the degree of parallelism available in the system. Our results also show that, for small-sized content, smaller pieces enable shorter download times, and as a result, *BitTorrent's design choice of further dividing content pieces into subpieces is unnecessary for such content*. We evaluate the overhead that small pieces incur as content size grows and demonstrate a trade-off between piece size and available parallelism. We also explain how this trade-off motivates the use of both pieces and subpieces for distributing large content, the common case in BitTorrent swarms.

The rest of this paper is organized as follows. Section 2 provides a brief description of the BitTorrent protocol, and describes our experimental methodology. Section 3 then presents the results of our experiments with varying piece sizes, while Section 4 discusses potential reasons behind the poor performance of small pieces when distributing large content. Lastly, Section 5 describes related work and Section 6 concludes.

2 Background and Methodology

BitTorrent Overview BitTorrent is a popular peer-to-peer content distribution protocol that has been shown to scale well with the number of participating clients. Prior to distribution, the content is divided into multiple *pieces*, while each piece is further divided into multiple *subpieces*. A *metainfo file* containing information necessary for initiating the download process is then created by the content provider. This information includes each piece's SHA-1 hash (used to verify received data) and the address of the *tracker*, a centralized component that facilitates peer discovery.

In order to join a *torrent*—the collection of peers participating in the download of a particular

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content—a client retrieves the metainfo file out of band, usually from a Web site. It then contacts the tracker, which responds with a *peer set* of randomly selected peers. These might include both *seeds*, who already have the entire content and are sharing it with others, and *leechers*, who are still in the process of downloading. The new client can then start contacting peers in this set and request data. Most clients nowadays implement a *rarest-first* policy for piece requests: they first ask for the pieces that exist at the smallest number of peers in their peer set. Although peers always exchange just subpieces with each other, they only make data available in the form of complete pieces: after downloading all subpieces of a piece, a peer notifies all peers in its peer set with a *have* message. Peers are also able to determine which pieces others have based on a *bitfield* message, exchanged upon the establishment of new connections, which contains a bitmap denoting piece possession.

Each leecher independently decides who to exchange data with via the *choking algorithm*, which gives preference to those who upload data to the given leecher at the highest rates. Thus, once per *rechoke period*, typically every ten seconds, a leecher considers the receiving data rates from all leechers in its peer set. It then picks out the fastest ones, a fixed number of them, and only uploads to those for the duration of the period. Seeds, who do not need to download any pieces, follow a different unchoke strategy. Most current implementations unchoke those leechers that *download* data at the highest rates, to better utilize seed capacity.

Experimental Methodology We have performed all our experiments with private torrents on the PlanetLab platform [5]. These torrents comprise 40 leechers and a single initial seed sharing content of different sizes. Leechers do not change their available upload bandwidth during the download, and disconnect after receiving a complete copy of the content. The initial seed stays connected for the duration of the experiment, while all leechers join the torrent at the same time, emulating a flash crowd scenario. The number of parallel upload slots is set to 4 for the leechers and seed. Although system behavior might be different with other peer arrival patterns and torrent configurations, there is no reason to believe that the conclusions we draw are predicated on these parameters.

The available bandwidth of most PlanetLab nodes is relatively high for typical real-world clients. We impose upload limits on the leechers and seed to model more realistic scenarios, but do not impose any download limits, as we wish to observe differences in download completion time with varying piece sizes. The upload limits for leechers follow a uniform distribution from 20 to 200 kB/s, while the seed's upload capacity is set to 200 kB/s.

We collect our measurements using the official (mainline) BitTorrent implementation, instrumented to record interesting events. Our client is based on version 4.0.2 of the official implementation and is publicly available for download [1]. We log the client's internal state, as well as each message sent or received along with the content of the message. Unless otherwise specified, we run our experiments with the default parameters.

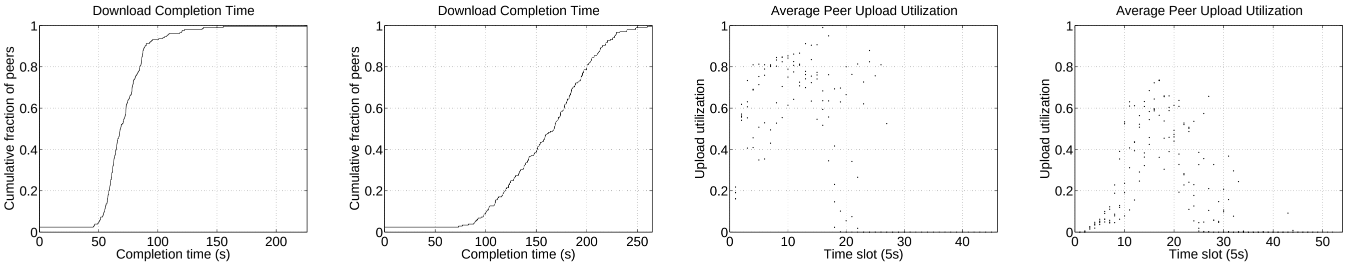
The protocol does not strictly define the piece and subpiece sizes. An unofficial BitTorrent specification [3] states that the conventional wisdom is to "pick the smallest piece size that results in a metainfo file no greater than 50–75 kB". The most common piece size for public torrents seems to be 256 kB. Additionally, most implementations nowadays use 16 kB subpieces. For our experiments, we always keep the subpiece size constant at 16 kB, and only vary the piece size. We have results for all possible combinations of different content sizes (1 MB, 5 MB, 10 MB, 20 MB, 50 MB, and 100 MB) and piece sizes (16 kB, 32 kB, 64 kB, 128 kB, 256 kB, 512 kB, 1024 kB, and 2048 kB).

3 Results

Our results, presented in this section, demonstrate that small pieces are preferable for the distribution of small-sized content. We also discuss the benefits and drawbacks of small pieces for other content sizes, and evaluate the communication and metainfo file overhead that different piece sizes incur for larger content.

3.1 Small Content

Even though most content distributed with BitTorrent is large, it is still interesting to examine the impact of piece size on distributing smaller content. In addition to gaining a better understanding of the trade-offs involved, it may also sometimes be desirable to utilize BitTorrent to avoid server overload when distributing small content, e.g., in the case of websites that suddenly become popular. Figure 2 shows the median download completion times of the 40 leechers downloading a 5 MB file, for different numbers of pieces, along with standard deviation error bars. Clearly, *smaller piece sizes enable faster downloads.* In particular, performance



(a) Piece size of 16 kB (b) Piece size of 512 kB (c) Piece size of 16 kB (d) Piece size of 512 kB

Figure 1: CDFs of peer download completion times and scatterplots of average upload utilization for five-second time intervals when distributing a 5 MB content (averages over 5 runs). *Small pieces shorten download time and enable higher utilization.*

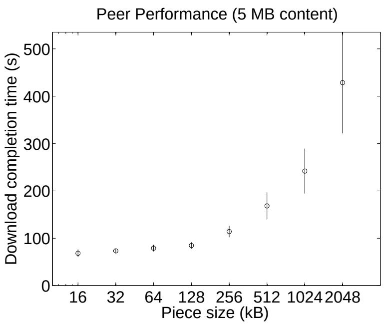


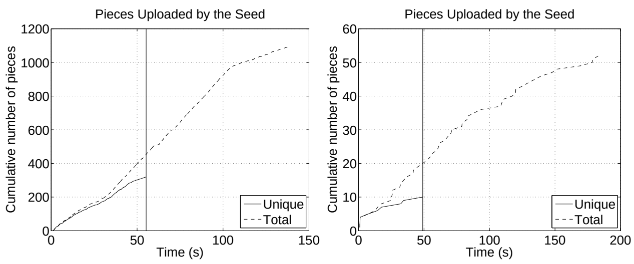
Figure 2: Download completion times for a 5 MB content (medians over 5 runs and standard deviation error bars). *Smaller pieces clearly improve performance.*

deteriorates rapidly when increasing the piece size beyond 256 kB. The same observations hold for experiments with other small content (1 and 10 MB).

To better illustrate the benefits of small pieces, Figure 1 shows the cumulative distribution functions (CDF) of leecher download completion times for 16 and 512 kB pieces (graphs (a) and (b)). With small pieces, most peers complete their download within the first 100 seconds. With larger pieces, on the other hand, the median peer completes in more than twice the time, and there is greater variability. The reason is that *smaller pieces let peers share data sooner.* As mentioned before, peers send out *have* messages announcing new pieces only after downloading and verifying a complete piece. Decreasing piece size allows peers to download complete pieces, and thus start sharing them with others, sooner. This increases the available parallelism in the system, as it enables more opportunities for parallel downloading from multiple peers.

This benefit is also evident when considering *peer upload utilization*, which constitutes a reliable metric of efficiency, since the total peer upload capacity represents the maximum throughput the system can achieve as a whole. Figure 1 shows utilization scatterplots for all five-second time intervals during the download (graphs (c) and (d)). Average upload utilization for each of 5 experiment runs is plotted once every 5 seconds. Thus, there are five dots for every time slot, representing the average peer upload utilization for that slot in the corresponding run. The metric is torrent-wide: for those five seconds, we sum the upload bandwidth expended by leechers and divide by the available upload capacity of all leechers still connected to the system. Thus, a utilization of 1 represents taking full advantage of the available upload capacity. As previously observed [9], utilization is low at the beginning and end of the session. During the majority of the download, however, a smaller piece size increases the number of pieces peers are interested in, which leads to higher upload utilization.

These conclusions are reinforced by the fact that small pieces enable the seed to upload less duplicate pieces during the beginning of a torrent's lifetime. Figure 3 indeed plots the number of pieces (unique and total) uploaded by the single seed in our 5 MB experiments, for two representative runs. Although the seed finishes uploading the first copy of the content at approximately the same time in both cases (vertical line on the graphs), it uploads 139% more duplicate data with larger pieces (5120 kB for 512 kB pieces vs. 2144 kB for 16 kB pieces), thus making less efficient use of its valuable upload bandwidth. Avoiding this waste can lead to better performance, especially for low-capacity seeds [9]. This behavior can be explained as follows. The official BitTorrent implementation we are using always issues requests for the rarest pieces *in the same order.* As a result, while a leecher is downloading a given piece, other leechers might end up requesting the same piece from the seed. With smaller pieces, the time interval before a piece is completely down-



(a) Piece size of 16 kB (b) Piece size of 512 kB

Figure 3: Number of pieces uploaded by the seed when distributing a 5 MB content, for two representative runs. The *Unique* line represents the pieces that had not been previously uploaded, while the *Total* line represents the total number of pieces uploaded so far. The vertical line denotes the time the seed finished uploading the first copy of the content to the system. *The duplicate piece overhead is significantly lower for small pieces.*

loaded and shared becomes shorter, mitigating this problem. This could be resolved by having leechers request rarest pieces in random order instead.

In summary, small pieces enable significantly better performance when distributing small content. As a result, *the distinction of pieces and subpieces that the BitTorrent design dictates is unnecessary for such content.* For instance, in our 5 MB experiments, pieces that are as small as subpieces (16 kB) are optimal. Thus, the content could just be divided into pieces with no loss of performance.

3.2 Piece Size Impact

Before investigating the impact of piece size on the distribution of larger content, let us first examine the advantages and drawbacks of small pieces. We have seen that their benefits for small content are largely due to the increased peer upload utilization such pieces enable. Since small pieces can be downloaded sooner than large ones, leechers are able to share small pieces sooner. In this manner, there is more data available in the system, which gives peers a wider choice of pieces to download. In addition to this increased parallelism, small pieces provide the following benefits (some of which do not affect our experiments).

- They decrease the number of duplicate pieces uploaded by seeds, thereby better utilizing seed upload bandwidth.
- The rarest-first piece selection strategy is more effective in ensuring piece replication. A greater number of pieces to choose from entails a lower probability that peers download the same piece, which in turn improves the diversity of pieces in the system.
- There is less waste when downloading corrupt data. Peers can discover bad pieces sooner and re-initiate their download.

On the other hand, for larger content, the overhead incurred by small pieces may hurt performance. This overhead includes the following.

- Metainfo files become larger, since they have to include more SHA-1 hashes. This would increase the load on a Web server serving such files to clients, especially in a flash crowd case.
- *Bitfield* messages also become larger due to the increased number of bits they must contain.
- Peers must send more *have* messages, resulting in increased communication overhead.

In the next section, we shall see that these drawbacks of small pieces outweigh their benefits, for larger content. Thus, the choice of piece size for a download should take the content size into account.

3.3 Larger Content

Figure 4 shows the download completion times of the 40 leechers downloading a 100 MB file for different piece sizes. We observe that small pieces are no longer optimal. In this particular case, sizes around 256 kB seem to perform the best. Experiments with other content sizes (20 and 50 MB) show that *the optimal piece size increases with content size.* For instance, for experiments with a 50 MB content, the optimal piece size is 64 kB. Note that the unofficial guideline for choosing the piece size, mentioned in Section 2, would yield sizes of 32 and 16 kB for a 100 MB and 50 MB content respectively, a bit off from the optimal values.

In an effort to better understand this trade-off regarding the choice of piece size, we evaluate the metainfo file and communication overhead. The former is shown in Figure 5. As expected, small pieces produce proportionately larger metainfo files (note that the x axis is logarithmic). 16 kB pieces, for instance, produce a metainfo file larger than 120 kB, as compared to a less than 10 kB file for 256 kB pieces. For large content in particular, this might have significant negative implications for the Web server used to distribute such files to clients.

Bitfield messages become proportionately larger too. For instance, for the 100 MB content, these messages are 805 and 55 bytes for 16 and 256 kB pieces respectively. Figure 6 additionally shows the

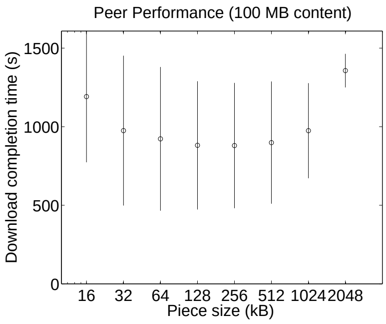


Figure 4: Download completion times for a 100 MB content (medians over 5 runs and standard deviation error bars). *Small pieces are no longer optimal.*

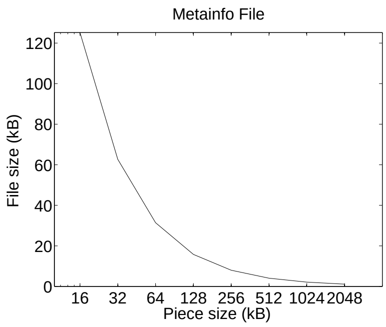


Figure 5: Metainfo file sizes for distributing a 100 MB content. *Smaller pieces produce proportionately larger files.*

communication overhead due to *bitfield* and *have* messages, expressed as a percentage of the total upload traffic per peer. The overhead ranges from less than 1% for larger piece sizes to around 9% for 16 kB pieces. However, it is not clear that this overhead is responsible for the worse performance of smaller pieces. Although these control messages do occupy upload bandwidth, they do not necessarily affect the data exchange among peers, and thus their download performance. For example, looking at the corresponding overhead for smaller content, we observe that the overhead curve looks very similar. This indicates that *increased communication overhead is most likely neither the cause of the worse performance of small pieces for larger content*, nor does it explain the observed trade-off. In the next section, we formulate two hypotheses that might help identify the true cause of this behavior.

In summary, when distributing larger content, the optimal piece size depends on the content size, due to a trade-off between the increased parallelism small pieces provide and their drawbacks. *BitTorrent arguably attempts to address this trade-off by further dividing pieces into subpieces*, to get the best of both worlds: subpieces increase opportunities for parallel downloading, while pieces mitigate the drawbacks of small verifiable units.

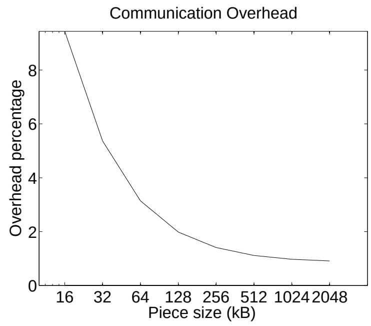


Figure 6: Communication overhead due to *bitfield* and *have* messages when distributing a 100 MB content. *Small pieces incur considerably larger overhead.*

4 Discussion

The results presented in the previous section point to a hidden reason behind the poor performance of small pieces when distributing large content. We have two hypotheses that might help explain that.

First, small pieces *reduce opportunities for subpiece request pipelining*. In order to prevent delays due to request/response latency, and to keep the download pipe full most of the time, most BitTorrent implementations issue requests for several consecutive subpieces back-to-back. This pipelining, however, is restricted within the boundaries of a single piece. This is done in order to use available bandwidth to download complete pieces as soon as possible, and share them with the rest of the swarm. Similarly, peers do not typically issue a request for subpieces of another piece to the same peer before completing the previous one. Thus, for a content with 32 kB pieces, for instance, only two subpiece requests per peer can be pending at any point in time. For small content, the impact of reduced pipelining is negligible, as the download completes quickly anyway. For larger content, however, it might severely affect system performance, as it limits the total number of simultaneous requests a peer can issue. Additionally, this matter gains importance as available peer bandwidth rises, since the request/response latency then starts to dominate time spent on data transmission.

Furthermore, small pieces *may incur slowdown due to TCP effects*. With a small piece size, a given leecher is more likely to keep switching among peers to download different pieces of the content. This could have two adverse TCP-related effects: 1) the congestion window would have less time to ramp up than in the case of downloading a large piece entirely from a single peer, and 2) the congestion window for unused peer connections would gradually decrease after a period of inactivity, due to

TCP congestion window validation [4], which is enabled by default in recent Linux kernels, such as the ones running on the PlanetLab machines in our experiments. A large piece size, on the other hand, would enable more efficient TCP transfers due to the lower probability of switching from peer to peer. Note, however, that, even in that case, there is no guarantee that all subpieces of a piece will be downloaded from the same peer.

5 Related Work

To the best of our knowledge, this is the first study that systematically investigates the optimal piece size in BitTorrent. Bram Cohen, the protocol's creator, first described BitTorrent's main algorithms and their design rationale [6]. In version 3.1 of the official implementation he reduced the default piece size from 1 MB to 256 kB [2], albeit without giving a concrete reason for doing so. Presumably, he noticed the performance benefits of smaller pieces.

Some previous research efforts have looked into the impact of piece size in other peer-to-peer content distribution systems. Hoßfeld *et al.* [8] used simulations to evaluate varying piece sizes in an eDonkey-based mobile file-sharing system. They found that download time decreases with piece size up to a certain point, confirming our observations, although they did not attempt to explain this behavior. The authors of Dandelion [12] evaluate its performance with different piece sizes, and mention TCP effects as a potential reason for the poor performance of small pieces. However, small pieces in that system may also be harmful because they increase the rate at which key requests are sent to the central server. CoBlitz [10] faces a similar problem with smaller pieces requiring more processing at CDN nodes. The authors end up choosing a piece size of 60 kB, because that can easily fit into the default Linux outbound kernel socket buffers. The Slurpie [11] authors briefly allude to a piece size trade-off, and mention TCP overhead as a drawback of small pieces. Lastly, during the evaluation of the CREW system [7], the authors find a piece size of 8 kB to be optimal for distributing a 800 kB content, but they do not attempt to explain that.

6 Conclusion

This paper presents results of real experiments with varying piece sizes on a controlled BitTorrent testbed. We show that piece size is critical for performance, as it determines the degree of parallelism in the system. Our results explain why small pieces are the optimal choice for small-sized content, and why further dividing content pieces into subpieces is unnecessary for such content. We also evaluated the overhead small pieces incur for larger content, and discussed the design trade-off between piece size and available parallelism.

It would be interesting to investigate our two hypotheses regarding the poor performance of small pieces with larger content. We would also like to extend our conclusions to different scenarios, such as video streaming, which imposes additional real-time constraints on the protocol.

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