# BitTorrent Experiments on Testbeds: A Study of the Impact of Network Latencies

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***Abstract*—In this paper, we study the impact of network latency on the time required to download a file distributed using BitTorrent. This study is essential to understand if testbeds can be used for experimental evaluation of BitTorrent. We observe that the network latency has a marginal impact on the time required to download a file; hence, BitTorrent experiments can performed on testbeds.**

## I. Introduction

Testbeds such as PlanetLab and Grid5000 are widely used to study the performance of communication protocols and networking applications. One commonly used practice while performing experiments on such testbeds is to run multiple instances of the application being studied on the same machine. However, one primary shortcoming of this approach is the absence of any network latency between the instances of the application running on the same machine. Further, in experiments involving more than one machine, the latency between the machines present in the same local area network (LAN) is negligible. In this paper we study the impact of network latency on the outcome of experiments that are performed on testbeds to evaluate the performance of BitTorrent.

The BitTorrent Protocol internally uses the Transmission Control Protocol (TCP) while distributing the content [1]. The steady-state throughput of TCP is function of the round-trip time (RTT) [2]. Further, the slow start and congestion avoidance phase of TCP introduce a *ramp up period* which is required to attain a throughput equal to the minimum of the network throughput and the rate at which the application is sending data. This ramp up period is a function of the RTT and the rate at which the data is being uploaded. BitTorrent allows the users to limit the rate at which data is uploaded; as the time duration of an upload by a peer is in the order of seconds, we believe that the time required to transfer pieces of a file is not affected by such variations in the TCP throughput. Our experiments show that the RTT (and hence the latency) between the peers in the torrent has a marginal impact (less than $15\%$) on the time required to download a file.

The details of the methodology and the tools used are presented in Section II. We initially assume the latency between any two peers in the torrent to be the same (*homogeneous latency*); the impact of homogeneous latency on the time required to download a file are presented in Section III. The results without this assumption are presented in Section IV, followed by the conclusions in Section V.

## II. Methodology

In this paper we use the terminology used by the BitTorrent community. A *torrent*, also known as a BitTorrent session or a swarm, consists of a set of peers that are interested in having a copy of the given content. A peer in a torrent can be in two states: the *leecher* state when it is downloading the contents, and the *seed* state when it has a copy of the content being distributed. A *tracker* is a server that keeps track of the peers present in the torrent.

### A. Experiment Scenarios

We consider a torrent consisting of one tracker and a finite number of peers; a few of these peers are seeds, while the rest of the peers are leechers. We assume that the peers remain in the torrent until all the leechers have finished downloading the file.

The metric used to study the impact of the network latency between the peers is the *download completion time*, the time required to the download the file distributed using BitTorrent. We use the following network topologies to evaluate the impact of latency on download completion time of a file.

1) *Homogeneous Latency.* The latency between any two peers in the torrent is the same in this network topology. This topology provides *an upper bound on the download completion time* when the maximum round trip time between the peers in a torrent is known. Further, this setting was used to give an insight on the threshold of the latency between the peers beyond which the latency affects the download completion time.
2) *Heterogeneous Latency.* The peers are grouped together to abstract Autonomous Systems (AS). We assume that the latency between any two peers in a given AS is the same and that all ASes are fully meshed. Further, we assume that the inter-AS latency is greater than the intra-AS latency; we also assume symmetric latency in the upload and download links within an AS and between ASes.

All the experiments were performed in a private torrent consisting of one tracker, one initial seed (henceforth called as the seed), and 300 leechers; these experiments were carried out on the Grid'5000 experimental testbed [3]. A 50 MB file was distributed in this torrent where the upload rates of the leechers and the seed was varied from 10 kB/s to 100 kB/s. As shown in Figure 1, four machines with Linux as their operating system were used to run the instances of the peers

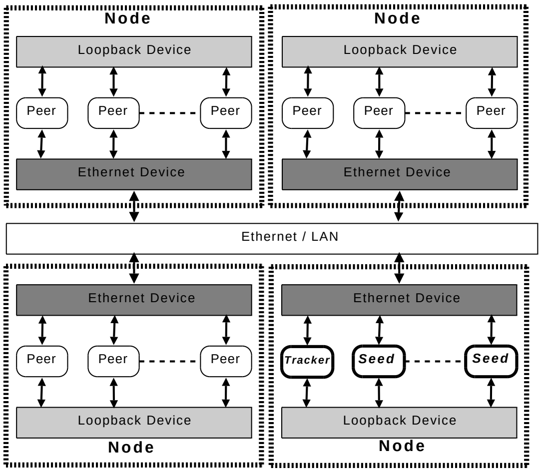



Fig. 1: Topology of the peers in the machines used for the experiment. One machine for the tracker and the initial seed, and three machines each with one hundred leechers.

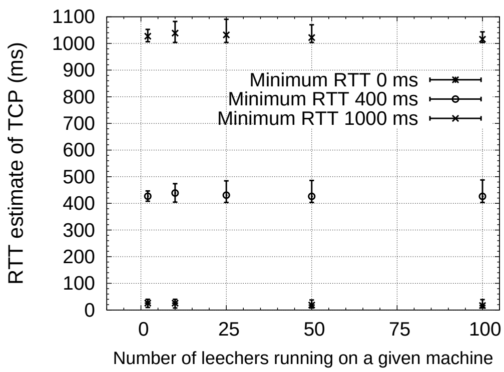



Fig. 2: Impact of the number of leechers running on a machine on the RTT estimate of TCP. Error bars indicating the $5^{th}$ and $95^{th}$ percentile of RTT estimated by TCP for all the peers in five iterations. Increasing the number of leechers running on a given machine has a marginal impact on the RTT estimated by TCP.

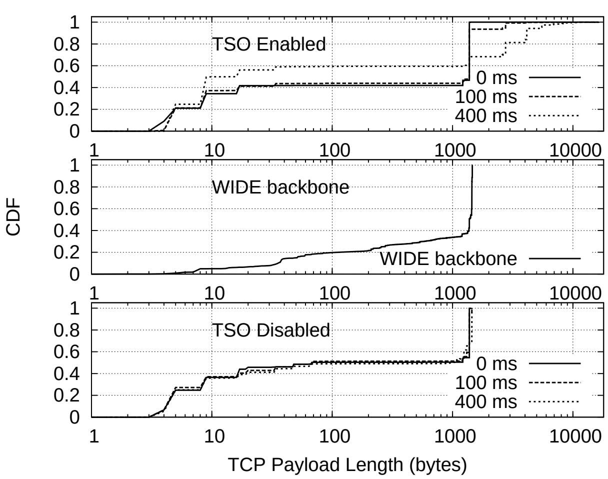



Fig. 3: CDF of TCP Payload Length. The maximum payload length with TSO enabled is much greater than that observed in the WIDE Backbone. Disabling TSO ensures that the maximum payload length is similar to that observed in the WIDE backbone.

in the torrent; one machine was used for the tracker and the seed, and each of the other three machines ran 100 instances of the leechers. A pair of peers in the torrent, including the tracker, the seed, and the leechers, communicate with each other using either the loopback interface or the ethernet interface. The latency between the peers was varied from 0 ms to 500 ms using the Netem module [4]. This latency represents the one way delay observed by a packet, hence *the round-trip time between any two peers is at least twice the latency mentioned*. Homogeneous latency was achieved by adding the same latency on the loopback and the ethernet interface. Similarly, heterogeneous latency was achieved by adding a latency on the ethernet interface of a given machine that is greater than the latency added on the loopback interface of the same machine.

The following torrent configurations were used to vary the upload rate of the peers:

1) *Seed and Leechers Slow.* In this setting, the upload rate of the peers was limited to 10 kB/s and 20 kB/s.
2) *Seed and Leechers Fast.* In this setting, the upload rate of the peers was limited to 50 kB/s and 100 kB/s.
3) *Seed Fast and Leechers Slow.* In this setting, the upload rate of the initial seed was limited to 50 kB/s while the upload rate of the leechers was limited to 20 kB/s.

### *B. Testbed Configuration*

The Netem module buffers the TCP frames which are in flight for a time period equal to the latency being emulated. A buffer size of 100000 frames was used in each machine to support up to 1000 frames of each peer to be in flight. To ensure that the machines are capable of running 100 peers uploading at 100 kB/s without affecting the added latency, we varied the number of leechers running on a machine from 4 to 100. The `TCP_INFO` option for the `getsockopt` method of the socket library was used to sample the RTT estimated by TCP each time a `send` system call was issued on a socket. Figure 2 shows the average RTT estimate with the error bars representing the 95th and 5th percentiles of all the peers in five iterations. We observe that the number of leechers running a given machine has a marginal impact on the average RTT estimated by TCP when each of the leechers has its maximum upload rate limited to 100 kB/s.

The Maximum Transmission Unit (MTU) for the loopback interface is typically greater than the MTU for other network interfaces such as Wi-Fi and ethernet. To avoid the impact of large frames being exchanged between the peers we set the MTU of the loopback interface to 1500 bytes (the default value set for the ethernet interface). Figure 3 (top plot) shows that despite setting the MTU to 1500 bytes, a significant number of frames have a size greater than the MTU. Further, we observe that increasing the latency between the peers results in a significant number of TCP segments having a large payload length; TCP segments with large payload lengths were also observed in frames being sent over the ethernet interface. This increase in payload lengths is due to a feature called TCP Segmentation Offloading (TSO) [5], which is enabled by default in the 2.6 series (the current series) of the Linux

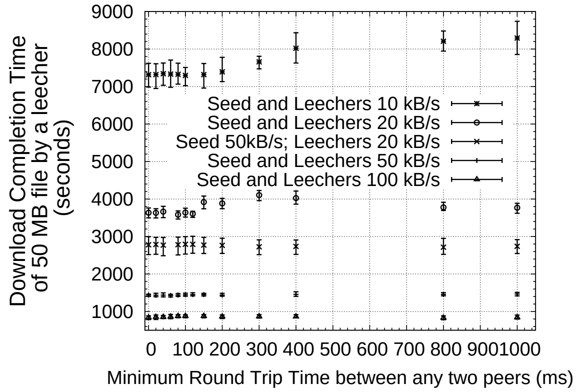



Fig. 4: Impact of latency on the Download Completion Time. RTT values mentioned are twice the latency added on a link using Netem. The latency increases the download completion time by at most $15\%$.

kernel. TSO enables the host machine to offload some of the TCP/IP implementation, such as segmentation, and calculation of IP checksum, to the network device. Further, to enhance the throughput, TSO supports the exchange of data in frames of sizes that can be greater that the underlying MTU size. The increase in the frame size can result in significant improvement in throughput; however, this improvement depends on various factors such as CPU processing power and the amount of data being transferred [6]. Figure 3 (middle plot) shows the packet lengths obtained from the publicly available traces of the Internet traffic in the WIDE backbone [7]. The values presented are from the sample taken on the WIDE backbone on November 29, 2009. As hardware support on all the devices in the communication link is essential for handling large segments, the graph shows that the devices on most of links (including end hosts or intermediate nodes) in the Internet do not support TSO. In this paper we restrict ourselves to study the impact of the latency, hence TSO was disabled in the subsequent experiments. Figure 3 (bottom plot) shows that the maximum payload length of the frames is similar to that observed in the Internet when the MTU is set to 1500 bytes and TSO is disabled.

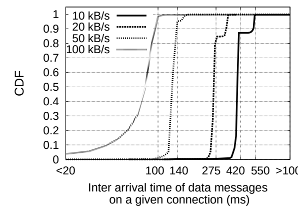
The impact of the homogeneous latency and heterogeneous latency between the peers are presented in the subsequent sections. The plots presented are the outcome of 10 iterations.

## III. Homogeneous Latency

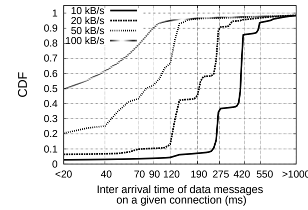
We now present the impact of homogeneous network latency between any two peers in a torrent on the download completion time of a file.

### A. Presentation of Results

When the maximum upload rate of the seed and leechers is limited to 10 kB/s, Figure 4 shows that an RTT greater than 200 ms results in the average download completion time increasing by at most $15\%$. Further, when the upload rate of all the peers is limited to 20 kB/s we observe that the download completion time is not a monotonously increasing function of the RTT; peers having an RTT of 1000 ms have a lower

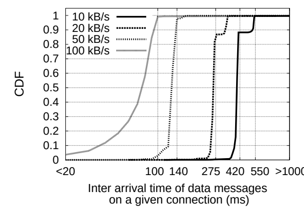



(a) Distribution of the inter-arrival time of messages at the initial seed when RTT between peers is 0 ms.

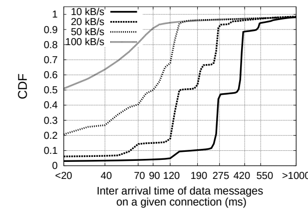



(b) Distribution of the inter-arrival time of messages at the leechers when RTT between peers is 0 ms.

Fig. 5: Distribution of the inter-arrival time of data messages when the RTT between the peers is 0 ms.




(a) Distribution of the inter-arrival time of messages at the initial seed when RTT between peers is 400 ms.




(b) Distribution of the inter-arrival time of messages at the leechers when RTT between peers is 400 ms.

Fig. 6: Distribution of the inter-arrival time of data messages when the RTT between the peers is 400 ms.

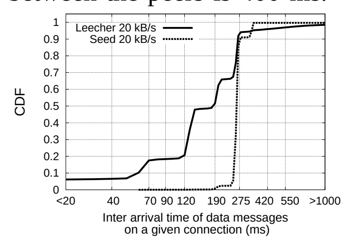



Fig. 7: Distribution of the inter-arrival time of messages at the initial seed and leechers when RTT between peers is 1000 ms.

download completion time compared to peers having an RTT of 300 ms.

However, when the maximum upload rate of the seed is increased to 50 kB/s while that of the leechers is limited to 20 kB/s, we observe that an RTT of even 1000 ms between the peers has a marginal impact on the download completion time of the file. A similar observation is made when the limit on maximum upload rates of all the peers is increased to 50 kB/s; this is also true when the upload rates are limited to 100 kB/s.

Figure 5, Figure 6, and Figure 7 show the distribution of the time between successive `send` system calls while uploading the blocks (and pieces) of the file being distributed. Figure 5a, Figure 6a, and Figure 7 show that the distribution at the seed is similar for an RTT of 0 ms, 400 ms, and 1000 ms; further, from Figure 5b and Figure 6b, we observe that the distribution at the leechers for upload rates of 50 kB/s and 100 kB/s is the similar when the RTT is 0 ms and 400 ms. This shows that the RTT has a marginal impact on the upload process at the peers when their maximum upload rates are limited to 50 kB/s and 100 kB/s. However, for the upload rates of 10 kB/s and 20 kB/s we observe that the leechers tend to have a smaller time between successive `send` system calls

| AS | Latency over Loopback (ms) | Latency over Ethernet (ms) |
|---|---|---|
| $AS_1$ | 2 | 5 |
| $AS_2$ | 5 | 15 |
| $AS_3$ | 10 | 25 |
| $AS_4$ | 25 | 100 |
| $AS_5$ | 50 | 100 |

TABLE I: Latency values for the *ingress* and *egress* of the loopback and ethernet device while emulating an AS on a machine.

when the RTT is 400 ms (or, 1000 ms) compared to an RTT of 0 ms. As the peers can simultaneously upload to many peers in parallel, the low inter-arrival time implies that the upload capacity is being utilized to upload data to a smaller number of peers.

### B. Discussion of Results

For upload rates of 10 kB/s and 20 kB/s, Figure 4, Figure 5, and Figure 6, show that when the time between successive `send` system calls is less than the RTT, the RTT does not have an impact on the download completion time. Further, we observe that the ramp-up period required to attain a throughput equal to the upload rate of 50 kB/s (or 100 kB/s) does not have an impact on the download completion time. However, we currently do not have an accurate reason for the non-monotonous increase in the download completion time for upload rates of 20 kB/s.

The above results show that network latency has a negligible impact on the download completion time of a file if the peers are fast (capable of uploading at high rates such as 50 kB/s). However, we observe that the latency affects the download completion time when the peers are slow (upload rates are less than or equal to 20 kB/s). Further, we observe that a single fast seed is capable of mitigating the impact of network latency on a torrent consisting of slow leechers.

## IV. Heterogeneous Latency

The latency between two peers in a given AS, is usually less than the latency between a peer from the given AS and another peer present in an adjacent AS. We emulated ASes by ensuring that the latency on the loopback interface is less than that on the ethernet interface on each of the machines used; hence, two peers running on a given machine have an RTT less than the RTT between a peer running on the given machine and another peer running on another machine. Further, we assume all the ASes to be fully meshed.

### A. Abstraction of ASes

As in the case of homogeneous latency, we consider a torrent consisting of three hundred leechers, one tracker, and one initial seed; we emulated three ASes with one hundred leechers each, while the seed and the tracker were placed in the fourth AS. The four ASes used in these experiments were chosen from a set five ASes; the latency values added on the *ingress* and *egress* of the loopback and ethernet device of the machines while emulating these five ASes are given in Table I.

| | $AS_1$ | $AS_2$ | $AS_3$ | $AS_4$ | $AS_5$ |
|---|---|---|---|---|---|
| $AS_1$ | 8 ms | 40 ms | 60 ms | 210 ms | 210 ms |
| $AS_2$ | 40 ms | 20 ms | 80 ms | 230 ms | 230 ms |
| $AS_3$ | 60 ms | 80 ms | 40 ms | 250 ms | 250 ms |
| $AS_4$ | 210 ms | 230 ms | 250 ms | 100 ms | 400 ms |
| $AS_5$ | 210 ms | 230 ms | 250 ms | 400 ms | 200 ms |

TABLE II: RTT between a pair of leechers. RTT between a leecher in $AS_1$ and a leecher in $AS_5$ is 210 ms.

| | $AS_1$ | $AS_2$ | $AS_3$ | $AS_4$ | $AS_5$ |
|---|---|---|---|---|---|
| $AS'_1$ | 20 ms | 40 ms | 60 ms | 210 ms | 210 ms |
| $AS'_2$ | 40 ms | 60 ms | 80 ms | 230 ms | 230 ms |
| $AS'_3$ | 60 ms | 80 ms | 100 ms | 250 ms | 250 ms |
| $AS'_4$ | 210 ms | 230 ms | 250 ms | 400 ms | 400 ms |
| $AS'_5$ | 210 ms | 230 ms | 250 ms | 400 ms | 400 ms |

TABLE III: RTT between the initial seed and the other peers (except the tracker) in the torrent. RTT between the seed in $AS'_1$ and a peer in $AS_1$ is 20 ms.

We now show how Figure 1 and Table I can be used to find the RTT between a pair of peers.

As a machine is used to emulate an AS, a peer in $AS_1$ uses the ethernet interface to communicate with a peer in $AS_2$, the RTT between this pair of peer is therefore 40 ms (5+15+15+5); as a peer in $AS_1$ uses the loopback interface to communicate with another peer in $AS_1$, the RTT between this pair of peers is 8 ms (2+2+2+2). Table II gives the RTT values between all such pairs of peers that are initially leechers.

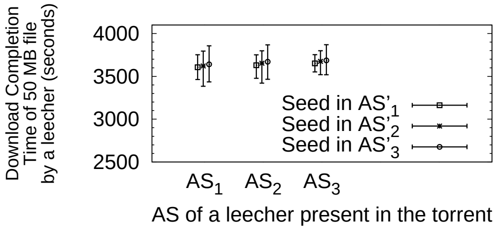
Similarly, from Figure 1, as the initial seed (henceforth called as the seed) and leechers are placed in different machines, the seed uses the ethernet interface of the machine to communicate with all the leechers present in the torrent. We use $AS'_i$ to denote that the seed and the tracker are placed in an AS with an inter-AS latency and intra-AS latency equal to that of $AS_i$; for example, $AS'_1$ implies that the seed and tracker are placed in an AS having the same latency values as $AS_1$. Therefore, the RTT between the seed in $AS'_1$ and a leecher in $AS_1$ is 20 ms ($5 + 5 + 5 + 5$), while the RTT between the same seed and a leecher in $AS_5$ is 210 ms. The RTT between the seed and the peers are given in Table III.

From Table II, the RTT between a peer in either $AS_1$, $AS_2$, or $AS_3$, and another peer in either $AS_1$, $AS_2$, or $AS_3$, is less than 100 ms. Further, the RTT between a peer in $AS_4$ and another peer in $AS_4$ is 100 ms, while the RTT from this peer to any other peer is greater than 200 ms. Similarly the RTT from a peer in $AS_5$ to any other peer, irrespective of its AS, is greater than 200 ms.

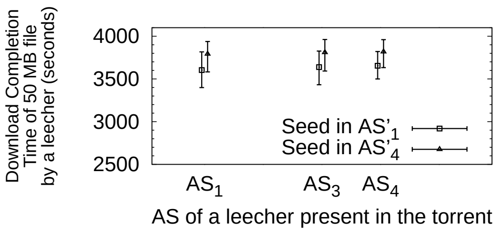
### B. Presentation and Discussion of Results

Figure 8 and Figure 9 show the impact of heterogeneous latency on the download completion time of a 50 MB file when the upload rate of the peers is limited to 20 kB/s and 50 kB/s respectively. The X-axis represents the AS of the leechers present in the torrent, and the Y-axis represents the download completion time in seconds; the error bars indicate the minimum and maximum download completion time of the leechers in 10 iterations.

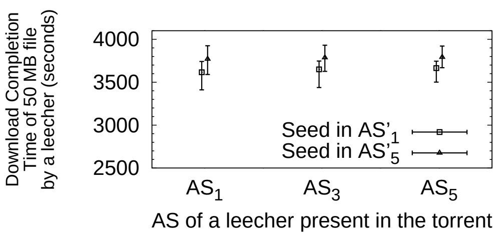
Figure 8a shows the outcome of three experiments having the leechers placed in $AS_1$, $AS_2$, and $AS_3$; for the first




(a) Download completion time for leechers present in $AS_1$, $AS_2$, and $AS_3$.




(b) Download completion time for leechers present in $AS_1$, $AS_3$, and $AS_4$. Having peers in an AS with large latency ($AS_4$) and the initial seed in an AS with large latency ($AS'_4$) affects the download completion time.




(c) Download completion time for leechers present in $AS_1$, $AS_3$, and $AS_5$. Having peers in an AS with large latency ($AS_5$) and the initial seed in an AS with large latency ($AS'_5$) affects the download completion time.

Fig. 8: Download completion time of a 50 MB file by leechers in a given AS when the maximum upload rate of all the peers is 20 kB/s.

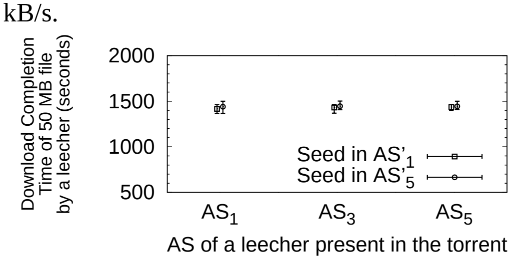



Fig. 9: Download completion time of a 50 MB file by leechers present in a given AS when the maximum upload rate of all the peers is 50 kB/s.

experiment the seed was placed in $AS'_1$, for the other two experiments, the seed was placed in $AS'_2$ and $AS'_3$ respectively. The figure shows that the RTT between the peers does not affect the download completion time. According to Table II, the RTT between any two peers in these experiments was less than 120 ms, hence, as in the case of homogeneous latency, we observe that an RTT of less than 120 ms does not affect the download completion time when the upload rates are limited to 20 kB/s.

When some of the peers are present in an AS having a large RTT ($AS_4$ or $AS_5$), and the seed is also present in another AS with a large RTT ($AS'_4$ or $AS'_5$), then Figure 8b, and Figure 8c, show that the RTT affects the download completion time. However, we observe that the increase in average download completion time is not more than $15\%$ of the average download completion time when all the peers in a torrent have an RTT less than 120 ms.

Figure 9 shows the impact of heterogeneous latency on the download completion time when the maximum upload rate of all the peers in the torrent is limited to 50 kB/s. We observe that an RTT of 400 ms, between the seed in $AS'_5$ and the leechers in $AS_5$, does not have a significant impact on the download completion time of the file. These observations are in line with the observations in Section III.

Figure 4, Figure 8, and Figure 9, confirm that the topology of homogeneous latency provides an upper bound on the download completion time of a file when the maximum latency between any two peers in a torrent is known. Further, the observations made in Section III can be used in experiments where the latency between a pair of peers is heterogeneous.

## V. Conclusion

The network latency between the peers has a marginal impact on the download completion time when the peers have their upload rates limited to high values such as 50 kB/s and 100 kB/s; our experiments show that the ramp-up period which is required to attain the throughput equal to these upload rates has a marginal impact on the download completion time. When the peers are slow (upload rates limited to values less than or equal to 20 kB/s) we observe that the download completion time is affected by the network latency; however, the increase in the average download completion time is not more than $15\%$ of the average download completion time when there is no network latency between the peers. As the network latency has a marginal impact on the time required to download a file, *BitTorrent experiments can be performed on testbeds without explicitly emulating latency between the peers in a torrent*.

## VI. Acknowledgment

Experiments presented in this paper were carried out using the Grid'5000 experimental testbed, being developed under the INRIA ALADDIN development action with support from CNRS, RENATER and several Universities as well as other funding bodies (see https://www.grid5000.fr).

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