Performance Evaluation of P2P Caches: Flash-Crowd Case

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***Abstract*—Peer-to-peer (P2P) based content distribution networks (CDNs), e.g., BitTorrent, are widely used in the today's Internet. Since all peers interested in a specific content provide storage and upload capacity those CDNs facilitate a cheap and easy distribution of large amounts of data. However, they generate a lot of costs for Internet Service Providers (ISPs) as normal users also act as a source for downloads.**

One option for ISPs to encounter the problem of the costly inter-domain traffic is to establish P2P caches. In this study we investigate the potential of those caches in flash-crowd scenarios, i.e., when a large number of peers tries to download the content at the same time. To that end, we perform simulations as well as experiments with real BitTorrent clients. The evaluation shows that ISPs as well as P2P users will benefit from the use of caches.

***Index Terms*—BitTorrent, caching, peer-to-peer (P2P).**

I. Introduction

For many people, the most important group of applications used in the Internet is Peer-to-Peer (P2P). Although the popularity of file sharing decreased over the last two years, such services still generate most of traffic in the Internet, ranging from 43% in Northern Africa to 70% in Eastern Europe [1]. P2P traffic consists of bandwidth intensive file downloads as well as video streams and voice calls. It might be, and in many cases is, difficult to ensure Quality of Service guarantees for delay and loss sensitive connections as well as fair bandwidth allocation for best effort traffic in networks with dominant volume of the P2P traffic. Users of file sharing applications tend to use as much bandwidth as possible giving no chance to other transfers to be served with sufficient quality. A significant portion of this traffic is exchanged between different domains. It is a real problem for ISPs (Internet Service Providers) [2], because of the possibility of congestion on inter-domain links and also due to high costs of such links.

In general, there are two basic groups of solutions that allow a decrease of the volume of the inter-domain traffic: locality (proximity) awareness and network caching [2]. In both cases a portion of the traffic is exchanged within ISP's domain instead of being transfered between various domains. It allows for decreasing the volume of the inter-domain traffic, reducing the operators cost of transmission and improving user-perceived application performance. The paper deals with caching solutions but the other group is also briefly described.

The main idea behind solutions related to the locality awareness is that a peer makes a decision on which peers to download a content from, taking into account their localization. The nearest peers are selected more likely than others. This can be done by peers either with the carrier cooperation or without it (e.g., methods based on measurements performed by peers themselves). The latter group of solutions encompasses such solutions as for instance: the biased neighbor selection [3], the ONO plugin to Vuze BitTorrent client (that uses locality information based on DNS lookup correlated with a global CDN, like Akamai) [4], or the idea of clusterization/grouping of peers [5]. However, most recent concepts focus on cooperation between ISPs and P2P networks. Aggarwal et al. [6] propose the introduction of an ISP-owned facility called oracle, that provides a P2P client with the peer locality information. A similar approach is known as P4P [7]. Lately, an IETF Application Layer Traffic Optimization working group has been established to collect the effort performed so far and to prepare a protocol that can be used between P2P nodes and operator facilities [8]. While those ideas focus rather on a client-ISP interaction, works of the EU SmoothIT project [9] emphasize the practical methods to effectively gain and use the relevant locality-related information.

The second large group of proposals involves placing caches at the ISP's domain. This method can be performed by the operator even without the P2P nodes recognition, i.e., this is mainly operator-side influence on P2P networks. The content placed into the caches must be controlled. In our paper, we consider P2P networks assuming that the offered content is legal and may be distributed. According to the authors' knowledge, the first work that studied the potential of the caches usage to improve the operation of P2P networks was presented in [10], where the possibility to decrease bandwidth usage was noticed. The positive influence of caching on FastTrack (KaZaA) traffic was experimentally shown in [11]. Inter-connection and cooperation between caches located in different domains is studied in [12]. Caches cooperation with P2P networks is theoretically modeled taking into account files popularity in [13]. Caching is also studied from the standpoint of each peer storage usage, for instance, [14] considers such a case and studies the replacement policies for P2P-based video on a demand overlay. General considerations on to what extent caching can be useful in different types of networks (including also P2P systems) are presented in [15].

Introducing caches into BitTorrent networks may be considered in at least two important scenarios: steady-state and flash crowd. In the first case, peers connect to the cache and disconnect after completing a file. This process is stable and the number of peers connected to the cache does not change significantly. The second situation is observed when, e.g., very popular content is placed into a cache and a large number of peers decides to download it as soon as possible. It is possible to analyze the first scenario by mathematical models and simulations while the second one better fits for the practical experiments in small labs (in such a case it might not be possible to observe the steady-state tranfer).

This paper is organized as follows. Section II shows the description of BitTorrent operation and implementation of caches. In Section III, the performance evaluation is provided. Section IV summarizes the paper.

II. BitTorrent and Caches

Today, BitTorrent [16] is the most popular P2P application in the Internet. For a detailed description, please refer to [17] and [18]. To improve the performance of a BitTorrent overlay network, an operator may consider introducing caches into the network. A cache is a regular BitTorrent client participating in regular swarms, however, it is attached to the network with a higher capacity connection. As caches are owned by ISPs, they are referred to in the paper as ISP-owned Seeds (IoS) or ISP-owned Peers (IoP). The distinction between IoP and IoS is analogous to a peer (a 'leecher,' containing less than 100% of content) and a seed (100% of content). For an ISP, introducing caches is feasible as they can be plugged almost directly to the core. Numerous issues have been identified regarding the implementation of caches. Some of them include: how should the initial content be provided?, should caches serve all peers or just peers in the ISP's administrative domain?, how should peers be informed about the existence of caches?

According to the solution proposed and investigated in this paper caches participate in the swarms just as a regular peer does. There is no modification of the tracker, nor in the BitTorrent clients or protocol. Just by having a great capacity connection a cache becomes an attractive partner for the peers in the swarm. The most important advantage of this approach is the fact that virtually nothing needs to be changed in order to introduce it. It is also possible to enhance the BitTorrent operation by modifying a tracker, so that every peer gets the cache of its AS if one is present. The only parameters that must be manipulated are the setup parameters of the cache itself. For instance, a cache might be allowed to communicate only with peers in the same administrative domain. Such an approach is also evaluated throughout the paper.

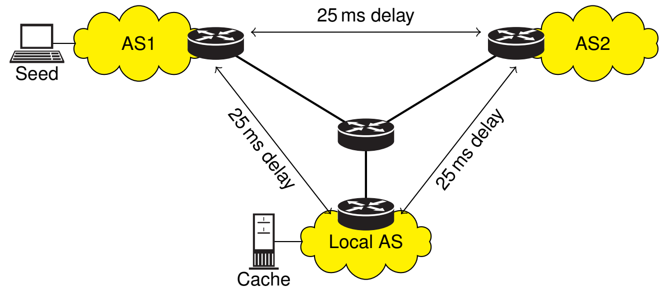

Fig. 1. Testbed layout.

TABLE I
Parameters set for different types of BitTorrent clients

Host type	Download speed	Upload speed
Peer (leecher, AS1, AS2, Local AS)	2 Mbit/s	256 kbit/s
Seed (AS1)	3.2 Mbit/s	3.2 Mbit/s
Cache (Local AS)	20 Mbit/s	2.56 Mbit/s

III. Performance Evaluation

The influence of the introduction of caches on the inter-domain traffic volume as well as the performance of a BitTorrent application were evaluated. The potential decrease of inter-domain traffic is important from the ISP's perspective. On the other hand, download times reflect the performance from a P2P user's point of view. The evaluation was performed in twoways: with a testbed and by simulations. In the testbed a small but real network was established and the real BitTorrent application, namely µTorrent, was run. The testbed experiments allowed for a performance evaluation in case of a small swarm size in a real environment. The simulation setup extends the experiments to a large case scenario.

A. Testbed

1) Testbed Setup: In the testbed, three autonomous systems (ASes) were established with the usage of Cisco routers (see Fig. 1). A static routing is used, as a dynamic routing is not necessary in this case. The bottleneck delays between all pairs of ASs as well as bandwidth limiting were introduced to emulate the real situation in the Internet. **AS1** emulated all networks located in the proximity of the initial seed. **Local AS**, emulated the network of the operator that decides to use the caching mechanisms. **AS2** emulates 'the rest of the Internet.'

In each AS, eight hosts were established with µTorrent application as a BitTorrent client. The parameters set for different types of hosts are gathered in Table I. All other settings were left default, e.g., unchoking interval. The tracker is located in AS1 (the same host as the seed) and is also established on the basis of built-in µTorrent tracker functionality.

The size of the downloaded file was 57 MB. In total, eleven scenarios were tested. The configuration parameters for each experiment are summarized in Table II. At the beginning of each experiment, none of the regular peers had the desired content. Those peers started downloading the file. Experiment was finished when all peers downloaded the whole content. In experiments 1, 6, and 9 no cache was used. In the other

TABLE II
PARAMETERS RELATED TO DIFFERENT TESTBED EXPERIMENT SCENARIOS

Experiment ID	Inter-AS bandwidth	Cache type	Communication limitations
1	100 Mbit/s	—	—
2	100 Mbit/s	IoP	Unlimited
3	100 Mbit/s	IoP	Cut-off
4	100 Mbit/s	IoS	Unlimited
5	100 Mbit/s	IoS	Cut-off
6	1 Mbit/s	—	—
7	1 Mbit/s	IoP	Cut-off
8	1 Mbit/s	IoS	Cut-off
9	2 Mbit/s	—	—
10	2 Mbit/s	IoP	Cut-off
11	2 Mbit/s	IoS	Cut-off

Inter-AS delay: 25 ms.

experiments the operator of the Local AS introduced a cache. Two scenarios were tested:

- ISP-owned peer (IoP) that initially does not have the file and it downloads it similarly like other peers,
- ISP-owned seed (IoS) that has the content from the beginning of an experiment.

Two types of operator policy regarding the availability of a cache to the users were checked. In the first scenario, called 'unlimited communication,' all peers regardless of their localization are allowed to download the content from the cache (either IoS or IoP). The operator can also ban the communication of the cache with peers outside its domain, i.e., the cache then serves only peers located in the same AS. This is called a 'cut-off' policy. If this policy is used with IoS, the communication of the cache is limited to local domain from the beginning of the experiment. In case of experiments with IoP, the unlimited communication is allowed until the cache downloads the whole content. Afterwards, the communication outside the domain is banned.

2) Results of the Testbed Experiment: Results are presented in Figs. 2-5. Fig 2 shows results for experiments 1 to 5 where capacities of inter-domain links were equal to 100 Mbit/s (practically unlimited). In experiments 6 to 11 the bandwidth of the links was limited.

The experiment results are drawn from a single run due at least the following two reasons: first, real experiments are time-consuming and difficult to perform and second, the quantitative results and the variability of the results is assessed via simulations (that are easier to be performed and assessed).

a) Inter-Domain Traffic: The introduction of an IoP with unlimited communication did not change the overall inter-domain traffic exchanged by Local AS. In all cases, the introduction of a cache decreased the inbound traffic because local peers started to download more content from a cache and less from other domains. On the other hand, if unlimited communication with the cache was allowed, the outbound traffic got increased since the cache became attractive to peers outside the Local AS. This is prevented by the cut-off communication (experiments 3 and 5). However, in the case of an IoP some increase of outbound traffic is still observed since the IoP must serve also peers from other domains until it has

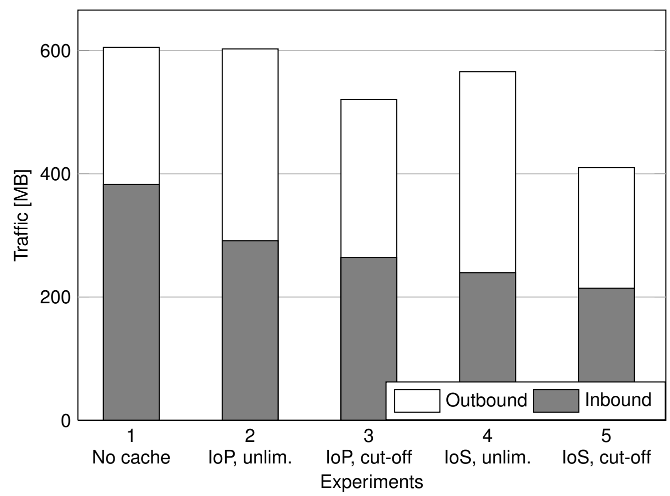

Fig. 2. Testbed experiment results with the inter-AS bandwidth equal to 100 Mbit/s: inter-domain traffic (sum of inbound and outbound) related to the Local AS.

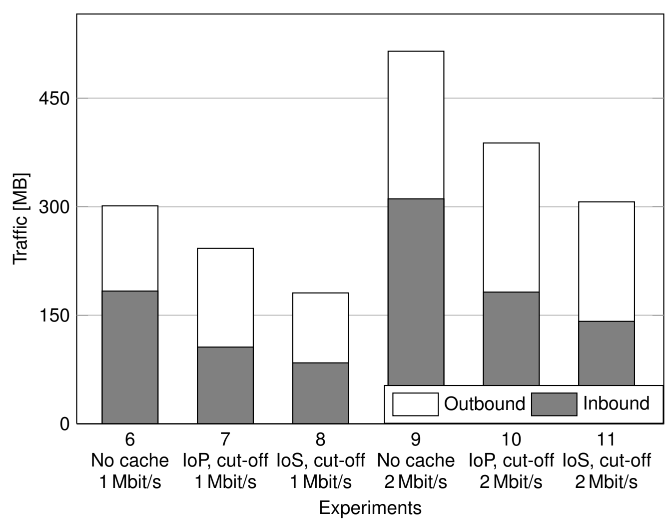

Fig. 3. Testbed experiment results with the limited inter-AS bandwidth: inter-domain traffic (sum of inbound and outbound) related to the Local AS.

downloaded the whole content. Nevertheless, the overall inter-domain traffic is decreased in comparison to the case without cache.

Similar observations were made for the experiments with limited inter-AS bandwidth (Fig. 3). The described effects, caused by the introduction of caches with cut-off communication, are even more apparent here.

b) Download Times: As presented in Figs. 4 and 5, the introduction of a cache decreased the download time for all peers regardless of the domain they are located in. In experiment 1, the average download time for peers in each domain was approximately the same. The introduction of an IoP with unlimited communication resulted in a decrease of the download time but it still did not differ between domains. However, in the case of IoP cut-off or IoS with unlimited and cut-off communication, the peers located in the Local AS

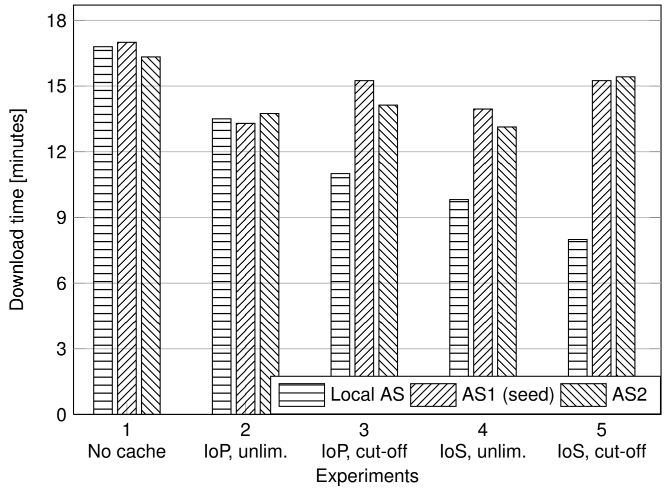

Fig. 4. Testbed experiment results with the inter-AS bandwidth equal to 100 Mbit/s: download time.

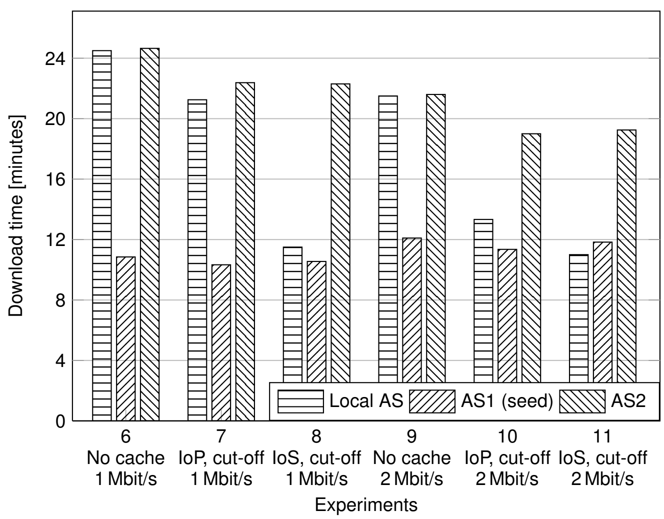

Fig. 5. Testbed experiment results with the limited inter-AS bandwidth: download time.

benefits more than the others. In the latter case the download time for local peers is even two times shorter than the one experienced by peers in other domains (Fig. 4).

If the inter-domain link capacities are limited, peers located in the same AS as the seed (AS1) apparently experience a shorter download time what can be explained by the fact that their access to the seed is not limited by bottlenecks. If there was no cache, the download time for peers located in AS2 and Local AS was more than two times larger. The introduction of an IoP with cut-off communications decreased the download time for peers in those domains. Local peers benefit most, however, if an IoS is introduced. Then, the average download time of peers in Local AS is comparable to the one observed in AS1.

B. Simulation

1) Simulation Setup: For the simulations the P2P simulation framework ProtoPeer [19] was used. The implementation contains all key mechanisms of BitTorrent, in particular, the neighbor set management, the piece selection, and the unchoking process. The simulation of the underlying network is based on data flows instead of packets. This permits an increased runtime speed of the simulation while it still mimics the property of TCP that the available bandwidth is shared among all flows/connections using a network link. We modified the tracker, so that every peer gets the address of the cache for its AS if one is present. In the experiments, that behavior was also the case but for a different reason: all peers know the cache in the experiment because the number of peers is so small that the tracker returns all peers in the swarm to requesting peers at once.

Like in the experiments, all peers enter the swarm when the simulation starts. The simulation is finished when all peers have downloaded the whole file. Ten simulation runs per scenario were performed and average values are presented in the following.

2) Results of the Simulation Study: The simulation scenarios are the same as the ones investigated by the testbed experiments (see Tables I and II). However, the simulations permit an investigation of larger swarms than those used in the experiments. Therefore, the number of peers and the access bandwidths of the IoS/IoP were scaled by a factor of 5. Consequently, there are 40 peers per AS in the simulations and the IoS/IoP has an upload capacity of 12.8 Mbit/s. In the following, the impact of an IoP/IoS on the inter-domain traffic and the download times in this larger swarm (120+ peers) is considered.

All simulation-based performance evaluation results are given as mean values where the relative error (defined as the half-width of the confidence-interval on a 95%-level divided by the corresponding mean value) is below 5%.

a) Inter-Domain Traffic: The amount of the inter-domain traffic was measured in intervals of 1 minute. The sum of all measurement intervals is reported. First, the authors considered the impact of an IoP/IoS on the inter-domain traffic in cases where the inter-domain bandwidth is unlimited (see Fig. 6). The introduction of an IoP decreases the amount of incoming traffic both for the unlimited and the cut-off communication because peers in the local AS can download a fraction of the file from the IoP. However, the outgoing traffic is increased in case of the unlimited communication. The reason is that the IoP also uploads to remote peers. With the cut-off option, the outgoing traffic remains unaffected. The same holds also for the IoS. Since the IoS has the complete file at the simulation start, the inter-domain traffic is slightly smaller than with the IoP.

Compared to the scenarios without inter-domain bandwidth limitations, the inter-domain traffic is considerably smaller when the inter-domain links have bandwidth limitations (see Fig. 7). This is caused by the BitTorrent tit-for-tat mechanism which favors connections with high bandwidth. Although the

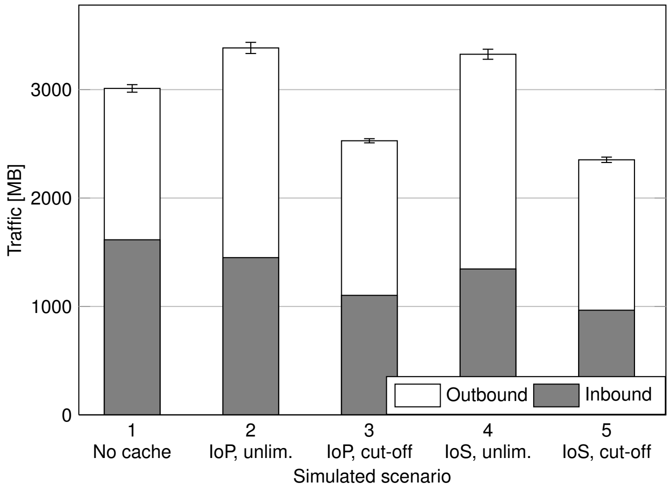

Fig. 6. Simulation results with the unlimited inter-domain bandwidth: inter-domain traffic (sum of inbound and outbound) related to the Local AS.

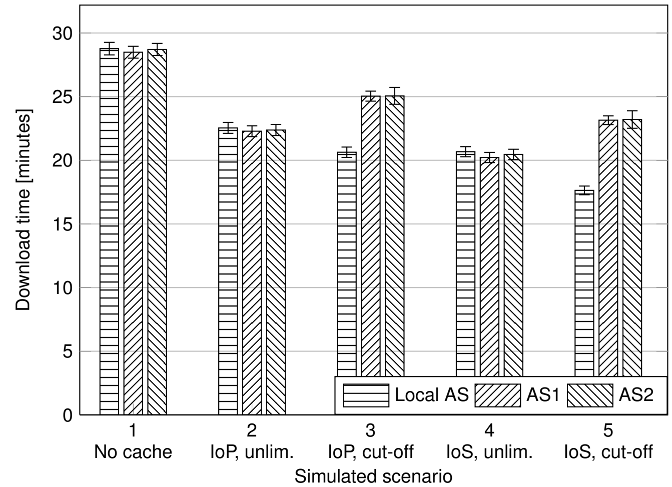

Fig. 8. Simulation results with the unlimited inter-domain bandwidth: average download times.

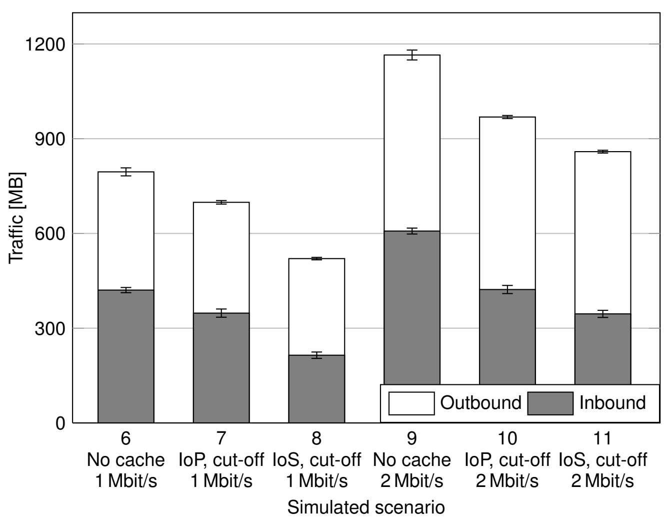

Fig. 7. Simulation results with the limited inter-domain bandwidth: inter-domain traffic (sum of inbound and outbound) related to the Local AS.

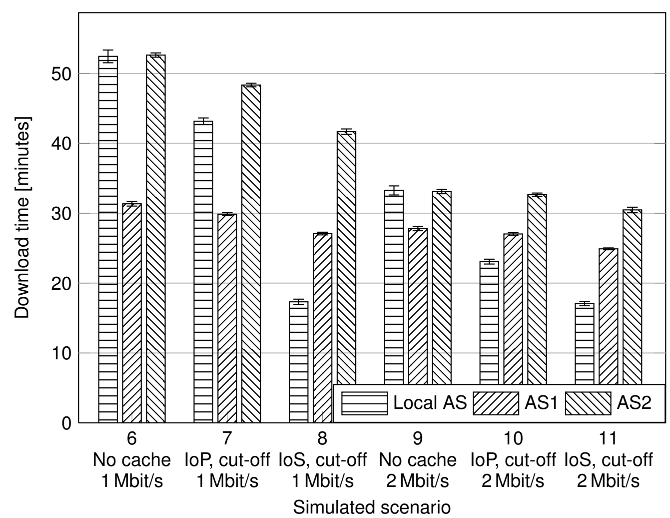

Fig. 9. Simulation results with the limited inter-AS bandwidth: average download times.

inter-domain traffic is already small, an IoP or IoS can further reduce it. This is true in scenarios where the inter-domain links allow 1 Mbit/s (scenarios 6 to 8) or 2 Mbit/s (scenarios 9 to 11).

b) Download Times: Results for the scenarios without inter-domain bandwidth limitations are shown in Fig. 8. In case of the unlimited upload policy of the IoP/IoS, the peers in all ASes profit to the same degree from the insertion of the IoP/IoS. In contrast, only the peers in the Local AS profit when the cut-off communication strategy is used by the IoP/IoS.

When the inter-domain bandwidth is limited (see Fig. 9), the download times for peers in AS1 remains at about 30 minutes in all investigated scenarios, because for all scenarios here the cut-off strategy is used. We first focus on the scenarios with a bandwidth limitation of 1 Mbit/s. The peers in the Local AS can download the file faster when an IoP is present and even faster with an IoS. The reason is that an IoS does not need to download the file and whole inter-domain bandwidth can therefore be used by the peers. Peers in AS2 also profit from an IoP/IoS because the content distribution in the Local AS is faster which creates more sources for possible data transfers. The effects for a bandwidth limitation of 2 Mbit/s (scenarios 9 to 11) are very similar. Hence, the simulations lead to the same conclusions as the testbed experiments.

IV. Summary

This study investigates the performance impact of caches on peer-to-peer based content distribution networks. Caches serve as simple means for ISPs to reduce the costly inter-domain traffic because regular BitTorrent clients can be used as caches, they only need to be equipped with sufficient upload capacity.

The experiments with real BitTorrent clients as well as the simulation study considers two different types of caches: the ISP-owned seed and the ISP-owned peer. The first one has already the entire content at the beginning, the other starts empty as the regular peers. The results show that both types can reduce inter-domain traffic as well as download times in the scenarios investigated in this study. Hence, the authors consider caches as a promising approach to improve the performance of peer-to-peer based content distribution networks for network operators and P2P users. However, caches can only be used for the distribution of legal content. Otherwise, network operators would be legally liable for participating in the distribution of copyrighted content.

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