# A framework of economic traffic management employing self-organization overlay mechanisms

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**Abstract.** Applications based on overlays have become very popular, due to the separation they provide and the improvement of perceived QoS by the end-user. Recent studies show that overlays have a significant impact on the traffic management and the expenditures of the underlying network operators. In this paper, we define a framework for Economic Traffic Management (ETM) mechanisms that optimize the traffic impact of overlay applications on ISP and telecommunication operator networks based on the interaction of network operators, overlay providers and users. We first provide a definition and an overview of Self-Organization Mechanisms (SOMs) and ETM for overlays. We then describe a basic framework for the interaction of components of SOMs and ETM, in terms of information and metrics provided, decisions made etc. Finally, we describe in detail how SOMs can be used to support ETM and we illustrate our approach and its implications by means of a specific example.

## 1 Introduction

Today's largest contributor to internet traffic is Peer-to-Peer (P2P) in its different forms. While up to now, P2P file-sharing caused the bulk of the traffic, recently Video-on-Demand applications that are also partly based on P2P are on the rise. What makes P2P traffic disadvantageous for Internet Service Providers (ISPs) is the fact that traffic is forwarded via logical overlay connections. These do not normally take into account the structure or load in the physical network, leading to the usage of many cross-ISP links, which incurs a high cost.

As a result, some providers have started to influence this traffic by throttling or even terminating P2P connections that leave their ISP network. As a short-term solution, it has the desired effect of lowering the provider's cost for forwarding traffic to a remote network. In the long run, however, the service quality for the ISP's customers is diminished, possibly leading to dissatisfaction and less income.

To overcome this dilemma, a solution needs to be found that does not negatively affect the service of the end users, but still lowers the cost for the providers. This is termed Economic Traffic Management (ETM). Currently, several research efforts are aiming at the shaping of P2P traffic according to Economic Traffic Management principles. One of these efforts is the ICT project SmoothIT[1], the main objective of which is to employ ETM to traffic generated by overlay applications in a way that is beneficial to all players involved.

In this work, we want to describe the general interaction possibilities between the physical network and ISP on one hand and the overlay on the other hand. To this end, we will first provide an overview of the related work and we continue by giving definitions and descriptions of the main two concepts used in this paper, Self-Organization (SO) and ETM. The notion of economic incentives in this context is also discussed. Then, we describe how overlays can be influenced and present an example for an architecture that includes these concepts. Finally, we provide some concluding remarks.

## 2 Background and Related Work

Since P2P systems organize nodes in an overlay network, a significant research effort is currently devoted to the design of scalable, fault-tolerant and communication-efficient overlay topologies. The third objective has become the most important since several studies, such as [2] and [3], show that especially peer-to-peer traffic has the largest share of the Internet traffic. Also, other ones indicate that emerging overlay services have rendered current traffic engineering techniques used by ISPs inadequate to keep the networks performance at a desired level [4].

In initial overlay construction algorithms, especially deterministic ones like CHORD [5], neighbors were chosen at random without any knowledge about the underlying physical topology [6]. This approach offered relatively simple overlay maintenance, but caused significant problems [7]; a packet along an overlay path may visit the same physical node several times [8], a low-bandwidth physical link may be shared by many overlays leading to high congestion and performance degradation, and traditional traffic management techniques may collide with overlay reorganization causing traffic oscillations [4].

In order to avoid such undesirable effects certain researchers proposed overlay construction and maintenance algorithms trying to bridge the gap between the overlay topology and the physical (underlay) network. Most approaches, like [9], [10], [11], probe candidate neighbors in order to select those that are relatively close. But having a large number of independent overlays performing network-layer measurements creates significant traffic. The authors of [12], trying to mitigate this problem, proposed a routing-underlay for overlays and an architecture for inter-overlay cooperation respectively, aiming to reuse underlay information by many different overlay applications. The performance of these approaches is evaluated to a very limited extent. Moreover, there is very little analysis of the issue of players incentives that would make such a collaboration and sharing of information achievable.

The well known capability of overlay networks to launch a new service globally on the Internet with a minimum of network resources being involved from the service provider's point of view has to be emphasized as a strong design approach for commercially successful applications. Therefore, the efficiency of support by caches in network nodes and in terminal equipment has to be considered a key factor with regard to all overlay structures, providing a benefit for ISPs and end-users. An economical evaluation of this practice can be found in [13].

## 3 Main concepts

In this section, we will give definitions of the main concepts used in our framework, and we will also briefly discuss the importance of the correct incentives for the stakeholders.

### 3.1 Self-Organization

The term self-organization (SO) is, in the following, defined on the level of overlay networks, i.e. logical networks above the physical network. In the context of overlays, SO means that a overlay network structure evolves by local decisions made by the peers participating in the network, without any higher authority directly intervening.

A SOM is a concrete algorithm implemented at each peer forming the overlay. It makes the local decisions that, in interplay with the decisions made at other peers, achieve self-organization. In order to influence the overlay network, the SOMs presented here make some kind of choice, e.g. between peers used as overlay neighbors. This choice is based on locally available data that is the input to the algorithm.

Examples for SOMs are the peer and chunk selection processes in file-sharing networks, such as tit-for-tat or Least-Shared-First [14]. Proximity Neighbor Selection and Geographic Layout in DHTs [15] are examples where underlay information is taken into account to form a structured overlay.

The data used as input for a SOM may be provided by other peers or by the underlay. The choice is made by applying a metric to this input. This metric provides semantics to the choice process by defining what makes one alternative 'better' than the other. To give a short example, using RTT as a metric in a SOM would structure an overlay completely differently than using the similarity in shared content as a criterion for selecting an overlay neighbor.

If the input for the SOM can not be provided by the peers themselves, the results of the SO depend on the quality of information available to the mechanism. A RTT measurement done by a peer, for example, may not be as reliable as similar information provided by the underlay itself.

### 3.2 Incentives for stakeholders

Stakeholders in the content of this paper are the end-users, the overlay providers and the network operators. As already mentioned, there are various implications of overlay traffic to the cost structure of an ISP that lead to a tussle between ISPs and overlay networks.

There are many types of incentives per stakeholder that favor (or not) the existence of overlay networks. The two most important ones, common for all the stakeholders, are the *monetary benefits* and the *performance improvements*. A common phenomenon is that incentives provided to one stakeholder may introduce negative effects to another one. For example, the performance improvements that an overlay provider may want to introduce may come in direct conflict with the economic incentives for the operator (ISP), since such improvements may change the traffic patterns, affecting the interconnection agreements and charges for the specific ISP. Furthermore, an action taken on the overlay may provide both monetary benefits and performance improvements for the same stakeholder, i.e., reduction of inter-domain traffic causes interconnection costs to decrease while the performance of the network might increase.

At this point, it is necessary to make an important observation: although the stakeholders in this environment are three, conflicts may appear only between the underlay (network operator) and the overlay (end-users and overlay provider) entities. Indeed, conflicts between the end-user and the overlay provider can only occur in the (improbable) case that the provider makes some drastic changes to the overlay application that alter the nature of the service provided, rendering it not beneficial for the end users.

Below, we provide a list of principals that may hold, so that we can reach a situation where all stakeholders are better off with the existence of an overlay network, i.e., such that a win-win-win situation occurs.

- Monetary benefits can offer the desired outcome, if there is a possibility of transferring/recovering costs through charging schemes.
- Monetary benefits can also apply when combined with performance improvements or with service differentiation in general.
- Performance improvements should not be considered as substitutes but as complementary to monetary benefits.
- Performance improvements for one stakeholder can provide monetary benefits for another one or vice versa. In other words, the type of incentives provided may not be the same for all stakeholders.

### 3.3 Economic Traffic Management

Economic Traffic Management (ETM) is one of the key concepts of this work and was already described in [16]. Its main objective is to achieve the co-operation between the overlay and the underlay, resulting in traffic patterns that optimize the use of network resources according to some given criteria. This is attained by means of ETM mechanisms that are beneficial for all players involved. That is, such mechanisms promote mutual compatibility of the incentives mentioned in the previous subsection.

In particular, ETM employs mechanisms that are related to economic incentives of the users in the overlay. That is, they affect (overlay and underlay) decisions, leading to a) a reduction of the economic cost incurred by the user and/or b) an improvement of the performance as perceived by the user.

At the same time, the way these incentive mechanisms operate and the state to which they lead the overlay is affected by information generated by the underlay and/or by policies employed therein. This way, the outcome of ETM is influenced by the underlay and its objectives. The objective of the ISP is to render this influence beneficial for himself as well.

The main toolkit of ETM is based on incentive mechanisms. The objective of such a mechanism is to shape the behavior of a participating agent by offering choices to him. The agent responds selfishly to the existence of the incentive mechanism and to choices he is offered. In particular, he performs such a selection so as to optimize his own objective function, in this case the performance of the service he is using. That is, he adopts among the valid alternatives the one that optimizes this index. Usually, each choice represents a trade-off between: a) the utility for the agent by the outcome given his choice and b) the relevant cost for him.

To illustrate this, we consider an ISP offering certain ADSL packages, namely different download rates at different charges. Some cases of the customers' objectives include the selection of: a) the highest rate that does not exceed a certain budget threshold, b) the lowest-cost package that exceeds a certain rate threshold, c) the package that represents the best value-for-money, i.e. the best trade-off between download rate and charge where both are considered as flexible.

A widely accepted objective function that quantifies such a trade-off is the net benefit, which equals the difference between the utility and the charge. In general, it is assumed that in order for a choice to be acceptable by an agent the resulting net benefit has to be non-negative.

To summarize what applies to our case: the provider (or in general the entity setting the mechanism) imposes a mechanism, to which the participating agents respond selfishly and there arises an overall outcome; the mechanism should be such that the objective function of the provider is optimized; in this case, his costs are minimized. Of course, the provider should also take into account the fact that certain agents may not participate due to the mechanism, which would, e.g., be the case for the bandwidth throttling mentioned before.

In the context of an overlay offering a specific service, e.g., file download or VoD, an increase in the service quality may always be considered as a benefit to the end user. Therefore, it should be the aim of ETM to encourage peer behaviour that incurs traffic where a provider prefers it, while simultaneously improving the quality of the service it is offering to the user. If it is not technically possible to do this, the user should be compensated in a different way. Still, a win-win situation is sought by ETM.

## 4 Interaction possibilities between SOMs and ETM

What makes SOMs useful to ETM is the fact that they run in the overlay; in fact most of the SOMs are already in place with the existing protocols. Of course, not all SOMs are appropriate for ETM. To see why this applies, we first classify the SOMs according to the selections they provide to the users in the overlay. In particular, the following possibilities apply:

1. SOMs offering no selections; e.g. DHT-based content location in Chord.
2. SOMs offering to the user selections that are not based on immediate incentives: e.g. the list of Kademlia-based "neighboring" peers, which, apart from preferring peers with a longer uptime, does not relate directly to any actual distance or other performance-related improvement.
3. Selections based on immediate application-layer incentives: e.g. which chunk to download first in BitTorrent ("rarest first replication"); this does relate to a performance-related improvement , which however is not related to the underlay conditions.

4. Selections based on immediate incentives that are related to the underlay: e.g. bandwidth-based selection of peer to download from in BitTorrent.

It is mainly the last category of SOMs that can serve as enablers of ETM. In particular, the underlay provides agents (i.e. users) participating in such SOMs with the information employed in order to make the selections that the SOM actually prescribes; e.g. RTT or other physical proximity metrics, for SOMs that prescribe that the selection of preferred peers is based on such metrics. This might, for example, be done by a) including such information to the tracker in BitTorrent, which will in turn provide it to the peers b) introducing a separate tracker in a BitTorrent like system that provides additional information about the network location of peers in a swarm, or c) having the underlay provide an interface for more reliable RTT measurements.

Furthermore, the selections made in the context of SOMs influence the traffic actually arising in the underlay, since they influence both the demand for traffic as well as the way it is routed. These interactions are depicted in Figure 1. Of course, the cases and the methods how the underlay can influence such SOMs for the benefit of all players involved are matters for further study, falling out of the scope of the present paper.

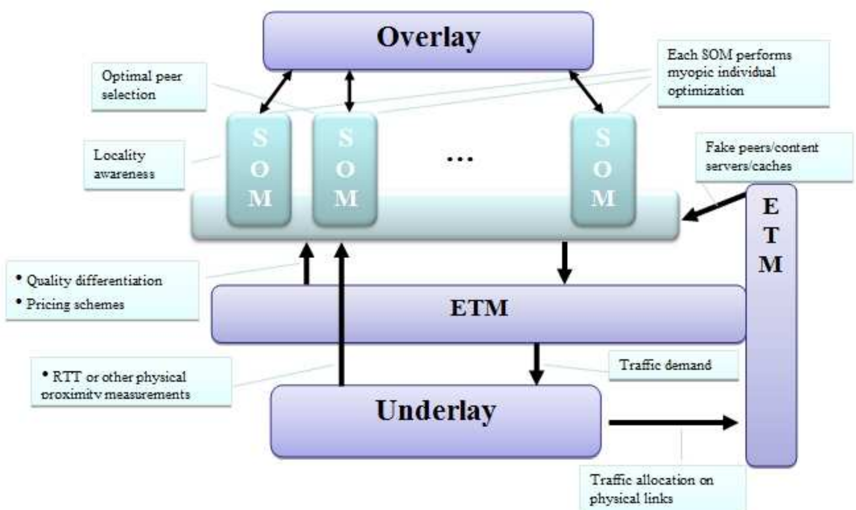



**Fig. 1.** Interactions among underlay, ETM, SOMs and overlay.

Since most of the applications considered are already implemented and working without the application of ETM, the latter should indeed provide extra benefits to the overlay layer, in order for these applications to adopt changes. This is to be achieved by offering incentives to all parties involved, e.g. better QoS/QoE for end users and less cost for ISPs, as discussed in Section 3.2. It should also be noted that SOMs already run under the existing protocols. On the one hand, this imposes constraints to the way ETM can be realistically applied, but on the other hand does provide an opportunity and a challenge for their implementation.

### 4.1 Realization of Interworking

The purpose of the interworking between ETM and SOMs is the improvement of all players' payoff. That is, the end-users, the overlay provider and the ISP should all benefit from such an interworking, which should thus lead to a win-win-win situation.

Realization of ETM can be divided into two major categories of approaches based on the "transparency" of those mechanisms as it is seen from the point of view of the overlay. In particular, the first category comprises non- transparent ETM approaches where ETM is not enforced, but there are incentives given to the overlay provider in order to adopt ETM with them, e.g. by means of price differentiation, QoE, etc. The second category comprises transparent (for the overlay provider) ETM approaches where the overlay provider is not involved; on the contrary either the user is given incentives to alter his behaviour according to the information provider by ETM, or ETM is performed "directly" by introduction of hardware components or other network entities, etc. Three major approaches that reflect the above discrimination are described below.

**1. Interworking of SOM and ETM performed by the overlay provider - Non-transparent ETM** In this case, the overlay provider can be given incentives in order to modify his overlay protocol, although these incentives are rather indirect. Here, the interaction between the overlay provider and the operator leads to a win-win situation. Indirectly, 'win' for the overlay provider implies also 'win' for the end-users (see Section 3.2). In order to perform SOMs, it is necessary that the overlay provider is aware of underlay information, e.g. proximity measurements, RTT, link congestion, link costs, etc. This information is provided to the overlay provider by the ETM mechanism. The changes to the overlay protocol that are required have to be implemented, perhaps by means of plugins to the existing software, but have to be carefully done in order to be compatible with older versions of the protocol. In fact, provision of two versions of the software may lead to an even higher benefit for the overlay provider besides the extra satisfaction of the users. For example, he may introduce some charge to the improved version, while keeping the standard version for free. Another possible gain for the overlay provider can be imagined in a scenario where the content is originally offered by the overlay provider, e.g., software patches distributed via BitTorrent. In this case, a fast and efficient download directly influences the popularity of the content provider (which is here the overlay/tracker provider) with his customers.

**2. Interworking of SOM and ETM performed by the end-users - Transparent ETM** In this case, we assume that the overlay provider is reluctant to modify the application protocol, although this does not necessarily imply that such a modification would not be beneficial to him. So, the interworking between ETM and SOM leads to a win-win situation for the end-users and the operator. Here, the end-users can be given incentives, e.g. QoE, price differentiation, in order to make different choices based on new criteria that would complement or substitute the existing ones. Again, all the information that is necessary is provided to the end-users' clients by the ETM, e.g. by an ISP-provided information service.

Other example of this approach could be the QoS differentiation according to the end users' requests that is being defined in the ITU-T NGN or in ETSI/TISPAN. In this scenario, the end users could request enhanced network performance for overlay based applications in order to optimise the different traffic profiles. In particular, according to the Y.1541[17] the classes of services *HighThroughputData* and *MMStreaming* are specified, the provisioning of network performance guarantees could benefit BitTorrent and/or Joost users.

Effectively, in this scenario, the user could request enhanced capabilities for its overlay application. In this case the ETM must be able to dynamically configure the network resources according to the end users' demands. This request could be also associated with a locality manager. In order to meet this requirement, the ETM could take advantage of the control planes of the next generation networks that allows the dynamic configuration of network resources. Therefore, the ETM must also cover the interaction with the management modules in charge of reserving and configuring network resources, such as the ETSI/TISPAN RACS [18].

This could be the way to build carrier class services based on overlay networks: the ETM mechanisms will receive the request to improve the performance for the overlay application and the ETM could apply different algorithms, such as the combination of locality with QoS guarantees. This could be the basis to implement differentiated pricing schemes: for all those end users that will like to enjoy improved quality, differentiated services will be available, not only for specific operators services but also for overlay applications.

**3. Intervention of ISP to SOMs -Transparent ETM** In this case, the operator interferes in the overlay protocol and plays an active role in the re-organization of the overlay network. This can be implemented by introducing extra equipment to its premises. For instance the operator inserts new entities in the overlay network, e.g. caches, ISP-owned peers, etc., that affect the overlay formation. While the mechanisms described there are somewhat artificial with respect to the SO aspect of the overlay, they may provide the possibility for a more direct influence for an ISP.

In this case, the underlay operator participates in the SOMs through these entities in order to achieve its own performance and cost optimization, e.g. reduction of resources consumption, reduction of inter-domain traffic, reduction of monetary cost paid to other operators (transit agreements). There are examples where an ISP just considers its own advantage, e.g., by throttling P2P traffic, regardless of the wishes of its customers. However, the operator must also ensure that the end-users' performance does not degrade; otherwise he will end up losing customers. Here, the interaction of ETM and SOMs results in a win- non-lose situation, because it is enough if the end-users' performance remains the same. In addition, when intervention to SOMs is performed by the operator, all necessary underlay information is directly available by the operator himself. ETM, also by the operator, is necessary in order to concentrate and organize this information.

### 4.2 Other Issues

There are several other issues concerning the aforementioned interactions. The information exchange between the overlay and the underlay plays a large role, making the timescale of updates and the reliability of information important considerations. Also, it is unclear how the provision of information about the underlay structure may be exploited by malicious peers or overlays. Due to space limitations we will not provide a detailed discussion about these topics here.

## 5 Application of interworking approaches to BitTorrent

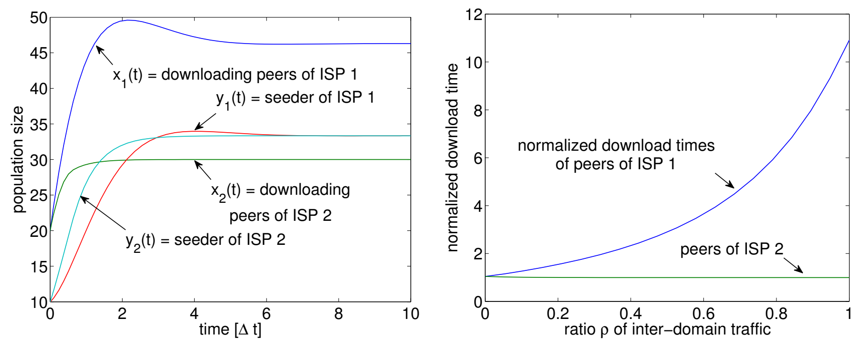
In this section, we will provide an example to illustrate how our framework applies to a concrete P2P system. We consider the application file-download, supported by the BitTorrent overlay. The main objective to achieve by implementing changes to this P2P network is to lower the traffic in the inter-ISP links between providers.

To achieve a traffic reduction on transit links purely by overlay means, a SOM is utilized here. The aim is that peers should prefer download connections to other peers in the same AS instead of exchanging data with remote peers. The SOM used to achieve this goal is the neighbor selection done at the tracker. The tracker assembles a list of peers and returns this list to the querying peer. The decision on which peers to include in that list is made so that the ETM aim is supported. Since in BitTorrent a new peer, who wants to download a specific piece of content, must contact the tracker for that file, this affects every peer in the network.

To this end, information describing the underlay situation must be made available to the overlay. In this case, this is less complicated than in a completely distributed scenario, since only the tracker has to be informed. A possible implementation of this information exchange follows the pull model, where the tracker contacts a separate, ISP-provided information service with the IP of the peer requesting neighbor data. Thus, this method is a non-transparent ETM as described in the previous section. An example of such a service is presented in [19]. The information service is also informed about all peers currently participating, and in case of peers connected via the local ISP also their location and other characteristics. It selects the peers it deems beneficial to both the network and the peer in question using a metric. Then it returns this list to the tracker, which may forward or modify it. To this end, a mapping of peers to ISPs has to take place, in order to allow the tracker to contact the information service of the correct ISP. Alternatively, one central information service might be created, with different implications for the distribution of provider-dependent information. The interface between the tracker and the ISP-provided information service thus serves as an information exchange between the over- and the underlay.

A metric reflecting the ETM purpose described is, e.g., the cost generated by a connection between the local peer and the peer that is evaluated by the metric. This need not be the actual money that has to be spent by the ISP to maintain that connection, but may be normalized. It also could reflect link utilization, i.e., less congested links are treated as less costly. In general, this metric should return better values for peers close to the local peer, i.e., that have short physical links in the same ISP network. The metric allows for an ordering of the peers the tracker knows with respect to the peer requesting a neighbor list. The $n$ best peers are put on the list, perhaps along with a small selection of random peers in order to enhance the stability of the overlay.

As a result in the above example, the response times of the chosen peers are expected to be shorter, and the available bandwidth in a link between the local peer and these




(a) Population sizes (b) Normalized download times

**Fig. 2.** Qualitative performance results when ISP 1 blocks incoming traffic

peers is expected to be higher, since physical links with low utilization are preferred. Data transfer connections between the local peer and his neighbors therefore may expect higher throughput. This, however, has to be weighted against the different selection of download sources for peers. If extreme precedence is given to peers in the same ISP network as neighbors, the danger of a network separation is created. In this case, peers would experience a much worse download performance, since the resources of all peers sharing the same file are no longer pooled. In general, the neighbor selection process has to avoid compromising the overlay network stability and performance. If it can not be avoided that peers experience a performance degradation, alternatively, other methods of compensation have to be provided by the ISP in order to secure the participation of the users.

Another example for a negative influence of an ETM mechanisms on overlay performance is the naive implementation of peer selection together with traffic blocking. In this scenario, a modified tracker responds to a client's request only with a share $\rho$ of clients in remote ISPs' networks. Additionally, one ISP in this scenario blocks all incoming P2P traffic. We assume that outgoing traffic is not blocked.

To illustrate the impact of ETM on the performance of the peers in that ISP's network, we use the simple fluid model for BitTorrent in [20] and modify it appropriately to take several ISP's networks into account. This allows for a first, rough estimation of the effects of ETM in some abstract scenarios. In the model $x_i(t)$ and $y_i(t)$ is the number of downloaders and seeds within ISP $i$ at time $t$, respectively. File requests follow a Poisson process with rate $\lambda_i$ within ISP $i$. The seeds within ISP $i$ leave the system at rate $\gamma_i$. The uploading and downloading bandwidth of a peer is $\mu$ and $c$, respectively. The parameter $\eta$ describes the effectiveness of the file sharing system and is derived in [20]. The parameter $\rho$ describes the ratio of inter-domain traffic between different ISPs. Then, the system can be described by the following equations:

$$r_1 = \min\{cx_1(t), \mu(1-\rho)\,(\eta x_1(t) + y_1(t))\} \tag{1}$$

$$r_2 = \min\{cx_2(t), \mu\rho\,(\eta x_1(t) + y_1(t)) + \mu\,(\eta x_2(t) + y_2(t))\} \tag{2}$$

$$\frac{dx_i}{dt} = \lambda_i - r_i \ , \ \frac{dy_i}{dt} = r_i - \gamma_i y_i(t) \tag{3}$$

Fig. 2 shows that the peers in question experience longer download times due to a lower number of eligible sources. Of course, this very coarse-grained model can only give qualitative results hinting at the real system behavior. As a consequence, we plan to investigate such dependencies in-depth in our future work. In general, the incentive for the ISP to provide cost information is the fact that if the overlay prefers to establish low-cost connections, the cost for the ISP to handle the traffic now flowing over these connections is lowered. On the other hand, the end user should be able to observe shorter download times, i.e., a better service quality. Since both parties involved gain an advantage by using the described system instead of the original implementation, it is likely to be accepted.

A transparent alternative to reduce inter-ISP traffic without diminishing the application performance is to attract traffic away from remote networks by simply offering better conditions for downloads in the local network. This can be achieved by placing caches or provider-owned peers that have a high amount of resources to offer.

Due to peer selection mechanisms like tit-for-tat, these entities can bind traffic to them by offering higher upload rates and shorter answer times than remote peers. The client 'chooses' to download from the local caches instead of from remote peers because it experiences a higher throughput by doing so. Therefore, the incentive for the user can be assumed, even if there is no conscious choice, in contrast to the first example, where the overlay/tracker provider or the client version can be changed. Additionally, no information about the underlay is explicitly disclosed to the overlay, which might be an important issue with an ISP.

If popular files are cached, a large portion of the data traffic from the overlay can be affected. No changes in the protocol are necessary for the original peers, making this method transparent to the overlay. The provider alone can implement it without being dependent on a cooperation with the users or overlay providers. Additionally, the provider is able to gather more information about the traffic characteristics of that application and feed it into its network management process.

However, this mechanism has several disadvantages as well. Since much more traffic is created by provider controlled peers than by the information service described above, the resulting cost is also higher. Also, not all peers may be attracted to the provider peers, leading to a comparably lower reduction of traffic on the inter-ISP links. Apart from this, legal issues might prevent a provider from offering storage space for data exchanged in a file-sharing network.

## 6 Conclusions

In this paper we have investigated the interaction possibilities between the overlay and underlay network. More specifically, due to the tussle between overlay providers and network operators, there exists the need to provide common incentives to all stakeholders to achieve an efficient co-existence of overlay and underlay networks. Initially, we propose to use SOMs as a mean to deploy economic-aware traffic management techniques, leading to minimization of expenditures for the network operators, while offering performance improvements for the end-users. The main contribution of this work is the investigation of the cooperation possibilities that exist between SOMs and ETM. We examine all different approaches to achieve this and we further illustrate our vision by means of a realistic example, specific to the BitTorrent application.

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