Towards the Future Internet
G. Tselentis et al. (Eds.)
IOS Press, 2009
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doi:10.3233/978-1-60750-007-0-24

An Economic Traffic Management Approach to Enable the TripleWin for Users, ISPs, and Overlay Providers

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Abstract. Socio-economic aspects play an increasingly important role in the Future Internet. To enable a TripleWin situation for the involved players, i.e. the end users, the ISPs and telecommunication operators, and the service providers, a new, incentive-based concept is proposed referred to as Economic Traffic Management (ETM). It aims at reducing costs within the network while improving the Quality-of-Experience (QoE) for end users. In particular, peer-to-peer (P2P) overlay applications generate a large amount of costs due to inter-domain traffic. ETM solution approaches have to take into account (a) the traffic patterns stemming from the overlay application, (b) the charging models for transit traffic, and (c) the applicability and efficiency of the proposed solution. The complex interaction between these three components and its consequences is demonstrated on selected examples. As a result it is shown that different ETM approaches have to be combined for an overall solution. To this end, the paper derives functional and non-functional requirements for designing ETM and provides a suitable architecture enabling the implementation of a TripleWin solution.

Keywords. Economic Traffic Management, inter-domain traffic, locality-awareness, P2P VoD, SmoothIT architecture

1. Introduction

One of the key applications in today's and probably also the Future Internet is P2P content distribution. This ranges from straightforward file-sharing to the more recent P2P-based video streaming, which is projected to rise even more in popularity. The large numbers of users these systems attract as well as the huge amount of data they efficiently distribute shows their scalability and is one reason for their success.

However, these same features create new difficulties for network and Internet Service Providers (ISPs). Overlay connections used by the P2P networks are up to now generally network agnostic and therefore wasteful with resources. Especially the liberate use of inter-domain connections, i.e., the transit links between ISPs, causes a high cost. Also, the high probability that a connection spans the networks of several providers complicates the provision of end-to-end traffic management needed for specific services. This is compounded by the fact that most P2P overlays do not use one single connection to provide such a service, e.g., one video stream, but many at the same time. The number and quality of these flows changes dynamically with the overlay's topology and population. Supporting application diversity by service differentiation poses a challenge to the provider, since the user's experienced service quality (Quality of Experience QoE) depends on the individual flows' QoS. Currently, the IETF ALTO (Application-Layer Traffic Optimization) Working Group has been established which also identifies the above mentioned problems and focuses on improving P2P performance and lowering ISP costs.

To resolve this, several approaches exist. On is to simply stifle P2P traffic as a provider, with the aim to improve the performance of other services and to lower its cost. However, this strategy runs the danger of having a detrimental effect on customer satisfaction, and is therefore not an optimal choice.

A different solution to the problem described above is Economic Traffic Management (ETM), see [Fern08,O+08]. It operates under the assumption that all parties involved (ISP, user and, if applicable, overlay provider) will participate voluntarily in a management scheme they all profit from. As a consequence, this scheme has to provide incentives to these players to cooperate, so that in the end, a 'TripleWin', i.e., a win-win-win situation is created. In the following, we demonstrate the complex interaction between ETM solution approaches, the charging models used by ISPs, and overlay traffic characteristics and evaluate qualitatively their applicability. We discuss (1) the ETM mechanisms locality promotion and ISP-owned peers, (2) the 95th percentile rule as charging model, and (3) the applications BitTorrent-based file sharing and VoD. Based on this discussion, functional and non-functional requirements for the design of an overall ETM solution achieving the TripleWin situation is derived.

Finally, the SmoothIT overall architecture takes into account these requirements and allows the implementation of various ETM approaches. This is put into context of related work and existing other projects in the same area of interest.

2. ETM Solution Approaches

In the following, we discuss two different ETM solution approaches, locality promotion and ISP-owned peers (IoP). Locality promotion aims at reducing inter-domain traffic by fostering the exchange of data among the peers within one domain. Therefore, topology information is exchanged between underlay and overlay resolving the information asymmetry. The IoP approach aims at increasing QoE and reliability of a content distribution network by providing additional capacity supporting the dissemination of popular contents.

2.1. Locality Promotion / Locality Awareness

Locality promotion aims at keeping traffic in the same Autonomous System (AS), instead of having long connections spanning several networks. The goal is to lower costs that are created by two effects of these long-reaching connections.

The first is that connections that are long in terms of hops consume more transmission, routing and switching resources than shorter ones. The second is that inter-carrier traffic has to be paid, depending on the agreement between the two ISPs in question. Therefore, the promotion of overlay traffic locality is a key issue under an operator's perspective since it may reduce both network investments and transit costs.

To illustrate this, consider a P2P overlay network where a peer knows of several sources for a (partial) file download. Some of these are in the same AS as the local peer, some are in an AS the local peer's ISP has a peering agreement with, and some can be reached only via transit links to other AS. Normal overlay selection mechanisms do however not consider this information (also because they do not possess it), therefore the data transfer connections are largely random from the ISP's point of view. Depending on the number and location of the potential sources, probability is high that some of these connections use expensive transit links.

Here, one method of promoting locality is to provide an information interface for the overlay, such as the SmoothIT Information Service (SIS) described in Section 7. It can be queried by a peer to provide an informed ranking of the potential sources based on locality, as well as providing a better QoS to users of this service, in order to improve their experienced service quality.

2.2. ISP-owned Peers

This approach does, in comparison to the locality promotion, not necessitate cooperation with the overlay to work. It works by adding more resources to the overlay network in the form of ISP-controlled peers, so that the usage of these resources, such as storage and upload capacity, may be utilized to the ISPs advantage. In a variation of this scheme, also a common peer that shows certain characteristics may be granted some of these resources by the ISP (e.g., Highly Active Peers (HAP)). In any case, this peer offers the same functionality as any other peer. However, there may still be some minor modifications, such as increasing the number of upload slots of that peer. Still, this peer is not percepted as a special entity in the system by the other peers.

By participating in the normal data exchange of the overlay, the ISP-owned Peer (IoP) is able to download and cache content and provide it to other peers as a seed. Since it should provide a higher bandwidth due to its allocated resources, it should be a popular overlay neighbor, depending on the mechanism the overlay uses. The tit-for-tat peer selection algorithm, e.g., prefers good uploaders. Apart from the fact that this addition of resources to the overlay improves its performance, it also allows for influencing traffic. The IoP serves as a traffic attractor, and additionally has the possibility to use locality-aware mechanisms such as biased peer selection.

If the overlay wants to cooperate with an ISP using this strategy, the tracker in a BitTorrent-like architecture is in a perfect position to announce or at least propose the IoP as a regular overlay neighbor to the normal peers. Also, helpful information like the global popularity of content useful to cache, or the size and distribution of swarms could be provided to the ISP. Otherwise, the ISP would have to monitor such information by implementing additional modules for the IoP.

3. Charging Models

The Internet is characterized as an informal hierarchy of operators [MPD+] and structured in three tiers. The first level includes the *Tier 1 IAPs* (Internet Access Providers), which interconnect with each other and form the "backbone" of the Internet. In the second level, we have the *Tier 2 ISPs*, which usually have some network of their own, limited to a geographic region, and they partly rely on Tier 1 IAPs to obtain world-wide access, by purchasing some level of transit. As, no traffic symmetry is expected between a Tier 1 IAP and a Tier 2 ISP, the Tier 2 provider pays to Tier 1 provider an amount specified by the details of the traffic rules in place. Depending on the status, the Tier 2 ISP could be charged for the volume of inbound traffic or for the difference between inbound and outbound traffic. Such a charging rule is referred to as *transit agreement*. At the same time, Tier 2 ISPs can have interconnection agreements with other Tier 2 ISPs, so-called *peering agreements*, without any charging due to symmetric traffic exchange. *Tier 3 ISPs* are purely re-sellers of Internet access services and rely solely to interconnection agreements with Tier 2 ISPs to gain Internet access.

Therefore, a Tier 2 ISP play an interesting role regarding TripleWin. One of a Tier 2 ISP's objectives is to reduce his interconnection costs which has to be achieved by a viable ETM solution. Throughout the paper, when we refer to an ISP we consider the case of a Tier 2 ISP.

3.1. The 95th Percentile Rule

One of the most prominent charging models for transit agreements is the 95th percentile rule. Let us consider a typical Tier 2 – Tier 1 transit agreement. The difference d_x between inbound and outbound data throughput of the Tier 2 ISP is measured for every Δt=5 minutes time slice *x*. Then, the Tier 2 ISP is charged on the monthly 95th percentile of the differences per time slice, formally $C_{month} = P95\{d_x\} \cdot Price/Mbps$.

One of the main tasks for ETM related to the 95th percentile pricing scheme is to determine which parameters affect the generated costs, so that we can devise ETM mechanisms that decrease those costs for the ISP. One parameter that can be influenced and has direct effects on the costs is the amount of traffic flowing in both directions. One way to do is applying locality awareness, as already mentioned. However, depending on the application (file sharing or video-on-demand) locality may decrease the traffic either in both directions (e.g. due to tit-for-tat for file-sharing) or only in one direction (e.g. using give-to-get for video-on-demand). In addition, the different overlay applications will show different traffic patterns.

3.2. Estimation of Parameter Sensitivity

Figure 1 shows the actual effects of different traffic patterns, as well as the effect of the duration *Δt* of the observation window. On the x-axis, *Δt* (in seconds) is given while the 95th percentile value is depicted on the y-axis.

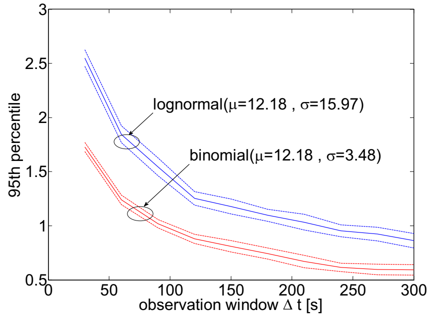

Figure 1. Impact of different distributions and duration of capturing window

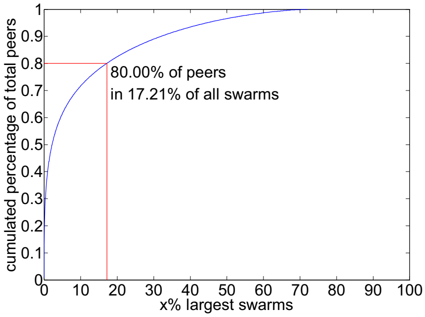

Figure 2. Measurement of population sizes of BitTorrent swarms

We simulate different types of traffic pattern where packets arrive according to a Poisson process, while the packet sizes follow a binomial and a lognormal distribution respectively. The simulations were repeated 1000 times and the average 95th percentile out of the repetitions as well as the 95% confidence intervals are given. As a result, we see that the traffic pattern but also the length of the observation window play an important role in the calculation of the 95^{th} percentile value.

4. Overlay Traffic Characteristics

The traffic generated by an overlay depends on several factors, such as the application class it belongs to and the size of the overlay. In the following, we will shortly illustrate these issues.

4.1. Differences between Overlay Application Classes

We compare the main mechanisms influencing the traffic behavior of two overlay classes, namely BitTorrent-like file-sharing and Video-on-Demand (VoD). They differ mainly in the peer and chunk selection processes used. For file-sharing, a Least-Shared First (LSF) strategy is used for chunk selection, while the peer selection is based on the tit-for-tat principle. In contrast, a VoD system has to also take into account the playout deadlines of chunks, and, due to the different playout positions of different peers, has to rely on a strategy like give-to-get for peer selection. Additionally, the peer selection here is much more important for the QoE of the end users, also because a video's quality is much more sensitive to QoS parameters, such as the minimum bandwidth achieved for a stream.

Another consequence of the different peer selection algorithms is that the different ETM approaches do not achieve the same effect, i.e., for a tit-for-tat strategy, traffic locality will lower both incoming and outgoing traffic. If the charging scheme works on the difference between the volumes of these two traffic streams, the effect on the ISP's cost may be minimal. Since give-to-get is not symmetric, the effect of the same approach in a VoD system can be expected to be much larger.

4.2. Measurement of BitTorrent Swarm Sizes

In a BitTorrent-like system, each separate piece of content (e.g., movie, archive or document) has its own overlay, the so-called swarm, where it is distributed. To estimate the effectiveness of ETM measures in one such swarm, its size has to be known. Figure 2 shows results from a study of typical swarm sizes of BitTorrent swarms. The measurements were conducted in August 2009 and 63,867 BitTorrent swarms offering video contents were investigated. It shows that a Pareto-principle governs the total peer distribution: a large share of the peers can be found in a small number of swarms. This has several consequences for the ETM mechanisms employed in such a system. Depending on the swarm size an IoP or HAP is participating in, its optimal position and allotted resources vary. Also, more popular content can be cached by participating in larger swarms, while on the other hand the increase of resources by adding one or a small number of IoPs to such a swarm may be negligible.

For locality promotion, the impact of these results is different. For this mechanism, it is important that swarms are large in order to provide local alternatives for remote neighbours. If a swarm is too small, only few peers are actually in the same network, prohibiting an overlay restructuring due to a lack of choices.

5. Exemplary ETM Solution for BitTorrent using Locality Promotion and IoPs

This section will discuss the mutual interdependency of ETM, charging scheme, and overlay characteristic at the example of BitTorrent file sharing. We have seen that there are many small BitTorrent and few very large BitTorrent swarms. As a consequence, BitTorrent swarms of all sizes contribute significantly to the overall BitTorrent traffic, and for an ETM to work efficiently it has to tackle swarms of – if possible – all sizes. Locality promotion potentially reduces the inter-domain traffic for large swarms. However, there is a critical number of peers per swarm required within an ISP's network in order to successfully use locality promotion for achieving a substantial reduction in inter-domain traffic without simultaneously decreasing the overlay's performance and thus violating the win-win-win maxim of ETM.

The IoP provides a solution for smaller swarm sizes. However, the number of swarms it can support simultaneously is limited mainly by the available storage. The achieved inter-domain traffic reduction per required storage capacity i.e. per CAPEX shrinks dramatically with the swarm size. A simulation study using ns-2 has been performed based on [E07]. In order to investigate the effects of locality promotion and IoP, simulations were performed on a 50 peer swarm subdivided 35 to 15 in two networks A and B. Locality promotion in B achieves a symmetric inter-domain traffic reduction of about 15%. Additionally inserting an IoP in network B leads to an asymmetric change reducing the ingress traffic of B by 45% while simultaneously increasing the ingress traffic of A by 55%.

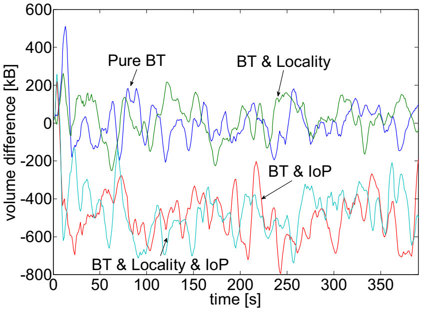

Figure 3. Simulation results of difference between inbound and outbound traffic

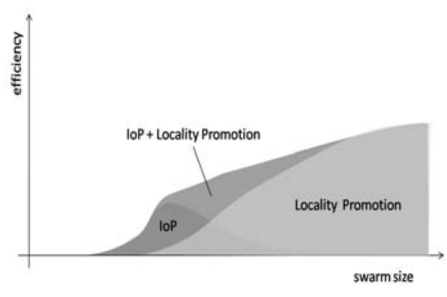

Figure 4. Qualitative illustration of inter-play of Locality Promotion and IoP

Now, the charging model comes into play when evaluating the usefulness of the ETMs. Our exemplary charging scheme is sensitive to asymmetric changes only while symmetric changes have no direct impact on the costs. Figure 3 shows the difference of inbound and outbound traffic for network A. Locality promotion does not affect this difference while the IoP clearly shifts the traffic difference in the favor of A deploying the ETMs. When interpreting A as a Tier 3-ISP and B as a Tier 2-ISP the use of an IoP is beneficial for the Tier 3-ISP. Whether there is an actual monetary benefit, on the one hand depends on the OPEX and CAPEX for the ETM and on the other hand on the exact charging model and the achieved traffic reduction which again depends on the swarm sizes.

For an efficient operation of ETMs we propose a combined and purposeful usage of ETM mechanisms depending on the present overlay application and its characteristics. E.g., the IoP is good for small to medium swarms. Its efficiency can be improved by a more directed use which is enabled by a SIS like architecture that resolves the information asymmetry. Figure 4 gives a qualitative impression on the regions of operation for the different ETM mechanisms. A qualitative statement on the efficiency of IoP and locality interplay is still subject to further studies.

6. Requirements for the ETM System Design

The requirements for the ETM system design are derived from the overall goals, the scope of solution approaches, and the overlay traffic characteristics as discussed in the selected examples above. Table 1 outlines main functional and non-functional requirements identified for the SmoothIT architecture.

Table 1. Functional and non-functional requirements for the ETM system design

ID	*Functional Requirement*	*ID*	*Non-functional Requirement*
R.1.	Improving P2P application performance while reducing the network traffic	R.10.	Easy deployment
R.2.	Incentive-compatibility for all player involved	R.11.	Extensibility for new overlay applications
R.3.	Support of different overlay applications	R.12.	Scalability in terms of large end-user population.
R.4.	Interface supporting various optimization schemes	R.13.	Efficiency of the SIS operation
R.5.	QoS support	R.14.	Robustness of the SIS against malicious behavior and against dynamic behavior
R.6.	Different operations: user anonymity mode (free services), user aware mode (premium services)	R.15.	Security: Secure communication between SIS entities and between SIS and overlay application
R.7.	Inter-domain support	R.16.	Standard compliance: The SIS shall use and based on standard protocols where applicable.
R.8.	OAM (Operation and Management) support	R.17.	Transparency: The SIS shall not apply Deep Packet Inspection (DPI).
R.9.	Mobile network support		

A key functional requirement is to manage overlay traffic and to improve P2P application performance in a way that results in a TripleWin situation for all involved entities. Additionally, the architecture shall support different overlay applications in an integrated manner, while providing various optimization schemes. The architecture shall also allow inter-domain interactions between ISPs. The integration of QoS and OAM (Operation and Management) support are also highly relevant in an operational environment. Finally, the architecture shall provide special optimization schemes for mobile networks.

In terms of non-functional requirements, to be able to deploy the SmoothIT architecture in a real world environment, an easy deployment is essential. The architecture and protocols used shall be extensible in order to be able to integrate new overlay applications, optimization schemes, and metrics. Furthermore, scalability, efficiency, and robustness are essential for a large-scale operational environment. Additionally, security mechanisms shall be integrated into the architecture and data privacy and regulations shall be considered. Finally, the architecture shall use existing standard protocols, where applicable.

7. SmoothIT Architecture Design

The SmoothIT architecture provides a flexible service that can be used with a variety of ETM schemes. The service – termed SmoothIT Information Service (SIS) – is an instantiation of the overall architecture developed. It includes interfaces for the bidirectional communication between ISPs and overlay applications and among different ISPs. The SIS is able to provide information about policy, locality, congestion, charging, and QoS, in order to help overlay applications decide how to efficiently build and maintain the overlay network. The SIS has to be provided in a way that prevents the exploitation of the SIS information by malicious users/applications and enables the ISP to hide sensitive network status information.

Figure 5 shows the functional components of the SmoothIT architecture. The SIS server provides the SIS service to the SIS Client and it is the core component of the architecture. It is responsible for providing support to the overlay formation process, aiming at optimizing both overlay and ISP interests. The SIS server is deployed by each ISP and provides the SIS service within the network of the ISP. Additionally, a SIS server can request preference information from other SIS servers deployed in other network domains. This server-to-server interaction is used to provide refined preference information for inter-domain connections.

The Admin component enables the ISP to configure SIS internal parameters over the administrative interface, such as the QoS classes of services, the maximum number of flows that can be prioritized, or how locality must be enforced. This is configured using a graphical management interface, which the network administrator can use to review the current configuration parameters and modify them as necessary.

The Metering component is responsible for performing network measurements. It can be composed of one or more modules that can perform different measurements. The results are combined by the SIS server, according to settings configured by the Admin component. The BGP Information Module, for example, retrieves locality information from the BGP protocol. It takes into account the local preference, the AS hop count, and the MED (Multi Exit Discriminator) BGP attributes.

The Security component provides access control to the SIS service, i.e. authentication and authorization for the SIS Client, the Admin, and other SIS servers. Additionally, data confidentiality and integrity are ensured by secure communication channels between components.

The Configuration database (Config DB) stores ISP policies and is responsible for any information that an ISP can configure for the SIS architecture. The database, which may be based on an existing repository of the ISP, contains information about different types of business relations the ISP has with other ISPs and performance related metrics corresponding to each network.

The QoS component checks the availability of network resources and guarantees resources requested by overlay applications, as well as enforces QoS policies in the network. The QoS component is important to enable the provisioning of premium services to end-users and overlay providers.

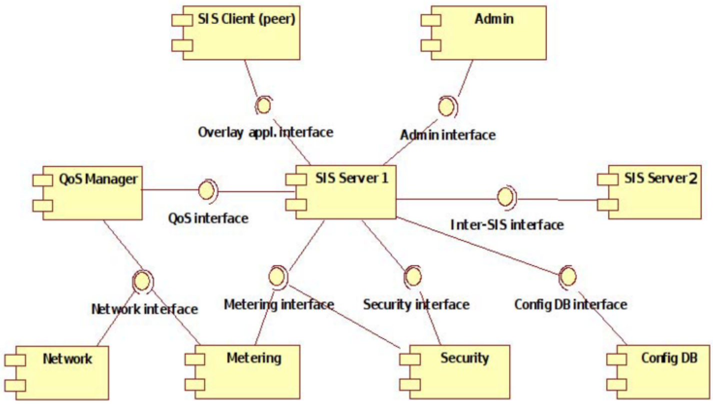

Figure 5. SmoothIT architecture

8. Related Work and Projects

Based on the review of related work and projects, we provide a concise comparison to the ETM and TripleWin approach described above and highlight the key differences.

The biased neighbor selection [BCC+06] relies on the popular file sharing tool BitTorrent [BT]. It adjusts the original protocol [C08], where a central tracker server provides new peers with a random set of other peers, so that new peers preferentially receive addresses of peers located in the same network domain. To this end, the tracker needs information about the network domain of all peers. The evaluation shows that biased neighbor selection reduces download times of files and inter-domain traffic.

Aggarwal et al. [ASF07] propose to use an oracle service to achieve the aforementioned goals. Peers send a list of potential neighbors to the Oracle Service which orders it according to the preferences of the network provider. Different metrics for the ordering are possible, e.g., the number of autonomous system (AS, [HB96]) hops on the path from the peer to its potential neighbor. Consequently, it is more application-independent than biased neighbor selection and allows a more fine-grained differentiation of possible connections. Simulations have shown that the oracle service significantly reduces the number of inter-domain connections and the amount of inter-domain traffic. A more detailed evaluation is given in [AAF08].

The network topology information desk service (NTIDS) [B03] is very similar to the oracle service. The network provider offers an information desk service which can be queried by peers. The service sorts a list of IP addresses of potential neighbors for a specific peer according to the network providers' preferences. For this purpose, it uses the routing information to determine the proximity of the given addresses.

The architecture of the P4P project [XKS+07, XYK+08], "Proactive Network Provider Participation for P2P", also provides an entity which maintains information about the network topology and location of peers. This entity is called iTracker and controlled by the network provider and be queried by a tracker or the peers depending if the system is tracker-based or tracker-less. The iTracker assigns all peers to locality clusters and keeps cluster-to-cluster preferences reflecting the preferences of the network provider, e.g., cost or the traffic policies. Simulations show that using an iTracker reduces inter-domain traffic and improves application performance.

This paper's ETM approach shows similarities with these approaches discussed, like an interaction between overlay applications and the underlying network in the form of a generic information service, the provisioning of locality information, and the reduction of inter-domain traffic. However, there are several key differences: (1) The ETM approach considers not only locality information, but additional approaches, such as applying differentiated pricing or providing QoS-enabled services. (2) Related projects consider mainly pure file-sharing. In contrast, TripleWin aims at developing a solution applicable for different overlay application types, like file sharing and video streaming, and, therefore, will consider different application characteristics. (3) Related projects rely on a cooperation of all involved players. But this may not be possible, if not all players can benefit from the solution proposed. Therefore, TripleWin focuses on incentives to achieve collaboration among players. This also involves investigating inter-domain interactions in closer detail. Finally, ETM within the SmoothIT project follows an overall picture, where the relationship between charging and incentive models, overlay application traffic characteristics, and ETM solutions is essential.

9. Conclusions

In this work we have introduced the concept of economic traffic management (ETM). In particular, we have shown that a successful application of ETM depends not only on the solution approaches, but also on the charging model and the overlay application. The complex interaction between these three components and its consequences is demonstrated on selected examples. As ETM solution approaches we consider locality promotion to reduce inter-domain traffic and ISP-owned peers to enhance the available resources within the network. The 95th percentile rule charging scheme is presented as a prominent example for transit agreements. The impact of different overlay applications are elaborated for BitTorrent-based file sharing and video-on-demand. We conclude that the spectrum of applicability of a single ETM mechanism is rather limited. Only the intelligent and coordinated usage of various ETM mechanisms can successfully exploit the optimization potential currently present in uncoordinated underlay-agnostic overlays. The paper derives functional and non-functional requirements for designing ETM and provides a suitable architecture, as well as a protocol proposal enabling the implementation of such a TripleWin solution. Finally, differences to existing projects and related work are outlined.

Our current research studies focus on investigating the mutual interdependency of ETM, charging schemes, and overlay applications, not only qualitatively, but also quantitatively. In detail, we have to investigate the overall costs when keeping traffic locally; on one hand we save inter-domain traffic and costs, on the other hand we may increase the number of "internal" hops and therefore costs or we might introduce additional components, like IoPs or SIS which consume CAPEX and OPEX costs. Furthermore, we have to keep in mind the diversity of transit agreements and their impact on the ISP's costs for overlay traffic. Depending on the results, we may propose pricing rules for Tier 1, Tier 2 or Tier 3 providers, specifically designed for achieving a TripleWin situation when applying ETM. Methods from game theory seems to be appropriate for identifying and validating them. The proposed architecture will be implemented and the usefulness as well as the feasibility of the different ETM solutions will be demonstrated in experimental facilities.

Acknowledgements

This work has been performed partially in the framework of the EU ICT Project SmoothIT (FP7-2007-ICT-216259). Furthermore, the authors would like to thank all SmoothIT project members for providing insights and their discussions.

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