

Internet Design Principles for Economic Traffic Management

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Abstract. Traditional traffic management techniques employed by Internet Service Providers (ISP) cannot successfully deal with the increasingly high volumes of overlay traffic and lead both overlay and underlay to sub-optimal behavior. Individual optimizations as performed on each different layer result in low Quality-of-Experience (QoE) for the overlay users and, therefore, limited business opportunities for the Overlay Providers (OP) as well as high inter-connection charges for the ISPs. A solution to this problem is Economic Traffic Management (ETM), an incentive-based approach, which employs economic concepts and mechanisms and promotes cross-layer cooperation in order to deal with the overlay traffic and lead to a beneficial situation for all (Future) Internet stakeholders. In order for the ETM framework to be successfully employed, current Internet design principles should be revisited and new ones need to be defined to meet Future Internet's requirements. In particular, these new Internet design principles that will help to define the Future Internet's architecture include the promotion of cooperation between different layers and players, and the information exchange between them.

Keywords: Economic Traffic Management; Future Internet; cross-layer; cross-player; information exchange; design principles; requirements.

1 Introduction

Overlay applications generate huge volumes of traffic in the Internet due to their grand popularity and large sizes of files they are typically exchanging. This typically underlay-agnostic overlay traffic results in high inter-domain traffic, which implies significant charges for Internet Service Providers (ISP). As a consequence, ISPs often take routing decisions ignoring overlay's requirements. Individual optimization in the overlay (decisions made either at random or taking partly into account underlay information) and in the underlay (as in traditional Traffic Engineering) may lead both layers to a sub-optimal situation, *e.g.*, involving traffic oscillations on the physical layer and degraded Quality-of-Experience (QoE) for the overlay users [1].

This Information Asymmetry problem (as described above), which arises between the two layers, overlay and underlay, can be addressed by an approach based on incentives that promotes cross-layer cooperation. Such an approach employs economic concepts and mechanisms to deal with the overlay traffic in a way that is incentive compatible for all parties involved and, thus, leads the system to a situation that is mutually beneficial for all end users, Overlay Providers (OP) and ISPs. The so-called "All-Win" situation is the main target of the Economic Traffic Management (ETM) framework [2] proposed by the SmoothIT¹ project [3]. The ETM framework deals with performance requirements of traffic at both overlay and underlay levels, and enables the reduction of ISP inter-connection costs.

The current Internet was designed at times when its use was quite limited. The research community believed that connectivity was more valuable than any application, and intelligence was available at the edges of the network rather than within the network itself [4]. The architecture of the current Internet is based on a number of design principles that include: simplicity, modularity, scalability, the self-describing datagram packet, the end-to-end argument, heterogeneity in technology, and global addressing.

However, as the Internet has moved from being an object of research to a massively used commercial component and the popularity of overlay applications has dramatically increased, too, new requirements emerged, which cannot be adequately addressed by the current Internet design principles any more. Therefore, current design principles need to be revisited and updated in order to define the context and rules that will govern the architecture of the Future Internet in which ETM can play a primal role. In this paper, ETM objectives are described as well as new design principles are outlined, which successfully address ETM's design objectives.

The remainder of this paper is organized as follows: Section 2 describes the design space of the ETM framework, in Section 3 proposes and discusses the new Internet design principles that should govern the Future Internet architecture and the ETM framework, and finally, Section 4 concludes the work.

2 ETM Design Objectives

The goal of the ETM framework is to employ economic concepts and economic-aware incentive-based mechanisms in order to promote the collaboration across layers for the efficient management of overlay traffic. The main focus is P2P traffic (of either file sharing or video streaming applications), but it can be extended to all kinds of overlay traffic that deals with or requires the efficient sharing of content/information, *e.g.*, Cloud Computing or Content Delivery Networks.

In this context, the high-level design objectives of the ETM framework are the following:

¹ The SmoothIT project started in January 2008 to investigate and provide a solution to the questions of optimizing peer-to-peer traffic by economic means.

- **Cross-layer optimization:** the framework should support overlay traffic optimization in both layers, underlay (any network-related protocols) and overlay (any protocol above TCP/UDP),
- **Cross-player optimization:** the framework should support overlay traffic management in a way that all players "win", ISPs in terms of operational (*e.g.*, inter-connection) cost reduction, users in terms of QoE, and OPs in terms of business opportunities,
- **Promotion of cooperation between players and layers, respectively:** the framework should provide incentives to all different players and layers, respectively, to exchange information.

Analyzing in depth the aforementioned high-level objectives, one can deduce the lower-level design objectives:

- i) **Genericity:** the framework should support any incentive-based economic-aware mechanism, various rating functions, and can interact with any kind of overlay traffic,
- ii) **Scalability:** the framework should scale up in order to cope with the scaling of the overlay network, particularly its number of peers and ISPs,
- iii) **Robustness/Stability:** the framework should deal with malicious behavior and should be fault tolerant,
- iv) **Security:** wherever applicable, communication between entities in the same or different layers should be secure, and
- v) **Simplicity and Cost-Effectiveness:** the framework should be kept simple so that resulting costs due to its introduction can be outbalanced by the respective attained benefits.

The aforementioned ETM objectives are also compatible with the goals of the ALTO WG² (Application Traffic Optimization work group) [5] and its requirements [6]. The ETM formulation introduced in this paper and within the SmoothIT project has been undertaken independently and to a large extent developed in parallel to IETF initiatives within ALTO WG.

3 ETM Design Principles and Example Discussion

The set of design requirements and limitations, which a traditional protocol-based approach does follow, have been outlined in the FIA Arch document [7]. However, the inclusion of additional dimensions of importance, especially the economic as well as inter-stakeholder relations, leads to a set of three additional design principles. Those include in case of the ETM approach the following three principles and they enable an open outcome as well as different players' behaviors:

- Approaching inter-connection aspects inherently into the design.

² The IETF ALTO WG was established during 2008 to specify and design a special ALTO service providing applications (whatever the type) with information influencing the choice of resources (servers or peers) and in consequence to perform better than-random overlay traffic management.

- Delivering a compromise in modularization compared to the strict layering.
- Addressing locality information besides pure routing knowledge.

The key results obtained in the design as well as implementation of ETM mechanisms within the framework of the SmoothIT work show that such design rules reveal a full-fledged and strong set of viable principles. In particular, those results include qualitative studies related to the reliability and scalability constraints of ETM mechanisms, which address specifically the inter-connection views of Internet Service providers as well as the locality information of communicating hosts. In addition, the modularization undertaken in the ETM approach shows that further functional components can be added seamlessly to the existing Internet protocol architecture, without changing those known layering principles.

Furthermore, quantitative studies on a set of many different ETM mechanisms have been undertaken, which are based on simulative research, taking into account very different scenarios and many diverse conditions [8]. Finally, a variety of studies has been carried out on a theoretical basis, but they are also supported with extended simulation studies, including stochastic modeling and game theory. Thus, these studies mentioned here give clear indications that those three design principles have been achieved and that respective ETM mechanisms can be used and applied in real networks. The technical investigations undertaken summarize key results on all investigated ETM mechanisms and design principles by presenting detailed conclusions derived by those investigations; for technical details refer to [9].

Thus, in turn, the combination of ETM objectives and requirements suggest new design principles that will play a primal role in the architecture of the Future Internet. Therefore, the refined and applied design principles to govern an entire ETM framework are as follows:

- Allow the exchange of information between different players and layers (*e.g.*, between underlay and overlay, between ISPs) to coordinate the objectives of each player and layer, respectively. Thus, the interconnection and modularization principle is met.
- Avoid revealing all details of information gathered by each player and layer, by aggregation and normalization through the use of generic rating functions. A rating function transforms specific metric values owned by one layer into abstracted values that can still serve the purposes of the other layer. Thus, the locality principle is met.
- Pursue the “All-Win” situation through the following means:
 - Promote the discovery and consumption of local³ resources, by the introduction of economic- and/or performance-based incentives.
 - Provide economic- and/or performance-based incentives to affect the behavior of overlay entities towards a more underlay-friendly behavior.

³ Local resources are resources that reside in the same administrative domain with the consuming entity.

The design principles in general for ETM as well as its refined ones for ETM mechanisms promote the cooperation between players and layers, respectively, and provide relevant and viable incentives to players to take decisions rather than forcing them to adopt certain behavior. The design for incentives' provisioning and the cooperation promotion is compatible with in the work on tussles [10], where a new design principle was introduced to address the variation in the outcome. This principle suggests that the Internet design should not *dictate* the outcome, rather *permit* different players to express their preferences.

3.1 The BGP-Loc Example

The BGP-Loc (Border Gateway Protocol Locality) ETM mechanism [11] proposed by the SmoothIT project is designed based on the aforementioned design principles. BGP-Loc employs BGP information similar as for traffic control in the underlay to characterize resources (*e.g.*, servers or peers) in order to promote locality in the overlay's choices. In particular, an overlay entity provides an underlay service a list including a set of other overlay entities possessing some content (resources). The underlay service assesses the set of overlay resources and replies to the overlay querying entity by providing a rate calculated based on real BGP values for each overlay resource in the list. Then, the overlay entity is free to decide whether it will select resources based on the rates provided by the underlay service or not.

An underlay service (operated by the ISP) using BGP routing information in order to calculate a rating value for peers providing a certain resource (resource providers) has been proposed in an ALTO draft [12], while the interface for the communication between the overlay entity and the underlay service was covered in [13] ALTO draft. Consequently and complementarily, the [14] draft has covered communication between ALTO servers to exchange useful information for advanced peer ranking algorithm.

The information exchange between the two layers addresses the Information Asymmetry problem, since BGP proximity information is made available to the overlay (which would not be in any other case), without though revealing critical information of the underlay. The BGP-Loc ETM mechanism has proven be means of simulations, test-bed and real field experiments to significantly improve inter-domain traffic of the underlay, and improvement of overlay users QoE, especially when they belong to larger domains.

3.2 Studies on ETM Mechanisms

Within the ETM framework, a multitude of additional ETM mechanisms is available, such as the ISP-owned-Peer (IoP), the Highly Active Peer (HAP), and the Inter-SmoothIT-Information-Service (Inter-SIS) mechanism, all of which have been

investigated in detail and which can run as an example for the applicability, viability, and effectiveness of them in a real, productive Internet-based network [9].

Below, the following key results are summarized, and they have been obtained by simulative and analytical evaluations of the aforementioned ETM mechanisms:

- In comparison to native overlay operation, even the simplest locality ETM mechanism (studied most extensively) is profitable, generating "All-Win" situations.
- To address the inter-connections issues explicitly, it is advisable that the simple locality mechanism is used in combination with the so-called Inter-SIS mechanisms to deal with the inter-domain paths asymmetry. In addition, to control intelligently the traffic between peering and transiting inter-domain links this mechanism is able to diminish a possible unfairness related to different sizes of Autonomous Systems (AS).
- The ISP-owned-Peer (IoP) ETM mechanism is advantageous – in comparison to the pure overlay operation – especially for smaller ASes.
- Finally, the Highly Active Peer (HAP) ETM mechanism is fully independent of other functionality in the network and shows a very promising mechanism, since its operation is positively influenced by real human behavior, thus, the user of network and communication services.

4 Conclusions

Concluding this paper on the definition, short discussion, and brief explanation of design principles investigated and proven in the domain of economic and stakeholder relations for Internet-based communications, the following facts can be stated:

- i) ETM mechanisms are applicable and technically feasible,
- ii) ETM mechanisms are effective as well as outcome-open,
- iii) ETM mechanisms exist, which show low overhead in many cases and reasonable efforts in others,
- iv) ETM mechanisms can be integrated into the Internet protocol suite without changes, as applications and their respective clients may need optional interface and parameter adaptations,
- v) The use of ETM mechanisms is not mandatory, however, incentives exist to apply them within in a stakeholder's domain, and
- vi) ETM mechanisms are transparent in their use.

The application of ETM mechanisms follows successfully the new design principles of addressing inherently inter-connection, a balanced modularization, and locality aspects. As many simulations and the trials have shown in an implemented prototype, the advantages as well as quantifiable gains are showing an economically considerable viable approach, which can lead, upon its implementation, to an

optimization of traffic management problems of inter-ISP communications under well-defined guidelines.

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