Investigating the Influence of Market Shares on Interconnection Settlements

Ruzana Davoyan and Jörn Altmann

***Abstract*— This paper investigates the role of providers' market shares for consumers and websites on interconnection settlements between networks. We proposed to differentiate traffic into two types, referred to as native and stranger in order to determine an original initiator of transmission in the IP network and to compensate the interconnection costs. In comparison to the existing financial settlement, under which the payments are based on the net traffic flows, the proposed model governs cost compensation according to the differentiated traffic flows. Analytical studies were provided using Nash bargaining solution to explore how the presented approach affects the providers' payments. The key consequence of the obtained results shows that symmetry of the costs is not required prerequisite for peering, and asymmetric providers can arrange interconnection without monetary transfers.**

***Index Terms*— Interconnection arrangement, intercarrier compensation, Internet economics.**

I. Introduction

The Internet is a system of interconnected networks, which are connected either through a direct link or through an intermediate point, called Internet exchange point (IXP) to exchange traffic. Currently the Internet provides two types of interconnections, such as peering and transit [1]. Peering is the arrangement of traffic exchange on the free-settlement basis, called bill-and-keep (BAK), so that the Internet service providers (ISPs) do not pay each other and derive revenues from the respective customers [2]. In the transit model a customer provider pays a transit provider to deliver the traffic between the customers. Negotiation process over being a transit or peered customer reflects on the assessment of the actual cost of traffic exchange and was studied in [3-4]. Peering offers several advantages in terms of interconnection costs and quality of data transmission, however, limits access to the network. As cited in [5] according to the estimates, 80% of the Internet traffic is routed via private peering. In some cases, however, in order to recover the infrastructure costs, instead of peering with the smaller ISPs, the larger ISPs offer transit arrangements that might be expensive, but give access to the whole Internet.

Due to rapid growth of the Internet traffic, bottleneck occurs at IXPs among the networks [6]. The reasons of peering bottleneck at the interconnection points are mostly economic. First, there is no money exchange between peers, since originated traffic volumes are symmetric and providers would both benefit equally. As a result, networks have little or no economic incentive to increase capacity to terminate traffic [7]. Second, lack of pricing at the peering points leads to the overuse of the network resources, and eventually, IXPs become congested.

Traditionally, before interconnection the provider calculates whether the interconnection benefits would outweigh the costs [8]. In case of telephony, the study [9] argued that both calling and called parties benefit from the call, and consequently, should share the interconnection costs. In the Internet, under symmetry of traffic volumes, the termination costs are set to zero, since it is assumed that the termination fees are roughly the same, and peering arrangement is used. If traffic is unbalanced, interconnection arrangement is governed by the financial compensation in a unilaterally or bilaterally negotiated basis to recover the costs of the network. The survey and discussion on interconnection with the two-sided benefits are provided in [10-11].

Various aspects of interconnection of ISPs have been analyzed by [9], [12-14]. This work is focused on private peering arrangement and addresses the problem of cost sharing between providers. Generally, when providers are asymmetric in terms of size, peering model is not appropriate, since it is assumed that providers incur different costs and benefit differently. When analyzing economics of interconnection, existing literature considers intercarrier compensation based on the flows of traffic. However, it was cited in [5] that traffic flows are not a reasonable indicator to share the costs, since it is not clear who originally initiated any transmission and therefore, who should pay for the costs. In other words, compensation between providers cannot be solely done based on the traffic flows.

The main objective of this research is to investigate the impact of providers' market shares for consumers and websites on interconnection settlements between them. For this purpose we suggest to determine an original initiator of transmission by means of traffic differentiation into two types, referred to as *native* that is originally initiated by the provider's own customers and *stranger*, which is initiated by the customers of a rival network. In comparison to the existing negotiated-financial settlement [3], under which the payments are based on the net traffic flows, this study proposes to compensate the costs according to the differentiated traffic flows. More specifically, each ISP compensates fully the termination costs incurred from delivering native traffic and

R. Davoyan is with the Department of Mathematics and Computer Science, University of Mannheim, 68131 Mannheim, Germany (email: rdavoyan@mail.uni-mannheim.de).

J. Altmann is with the School of Information Technology, International University, Campus 3, 76646 Bruchsal, Germany, and with TEMEP, School of Engineering, Seoul National University, South-Korea (email: jorn.altmann@acm.org).

978-1-4244-2324-8/08/$25.00 © 2008 IEEE.

This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE "GLOBECOM" 2008 proceedings.

partially the termination costs incurred from carrying stranger traffic. Traffic differentiation allows introducing a caller concept similar to the telephony in the Internet. However, in contrast to the telephony, according to the proposed approach a transmission initiator is not considered as a cost causer, who should cover the joint costs, but rather both parties share the costs.

Analytical studies based on the bargaining model were provided to determine the payments of the providers. The obtained results demonstrated that asymmetric providers under asymmetry of traffic flows could benefit equally, and on the other hand, identical providers in terms of size could benefit differently. Therefore, symmetry of costs structure is not required for peering.

This paper is organized as follows. Section II examines existing intercarrier compensation arrangements. Section III presents the motivation for traffic differentiation. Section IV provides analytical studies. Finally, Section V concludes the paper.

II. Intercarrier Compensation

There are essentially two possible arrangements of intercarrier compensation for the telecommunication networks, such as BAK and calling party's network pays (CPNP) [2]. The BAK model is fair and efficient under symmetry of traffic flows as well as termination charges and costs. However, because no termination cost is charged, BAK is considered inefficient in terms of the cost compensation [15]. Indeed, cost allocation is the issue of the combined marginal costs allocation, and therefore, costs should be allocated according to the benefits obtained by each party. Assuming that both parties benefit equally, under balanced traffic flows in both directions, BAK is appropriate.

Unlike BAK, the CPNP arrangement assumes that the subscribers do not pay for the incoming calls. Instead, access charges are designed to compensate the interconnection costs. Under CPNP, the calling subscriber pays originating access charge to the calling party's local exchange carrier (LEC) and terminating access charge to the called party's LEC. The fundamental problem of this model is that terminating carrier, irrespective to its size, has a termination monopoly and can increase termination charges without lost of its customers [15]. The CPNP model is used in public switched telephone network (PSTN), however, is not applicable in the Internet. The principle reason is the difference in the infrastructures of these two networks. Unlike PSTN, which is circuit-based and connection-oriented, the Internet is packet-based and connectionless.

III. Traffic Differentiation

The principle that we follow is that both parties derive benefits from the exchanged traffic and should share the interconnection costs. Considering a system without externalities [3], [16], the costs should be shared based on the benefits obtained by each party. However, in real world, it is impossible to measure the benefits of parties and so to share the costs. When content is not equally distributed between providers, traffic imbalance occurs, and therefore, costs and revenues are not shared evenly. Indeed, the network that sends more traffic incurs lower cost, than the network that receives more traffic [17]. As cited in [18], traffic flow is dominant towards a customer requested the content and generates 85% of the Internet traffic. This implies that inbound traffic is much more compared to outbound traffic of content request.

Generally, providers arrange the financial settlements in order to determine the distribution of the interconnection costs. To examine the financial settlements [3], [19] in the Internet, first, consider a telephony system where Alice makes a call to Bob. Accepting the call, Bob incurs termination costs to its provider that should be covered either directly by billing Bob or indirectly by billing calling party's carrier. As cited in [15], "existing access charge rules and the majority of existing reciprocal compensation agreements require the calling party's carrier, …, to compensate the called party's carrier for terminating the call". Thus, an initiator of the call, i.e. Alice pays the subscribed provider for the entire call, since Alice asked to reserve the circuit. In contrast to the telephony, in the Internet, Alice does not make any reservation of the circuit, and usually packets between Alice and Bob are routed independently via different paths. As cited in [12] "at this point, it is very important to distinguish between the *initiator* and the *sender*, and likewise between the *destination* and the *receiver*". The initiator is the part that initiates a call or a session, and the destination is the part that receives a call. In comparison, the sender (the originator) is the part that sends traffic, and the receiver (the terminator) is the part that receives traffic.

In telephony the initiator is considered as the originator and is charged based on the transaction unit, namely a "call minute" for using the terminating network. In the Internet, it might be argued that TCP session can be considered as a call, where the initiator of a session pays for the entire traffic flow. However, considering actual use of the network resources, financial settlement should be done at the IP level, accounting each packet of a flow. In this case, money flow direction coincides with the traffic flow direction. In summary, session-based accounting, which faces with technical difficulties, is more complicated than a simple packet-based accounting, under which the volume of the exchanged traffic in both directions should be measured. Therefore, generally, providers adopt the negotiated-financial settlement, where payments are based on the net traffic flows. For detailed discussion see [3], [12], [20].

According to [5], the traffic flows are not a good meter for costs sharing, since "it is impossible to determine who originally initiated any given transmission on the Internet". On the other hand, providers are unwilling to inspect the IP header of a packet, since "the cost of carrying an individual packet is extremely small, and the cost of accounting for each packet may well be greater than the cost of carrying the packet across the providers" [20].

In order to determine a party that originally initiated the traffic we propose to differentiate traffic into two types, referred to as *native*, which is originally initiated by the provider's own customers, and *stranger* that is originally initiated by the customers of the peered network. Indeed, outgoing traffic of ISP$_i$ that is the same as rival provider's incoming traffic may be i) either a part of transmission initiated by a customer of ISP$_i$, ii) or a part of transmission initiated by a customer of the peered network. Hence, it is assumed that the provider compensates the termination costs i) fully, if the exchanged traffic is native, and ii) partially, if the originated traffic is stranger. More specifically, the private peering networks settle the proposed agreement, whereby each partner is compensated for the termination costs that it incurs in carrying traffic according to the differentiated traffic flows.

IV. The Model of Interconnection

Analytical studies are based on the bargaining process that is explored using Nash bargaining solution. The intuition behind this principle is that peering is long term and repeated process, arranged under mutual benefit, and hence, sustainable cooperation between the interconnected providers is reasonable. This approach was studied in [21]. In analysis two types of the customers, namely consumers and websites are considered [13]. Actually, traffic is exchanged 1) between consumers, 2) between websites, 3) from websites to consumers, and 4) from consumers to websites. Generally, traffic between websites and from consumers to websites is negligible. Recently, peer-to-peer (P2P) traffic has increased rapidly. The significant part of the Internet traffic, comprised of FTP, Web, and streaming media traffic, is from websites to consumers. In order to investigate how the interconnection settlements depend on market shares for consumers and websites, we focus on traffic exchange i) between consumers, ii) from consumers to websites, and ii) from websites to consumers. Traffic between websites is neglected, since it does not have any significant impact on the results of the analysis. To simplify the analytical studies the following assumptions were made throughout the paper:

Assumption 1 Let $\alpha_i \in (0,1)$ network *i*'s market share for consumers and $\beta_i \in (0,1)$ its market share for websites. It is assumed that there exist two providers $i \neq j = 1,2$ and $\alpha_i + \alpha_j = 1$ $\beta_i + \beta_j = 1$.

Assumption 2 The number of consumers and websites in the market is given by N and M respectively. Each customer chooses only one provider to join, because of homogeneity of the services.

Assumption 3 For simplicity we assume a balanced calling pattern, where each consumer calls to any consumer, requests a call from any consumer as well as requests any website in any network with the same probability. In addition, each consumer downloads a fixed amount of content.

We start by examining a scenario, when ISP$_i$ fails to sign an interconnection agreement with ISP$_j$. The utility or benefit of joining ISP$_i$ for each consumer is $u(\alpha_i + \beta_i, N, M) = f(\alpha_i + \beta_i)$, and each website's utility is $h(\alpha_i, N) = g(\alpha_i)$. The presence of network positive externalities assumes that $f'(\cdot) > 0$ and $g'(\cdot) > 0$ [16]. In case of disagreement between providers, the total traffic volume generated by ISP$_i$ is given by

$$t_i = \alpha_i N(\alpha_i N - 1) + \alpha_i \beta_i NM + \alpha_i \beta_i NMx \quad (1)$$

where x is the average amount of traffic generated by each website. It is assumed that each consumer originates one unit of traffic per each request of website. Thus, pre-interconnection demand function of network *i* is described by

$$D_i^{pre} = t_i \;\; if \;\; f(\alpha_i + \beta_i) \geq 0 \;\; and \;\; g(\alpha_i) \geq 0 \quad (2)$$

Let network *i*'s marginal costs of origination and termination are $c_i^o > 0$ and $c_i^t > 0$ respectively, where $c_i^o = c_i^t$ and c_i is the total marginal cost [13]. We do not consider fixed network cost, and for simplicity assume that transmission cost is normalized to zero, since peering model is considered. The profit of ISP$_i$ from on-net traffic is defined by

$$\pi_i = [\alpha_i N f(\alpha_i + \beta_i) + \beta_i M g(\alpha_i)] - c_i t_i \quad (3)$$

Suppose that ISP$_i$ obtained an agreement with ISP$_j$. It is assumed that providers' market shares for customers do not change in case of interconnection. In this case each consumer's utility is $u(\alpha + \beta, N, M) = f(\alpha + \beta)$ and each website's utility is given by $h(\alpha, N) = g(\alpha)$. The volumes of the differentiated traffic exchanged from ISP$_i$ to ISP$_j$ are given by

$$t_{ij}^{nat} = \alpha_i \alpha_j N^2 + \alpha_i \beta_j NM \quad (4)$$

$$t_{ij}^{str} = \alpha_j \beta_i NMx \quad (5)$$

where t_{ij}^{nat} and t_{ij}^{str} denote native and stranger traffic volumes with respect to ISP$_i$. Similarly, the traffic volumes from ISP$_j$ to ISP$_i$ are given by

$$t_{ji}^{nat} = \alpha_i \alpha_j N^2 + \alpha_j \beta_i NM \quad (6)$$

$$t_{ji}^{str} = \alpha_i \beta_j NMx \quad (7)$$

where t_{ji}^{nat} and t_{ji}^{str} are native and stranger traffic volumes with respect to ISP$_j$. The total traffic volumes are defined by

$$t_{ij} = t_{ij}^{nat} + t_{ij}^{str} \quad (8)$$

$$t_{ji} = t_{ji}^{nat} + t_{ji}^{str} \quad (9)$$

Thus, in case of agreement the demand of ISP$_i$ is defined by

$$D_i = t_i + t_{ij} \;\; if \;\; f(\alpha + \beta) \geq 0 \;\; and \;\; g(\alpha) \geq 0 \quad (10)$$

Let a_i and b_i are network *i*'s access charges for terminating native and stranger traffic respectively, where $a_i > b_i$, since the provider compensates partially the costs of terminating stranger traffic. To carry out analysis, it is assumed that each network access charge for terminating native traffic is set to the termination marginal cost, i.e. $a_i = c_i^t$. The access charge for terminating stranger traffic determines how the costs are shared between consumers and websites. It is defined by $b_i = \varepsilon a_i$, where $0.5 \leq \varepsilon < 1$. However, in order to simplify analysis it is assumed that $\varepsilon = 0.5$. The profit of ISP$_i$ obtained interconnection is calculated as follows

$$\Pi_i = \pi_i + \sigma_i \quad (11)$$

where σ_i is the *incremental profit* that ISP$_i$ gets from the interconnection, i.e. from off-net traffic exchange, which is destined to a subscriber of another network and is given by

$$\sigma_i = \alpha_i N f(\alpha + \beta) + \beta_i M g(\alpha) + t_{ij}^{nat}(-c_i^o - a_j) + t_{ij}^{str}(-c_i^o - b_j) + t_{ji}^{nat}(a_i - c_i^t) + t_{ji}^{str}(b_i - c_i^t) \quad (12)$$

The outcome of *i*'s network according to the bargaining game

[22] is defined by

$$\phi_i = 0.5(\Pi_i + \Pi_j + \pi_i - \pi_j) = 0.5(\sigma_i + \sigma_j) + \pi_i \qquad (13)$$

If $\sigma_i > \sigma_j$ then ISP$_j$ receives the net payment from ISP$_i$ that is

$$\phi_j - \Pi_j = 0.5(\sigma_i - \sigma_j) = 0.5\Delta\sigma \qquad (14)$$

It is assumed that the network externalities exhibit constant returns to scale, where $f''(\cdot) = 0$ and $g''(\cdot) = 0$, meaning that the networks have the same incremental revenues, while the incremental costs increase as the network size decreases. By substituting (12) in (14), it can be obtained that

$$\phi_j - \Pi_j = 0.5\left[t_{ji}^{nat}\left(2a_i + c_j^o - c_i^t\right) - t_{ij}^{nat}\left(2a_j + c_i^o - c_j^t\right)\right] + 0.5\left[t_{ji}^{str}\left(2b_i + c_j^o - c_i^t\right) - t_{ij}^{str}\left(2b_j + c_i^o - c_j^t\right)\right] \qquad (15)$$

The net interconnection charge can be interpreted as two independent components i) one for native traffic business, which is denoted by $\Delta\sigma_{ij}^{nat}$, and ii) another for stranger traffic business that is denoted by $\Delta\sigma_{ij}^{str}$.

Proposition 1 *The net payment from ISP$_i$ (ISP$_j$) to ISP$_j$ (ISP$_i$) is a) increasing in t_{ji}^{nat} and t_{ji}^{str} (t_{ij}^{nat} and t_{ij}^{str}), and b) decreasing in t_{ij}^{nat} and t_{ij}^{str} (t_{ji}^{nat} and t_{ji}^{str}).*

Proof: Partially differentiating $\Delta\sigma_{ij}^{nat} + \Delta\sigma_{ij}^{str} = \Delta\sigma$ with respect to the corresponding parameters leads to

$$\frac{\partial\Delta\sigma}{\partial t_{ij}^{nat}} = -\left(2a_j + c_i^o - c_j^t\right) < 0, \qquad \frac{\partial\Delta\sigma}{\partial t_{ji}^{nat}} = \left(2a_i + c_j^o - c_i^t\right) > 0$$

$$\frac{\partial\Delta\sigma}{\partial t_{ij}^{str}} = -\left(2b_j + c_i^o - c_j^t\right) < 0, \qquad \frac{\partial\Delta\sigma}{\partial t_{ji}^{str}} = \left(2b_i + c_j^0 - c_i^t\right) > 0$$

Proposition 2 *If $\alpha_i = \alpha_j = 0.5$ and $\beta_i = \beta_j = 0.5$, then the net payments between providers are zero.*

Proof: Since the networks are symmetric in terms of size, therefore $c_i^t = c_j^t$. From the conditions (4)-(7), (15) follows that $t_{ij}^{nat} = t_{ji}^{nat}$, $t_{ij}^{str} = t_{ji}^{str}$, $\sigma_i = \sigma_j$, and $\phi_i - \Pi_i = \phi_j - \Pi_j = 0$.

Proposition 3 *If $\alpha_i = \alpha_j$ and $\beta_i > \beta_j$ then ISP$_i$ subsidizes ISP$_j$ for native traffic.*

Proof: Since $\beta_i > \beta_j$ then $c_i^t < c_j^t$.

Native: From the conditions (4), (6) follows that $t_{ij}^{nat} < t_{ji}^{nat}$. Considering the component for the native traffic business, it is obtained that $\Delta\sigma_{ij}^{nat} = 0.5\left[t_{ji}^{nat}\left(2a_i + c_j^0 - c_i^t\right) - t_{ij}^{nat}\left(2a_j + c_i^o - c_j^t\right)\right] > 0$.
Here, ISP$_i$ receives higher incremental profit and subsidizes ISP$_j$.

Stranger: On the other hand, from the conditions (5), (7) follows that $t_{ij}^{str} > t_{ji}^{str}$. The net payment for stranger traffic is defined by $\Delta\sigma_{ij}^{str} = 0.5\left[t_{ji}^{str}\left(2b_i + c_j^o - c_i^t\right) - t_{ij}^{str}\left(2b_j + c_i^o - c_j^t\right)\right]$. This case is not straightforward and depends on $\left(t_{ji}^{str} c_j^o - t_{ij}^{str} c_i^o\right)$. Thus, it can be obtained that

$$\Delta\sigma_{ij}^{str} \begin{cases} <0 & if \quad t_{ij}^{str}/t_{ji}^{str} > c_j^o/c_i^o \\ =0 & if \quad t_{ij}^{str}/t_{ji}^{str} = c_j^o/c_i^o \\ >0 & if \quad t_{ij}^{str}/t_{ji}^{str} < c_j^o/c_i^o \end{cases} \qquad (16)$$

Proposition 4 *If $\beta_i = \beta_j$ and $\alpha_i > \alpha_j$ then ISP$_i$ (ISP$_j$) subsidizes ISP$_j$ (ISP$_i$) for stranger (native) traffic.*

Proof: Since $\alpha_i > \alpha_j$ then $c_i^t < c_j^t$.

Native: From the conditions (4), (6) follows that $t_{ij}^{nat} > t_{ji}^{nat}$. The net charge for native traffic is given by $\Delta\sigma_{ij}^{nat} = 0.5\left[t_{ji}^{nat}\left(2a_i + c_j^0 - c_i^t\right) - t_{ij}^{nat}\left(2a_j + c_i^o - c_j^t\right)\right] < 0$.
Here, ISP$_j$ gets higher incremental profit from native traffic exchange and subsides for it.

Stranger: From the conditions (5), (7), it can be obtained that $t_{ij}^{str} < t_{ji}^{str}$. The component for the stranger traffic business is given by $\Delta\sigma_{ij}^{str} = 0.5\left[t_{ji}^{str}\left(2b_i + c_j^o - c_i^t\right) - t_{ij}^{str}\left(2b_j + c_i^o - c_j^t\right)\right] > 0$
Then, ISP$_j$ receives the net charge for stranger traffic.

Assuming that $\alpha_i > \alpha_j$ and $\beta_i > \beta_j$, the following cases for the traffic volumes are obtained from the conditions (8)-(9): 1) $t_{ij} > t_{ji}$, 2) $t_{ij} < t_{ji}$, and 3) $t_{ij} = t_{ji}$. The cases 1) and 2) are analogous to those described above. We analyze the case when $t_{ij} = t_{ji}$.

Proposition 5 *If $\alpha_i > \alpha_j$, $\beta_i > \beta_j$, and $t_{ij} = t_{ji}$ then $\alpha_i = \beta_i$.*

Proof: The result is obtained from the conditions (4)-(9).

$$\alpha_i\alpha_j N^2 + \alpha_i\beta_j NM + \alpha_j\beta_i NMx = \alpha_i\alpha_j N^2 + \alpha_j\beta_i NM + \alpha_i\beta_j NMx$$

which gives: $\alpha_i(1-\beta_i) - \beta_i(1-\alpha_i) = \alpha_i - \beta_i = 0 \Rightarrow \alpha_i = \beta_i$.

Corollary 1 *If $\alpha_i > \alpha_j$, $\beta_i > \beta_j$, $t_{ij} = t_{ji}$ then $t_{ij}^{nat} = t_{ji}^{nat}$ and $t_{ij}^{str} = t_{ji}^{str}$.*

Proposition 6 *If $\alpha_i > \alpha_j$, $\beta_i > \beta_j$, and $t_{ij} = t_{ji}$ then ISP$_i$ subsidizes ISP$_j$ for stranger traffic.*

Proof: Since $\alpha_i > \alpha_j$ and $\beta_i > \beta_j$ then $c_i^t < c_j^t$.

Native: The net payment for native traffic, when $t_{ij}^{nat} = t_{ji}^{nat}$ is given by $\Delta\sigma_{ij}^{nat} = 0.5\left[t_{ji}^{nat}\left(2a_i + c_j^0 - c_i^t\right) - t_{ij}^{nat}\left(2a_j + c_i^o - c_j^t\right)\right] = 0$
Here, the incremental profits of the providers under symmetric traffic volumes are equal.

Stranger: Considering stranger traffic business when $t_{ij}^{str} = t_{ji}^{str}$, we get that $\Delta\sigma_{ij}^{str} = 0.5\left[t_{ji}^{str}\left(2b_i + c_j^o - c_i^t\right) - t_{ij}^{str}\left(2b_j + c_i^o - c_j^t\right)\right] > 0$
Under symmetric stranger traffic, ISP$_j$ receives the net interconnection charge.

Assuming that $\alpha_i > \alpha_j$, $\beta_i < \beta_j$ and recalling that costs are higher for the smaller network then the following cases for the termination costs are possible: 1) $c_i^t > c_j^t$, 2) $c_i^t < c_j^t$, and 3) $c_i^t = c_j^t$. The cases 1) and 2) are similar to those described above. The last case, when networks are identical in terms of size is examined below.

Proposition 7 *If $\alpha_i > \alpha_j$, $\beta_i < \beta_j$, and $c_i^t = c_j^t$ then ISP$_i$ (ISP$_j$) subsidizes ISP$_j$ (ISP$_i$) for stranger (native) traffic.*

Proof: Since networks are equal in terms of size, therefore

$$\alpha_i N + \beta_i M = \alpha_j N + \beta_j M$$

which gives $\alpha_i N = \beta_j M$ and $\beta_i M = \alpha_j N$.

Native: From the conditions (4), (6) follows that $t_{ij}^{nat} > t_{ji}^{nat}$. Considering native traffic business, it can be obtained that $\Delta\sigma_{ij}^{nat} = 0.5\left[t_{ji}^{nat}\left(2a_i + c_j^0 - c_i^t\right) - t_{ij}^{nat}\left(2a_j + c_i^o - c_j^t\right)\right] < 0$
Hence, ISP$_i$ gets the net payment from ISP$_j$.

Stranger: From the conditions (5), (7) follows that $t_{ij}^{str} < t_{ji}^{str}$. Considering the business for stranger traffic, it can be obtained

that $\Delta\sigma_{ij}^{str} = 0.5\left[t_{ji}^{str}\left(2b_i + c_j^o - c_i^t\right) - t_{ij}^{str}\left(2b_j + c_i^o - c_j^t\right)\right] > 0$.
In this case, ISP_j receives the net payment from ISP_i.

TABLE I
SUMMARY OF THE OBTAINED RESULTS

α	β	c^t	t^{nat}	$\Delta\sigma_{ij}^{nat}$	t^{str}	$\Delta\sigma_{ij}^{str}$
$\alpha_i = \alpha_j$	$\beta_i = \beta_j$	$c_i^t = c_j^t$	$t_{ij}^{nat} = t_{ji}^{nat}$	$\sigma_{ij}^{nat} = \sigma_{ji}^{nat}$	$t_{ij}^{str} = t_{ji}^{str}$	$\sigma_{ij}^{str} = \sigma_{ji}^{str}$
$\alpha_i = \alpha_j$	$\beta_i > \beta_j$	$c_i^t < c_j^t$	$t_{ij}^{nat} < t_{ji}^{nat}$	$\sigma_{ij}^{nat} > \sigma_{ji}^{nat}$	$t_{ij}^{str} > t_{ji}^{str}$	*is conditional, defined by (16)*
$\alpha_i > \alpha_j$	$\beta_i = \beta_j$	$c_i^t < c_j^t$	$t_{ij}^{nat} > t_{ji}^{nat}$	$\sigma_{ij}^{nat} < \sigma_{ji}^{nat}$	$t_{ij}^{str} < t_{ji}^{str}$	$\sigma_{ij}^{str} > \sigma_{ji}^{str}$
$\alpha_i > \alpha_j$	$\beta_i > \beta_j$	$c_i^t < c_j^t$	*if* $t_{ij}^{nat} = t_{ji}^{nat}$	$\sigma_{ij}^{nat} = \sigma_{ji}^{nat}$	*if* $t_{ij}^{str} = t_{ji}^{str}$	$\sigma_{ij}^{str} > \sigma_{ji}^{str}$
$\alpha_i > \alpha_j$	$\beta_i < \beta_j$	$c_i^t > c_j^t$ $c_i^t < c_j^t$ $c_i^t = c_j^t$	$t_{ij}^{nat} > t_{ji}^{nat}$	*if* $c_i^t = c_j^t$, $\sigma_{ij}^{nat} < \sigma_{ji}^{nat}$	$t_{ij}^{str} < t_{ji}^{str}$	*if* $c_i^t = c_j^t$, $\sigma_{ij}^{str} > \sigma_{ji}^{str}$

Table I summarizes the outcomes of the analytical studies. From the obtained results it can be concluded that asymmetric providers may decide to interconnect without monetary transfers. In this case, the net payment from ISP_i for a particular type of traffic is the same as that from ISP_j for another type of traffic, i.e. $\Delta\sigma_{ij}^{nat} + \Delta\sigma_{ij}^{str} = 0$. On the other hand, the results showed that identical providers in terms of size could benefit differently. In this case, due to asymmetry in market shares for consumers and websites providers face different demand. Thus, compensation based on the net traffic flows is not straightforward; determination of an initiator of transmission by means of traffic differentiation encourages a more fair cost sharing between providers.

In addition, taking into account the fact that no valid mathematical modeling of the evolution in the traffic distribution between networks exists, the most research works make the Assumption 3. Therefore, it is more reasonable to determine an initiator of the traffic to balance interconnection costs in reality.

V. CONCLUSIONS

In this paper the impact of providers' market shares for consumers and websites on the interconnection settlements between providers was explored. The key aspect of the proposed approach is based on determination of an original initiator of transmission by means of traffic differentiation into two types, referred to as native and stranger. In comparison to the existing financial settlement, under which the payments are based on the net traffic flows, the proposed approach governs cost compensation according to the differentiated traffic flows. More specifically, each provider compensates fully the termination costs incurred from delivering native traffic that is originally initiated by its own customers, and partially the termination costs incurred from carrying stranger traffic, which is originally initiated by the customers of the peered network.

Several conclusions provided below are based on the analytical studies that investigated how the interconnection settlements depend on providers' market shares (see Table I). Firstly, generally, in spite of termination costs the more incoming traffic of a particular type the more provider benefits from that type of traffic. Secondly, identical providers in terms of size due to different market shares for consumers and websites can benefit differently. And finally, asymmetric providers under asymmetry of traffic flows can arrange interconnection without monetary transfer. Therefore, the key consequence of the obtained results is that symmetry of the costs is not required prerequisite for peering.

ACKNOWLEDGMENT

The authors would like to thank Prof. Wolfgang Effelsberg and Kristina Davoian for their useful comments and helpful discussions.

REFERENCES

[1] W. Norton, "Internet service providers and peering", Draft 2.5, Equinix White Papers, 2001.
[2] C. Courcoubetis, R. Weber, "Pricing communication networks: economics, technology and modeling", *Wiley*, March 2003.
[3] G. Huston, "Interconnection, peering, and settlement", Part II, *Internet Protocol Journal*, Cisco Publications, 2(2), 2-23, 1999b.
[4] W. B. Norton, "A business case for ISP peering", 2001.
[5] M. Kende, "The digital handshake: connecting Internet backbones", Federal Communications Commission (FCC), OPP Working Paper No. 32, Sep. 2000.
[6] Akamai Technologies, "Internet bottlenecks: the case for edge delivery services", Technical Report, Akamai White Paper, 2000.
[7] J. Winkleman, "Getting connected", *America's Network*, Aug. 15, 1998.
[8] J. J. Laffont and J. Tirole, "Competition in telecommunications", Cambridge, *MIT Press*, 2000.
[9] P. DeGraba, "Bill and Keep at the central office as the efficient interconnection regime", FCC, OSP, Working Paper 33, Dec. 2000.
[10] M. Armstrong, "The theory of access pricing and interconnection", in Handbook of Telecommunications Economics, Vol. 1, Martin E. Cave, Sumit K. Mujumdar, and Ingo Vogelsang, (Eds.), *North-Holland*: Amsterdam, 2002.
[11] M. Armstrong, "Competition in two-sided markets", *RAND Journal of Economics*, 2006.
[12] K. Yoon, "Interconnection economics of all-IP networks", Review of Network Economics, V 5, 2006.
[13] J. J. Laffont, S. Marcus, P. Rey, and J. Tirole, "Internet interconnection and the off-net-cost pricing principle", *RAND Journal of Economics*, 34(2):370-390, 2003.
[14] M. Carter, J. Wright, "Interconnection in network industries", Review of Industrial Organisation, 1999.
[15] Federal Communications Commission, "In the matter of developing a unified intercarrier compensation regime", Notice of Proposed Rulemaking in CC Docket No. 01-92, Apr. 27, 2001.
[16] N. Economides, "The economics of networks", *International Journal of Industrial Organization*, Vol. 14, no. 6, pp. 673-699, October 1996.
[17] J. Marcus, "Interconnection in an NGN environment", Background paper for ITU Workshop on "What rules for IP-enabled NGNs?", 2006.
[18] G. Huston, "ISP survival guide: strategies for running a competitive ISP", *Wiley*, 1998.
[19] B. Stiller, "A survey of charging Internet services", In Managing IP Networks: Challenges and Opportunities, Salah Aidarous (Editor), Thomas Plevyak (Editor), *Wiley-IEEE Press*, Sept. 2003.
[20] G. Huston, "Interconnection and peering", Broad Band Satellite, November 2000.
[21] S. Besen, P. Milgrom, B. Mitchell, and P. Srinagesh, "Advancing in routing technologies and Internet peering agreements", *American Economic Review*, 91:292–296, 2001.
[22] E. Rasmusen, "Games and information: an introduction to game theory", 3rd Edition, Blackwell, 2001.

978-1-4244-2324-8/08/$25.00 © 2008 IEEE.
This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE "GLOBECOM" 2008 proceedings.