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Exploring the Effect of Traffic Differentiation on Interconnection Cost Sharing

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Abstract - This paper addresses the inter-provider costs sharing issue by exploring the effect of the traffic differentiation on the interconnection payments. In particular, we determine an original initiator of a transmission by means of traffic differentiation into two types, referred to as native and stranger. Unlike the existing financial settlement, under which the interconnection payments are made based on the net traffic flow, the proposed model governs cost compensations according to the differentiated traffic flows. Analytical studies were provided using Nash bargaining solution to explore how the determination of a transmission initiator affects intercarrier compensation. For this analysis we considered reciprocal and non-reciprocal access charges.

Keywords: Interconnection arrangement, intercarrier compensation, Internet economics.

JEL Classification Numbers: C61, C62, D40, D45, D86, L14, L86, L96, M15, M21.

1 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. Historically, the Internet provides two types of interconnection arrangements: peering and transit [1]. Peering is the arrangement of traffic exchange on a free-settlement basis, called bill-and-keep (BAK), so that the Internet service providers (ISPs) do not pay each other and derive revenues from their own customers [2]. It is fair and efficient under symmetry of traffic flows, termination charges, and costs. Under the transit model, a customer provider pays a transit provider to deliver the traffic between customers. The outcome of the negotiation process of being a transit or peered customer reflects on the assessment of the actual cost of traffic exchange [3-4]. In addition to this, new types of interconnection models, such as paid peering and partial transit, emerged in the market [5].

Traditionally, before interconnecting, a provider calculates whether the benefits would outweigh the costs [6]. The simple economic principle suggests sharing the costs between all parties. The survey and discussion on interconnection with two-sided benefits are provided in [7-8]. 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 flows, the termination costs are set to zero, since it is assumed that the termination fees are roughly the same, and a peering arrangement is used. However, because no termination fee is charged, BAK is considered inefficient in terms of cost compensation [10]. If providers are asymmetric in terms of size and, therefore, incur different costs, the peering model is not appropriate. The study [11] showed that peering as a result of bargaining process could take place also when providers are asymmetric. However, generally, if traffic is unbalanced, interconnection arrangement is governed by the financial compensation in a bilaterally negotiated (paid peering) or unilaterally negotiated (transit) basis to recover the costs of the network. In the bilateral settlements, the payments are done based on the net traffic flow. In unilateral settlements, a customer provider pays for sent and received traffic, even though traffic flows in both directions. As cited in [12], it was recommended to establish bilateral arrangements and to compensate each provider for the costs that it incurs in carrying traffic generated by the other network. However, the study [12] argued 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, which provide a poor basis for cost sharing.

Analytical studies, provided in [13-15], investigated the impact of an original initiator of a transmission on intercarrier compensation, demand, and profits of providers. However, the remaining existing literature on economics of interconnection only considers intercarrier compensation based on flows of traffic [9, 11, 16-19].

This paper explores the benefits of the traffic differentiation on the interconnection payments in regulated and deregulated environments. We introduce a model, called the *differentiated traffic-based interconnection agreement* (*DTIA*) for intercarrier compensation in private peering arrangements, and its management mechanism. The DTIA model distinguishes two types of traffic, called *native* and *stranger* in order to determine the transmission initiator in the IP networks and to compensate the interconnection costs. In contrast to the existing bilaterally negotiated-financial settlements [3], under which the payments are based on the net traffic flow, the proposed model establishes costs compensation according to the differentiated traffic (DT) flows. More specifically, each ISP compensates fully the termination costs incurred from delivering native traffic (i.e. originally initiated by the provider's own customers), and partially the termination costs incurred from carrying stranger traffic (i.e. originally initiated by the customers of the other network). Unlike telephony, the presented model does not consider a transmission initiator as a cost causer, who should cover the joint costs. Instead, both parties share the joint costs.

Within the paper analytical studies were provided to investigate how the intercarrier compensation payments depend on the DT flows. The analysis covered two cases of access charges (ACs): reciprocal (i.e. in a regulated market) and non-reciprocal (i.e. in a deregulated market).

The rest of the paper is organized as follows. Section II examines financial settlements between providers. Section III describes the motivation of DTIA. Section IV presents the design of the traffic management mechanism. Section V provides analytical studies. Section VI concludes this paper.

2 Financial settlements

Generally, providers arrange financial settlements in order to determine the distribution of the interconnection costs [3, 20]. Before examining financial settlements within the Internet, we consider the telephony system. As an example, assume the scenario, in which 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 the calling party's carrier. As cited in [10], "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 to the subscribed provider for the entire call, since Alice asked to reserve the circuit. In contrast to the telephony example, establishing a connection in the Internet does not require any reservation of the circuit. Usually packets between Alice and Bob are routed independently, sometimes even via different paths. Therefore, as cited in [16], "it is very important to distinguish between the *initiator* and the *sender*, and likewise between the *destination* and the *receiver*". The initiator is the party that initiates a call or a session, and the destination is the party that receives a call. In comparison, the sender (the originator) is the party that sends traffic, and the receiver (the terminator) is the party that receives traffic.

In telephony, the initiator is considered to be 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 a TCP session can be considered as a call, where the initiator of a session pays for the entire traffic flow. However, considering the actual use of the network resources, financial settlement should be performed at the IP level, accounting each packet of a flow. In addition to this, session-based accounting, which faces technical difficulties, is more complicated than simple packet-based accounting, under which the volume of the exchanged traffic in both directions is measured. Therefore, generally, under unilateral business relationships, providers adopt service-provider settlements, where a customer ISP pays to the provider ISP for sent and received traffic, and under bilateral relationship, providers accept negotiated-financial settlements, where the payments are based on the net traffic flow. For detailed discussion see [3, 16, 21].

3 Motivation for traffic differentiation

The principle that we follow is that both parties derive benefits from the exchange of traffic and, therefore, should share the interconnection costs. If content is not equally distributed between providers, traffic imbalance occurs, and hence, costs and revenues are not shared evenly. Indeed, the network that sends more traffic incurs lower cost than the network that receives more traffic [22]. As cited in [23], traffic flows are dominant towards customers requested the content and generate 85% of the Internet traffic. This implies that inbound traffic is much more compared to outbound traffic of content request. It was recommended to compensate a provider for the costs, which it incurs in carrying traffic based on the traffic flows. However, according to [12], 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" and therefore, provide a poor basis for cost sharing. Furthermore, 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" [21].

In order to determine the party, which originally initiated the transmission, we 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 a transmission initiated by a customer of ISP*i*, ii) or a part of a transmission initiated by a customer of the peered network. In particular, we suggest that a provider compensates the incurred costs i) fully, if the exchanged traffic is native, and ii) partially, if the originated traffic is stranger. More specifically, interconnected networks settle DTIA, whereby each partner is compensated for the costs, which it incurs in carrying traffic according to the DT flows.

4 Traffic management mechanism

The traffic management mechanism for interconnection agreement, which we propose, allows recognizing the packet type between peered networks. The key aspect of the proposed model is the identification the type of traffic based on a one-bit field in the IP packet header, referred to as the *Membership Label* (*ML*).

We assume that all nodes within the network support packet marking, where each node sets the ML field of native packet to *'1'* and the packet of stranger traffic to *'0'*. The assignment of the label to *'1'* is done once, when a node originally initiates a transmission. It is obvious, that native traffic with regard to one network is considered to be stranger from the perspective of the other. Consequently, it is necessary to differentiate the exchanged traffic between the networks. In order to achieve this, we distinguish the provider's border nodes, which we refer to as the *Provider-to-Provider Border* (*PPB*) nodes. These nodes are trust boundaries and maintain the connection with the peered network. For outgoing traffic, a PPB node performs the NOT logical operation on the label. In addition, in order to carry out intercarrier compensation based on the DT flows, each PPB node keeps two counters (one for inbound and another for outbound traffic), which calculate the volume of a particular type of traffic, i.e. either native or stranger with regard to the network. The volume of the other type of traffic can be easily determined by subtracting the counted volume from the total one.

The website requested by a consumer can be subscribed either to the local network or to the peered network. As a result, traffic originated by the endpoint of a transmission (e.g. destination) can be part of the transmission initiated either by the network's customer or by the customer of the peered network. Therefore, the identification the type of traffic (i.e. native or stranger) originated by the transmission endpoint is necessary. This is achieved by the fact that the transmission endpoint does not re-examine the label and simply sends response packets with the same ML field (i.e. the value *'0'* or *'1'* is duplicated from the request packet). It is obvious that incoming network traffic with the bit set to *'1'* is a part of a transmission initiated by its own customers. An example that helps to understand how the described traffic management mechanism works is described below.

As an example, consider a model consisting of ISP_i, ISP_j, and their customers, where each provider calculates the volumes of native traffic. Assume that a customer of ISP_i requests data available on ISP_j. Let *N1* be the PPB router of ISP_i, which receives a packet marked by *'1'*. Before forwarding it to ISP_j, *N1* performs the NOT operation on the ML field of the outgoing packet and increases the counter for outgoing native traffic. The PPB node *N2* of ISP_j reads the IP header of the received packet and then forwards it to the destination, e.g. the *N3* node. After receiving the packet, *N3* sends a packet stream with the requested data, where the label value of each packet is set to *'0'*. A similar procedure follows on the inverse path with only difference that ISP_i considers incoming traffic as native, initiated by its own customers.

4.1 Incentive compatibility

It is well known that strategic agents have an incentive not to be truthful and, therefore, end-systems or the defined PPB nodes can perform mendacious packet marking. However, there are several favorable reasons to adopt our approach. First, we considered that PPB is a trust boundary, and, therefore, its operations can be recorded and then audited. Second, applying commonly used pricing scheme, such as flat-rate, creates no incentive to the end-systems to perform untruthful packet marking, since it does not affect fees and quality of service. Finally, interconnection is a long-term and repeated process, arranged under mutual benefits, and, therefore, sustainable cooperation between interconnected ISPs is a reasonable and natural solution. Nevertheless, we intend to address incentive compatibility in future work.

5 The model of DTIA

Analytical studies are based on a bargaining process that is explored using Nash bargaining solution (NBS), which provides a fair and Pareto efficient outcome. First, we consider the regulated environment with reciprocal access charges (ACs), and then examine the case, where providers set non-reciprocal ACs without regulation. In our analysis two types of the customers, namely consumers and websites are considered. 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 inter-provider payments depend on the DT flows, we focus on traffic exchange i) from consumers to websites, and ii) from websites to consumers. Traffic between consumers and between websites is neglected, since it does not have any significant impact on the results of the analysis. It is worth noting that according to the proposed approach, a node in a P2P network can be considered as a consumer as well as a website simultaneously, since it can act as a server and a client. 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. The market consists of 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, a balanced calling pattern, where each consumer requests any website in any network with the same probability is considered. Each consumer originates one unit of traffic per each request of website and downloads a fixed amount of content.

5.1 Reciprocal access charges

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

$$t_i^{nat} = \alpha_i \beta_i NM + \alpha_i \beta_i NMx \quad (1)$$

where the first component is the volume of traffic exchanged from consumers to websites, the second one denotes the volume of traffic exchanged from websites to consumers, and x is the average amount of traffic generated by each website. Let network i's marginal costs of origination and termination are $c_i^o > 0$ and $c_i^t > 0$ respectively, where $c_i^o = c_i^t$ [17]. We do not consider fixed networks cost, and for simplicity, assume that transmission cost is normalized to zero, since a peering model is considered. The profit of ISP$_i$ from on-net traffic is defined by

$$\pi_i = [\alpha_i Nf(\beta_i) + \beta_i Mg(\alpha_i)] - t_i^{nat}(c_i^o + c_i^t) \quad (2)$$

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

$$t_{ij}^{nat} = \alpha_i \beta_j NM \quad (3)$$

$$t_{ij}^{str} = \alpha_j \beta_i NMx \quad (4)$$

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

$$t_{ji}^{nat} = \alpha_j \beta_i NM \quad (5)$$

$$t_{ji}^{str} = \alpha_i \beta_j NMx \quad (6)$$

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

$$t_{ij} = t_{ij}^{nat} + t_{ij}^{str} \quad (7)$$

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

In this subsection we assume that the access charges are set by an industry regulator and then applied reciprocally. Therefore, the providers charge each other the same access charges a and b for terminating native and stranger traffic respectively, where $a > b$ (since the provider compensates partially the costs of terminating stranger traffic). The access charge determines how the costs are shared between consumers and websites. To carry out the analysis, the access charge for terminating native traffic is set to the lowest termination marginal cost, and for terminating stranger traffic is defined by $b = \varepsilon a$, $0.5 \le \varepsilon < 1$. However, in order to simplify analysis we fix $\varepsilon = 0.5$. The profit of ISP$_i$ obtained interconnection is calculated as follows

$$\Pi_i = \pi_i + \sigma_i \quad (9)$$

where σ_i is the incremental profit that ISP$_i$ gets from the interconnection and is given by

$$\sigma_i = \alpha_i Nf(\beta) + \beta_i Mg(\alpha) + t_{ij}^{nat}(-c_i^o - a)$$
$$+ t_{ij}^{str}(-c_i^o - b) + t_{ji}^{nat}(a - c_i^t) + t_{ji}^{str}(b - c_i^t) \quad (10)$$

The outcome of i's network according to the bargaining game [24] is defined by

$$\phi_i = 0.5(\Pi_i + \Pi_j + \pi_i - \pi_j) = 0.5(\sigma_i + \sigma_j) + \pi_i \qquad (11)$$

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

$$\phi_j - \Pi_j = 0.5(\sigma_i - \sigma_j) = 0.5\Delta\sigma_{ij} \qquad (12)$$

We consider the case when $f''(\cdot) = 0$ and $g''(\cdot) = 0$, so that the network externalities [25] exhibit constant returns to scale, meaning that the networks have the same incremental revenues, while the incremental costs increase as the network size decreases. Substituting (10) in (12), it can be obtained that

$$\phi_j - \Pi_j = 0.5\left[t_{ji}^{nat}\left(2a + c_j^o - c_i^t\right) - t_{ij}^{nat}\left(2a + c_i^o - c_j^t\right)\right]$$
$$+0.5\left[t_{ji}^{str}\left(2b + c_j^o - c_i^t\right) - t_{ij}^{str}\left(2b + c_i^o - c_j^t\right)\right] \qquad (13)$$

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 $\Delta\sigma_{ij}^{str}$, and are given by

$$\Delta\sigma_{ij}^{nat} = 0.5\left[t_{ji}^{nat}\left(2a + c_j^0 - c_i^t\right) - t_{ij}^{nat}\left(2a + c_i^o - c_j^t\right)\right] \qquad (14)$$

$$\Delta\sigma_{ij}^{str} = 0.5\left[t_{ji}^{str}\left(2b + c_j^o - c_i^t\right) - t_{ij}^{str}\left(2b + c_i^o - c_j^t\right)\right] \qquad (15)$$

Proposition 1 *If* $\alpha_i = \alpha_j$ *and* $\beta_i = \beta_j$ *then the net payments are zero.*

Proof: Since the networks are symmetric in terms of size, then $c_i^t = c_j^t = a$. From the conditions (3)-(6), (13), the net transfers are given by $\phi_i - \Pi_i = \phi_j - \Pi_j = 0$. □

Proposition 2 *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 $c_i^t < c_j^t$ and $a = c_i^t$.

Native: From the conditions (3)-(4) follows that $t_{ij}^{nat} < t_{ji}^{nat}$. Considering the component for the native traffic business (14) it can be obtained that $\Delta\sigma_{ij}^{nat} > 0$. Here ISP$_i$ gets higher profit from native traffic exchange and subsidizes ISP$_j$.

Stranger: From the conditions (5)-(6) follows that $t_{ij}^{str} > t_{ji}^{str}$. The component for stranger traffic (15) is not straightforward and is defined by

$$\Delta\sigma_{ij}^{str} \begin{cases} < 0 & if \quad t_{ij}^{str} / t_{ji}^{str} > c_j^o / \left(2c_i^t - c_j^t\right) \\ = 0 & if \quad t_{ij}^{str} / t_{ji}^{str} = c_j^o / \left(2c_i^t - c_j^t\right), \;\; 2c_i^t - c_j^t \neq 0 \\ > 0 & if \quad t_{ij}^{str} / t_{ji}^{str} < c_j^o / \left(2c_i^t - c_j^t\right) \end{cases} \qquad (16)$$

□

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

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

Native: From the conditions (3)-(4) follows that $t_{ij}^{nat} > t_{ji}^{nat}$. Considering the native traffic business, the condition (14) is not straightforward and depends on

$$\Delta\sigma_{ij}^{nat}\begin{cases} <0 & if \quad t_{ij}^{nat}/t_{ji}^{nat} > \left(2a+c_j^o-c_i^t\right)/\left(2a+c_i^o-c_j^t\right) \\ =0 & if \quad t_{ij}^{nat}/t_{ji}^{nat} = \left(2a+c_j^o-c_i^t\right)/\left(2a+c_i^o-c_j^t\right) \\ >0 & if \quad t_{ij}^{nat}/t_{ji}^{nat} < \left(2a+c_j^o-c_i^t\right)/\left(2a+c_i^o-c_j^t\right) \end{cases} \tag{17}$$

where $2a+c_i^o-c_j^t \neq 0$.

Stranger: Considering the conditions (5)-(6) we obtain that $t_{ij}^{str} < t_{ji}^{str}$. From the condition (15) follows that $\Delta\sigma_{ij}^{str} > 0$. Thus, ISP$_j$ receives the net payment for stranger traffic from ISP$_i$.

If $\alpha_i > \alpha_j$ and $\beta_i > \beta_j$, the following cases for the traffic volumes are obtained from the conditions (7)-(8): 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. The case when $t_{ij} = t_{ji}$ is analyzed below.

Proposition 4 *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 (3)-(8). □

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

Proposition 5 *If* $\alpha_i > \alpha_j$, $\beta_i > \beta_j$, *and* $t_{ij} = t_{ji}$ *then ISP$_i$ subsidizes ISP$_j$ for native and stranger traffic.*

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

Native: Considering the native traffic component (14) when $t_{ij}^{nat} = t_{ji}^{nat}$ it can be obtained that $\Delta\sigma_{ij}^{nat} > 0$. Here ISP$_i$ gets higher incremental profit and subsides ISP$_j$.

Stranger: From the condition (15) when $t_{ij}^{str} = t_{ji}^{str}$ follows that $\Delta\sigma_{ij}^{str} > 0$. Under symmetric stranger traffic flows, 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 than for the larger 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 equal in terms of size is examined below.

Proposition 6 *If* $\alpha_i > \alpha_j$, $\beta_i < \beta_j$, *and* $c_i^t = c_j^t = a$ *then ISP$_i$ (ISP$_j$) subsidizes ISP$_j$ (ISP$_i$) for stranger (native) traffic.*

Proof: *Native:* From the conditions (3)-(4) follows that $t_{ij}^{nat} > t_{ji}^{nat}$. Considering the native traffic business (14) we obtain that $\Delta\sigma_{ij}^{nat} < 0$. Hence, ISP$_i$ gets the net payment from ISP$_j$.

Stranger: From the conditions (5)-(6) follows that $t_{ij}^{str} < t_{ji}^{str}$. From the component (15) follows that $\Delta\sigma_{ij}^{str} > 0$. In this case, ISP$_j$ receives the net payment from ISP$_i$.

Table 1. Results of DTIA

α	β	c^t	t^{nat}	$\Delta\sigma_{ij}^{nat}$	t^{str}	$\Delta\sigma_{ij}^{str}$
$\alpha_i = \alpha_j$	$\beta_i = \beta_j$	$c_i^t = c_j^t$	$t_{ij}^{nat} = t_{ji}^{nat}$	$=0$	$t_{ij}^{str} = t_{ji}^{str}$	$=0$
$\alpha_i = \alpha_j$	$\beta_i > \beta_j$	$c_i^t < c_j^t$	$t_{ij}^{nat} < t_{ji}^{nat}$	>0	$t_{ij}^{str} > t_{ji}^{str}$	*defined by*
$\alpha_i > \alpha_j$	$\beta_i = \beta_j$	$c_i^t < c_j^t$	$t_{ij}^{nat} > t_{ji}^{nat}$	*defined by*	$t_{ij}^{str} < t_{ji}^{str}$	>0
$\alpha_i > \alpha_j$	$\beta_i > \beta_j$	$c_i^t < c_j^t$	*If* $t_{ij}^{nat} = t_{ji}^{nat}$	>0	*If* $t_{ij}^{str} = t_{ji}^{str}$	>0
$\alpha_i > \alpha_j$	$\beta_i < \beta_j$	*if* $c_i^t = c_j^t$	$t_{ij}^{nat} > t_{ji}^{nat}$	<0	$t_{ij}^{str} < t_{ji}^{str}$	>0

Table 2. Comparative Results of the Agreements Based on the Net Traffic Flow (TF) and DTIA Compensation (Reciprocal AC)

Case	α_i	β_i	t_{ij}^{nat}	t_{ij}^{str}	t_{ji}^{nat}	t_{ji}^{str}	$\Delta\sigma_{ij}^{nat}$	$\Delta\sigma_{ij}^{str}$	$\Delta\sigma_{ij}/2$	
									DTIA	TF
I: $\alpha_i = \alpha_j$ $\beta_i = \beta_j$ $c_i^t = c_j^t$	0.5	0.5	1500	52500	1500	52500	0	0	0	0
II: $\alpha_i = \alpha_j$	0.5	0.9	300	94500	2700	10500	3150	-15750	-12600	-54600
$\beta_i > \beta_j$	0.5	0.8	600	84000	2400	21000	2550	-5250	-2700	-34200
$c_i^t < c_j^t$	0.5	0.773	682	81136	2318	23864	2386	-2386	0	-28636
	0.5	0.7	900	73500	2100	31500	1950	5250	7200	-13800
	0.5	0.6	1200	63000	1800	42000	1350	15750	17100	6600
III: $\alpha_i > \alpha_j$	0.9	0.5	2700	10500	300	94500	-1650	68250	66600	108600
$\beta_i = \beta_j$	0.8	0.5	2400	21000	600	84000	-1050	57750	56700	88200
$c_i^t < c_j^t$	0.7	0.5	2100	31500	900	73500	-450	47250	46800	67800
	0.6	0.5	1800	42000	1200	63000	150	36750	36900	47400
IV: $\alpha_i > \alpha_j$	0.9	0.9	540	18900	540	18900	270	9450	9720	9720
$\beta_i > \beta_j$	0.8	0.8	960	33600	960	33600	480	16800	17280	17280
$c_i^t < c_j^t$	0.7	0.7	1260	44100	1260	44100	630	22050	22680	22680
	0.6	0.6	1440	50400	1440	50400	720	25200	25920	25920
V: $\alpha_i > \alpha_j$	0.7	0.167	3500	10500	300	122501	-3200	56001	52801	108801
$\beta_i < \beta_j$	0.65	0.25	2925	18375	525	102375	-2400	42000	39600	81600
$c_i^t = c_j^t$	0.6	0.333	2400	28000	800	84000	-1600	28000	26400	54400
	0.55	0.417	1924	39407	1126	67337	-798	13965	13167	27132

The summary of the obtained results is presented in Tables 1 and 2. Table 1 demonstrates how the net payments between peering ISPs depend on the DT flows and the provider's market shares. The comparison results between agreements based on the net traffic flow and DT flows compensations are reported in Table 2. In order to calculate specific outcomes, we impose the following values of termination costs i) $c_i^t = c_j^t = 1$ in Cases I and V, ii) $c_i^t = 1$, $c_j^t = 1.5$ in all other cases. Other parameters are $x = 35$, $N = 100$, and $M = 60$. The market shares for Case V were obtained so that the size of each network is equal to $0.5(N + M) = 80$. The net payment based on the net traffic flow compensation is calculated as follows: $\phi_j - \Pi_j = 0.5\left[t_{ji}\left(2a + c_j^o - c_i^t\right) - t_{ij}\left(2a + c_i^o - c_j^t\right)\right]$.

5.2 Non-reciprocal access charges

In this subsection, we explore how interconnection payments depend on the DT flows, when providers set non-reciprocal ACs. Let a_i and b_i are network i's access charges for terminating native and stranger traffic respectively, where $a_i > b_i$. To carry out analysis, we assume that customer network's access charge for terminating native traffic is set to the termination marginal cost, i.e. $a_i = c_i^t$, and for terminating stranger traffic is defined by $b_i = \varepsilon a_i$, where $0.5 \le \varepsilon < 1$. For simplicity we fix $\varepsilon = 0.5$. By substituting given access charges in (10), we get that the incremental profit of ISP$_i$ obtained from the interconnection is

$$\sigma_i = \alpha_i N f(\beta) + \beta_i M g(\alpha) + t_{ij}^{nat}\left(-c_i^o - a_j\right)$$
$$+ t_{ij}^{str}\left(-c_i^o - b_j\right) + t_{ji}^{nat}\left(a_i - c_i^t\right) + t_{ji}^{str}\left(b_i - c_i^t\right) \qquad (18)$$

The net payment from ISP$_i$ to ISP$_j$ is obtained by substituting (18) in (12) and is given by

$$\phi_j - \Pi_j = 0.5\left[t_{ji}^{nat}\left(2a_i + c_j^o - c_i^t\right) - t_{ij}^{nat}\left(2a_j + c_i^o - c_j^t\right)\right]$$
$$+0.5\left[t_{ji}^{str}\left(2b_i + c_j^o - c_i^t\right) - t_{ij}^{str}\left(2b_j + c_i^o - c_j^t\right)\right] \qquad (19)$$

The further investigation is done analogously to the case of the reciprocal access charges.

Table 3. Comparative Results of the Agreements Based on the Net Traffic Flow (TF) and DTIA Compensation (Non-Reciprocal AC)

Case	α_i	β_i	t_{ij}	t_{ji}	$\Delta\sigma_{ij}^{nat}$	$\Delta\sigma_{ij}^{str}$	$\Delta\sigma_{ij}/2$ DTIA	TF
I: $\alpha_i = \alpha_j$, $\beta_i = \beta_j$, $c_i^t = c_j^t$	0.5	0.5	54000	54000	0	0	0	0
II: $\alpha_i = \alpha_j$	0.5	0.9	94800	13200	3600	-36750	-33150	-122400
$\beta_i > \beta_j$	0.5	0.8	84600	23400	2700	-21000	-18300	-91800
$c_i^t < c_j^t$	0.5	0.773	74400	33600	1800	-5250	-3450	-61200
	0.5	0.7	72030	35970	1591	-1591	0	-54091
	0.5	0.6	64200	43800	900	10500	11400	-30600
III: $\alpha_i > \alpha_j$	0.9	0.5	13200	94800	-3600	89250	85650	122400
$\beta_i = \beta_j$	0.8	0.5	23400	84600	-2700	73500	70800	91800
$c_i^t < c_j^t$	0.7	0.5	33600	74400	-1800	57750	55950	61200
	0.6	0.5	43800	64200	-900	42000	41100	30600
IV: $\alpha_i > \alpha_j$	0.9	0.9	19440	19440	0	9450	9450	0
$\beta_i > \beta_j$	0.8	0.8	34560	34560	0	16800	16800	0
$c_i^t < c_j^t$	0.7	0.7	45360	45360	0	22050	22050	0
	0.6	0.6	51840	51840	0	25200	25200	0
V: $\alpha_i > \alpha_j$	0.7	0.167	14000	122801	-3200	56001	52801	108801
$\beta_i < \beta_j$	0.65	0.25	21300	102900	-2400	42000	39600	81600
$c_i^t = c_j^t$	0.6	0.333	30400	84800	-1600	28000	26400	54400
	0.55	0.417	41330	68462	-798	13965	13167	27132

Table 3 shows the comparison of the charges between agreements based on the net traffic flow and DT flows compensations. In order to calculate specific outcomes, we impose the following values of termination costs i) $c_i^t = c_j^t = 1$ in Case I and V, ii) $c_i^t = 1,\ c_j^t = 2$ in all other cases. All other parameters remain the same. The payment based on the net traffic flow is: $\phi_j - \Pi_j = 0.5[t_{ji}(2a_i + c_j^o - c_i^t) - t_{ij}(2a_j + c_i^o - c_j^t)]$.

5.3 Discussions

The following observation can be made from the obtained results. They demonstrated that under certain market shares, the net payment of ISP_i for a particular type of traffic is the same as that of ISP_j for another type of traffic (see Tables II and III, Case II). Specifically, $\Delta\sigma_{ij}^{nat} + \Delta\sigma_{ij}^{str} = 0$ and asymmetric providers decide to interconnect without monetary transfers. Furthermore, the comparison of the symmetric cases in terms of the originated traffic volumes (presented in Cases II and III of Tables II and III) showed that according to DTIA, the net payments that subsidies the smaller ISP_j in Case II is much less than the payments subsidized by the bigger ISP_i in Case III. Moreover, at certain market shares, the bigger provider compensates the smaller provider. Finally, the proposed model significantly reduces the interconnection payments. This is caused by the fact that the outcomes of our model are less deviated from the Nash solution than those, obtained according to the classical model. Therefore, it can be concluded that DTIA achieves a more sensible solutions for the interconnected providers.

6 Summary and conclusions

In this paper we analyzed the benefits of the traffic differentiation on the intercarrier compensation in private peering arrangements, by considering a model, called differentiated traffic-based interconnection agreement (DTIA). The main feature of the proposed approach is the determination an original initiator of a transmission by means of recognizing the type of traffic as native and stranger. This implies that the providers compensate differently for a particular type of traffic. More specifically, each provider compensates fully the termination costs incurred from delivering native traffic and partially the termination costs incurred from carrying stranger traffic.

The technical part of the paper describes the design of the traffic management mechanism for DTIA. The major advantage of the presented mechanism is that providers have not to inspect the IP header of packets in order to determine and record all subsequent packets of the transmission. Instead, the defined membership label (ML) allows accounting the volume of a particular traffic type, and therefore, leads to low computational complexity.

Several conclusions can be drawn from the results obtained from analytical studies, which considered reciprocal and non-reciprocal access charges (see Tables I-III). Firstly, the symmetry of the costs is not the required prerequisite for peering, and the asymmetric providers can arrange the interconnection without monetary transfers (see Case II of Tables II and III). Secondly, in contrast to the compensation based on the net traffic flow, the determination of an initiator of a transmission yields more fair outcomes for all parties (see

Cases II and III of Tables II and III). And finally, the proposed model outperforms the classical model in terms of net payments, which are relatively small (see Tables II and III).

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