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Intercarrier Compensation in Unilateral and Bilateral Arrangements

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TEMEP Discussion Paper No. 2010:41

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January 2010

Abstract: In terms of intercarrier compensation traffic flows are measured to allocate the costs between networks. This method provides a poor basis for sharing any costs. In this work we analyze the benefits of the traffic differentiation on the interconnection charges in unilateral and bilateral arrangements. We determine an original initiator of a transmission and compensate differently for the distinguished traffic flows. The presented approach was compared with the existing solutions, which perform cost compensation based on the traffic flows.

Keywords: *Interconnection arrangements, 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 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 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 the 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]. Peering offers several advantages in terms of interconnection costs and quality of data transmission, but gives access to a part of the entire Internet. According to the estimates in [5], 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 at a certain rate, providing access to the whole Internet. In addition to this, new types of interconnection models, such as paid peering and partial transit, emerged in the market [6].

Traditionally, before interconnecting, a provider calculates whether the interconnection benefits would outweigh the costs [7]. The simple economic principle suggests sharing the costs between all parties. A survey and discussion on interconnection with two-sided benefits are provided in [8-9]. In the case of telephony, the study [10] 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 [11]. Generally, if providers are asymmetric in terms of size, peering model is not appropriate, since providers incur different costs and benefit differently.

Therefore, 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. Considering the Internet hierarchical structure, Internet backbone providers (IBPs) sell wholesale services to competitive ISPs. As a result, in the unilateral settlements, a customer provider pays for sent and received traffic, even though traffic flows in both directions. As cited in [5], 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 [5] argued that traffic flows are not a reasonable indicator to share the costs, since it is not clear who originally initiated a 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 [12-14], investigated the impact of an original initiator of a transmission on intercarrier compensation, demand, and profits of providers in the case of private peering arrangement. Furthermore, the bilateral relationships only with symmetric access charges are investigated in [15]. However, the remaining existing literature on the economics of interconnection only considers intercarrier compensation based on the flows of traffic [10, 16-19].

The aim of this work is to explore the role of the traffic differentiation on intercarrier compensation in unilateral and bilateral arrangements. In particular, we determine an original initiator of a transmission by means of distinguishing the type of traffic as *native* (i.e. originally initiated by the provider's own customers) and *stranger* (i.e. initiated by the customers of any other network). In contrast to the existing solutions [3], under which the payments are based on the traffic flows, in this work we compensate based on the differentiated traffic (DT) flows. More specifically, a provider compensates fully the costs of carrying the native traffic and partially the costs of carrying the stranger traffic. Unlike telephony, the proposed model does not consider a transmission initiator as a cost causer, who should cover the joint costs. Instead, all parties share the joint costs. Further, we present a simple and scalable traffic management mechanism that supports the traffic differentiation approach.

Comparative studies of the agreements based on the traffic flow and differentiated traffic flows compensations were provided.

The rest of the paper is organized as follows. Section II discusses the financial settlements between providers. Section III describes the motivation for traffic differentiation. Section IV presents the design of traffic management mechanism for interconnection arrangements. Section V provides analytical studies. Finally, Section V 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 a scenario, 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 the calling party's carrier. As cited in [11], "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 done 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 s*ervice-provider* settlements, where a customer ISP pays to a 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. Considering a system without externalities [3, 22], the costs should be shared based on the benefits obtained by each party. However, in the real world, it is impossible to measure the benefits of parties and so to share the 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 [23]. As cited in [24], 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 each provider for the costs, which it incurs in carrying traffic based on the traffic flows. However, according to [5], 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 a party, which originally initiated a 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 any other network. Indeed, outgoing traffic of ISP_i that is the same as adjacent 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 any other 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 the presented model, called *differentiated traffic-based interconnection agreement* (*DTIA*), whereby each partner is compensated for the costs, which it incurs in carrying traffic according to the differentiated traffic flows.

4. Traffic Management Mechanism

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

4.1 Packet Marking by a Transmission Initiator

We assume that all nodes within the network support packet marking, where each node sets the *first bit* of the ML field of native packet to *'1'* and the packet of stranger traffic to *’0’*. The *assignment of the first bit of the label to ’1’ is done once*, when a node originally initiates a transmission.

A consumer can request a webpage either from a subscribed network or from any other network. This implies that a transmission endpoint, such as the destination can belong to the same network as the transmission initiator or to any other network. Therefore, a packet that appears in the network can be originated either by a local transmission endpoint or by an endpoint, which is located in any other network. Hence, we distinguish the location of a transmission endpoint originated a packet with respect to the network, where the packet appears.

The *second bit* of the label set to *‘1’* indicates that the endpoint is local, and *‘0’* shows that one is located in another network. The *assignment of the second bit of ML to ‘1’ is done once*, when an endpoint of a transmission originates a packet. Consequently, an original initiator of a transmission sets the ML field to *‘11’*. Table 1 presents the description of the four available values of the label, which will be discussed latter in this section.

4.2 Outgoing Packet Re-marking

It is obvious, that native traffic with regard to one network is stranger with regard to the other. Hence, it is necessary to differentiate the exchanged traffic between networks. In order to achieve that we distinguish provider’s border nodes, which are referred to as the *Provider-to-Provider Border (PPB)* nodes. These nodes are trust boundaries and maintain connection with an adjacent network. For calculating the *first bit* of the membership label of outgoing traffic, a PPB node performs the XOR logical operation on both bits of the ML label. Obviously, that the PPB nodes set the *second bit* to *‘0’*. Even though packets within a domain can be marked by any available value of ML, interdomain traffic can take on only *‘00’* or *‘10’* values of the label (i.e. stranger or native traffic originated by a transmission endpoint located in any network).

In addition, in order to carry out intercarrier compensation based on the differentiated traffic (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. native or stranger *with regard to its network*. The volume of the other type of traffic can be easily determined by subtracting the counted volume from the total one. Table 2 demonstrates the logic of the PPB nodes for outgoing packet re-marking and for counting outgoing native traffic.

4.3 Incoming Packet Re-marking

As mentioned before, the website requested by a consumer can be subscribed either to the local network or to any other network. As a result, traffic originated by the endpoint of a transmission (e.g. destination), can be part of a transmission initiated either by the network’s customer or by the customer of any other network. Therefore, the identification the type of traffic (i.e. native or stranger) originated by the transmission endpoint is necessary. For *incoming traffic that is destined to the network* (i.e. destination IP address is local), the PPB nodes perform the NOT logical operation on the *second bit* of the label and do not change the *first bit*.

A transmission endpoint does not re-examine the label. It simply sends *response* packets with the same ML field (i.e. the values *‘01’* or *‘11’* are copied from the request packet). It is obvious that incoming network traffic with the first bit set to *‘1’* and destined to the network is a part of a transmission initiated by its own customers. Table 3 shows the logic of the PPB nodes for incoming traffic and for counting incoming native traffic. An example that helps to understand how the described traffic management mechanism works is described below.

Table 1. Available Values of the ML field.

Values of ML	Description
00	Stranger packet, originated by the endpoint located in another network
01	Stranger packet, originated by the local endpoint
10	Native packet, originated by the endpoint located in another network
11	Native packet, originated by the local endpoint

Table 2. Outgoing Packet Re-marking and Counting.

Input	Output	Counter
00	00	counter1
01	10	counter1
10	10	counter1
11	00	counter1++

counter shows the current value of the counter for outgoing traffic

Table 3. Incoming Packet Re-marking and Counting.

Input	Output (Counter)	
	If destination IP address is local	Otherwise
00	01 (counter2)	00 (counter2)
10	11 (counter2++)	10 (counter2)

counter shows the current value of the counter for incoming traffic

As an example, consider a model consisting of ISP_i, ISP_j, and their customers as well as the transit network ISP_k, 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 node of ISP_i, which receives a packet marked by *'11'*. Before forwarding it to ISP_k, *N1* performs the XOR operation on the ML field of the outgoing packet (i.e. sets the label to *'00'*), and increases the counter for outgoing native traffic. The PPB node *N2* of ISP_k reads the destination IP address, however does not re-mark the label (since the packet is not destined to its network), and then forwards the packet to PPB node *N3*, which maintains connectivity with ISP_j. *N3* node performs the XOR operation on the outgoing packet label (as a result, the ML value remains the same, i.e. *'00'*) and forwards it to PPB node *N4* of ISP_j. *N4* node reads the destination IP address, and since the packet is destined for its network, applies the NOT operation on the label of the incoming packet (i.e. sets ML to *'01'*) and forwards it to the destination, e.g. the *N5* node. After receiving the packet, *N5* sends a packet stream with the requested data, where the label remains the same (*'01'* i.e. stranger traffic, which is originated locally). The similar procedure follows on the inverse path with only one difference that ISP_i considers the incoming traffic as native, initiated by its own customers.

4.4 Incentive Compatibility

It is well known that strategic agents have an incentive not to be truthful and, therefore, end-systems or the defined PPBs nodes can perform mendacious packet marking. However, there are several favorable reasons towards our approach. First, we considered that PPB is 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

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 the impact of the determination of a transmission initiator on the intercarrier compensation in its simplest way, 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 $\alpha_i \in (0,1)$ be a network's market share for consumers and $\beta_i \in (0,1)$ its market share for websites. The market consists of only one transit provider and two customer networks, *i* and *j*, where $i \neq j$, and $\alpha_i + \alpha_j = 1$, $\beta_i + \beta_j = 1$.

Assumption 2 The number of consumers and the number of websites in the market are denoted as 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 request of website and downloads a fixed amount of content.

We examine a scenario, in which ISP$_i$ and ISP$_j$ interconnect through the transit provider ISP$_k$. The amount of differentiated traffic originated from ISP$_i$ with destination ISP$_k$ is given by

$$t_{ik}^{nat} = \alpha_i \beta_j NM \quad (1)$$

$$t_{ik}^{str} = \alpha_j \beta_i NMx \quad (2)$$

where t_{ik}^{nat} and t_{ik}^{str} denote amount of outgoing native traffic (exchanged from consumers to websites) and stranger traffic (exchanged from websites to consumers) with respect to ISP$_i$ correspondingly, and x is the average amount of traffic generated by each website. Similarly, the DT traffic volumes originated by ISP$_j$ and destined to ISP$_i$ are given by

$$t_{jk}^{nat} = \alpha_j \beta_i NM \quad (3)$$

$$t_{jk}^{str} = \alpha_i \beta_j NMx \quad (4)$$

Here, t_{jk}^{nat} and t_{jk}^{str} are outgoing native and stranger traffic volumes with respect to ISP$_j$. The total traffic volumes from ISP$_i$ and ISP$_j$ are calculated as

$$t_{ik} = t_{ik}^{nat} + t_{ik}^{str} \quad (5)$$

$$t_{jk} = t_{jk}^{nat} + t_{jk}^{str} \quad (6)$$

5.1 Unilateral Arrangement

First we consider a unilateral model, in which the transit provider charges the customer providers for every unit of traffic sent and received. Let a_k and b_k are access fees that ISP$_k$ charges customer ISPs for the unit of native and stranger traffic respectively, where $a_k > b_k$ (since the providers compensate partially the costs of carrying stranger traffic). The access charge for the stranger traffic is set $b_k = \varepsilon a_k$, where $0.5 \le \varepsilon < 1$. However, in order to simplify analysis, we fix $\varepsilon = 0.5$. The interconnection payments of ISP$_i$ and ISP$_j$ to the transit provider are given by

$$q_i = a_k\left(t_{ik}^{nat} + t_{jk}^{str}\right) + b_k\left(t_{ik}^{str} + t_{jk}^{nat}\right) \quad (7)$$

$$q_j = a_k\left(t_{jk}^{nat} + t_{ik}^{str}\right) + b_k\left(t_{jk}^{str} + t_{ik}^{nat}\right) \quad (8)$$

The interconnection payments of ISP$_i$ (ISP$_j$) can be interpreted as two independent components i) one for the native traffic business, and ii) another for the stranger traffic business.

Proposition 1 *If $\alpha_i = \alpha_j$ and $\beta_i = \beta_j$, then the costs of the customer providers are the same.*

Proof: From the conditions (1)-(4) follows that $t_{ik}^{nat} + t_{jk}^{str} = t_{ik}^{str} + t_{jk}^{nat}$. As a result, using (7) and (8) it can be obtained that $q_i = q_j$. □

Proposition 2 *If $\alpha_i = \alpha_j$ and $\beta_i > \beta_j$, then the costs of ISP$_i$ are lower than the costs of ISP$_j$.*

Proof: Observing conditions (1)-(4) it can be obtained that $t_{ik}^{nat} + t_{jk}^{str} < t_{ik}^{str} + t_{jk}^{nat}$. Consequently, from the conditions (7) and (8) follows that $q_i < q_j$. □

Proposition 3 *If $\alpha_i > \alpha_j$ and $\beta_i = \beta_j$, then the costs of ISP$_i$ are higher than the costs of ISP$_j$.*

Proof: From the conditions (1)-(4) follows that $t_{ik}^{nat} + t_{jk}^{str} > t_{ik}^{str} + t_{jk}^{nat}$. Using (7)-(8) it can be obtained that $q_i > q_j$. □

When $\alpha_i > \alpha_j$ and $\beta_i > \beta_j$, the following cases for traffic volumes are obtained from the conditions (5)-(6): 1) $t_{ik} > t_{jk}$, 2) $t_{ik} < t_{jk}$, and 3) $t_{ik} = t_{jk}$. The cases 1) and 2) are analogous to those described above. The last case when $t_{ik} = t_{jk}$ is analyzed below.

Proposition 4 *If $\alpha_i > \alpha_j$, $\beta_i > \beta_j$, and $t_{ik} = t_{jk}$, then $\alpha_i = \beta_i$.*

Proof: The result is obtained from the conditions (1)-(6). □

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

Proposition 5 *If* $\alpha_i > \alpha_j$ *,* $\beta_i > \beta_j$ *, and* $t_{ik} = t_{jk}$ *then the costs of the customer providers are equal, i.e.* $q_i = q_j$ *.*

Proof: The result is obtained analogously to the previous cases from the conditions (7) and (8). □

Proposition 6 *If* $\alpha_i > \alpha_j$ *and* $\beta_i < \beta_j$*, then the costs of ISP*$_i$ *are higher than the costs of ISP*$_j$*.*

Proof: Considering conditions (1)-(4) it can be obtained that $t_{ik}^{nat} + t_{jk}^{str} > t_{ik}^{str} + t_{jk}^{nat}$. Consequently, from the conditions (7) and (8) follows that $q_i > q_j$.

□

Table 4. Results of DTIA

Case	α	β	t^{nat}	t^{str}	q
I	$\alpha_i = \alpha_j$	$\beta_i = \beta_j$	$t_{ik}^{nat} = t_{jk}^{nat}$	$t_{ik}^{str} = t_{jk}^{str}$	$q_i = q_j$
II	$\alpha_i = \alpha_j$	$\beta_i > \beta_j$	$t_{ik}^{nat} < t_{jk}^{nat}$	$t_{ik}^{str} > t_{jk}^{str}$	$q_i < q_j$
III	$\alpha_i > \alpha_j$	$\beta_i = \beta_j$	$t_{ik}^{nat} > t_{jk}^{nat}$	$t_{ik}^{str} < t_{jk}^{str}$	$q_i > q_j$
IV	$\alpha_i > \alpha_j$	$\beta_i > \beta_j$	*If* $t_{ik}^{nat} = t_{jk}^{nat}$	*If* $t_{ik}^{str} = t_{jk}^{str}$	$q_i = q_j$
V	$\alpha_i > \alpha_j$	$\beta_i < \beta_j$	$t_{ik}^{nat} > t_{jk}^{nat}$	$t_{ik}^{str} < t_{jk}^{str}$	$q_i > q_j$

Table 5. Comparative Results of the Agreements Based on the Traffic Flow (TF) and Unilateral DTIA Compensations

Case	α_i	β_i	t_{ik}^{nat}	t_{ik}^{str}	t_{jk}^{nat}	t_{jk}^{str}	q_i		q_j	
							DTIA	TF	DTIA	TF
I $\alpha_i = \alpha_j$ $\beta_i = \beta_j$	0.5	0.9	1500	52500	1500	52500	121500	162000	121500	162000
II $\alpha_i = \alpha_j$ $\beta_i > \beta_j$	0.5	0.9	300	94500	2700	10500	89100	162000	153900	162000
	0.5	0.8	600	84000	2400	21000	97200	162000	145800	162000
	0.5	0.7	900	73500	2100	31500	105300	162000	137700	162000
	0.5	0.6	1200	63000	1800	42000	113400	162000	129600	162000
III $\alpha_i > \alpha_j$ $\beta_i = \beta_j$	0.9	0.5	2700	10500	300	94500	153900	162000	89100	162000
	0.8	0.5	2400	21000	600	84000	145800	162000	97200	162000
	0.7	0.5	2100	31500	900	73500	137700	162000	105300	162000
	0.6	0.5	1800	42000	1200	63000	129600	162000	113400	162000
IV $\alpha_i > \alpha_j$ $\beta_i > \beta_j$	0.9	0.9	540	18900	540	18900	43740	58320	43740	58320
	0.8	0.8	960	33600	960	33600	77760	103680	77760	103680
	0.7	0.7	1260	44100	1260	44100	102060	136080	102060	136080
	0.6	0.6	1440	50400	1440	50400	116640	155520	116640	155520
V $\alpha_i > \alpha_j$ $\beta_i < \beta_j$	0.9	0.2	4320	4200	120	151200	236520	239760	123120	239760
	0.8	0.25	3600	10500	300	126000	202500	210600	113400	210600
	0.7	0.35	2730	22050	630	95550	164430	181440	107730	181440
	0.6	0.4	2160	33600	960	75600	142560	168480	110160	168480

Table 4 and Table 5 summarize the outcomes of the analytical studies. Table 4 shows how the interconnection payments of the customer providers depend on the DT flows. In addition to this, the results demonstrate the influence of providers' market shares on intercarrier compensation.

The comparison results between the unilateral settlements, which are based on the traffic flows and DT flows compensations are presented in Table 5. In order to calculation specific outcomes, we impose the following parameter values $a_k = 1.5$, $x = 35$, $N = 100$, and $M = 60$.

5.2 Bilateral Arrangement

In this subsection we explore how intercarrier compensation depends on the DT flows considering bilateral arrangement. We consider that providers set non-reciprocal access charges independently. The net interconnection payments of ISP$_i$ to ISP$_k$ and vice versa are denoted by q_{ik} and q_{ki} correspondingly:

$$q_{ik} = a_k t_{ik}^{nat} + b_k t_{ik}^{str} \quad (9)$$

$$q_{ki} = b_i \left(t_{jk}^{nat} + t_{jk}^{str} \right) \quad (10)$$

where b_i is network *i*'s access charge for every unit of received strange traffic with respect to ISP$_k$. It can be noticed that the transit provider is charged based on the rate for stranger traffic, because it does not have any customers of its own. Similarly, the net transfers from ISP$_j$ to ISP$_k$ and vice versa are denoted by q_{jk} and q_{kj} respectively:

$$q_{jk} = a_k t_{jk}^{nat} + b_k t_{jk}^{str} \quad (11)$$

$$q_{kj} = b_j \left(t_{ik}^{nat} + t_{ik}^{str} \right) \quad (12)$$

where b_j is network *j*'s access charge for every unit of received strange traffic with respect to ISP$_k$. To carry out analysis, we assume that each customer network access charge for terminating the native traffic is set to the termination marginal cost, and for terminating the stranger traffic is defined by $b_i = \varepsilon a_i$, where $0.5 \le \varepsilon < 1$. For simplicity we fix $\varepsilon = 0.5$. We examine the case when marginal cost exhibits increasing returns to scale meaning that the incremental costs of network decrease as the network size increases.

The further investigation is done analogously to the case of reciprocal access charges in unilateral arrangement. Table 6 reports the comparison results between agreements based on the unilateral model and bilateral DTIA compensations. In order to calculate specific outcomes, we impose the following values of access charges i) $a_i = a_j = 0.6$ in Cases I and V, ii) $a_i = 0{,}6$, $a_j = 1$ in all other cases. Other parameters are $a_k = 1.5$, $x = 35$, $N = 100$, and $M = 60$.

6. Conclusions

In this paper we analyzed the impact of the determination of a transmission initiator on the intercarrier compensation in unilateral and bilateral arrangements. For this reason we proposed a model, called differentiated traffic-based interconnection agreement (DTIA), which differentiates traffic into two types, called native and stranger, and calculates (compensates) costs according to a particular type of traffic flow.

Besides that we introduced a DTIA supporting traffic management mechanism, in which only border nodes perform packet management. The main advantage of the presented mechanism is its simplicity and scalability that is a basic requirement for a deployment in the Internet.

Table 6. Comparative Results of the Agreements Based on the Traffic Flow (TF) and Bilateral DTIA Compensations

Case	α_i	β_i	t_{ik}^{nat}	t_{ik}^{str}	t_{jk}^{nat}	t_{jk}^{str}	q_{ik}		q_{jk}		$q_k = q_{ki} + q_{kj}$		π_k	
							DTIA	TF	DTIA	TF	DTIA	TF	DTIA	TF
I $\alpha_i = \alpha_j$ $\beta_i = \beta_j$	0.5	0.9	1500	52500	1500	52500	41625	162000	41625	162000	32400	0	50850	324000
II $\alpha_i = \alpha_j$	0.5	0.9	300	94500	2700	10500	71325	162000	11925	162000	51360	0	31890	324000
$\beta_i > \beta_j$	0.5	0.8	600	84000	2400	21000	63900	162000	19350	162000	49320	0	33930	324000
	0.5	0.7	900	73500	2100	31500	56475	162000	26775	162000	47280	0	35970	324000
	0.5	0.6	1200	63000	1800	42000	49050	162000	34200	162000	45240	0	38010	324000
III $\alpha_i > \alpha_j$	0.9	0.5	2700	10500	300	94500	11925	162000	71325	162000	35040	0	48210	324000
$\beta_i = \beta_j$	0.8	0.5	2400	21000	600	84000	19350	162000	63900	162000	37080	0	46170	324000
	0.7	0.5	2100	31500	900	73500	26775	162000	56475	162000	39120	0	44130	324000
	0.6	0.5	1800	42000	1200	63000	34200	162000	49050	162000	41160	0	42090	324000
IV $\alpha_i > \alpha_j$	0.9	0.9	540	18900	540	18900	14985	58320	14985	58320	15552	0	14418	116640
$\beta_i > \beta_j$	0.8	0.8	960	33600	960	33600	26640	103680	26640	103680	27648	0	25632	207360
	0.7	0.7	1260	44100	1260	44100	34965	136080	34965	136080	36288	0	33642	272160
	0.6	0.6	1440	50400	1440	50400	39960	155520	39960	155520	41472	0	38448	311040
V $\alpha_i > \alpha_j$	0.9	0.2	4320	4200	120	151200	9630	239760	113580	239760	47952	0	75258	479520
$\beta_i < \beta_j$	0.8	0.25	3600	10500	300	126000	13275	210600	94950	210600	42120	0	66105	421200
	0.7	0.35	2730	22050	630	95550	20633	181440	72608	181440	36288	0	56952	362880
	0.6	0.4	2160	33600	960	75600	28440	168480	58140	168480	33696	0	52884	336960

q_k = total costs of the transit provider
π_k = $q_{ik} + q_{jk} - q_k$ provider k's profit obtained from interconnection

In particular, a provider has not to maintain a complex identification process of a transmission initiator, and 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 the appropriate traffic type and therefore, leads to low computational complexity (Table 1). The logic of the border nodes for packet marking and counting is demonstrated as well (Table 2 and Table 3).

Our analytical studies were carried out to investigate how the interconnection payments depend on the differentiated traffic flows (see Tables IV-VI). The following conclusions can be drawn from the obtained results. In comparison to the classical unilateral model, both the unilateral and bilateral DTIA models provided unequal and significantly decreased payments of the customer providers (except the equal traffic volumes presented in Case IV). This is achieved by sharing the interconnection costs between all parties including a transit provider. As a result, the profits of the transit provider obtained from the interconnection are lower in case of DTIA than in the existing scheme. It can be concluded that DTIA is beneficial for the customer providers, since it outperforms the classical model in terms of payments, which are relatively small.

7. Acknowledgment

The authors would like to thank Kristina Davoian from University of Münster for her useful comments.

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