

Internet Interconnection Economic Model and its Analysis: Peering and Settlement

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Abstract: Peering and transit are two types of Internet interconnection among ISPs. Peering has been a core concept to sustain Internet industry. However, for the past several years, many ISPs broke their peering arrangement because of asymmetric traffic pattern and asymmetric benefit and cost from the peering. Even though traffic flows are not a good indicator of the relative benefit of an Internet interconnection between the ISPs, it is needless to say that cost is a function of traffic and the only thing that we can know for certain is inbound/outbound traffic volumes between the ISPs. In this context, we suggest $\text{Max} \{ \text{inbound traffic volume}, \text{outbound traffic volume} \}$ as an alternative criterion to determine the Internet settlement between ISPs and we demonstrate this rule makes ISPs easier to make a peering arrangement. In our model, the traffic volume is a function of a market share. We will show the market share decides traffic volume, which is based on the settlement between ISPs. As a result, we address the current interconnection settlement problem with knowledge of inbound and outbound traffic flows and we develop an analytical framework to explain the Internet interconnection settlement.

Keywords: Internet interconnection, peering, transit, settlement

1 INTRODUCTION

The Internet industry is dynamic. The number of Internet Service Providers (ISPs) is increasing rapidly and the structure of the industry changes continuously. It is widely accepted that today's Internet industry has vertical structure: over 40 Internet Backbone Providers (IBPs) including

5 top-tier backbones constitute the upstream industry (Kende, 2000) and over 10,000 ISPs for accessing the Internet make up the downstream industry (Weinberg, 2000). A backbone provider service is critical for those ISPs to connect to the whole Internet. As the number of ISPs and IBPs increase, the Internet interconnection settlement¹ issue is becoming more significant. Under the current interconnection arrangement, it is uncertain to decide which (a sender or a receiver) has responsibility for the traffic to send or receive because current capacity based interconnection pricing scheme does not know which part has to pay a cost of that traffic. ISPs can use pricing based on inbound traffic volume, on outbound traffic volume, on a hybrid of inbound and outbound traffic volume, or on the line capacity regardless of volume (Hutson, 1998, p565). None of these methods gives full satisfaction to all of the service providers in the industry. Many scholars and industry experts say that a usage-based pricing scheme and a usage-based settlement system are the only alternative to overcome the current uncertainty. However, they agree that there are technical difficulties in changing the current Internet financial system to a usage-based system². Even though traffic flows are not a good indicator of the relative benefit of an Internet interconnection between the service providers (Kende, 2000, p36), it is needless to say that cost is a function of traffic and the only thing that we can know for certain is inbound/outbound traffic volumes between the service providers. We address the current interconnection settlement problem with knowledge of inbound and outbound traffic flows and we develop an analytical framework to explain the Internet interconnection settlement issues.

2 TYPES OF INTERNET INTERCONNECTION

There are two types of Internet interconnection among ISPs and IBPs: peering and transit. The only difference among these types is in the financial rights and obligation that they generate to their customers. First, we will examine the history of Internet interconnection.

2.1 History of Interconnection

To understand the relationship between peering and transit, it is necessary to review the situation before the commercialization of the

¹ Settlement can be thought of as payments or financial transfers between ISPs in return for interconnection and interoperability (Cawley, 1997)

² Various kinds of protocols, duplicate layers, packet dropping, dynamic routing, and reliability issues, etc.

Internet in 1995. During the early development of the Internet, there was only one backbone and only one customer, the military, so interconnection was not an issue. In the 1980s, as the Internet was opened to academic and research institutions, and the National Science Foundation (NSF) funded the NSFNET as an Internet backbone. Around that time, the Federal Internet Exchange (FIX) served as a first point of interconnection between federal and academic networks. At the time that commercial networks began appearing, general commercial activity on the Internet was restricted by Acceptable Use Policy (AUP), which prevented the commercial networks from exchange traffic with one another using the NSFNET as the backbone. (Kende, 2000, p5) In the early 1990s, a number of commercial backbone operators including PSINet, UUNET, and CerfNET established the Commercial Internet Exchange (CIX) for the purpose of interconnecting these backbones and exchanging their end users' traffic. The NSF decided to cease to operate the NSF backbone, which was replaced by four Network Access Points (NAPs)³. (Minoli and Schmidt, 1998, p28) The role of NAPs is similar to that of CIX. After the advent of CIX and NAPs, commercial backbones developed a system of interconnection known as peering.

2.2 What is Peering?

The term “peering” is sometimes used generically to refer to Internet interconnection with no financial settlement, which is known as “Sender Keeps All (SKA)” or “Bill and Keep” arrangement. Peering can be divided into several categories: (1) according to its openness, it can be private peering or public peering, (2) according to the numbers of peering partners it can be Bilateral Peering Arrangement (BLPA) or Multilateral Peering Arrangement (MLPA), and (3) according to the market in which it occurs, it can be primary peering in the backbone market or secondary peering in the downstream market.

The original 4 NAPs points for public peering. Anyone who is a member of NAP can exchange traffic based on equal cost sharing. Members pay for their own router to connect to the NAP plus the connectivity fee charged by the NAP. As the Internet traffic grew, the NAPs suffered from congestion. Therefore, direct circuit interconnection between two large IBPs was introduced, so called bilateral private peering, which takes place at a mutually agreed place of interconnection. This private peering is opposed to public peering that takes place at the NAPs. It is estimated that 80 percent of Internet traffic is exchanged via private peering (Kende, 2000, pp. 6-7).

³ 4 NAPs are Chicago NAP (Ameritech), San Francisco NAP (Pacific Bell), New York NAP (Sprint), and Washington D.C. NAP (Metropolitan Fiber Systems).

A peering arrangement is based on equality, that is, ISPs of equal size would peer. The measures of size could be (i) geographic coverage, (ii) network capacity, (iii) traffic volume, (iv) size of customer base, or (v) a position in the market. The ISPs would peer when they perceive equal benefit from peering based on their own subjective terms. (Kende, 2000, p8)

The followings are peering characteristics:

1. Peering partners only exchange traffic that originates with the customer of one ISP and terminates with the customer of the other peered ISP. As part of peering arrangement, an ISP would not act as an intermediary. And it would not accept the traffic of one peering partner for the purpose of transiting this traffic to another peering partner. This characteristic is called a “non-transitive relationship.”
2. Peering partners exchange traffic on a settlement-free basis. The only cost of each partner is its own equipment and the transmission capacity needed for the two peers to meet at each peering point
3. Peering partners generally meet in a number of geographically dispersed locations. In order to decide where to pass traffic to another, they have adopted what is known as “hot-potato routing,” where an ISP will pass traffic to another backbone at the earliest point of exchange.

According to Block (Cukier, 1999), there are two conditions necessary SKA peering, that is, peering with no settlement, to be viable: (1) The traffic flows should be roughly balanced between interconnecting networks; and (2) the cost of terminating traffic should be low in relation to the cost of measuring and billing for traffic. In sum, peering is sustainable under the assumption of mutual benefits and costly, unnecessary traffic measuring. Peering partners would make a peering arrangement if they each perceive that they have more benefits than costs from the peering arrangement. Most ISPs historically have not metered traffic flows and accordingly have not erected a pricing mechanism based on usage. Unlimited access with a flat rate is a general form of pricing structure in the Internet industry. Finally, peering makes billing simple: no metering and no financial settlement.

2.3 What is Transit?

Transit is an alternative arrangement between ISPs and IBPs, in which one pays another to deliver traffic between its customers and the customers of other provider. The relationship of transit arrangement is hierarchical: a provider-customer relationship. Unlike a peering relationship, a transit provider will route traffic from the transit customer to its peering partners. An IBP with many transit customers has a better position when negotiating a peering arrangement with other IBPs. Another difference between peering

and transit is existence of Service Level Agreement (SLA). In the peering arrangement, there is no SLA to guarantee rapid repair of problems. In the case of an outage, both peering partners may try to repair the problem, but it is not mandatory. This is one of the reasons peering agreements with the company short of competent technical staffs are broken. But in the transit arrangement it is a contract and customers could ask transit provider to meet the SLA. In the case of e-commerce companies, they prefer transit to peering. Since one minute of outage causes lots of losses to them, rapid recovery is critical to their business. Furthermore, in the case of transit, there is no threat to quit the relationship while in the case of peering a non-renewal of the peering agreement is a threat. When purchasing transit service, ISPs will consider other factors beside low cost: performance of the transit provider's backbone, location of access nodes, number of directly connected customers, and a market position.

3 ASSUMPTIONS OF THE INTERNET INTERCONNECTION ECONOMIC MODEL

To simplify the model, we made several assumptions:

1. There is only one IBP in the upstream backbone market and there are two ISPs in the downstream Internet access market. ISP-1 and ISP-2 sell the Internet connectivity to their customers. The interconnection to the IBP's network is the only way to do that because the IBP is the sole provider of the Internet backbone. The IBP does not support customers directly.
2. If the market share of ISP-1 is α , then that of ISP-2 is $(1-\alpha)$ because there are only two ISPs in the market ($0 < \alpha < 1$). This market share is a unique factor in determining traffic volume and α is a parameter, which can be given by the downstream Internet access market.
3. N is the total number of customers in the downstream Internet access market. If the market share of ISP-1 is α , the number of Internet subscribers of ISP-1 is $N \cdot \alpha$ and that of ISP-2 is $N \cdot (1-\alpha)$. Customers do not have to choose two ISPs at the same time because of homogeneity of the service.
4. There are three kinds of traffic in each ISP, T_{ij} , where $i = 1, 2$ (subscript for ISP) and $j = L, O, I$ (subscript for traffic type): local traffic (T_{1L}, T_{2L}), outbound traffic (T_{1O}, T_{2O}), and inbound traffic (T_{1I}, T_{2I}).
 - Each ISP generates two types of traffic: local traffic which uses only local network and outbound traffic which uses whole network including backbone network and the other ISP's network.

- The amount of local traffic depends on its market share. An ISP with large market share has a relatively large portion of local traffic compared to its outbound traffic, while an ISP with small market share has a relatively small portion of local traffic compared to its outbound traffic.
 - The amount of outbound traffic depends on the other ISP's market share. That is to say, ISP-1's outbound traffic (T_{1O}) depends on the market share of ISP-2, $(1-\alpha)$, and vice versa.
 - One ISP's inbound traffic is the same as the other ISP's outbound traffic, which means ISP-1's inbound traffic (T_{1I}) is the same as ISP-2's outbound traffic (T_{2O}) because there are only two ISPs in the market.
 - The assumption of dependency of market share comes from a concept of network externality⁴. An ISP with large customer base and many Internet resources such as FTP sites and Web sites is less dependent on other ISPs than an ISP with small customer base and less Internet resources.
5. The average traffic generated per subscriber is assumed that 3 G bits per month, which comes from the following assumptions and calculation:
- The two ISPs sell only 56 Kbps dial-up modem Internet connectivity⁵.
 - The average hours of Internet usage is 90 hours per month⁶.
 - We apply 1:6 bandwidth ratio. The bandwidth ratio occurs because a user does not consume whole 56 Kbps for the duration of the connection. For example, in the case of reading a news article in the Internet, a user can use a full capacity of downloading that news article, but after that, when he reads a news article, no traffic is transmitted.
 - $56 \text{ (Kbps)} * 90 \text{ (hours/month)} * 3600 \text{ (seconds/hour)} * 1/6 = 3 \text{ G bits per subscriber approximately.}$
6. The number of subscriber and the average traffic per subscriber determine the traffic volumes such as T_1 and T_2 .

⁴ Network externalities arise when the value or utility that a customer derives from a product or service increases as a function of other customers of the same or compatible products or services; that is, the more users there are, the more valuable the network. There are two kinds of network externality in the Internet. One is direct network externality: the more E-mail users, the more valuable the Internet is. The other is indirect network externality: the more Internet users there are, the more web contents will be developed, which makes the Internet even more valuable for its users. (Kende, 2000)

⁵ According to the report (2001) from USGAO (United States Government Account Office), 87.5% of Internet users use the narrow band dial-up modem.

⁶ According to the report (2001) from USGAO (United States Government Account Office), 15 ~ 25 hours per week is the most frequently selected Internet usage hours from which we choose 20 hours per week and converted it to 90 hours per month.

- The total traffic generated by ISP-1 (T_1) is the sum of local traffic (T_{1L}) and outbound traffic (T_{1O}): $T_1 = T_{1L} + T_{1O} = 3 \text{ G bits} * (\text{Number of ISP-1's Subscriber}) = 3 \text{ G bits} * (\alpha * N)$.
 - The total traffic generated by ISP-2 (T_2) is the sum of local traffic (T_{2L}) and outbound traffic (T_{2O}): $T_2 = T_{2L} + T_{2O} = 3 \text{ G bits} * (\text{Number of ISP-2's Subscriber}) = 3 \text{ G bits} * (1-\alpha) * N$.
7. The interconnection fee (settlement) is the only cost of each ISP to IBP. The IBP does not have any cost. This settlement is the only revenue of the IBP.
 8. Each ISP gets a fixed monthly access charge from its own users.

The following graph illustrates traffic flow and relationship between IBP and ISPs.

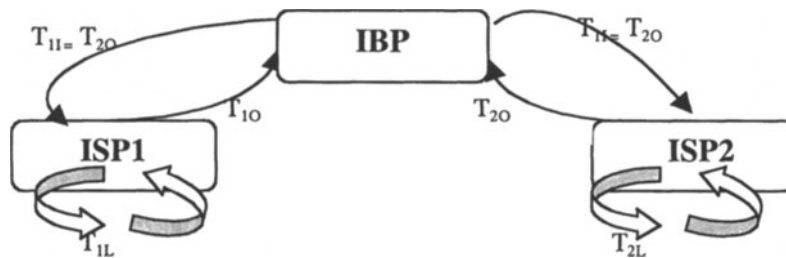


Figure1. Traffic flows

4 TRAFFIC FUNCTION

Because there are only two ISPs, if one ISP's market share is 100%, then all the traffic generated in this market comes from that ISP and therefore no connection to the backbone is needed. If the market shares of the two ISPs are the same ($\alpha=50\%$), the traffic from each ISP must be the same, because the traffic is dependent upon only the market share. The local traffic increases and the outbound traffic decreases as the market share increases, but the increasing or decreasing patterns are not linear. This non-linear characteristic comes from the number of servers on a network. Under the assumption that each user accesses each server with equal probability, average traffic is directly proportional to the number of servers on the network. The local traffic function (f_L) is non-linear only if the number of servers on the network is non-linear with respect to market share (α). One of the main reasons for non-linear number of servers with respect to market

share (α) is mirroring⁷ and caching⁸. The mirroring of servers like duplicate FTP servers or the caching of Web pages by ISPs, moves applications and data closer to the Internet users. As the number of subscribers increases, the mirroring servers and the caching servers increase more than linear, which means that local traffic also increases in a non-linear fashion. According to the report by Williams and Sochats (1999), investigating whether the amount of time Internet applications hold Interstate telecommunication resources is less than 10% of the total time an Internet user is connected to its local ISP, mirrored sites continue to expand and caching of Web pages by ISPs even more widespread, the percentage of time Internet applications will use the Interstate transmission facilities will continue to decrease. This result implies that as the number of the mirrored and caching servers increases, the portion of local traffic within the network increases sharply.

By use of the above concept, we use the quadratic monotonic increasing function satisfying the following three points in the market share plane (X-axis) and traffic plane (Y-axis): (0%, 0%), (50%, 50%), and (100%, 100%). The local traffic function (f_L) and outbound traffic function (f_o) satisfying the above conditions are:

$$f_L(\alpha) = \begin{cases} 2*\alpha^2 & : 0 < \alpha < 0.5 \dots\dots\dots(1) \\ -2*(1-\alpha)^2 + 1 & : 0.5 < \alpha < 1 \dots\dots\dots(2) \end{cases}$$

$$f_o(1-\alpha) = 1 - f_L(\alpha) = \begin{cases} 1 - 2*\alpha^2 & : 0 < \alpha < 0.5 \dots\dots\dots(3) \\ -2*(1-\alpha)^2 & : 0.5 < \alpha < 1 \dots\dots\dots(4) \end{cases}$$

The following figure shows graphs of local and outbound traffic using the above functions.

⁷ Content providers maintain duplicated web sites on a number of different servers to improve bandwidth efficiency and better service to the end-users.

⁸ Storing copies of frequently retrieved Web pages or data on servers that are geographically closer to end-users.

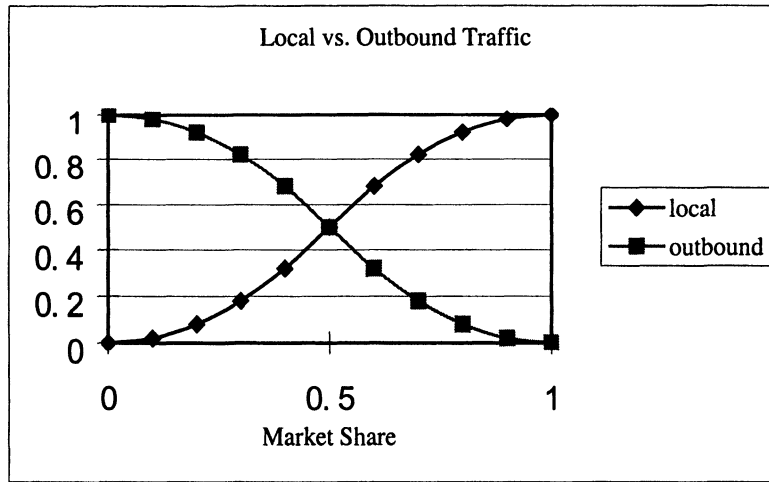


Figure2. Proportion of local and outbound traffic

5 TRAFFIC SUPPLY FOR INTERCONNECTION

As we mentioned earlier section, the traffic using ISP-1’s network (T_{1N}) consists of three types of traffic: (1) Local traffic only using ISP-1’s network (T_{1L}), (2) outbound traffic generated by ISP-1 and forwarding to ISP-2’s network (T_{1O}), and (3) inbound traffic generated by ISP-2 and coming into ISP-1’s network (T_{1I}). For the traffic using ISP-1’s network and ISP-2’s network, we can write the following equations:

$$T_{1N} = T_{1L} + T_{1O} + T_{1I} \dots\dots\dots(5)$$

$$T_{2N} = T_{2L} + T_{2O} + T_{2I} \dots\dots\dots(6)$$

One ISP’s outbound traffic is the same as the other’s inbound traffic. Therefore we can change equations (5) & (6) into equations (7) & (8):

$$T_{1N} = T_{1L} + T_{1O} + T_{2O} \dots\dots\dots(7)$$

$$T_{2N} = T_{2L} + T_{2O} + T_{1O} \dots\dots\dots(8)$$

According to equations (7) & (8), the traffic of one ISP’s network is the sum of its local traffic and total outbound traffic ($T_{1O} + T_{2O}$). The line capacity between ISP and IBP should be at least the sum of each ISP’s outbound traffic, which can be traffic supply in this model. We assume that the IBP has enough capacity to accommodate ISPs’ traffic in the downstream market.

6 MAXIMUM OUTBOUND TRAFFIC CRITERION FOR SETTLEMENT AND TRAFFIC DEMAND

These days, 80%-85% of all ISP traffic is traffic generated by receiver requests, such as Web page retrieval or downloading files (Hutson, 1998, p571). In these cases, the request traffic is generally very small compared to the traffic of web pages or downloaded files. That means there is much more inbound traffic compared to the outbound traffic for each service request. This is a typical asymmetric traffic flow pattern between inbound and outbound traffic.

The peering arrangement is based upon the symmetric traffic pattern. However, service oriented Internet providers such as Web hosting providers (web farm) produce more outbound traffic than the providers with a large customer base. Peering is basically SKA settlement system. Refusing a peering arrangement means that the refused partner has to pay the transit fee for interconnection service. The inbound and outbound traffic volumes are not a good indicator to determine Internet connectivity fees because we do not know well who can get more benefit and who uses more the other's network precisely. There is an uncertainty in matching benefit and cost of network usage. However, in reality, the knowledge of inbound and outbound traffic volumes is the only available information between ISPs' networks. Regardless of the type of service provider and the customer size of ISP, when an ISP connects to a backbone provider, **Max {inbound traffic volume, outbound traffic volume}** can be an alternative criterion to determine the interconnection fee between the two providers.

In the case of interconnection between ISP-1 and IBP, Max {inbound traffic volume, outbound traffic volume} can be rewritten as,

$$\begin{aligned}
 & \text{Max } \{T_{10}, T_{11}\} \\
 & = \text{Max } \{T_{10}, T_{20}\} \\
 & = \text{Max } \{f_O(\alpha)*T_1, f_O(1-\alpha)*T_2\} \\
 & = \text{Max } \{(1-f_L(\alpha))*T_1, (1-f_L(1-\alpha))*T_2\} \\
 & = \text{Max } \{(1-f_L(\alpha))*\alpha*3G \text{ bits}*N, (1-f_L(1-\alpha))*(1-\alpha)*3G \text{ bits}*N\} \\
 & = \begin{cases} (-2\alpha^3 + \alpha) * 3G \text{ bits} * N, & \text{when } 0 < \alpha < 0.5 \dots\dots\dots(9) \\ 2*(1-\alpha)^3 * 3G \text{ bits}*N, & \text{when } 0.5 < \alpha < 1 \dots\dots\dots(10) \end{cases}
 \end{aligned}$$

The equations (9) & (10) consist of two parts: deterministic terms (3 G bits *N) and variable terms that can be varied by the value of market share (α). The following table and graph are made by the only variable part of the equations (9) and (10) when a market share of ISP-1 (α) increases from 0% to 100%.

Market Share		Local Traffic		Outbound Traffic		Inbound Traffic		Max {T ₁₀ , T ₂₀ }
ISP-1	ISP-2	ISP-1	ISP-2	ISP-1	ISP-2	ISP-1	ISP-2	
α	(1 - α)	T _{1L}	T _{2L}	T _{1O}	T _{2O}	T _{1I}	T _{2I}	
0.00	1.00	0.000	1.000	0.000	0.000	0.000	0.000	0.000
0.10	0.90	0.020	0.980	0.980	0.020	0.020	0.980	0.098
0.20	0.80	0.080	0.920	0.920	0.080	0.080	0.920	0.184
0.30	0.70	0.180	0.820	0.820	0.180	0.180	0.820	0.246
0.40	0.60	0.320	0.680	0.680	0.320	0.320	0.680	0.272
0.50	0.50	0.500	0.500	0.500	0.500	0.500	0.500	0.250
0.60	0.40	0.680	0.320	0.320	0.680	0.680	0.320	0.272
0.70	0.30	0.820	0.180	0.180	0.820	0.820	0.180	0.246
0.80	0.20	0.920	0.080	0.080	0.920	0.920	0.080	0.184
0.90	0.10	0.980	0.020	0.020	0.980	0.980	0.020	0.098
1.00	0.00	1.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 1. Max {T₁₀, T₂₀}

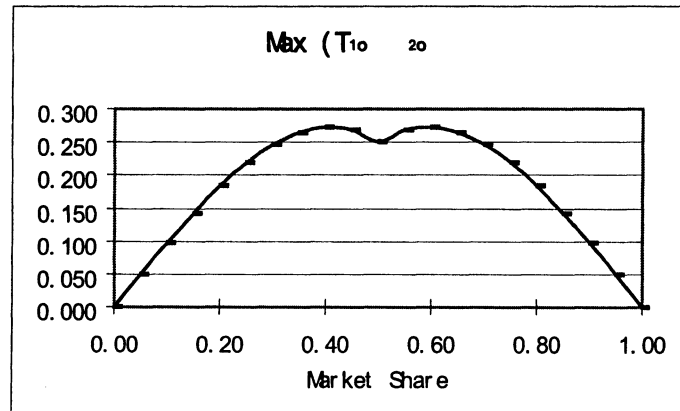


Figure 3. Max {T₁₀, T₂₀}

The maximum outbound traffic of the ISP-1 and ISP-2 can be the traffic demand for each ISP to determine settlement in this model.

- Traffic Demand (α) = Max {T₁₀, T₂₀}

From the above table and graph, we can draw the conclusion that the traffic demand for interconnection with the backbone provider depends on the market share α . And this demand is symmetric at 50%. The following table shows the traffic demand per month according to the market share α .

Share α	0.1/0.9	0.2/0.8	0.3/0.7	0.4/0.6	0.5
Traffic Demand	294Mbits*N (=3G*0.098)	552Mbits*N (=3G*0.184)	738Mbits*N (=3G*0.246)	816Mbits*N (=3G*0.272)	750Mbits N (=3G*0.250)

Table 2. Traffic Demand

The number of bits that can be accommodated by a single T-1 line in a month is 432,000 M bits per month⁹, which is calculated by the assumption of 4 peak hours a day. We can know how many T-1 lines are needed if we divide traffic demand per month by 432, 000 M bits. The following table shows the number of T-1 lines needed for traffic demand under the assumption of $N = 5,000$ users. For example, in the case of $\alpha = 0.1$, $\{294 \text{ M bits} * 5,000\} / 432,000 \text{ M bits} = 3.4 \text{ T-1 lines}$.

Market Share (α)	0.1/0.9	0.2/0.8	0.3/0.7	0.4/0.6	0.5
Number of T-1s	4	7	9	10	9

Table 3. Number of T-1s needed for Traffic Demand

The settlement is generally defined as a product of the traffic demand and the interconnection fee. In this case, the settlement can be expressed as a product of (Number of T-1 lines) and (T-1 transit price). For example, if the ISP-1 uses 4 T-1 lines and the Internet interconnection T-1 transit price is \$1,000 per month, then the settlement is \$4,000 per month. The transit price is usually determined by the provider's relative strength and level of investment in a particular area (Halabi, 2000, 42p). It is certain that T-1 transit prices have decreased continuously. In 1996, the Internet connectivity for T-1 was \$3,000 per month with \$1000 setup fee (Halabi, 1997, 40p). According to Martin (2001), the average price of a T-1 connection has continuously decreased for several years: \$1,729 (1999), \$1,348 (2000), and \$1,228 (2001).

We assume that the T-1 transit price is given by the market, which is equal to \$1,000 per month. The following table shows the amount of settlement payment from each ISP to the IBP. This settlement is also symmetric at the mid point of $\alpha = 0.5$.

Market Share	0.1/0.9	0.2/0.8	0.3/0.7	0.4/0.6	0.5
Settlement	\$4,000	\$7,000	\$9,000	\$10,000	\$9,000

Table 4. Settlement from ISP to IBP

⁹ 1.5 M bps * (3600 second * 4 peak hours * 30 days)

7 INTERNET ACCESS USER PRICE AND PEERING INCENTIVE

If we assume that each customer pays the fixed price per month for his accessing the Internet, by use of the cost and revenue function we can calculate how much a user price should be.

The following shows the procedure of calculation of user price P_1 and P_2 of ISP-1 and ISP-2 under the assumption of ISP-1's market share $0 < \alpha < 0.5$.

- Revenue of ISP-1 = $P_1 * (\text{Number of Subscribers})$
 = $P_1 * (\alpha * 5,000)$ (11)
- Cost of ISP-1 = (Settlement to IBP)
 = (No. of T-1 lines)*(T-1 transit price)
 = (No. of T-1 lines)* \$1,000.....(12)
- Profit of ISP-1 = (11) – (12)
 = $P_1 * (\alpha * 5,000) - (\text{No. of T-1 lines}) * \$1,000$
 = $1,000 * \{5 * P_1 * \alpha - \text{No. of T-1 lines}\}$(13)
- Equation (13) should be greater than '0'.
- User Price $P_1 > (\text{No. of T-1}) / (5 * \alpha)$ (14)

The same logic is applied to ISP-2.

- Revenue of ISP-2 = $P_2 * (\text{Number of Subscribers})$
 = $P_2 * ((1-\alpha) * 5,000)$ (15)
- Cost of ISP-2 = (Settlement to IBP)
 = (No. of T-1 lines)*(T-1 transit price)
 = (No. of T-1 lines)* \$1,000 (16)
- Profit of ISP-2 = (15) – (16)
 = $P_2 * ((1-\alpha) * 5,000) - (\text{No. of T-1 lines}) * \$1,000$
 = $1000 * \{P_2 * (1-\alpha) * 5 - (\text{No. of T-1 lines})\}$..(17)
- Equation (17) should be greater than '0'.
- User Price (P_2) $> (\text{No. of T-1}) / (5 * (1-\alpha))$ (18)

From the equation (14) and (18) we can calculate the breakeven user price P_1 and P_2 for ISP-1 and ISP-2 to survive in the downstream market. The following table shows the user prices P_1 and P_2 according to the change of market share α from 0.1 to 0.9.

ISP-1	ISP-2	ISP-1		ISP-2		IBP	ISP-1	ISP-2
α	$1-\alpha$	T-1s	Settlement	T-1s	Settlement	Revenue	Breakeven P1	Breakeven P2
0.1	0.9	4	\$4,000	4	\$4,000	\$8,000	\$8	\$0.89
0.2	0.8	7	\$7,000	7	\$7,000	\$14,000	\$7	\$1.75
0.3	0.7	9	\$9,000	9	\$9,000	\$18,000	\$6	\$2.57
0.4	0.6	10	\$10,000	10	\$10,000	\$20,000	\$5	\$3.33
0.5	0.5	9	\$9,000	9	\$9,000	\$18,000	\$3.6	\$3.6
0.6	0.4	10	\$10,000	10	\$10,000	\$20,000	\$3.33	\$5
0.7	0.3	9	\$9,000	9	\$9,000	\$18,000	\$2.57	\$6
0.8	0.2	7	\$7,000	7	\$7,000	\$14,000	\$1.75	\$7
0.9	0.1	4	\$4,000	4	\$4,000	\$8,000	\$0.89	\$8

Table 5. Breakeven User Price of ISPs

If the Internet access market user price is set to \$2.5 per month, then we can divide two regions according to the market share. In the region of ($0.3 \leq \alpha \leq 0.7$), both ISP-1 and ISP-2 will make a negative profit. Therefore, both ISPs have an incentive to make a peering arrangement. However, in the other region like ($\alpha < 0.3$ or $\alpha > 0.7$), the ISP with a larger market share has a positive profit and does not want to make a peering arrangement with the ISP with a smaller market share. This implies equality characteristic of peering. The following table shows each ISP's dominant strategy according to its market share.

ISP-1	ISP-2	ISP-1's	ISP-2's
α	$1-\alpha$	dominant Strategy	dominant Strategy
0.1	0.9	Peering	Transit
0.2	0.8	Peering	Transit
0.3	0.7	Peering	Peering
0.4	0.6	Peering	Peering
0.5	0.5	Peering	Peering
0.6	0.4	Peering	Peering
0.7	0.3	Peering	Peering
0.8	0.2	Transit	Peering
0.9	0.1	Transit	Peering

Table 6. ISP's Dominant Interconnection Strategy

In the peering arrangement, two ISPs can avoid expensive settlement payment to the IBP through bypassing an IBP's network and they can lease communication lines from bandwidth market to connect each other. The cost

of the leased line can be divided equally between two ISPs. They also know each other's inbound and outbound traffic volumes, because one ISP's inbound (outbound) traffic is the other ISP's outbound (inbound) traffic. Therefore $\text{Max} \{T_{10}, T_{20}\}$ criterion can also be applied in this case and there should be no settlement with each other. The only cost in this case is a half of the leased line to connect each ISP. The following graph shows relationship under the peering arrangement.

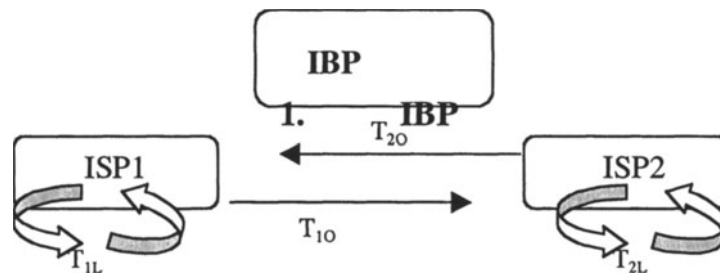


Figure 4. Traffic Flow under Peering Arrangement

To make a peering arrangement efficient, the cost of peering should be less than the lowest payment of settlement to the IBP. The minimum settlement from each ISP to the IBP in the region of $(0.3 < \alpha < 0.7)$ is \$9,000 per month. The half of the price of the leased line from the peering arrangement should be less than \$9,000 for the establishment of peering agreement.

For example, in the case of local peering, one T-1 lease line is assumed to be \$300 per month¹⁰, i.e., the half of monthly price of 10 T-1 lines is \$1,500, which is far lower than the minimum settlement to the IBP. If we assume ISPs are located at east and west coast and they use T3 line instead of 10 T-1 lines to connect each other, the monthly lease price of T-3 line¹¹ is \$6,000, the half of which is also lower than \$9000.

8 NEGOTIATION

If the two ISPs make a peering agreement, the revenue of the IBP is '0'. Because any amount of settlement is better than '0', the IBP wants to try to negotiate with each IBP to lower settlement payment. There are two reasons for the IBP to make a negotiation with the two ISPs:

¹⁰ www.bandwidthmarket.com (Pittsburgh local price, Jan. 2002) T-1(\$294)

¹¹ www.bandwidthmarket.com (LA – NYC, Jan. 2002), T-1(\$725), T-3(\$6,044)

1. If one of ISPs can not survive in the market, the relationship between upstream market and downstream market changes from (1-IBP vs. 2-ISPs) to (1-IBP vs. 1-ISP). In the monopoly-monopsony relationship, the IBP's negotiation power will reduce, that is not desirable to the IBP.
1. Expensive settlement makes the ISPs to raise their user access price, which can lead some of users out of market. If the number of users N decrease, outgoing traffic also decrease because outgoing traffic is dependent on the other ISP's market share. Finally the total market size may shrink and revenues of the IBP also shrink, that is also not desirable to the IBP.

9 APPLYING THIS MODEL TO THE REALITY

If we apply this model to the backbone market, the IBP in this model can be one of the top tiered IBPs¹² with a nationwide backbone network and ISP-1 and ISP-2 can be the second tiered IBPs which need Internet connectivity to those top tiered IBPs. In 1997, starting with UUNET, top tiered backbone providers announced not to peer with smaller backbone providers and content specialized backbone providers. (Kende, 2000) Five top tiered Internet backbone providers control nearly 80% of the Internet backbone (Weinberg, 2000), which means the Big Five's market power is enough to control over the whole Internet backbone market. The peering arrangement has been set among the Big Five, but everyone else must pay the price for passing traffic over Big Five's networks, which means the rest of IBPs have to make a transit agreement with Big Five. Because the terms and conditions of the peering agreement are usually not open, called 'Non Disclosure Agreement' and the other alternative to connect to the Internet is through Public Network Access Points (NAPs), which have been suffered by congestion. In reality, the bargaining power of Big Five would be greater than expected. According to the number of backbone providers, the market could be classified as a competitive market, but according to the Big Five's behaviors, the market could be closer to oligopoly. Their settlement decision is only based on the line capacity between two backbone providers regardless of traffic volume. If the industry uses the maximum {inbound traffic volume, outbound traffic volume}, it would be more effective and efficient to motivate peering arrangement with smaller backbone providers. If the second tiered backbone providers made a multilateral private peering

¹² According to Michael Kende's Digital Handshake, top tiered IBPs are Worldcom (UUNET), AT&T, Cable and Wireless, Genuity, and PSINet. According to Neil Weinberg's Backbone Bullies, top tiered IBPs are Worldcom, Genuity, AT&T, Sprint, and Cable and Wireless.

arrangement, it could make an equal power to the Big Five. Finally, the market will go toward more competitiveness.

10 CONCLUSION

Even though this economic model has many assumptions for simplification, this model gives us significant results.

1. The max {inbound traffic volume, outbound traffic volume} criterion has closer to the usage based pricing system than line capacity pricing, which gives easier way for peering each other because of symmetric characteristic.
2. By use of this criterion, ISPs with small market share have more difficult to survive in the downstream network access market than ISPs with large market share because of relatively expensive settlement.
3. Peering (bilateral or multilateral) is an alternative to avoid expensive settlement to the IBP and peering gives ISPs a negotiation power against the IBPs.

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