# INTERNET INTERCONNECTION

## CHAPTER 1: INTRODUCTION.

The project is a study of internet interconnection, delving into the details of peering and transit as the two main modes of interconnection. The objective of the study was to take a look at aspects of each type of interconnection and what makes the two modes different from each other. It was also the aim of this study to determine the best strategy in terms of the most suitable interconnection mode to be adopted depending on the market share as the main parameter. The approach taken to determine this was to develop an interconnection model which depending on market share as the main parameter aided in deciding the most suitable strategy.

The Internet is basically a system that makes it possible to send and receive information among all the personal (or individual) and institutional computers associated with it. The Internet industry is dynamic and integrates the equipment, software, and organisational infrastructure required for Internet communications.

The number of Internet Service Providers (ISPs) is rapidly increasing and the structure of the industry changes continuously. It is widely accepted that todayôs Internet industry has vertical structure: over 40 Internet Backbone Providers (IBPs) including 5 top-tier backbones constitute the upstream industry and over 10,000 ISPs for accessing the Internet make up the downstream industry. 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 settlement issue is becoming more significant. Settlement can be thought of as payment or financial transfers between ISPs in return for interconnection and interoperability. 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.

However, 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 system. Even though traffic flows are not a good indicator of the relative benefit of an Internet interconnection between the service providers, 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.

### *1.1 Internet Backbone Providers (IBPs)*

With some simplification, it can be said that the IBPs receive communications in bulk from Points of Presence (POPs) or Network Access Points (NAPs) and distribute them to other POPs or NAPs close to the destination. A POP is referred to as any site where networks interconnect. NAPs are public interconnection points where major providers interconnect their network and consist of a high speed switch or network of switches to which a number of routers can be connected for the purpose of traffic exchange. The NAPs are similar to major airport hubs; all Internet Access Providers (IAPs) and IBPs are gathered at the NAPs to connect each other. As the Internet continued to grow, the NAPs suffered from congestion because of the enormous traffic loads. Because of the resulting poor performance, private direct interconnections between big IBPs were introduced, called private peering. To make the Internet a seamless network, the IBPs have multiple POPs distributed over the whole world. Most frequently they are located in large urban centres. These POPs are connected to each other with owned or leased optical carrier lines. These POPs and optical carrier lines make up the IBP backbone network. The IBPôs POPs are also connected with the POPs of many IAPs. The relationship between an IAPôs POP and IBPôs POP is the same as that of IAPs and IBPs.[1]

### *1.2 Internet Service Providers (ISPs)*

An **Internet service provider** (**ISP**, also called **Internet access provider** or **IAP**) is a company that offers its customers access to the Internet. The ISP connects to its customers using a data transmission technology appropriate for delivering Internet Protocol datagrams, such as dial-up, DSL, cable modem or dedicated high-speed interconnects.

ISPs may provide Internet e-mail accounts to users which allow them to communicate with one another by sending and receiving electronic messages through their ISPs' servers. (As part of their e-mail service, ISPs usually offer the user an e-mail client software package, developed either internally or through an outside contract arrangement.) ISPs may provide other services such as remotely storing data files on behalf of their customers, as well as other services unique to each particular ISP.

ISPs employ a range of technologies to enable consumers to connect to their network. For home users and small businesses, the most popular options include dial-up, DSL (typically Asymmetric Digital Subscriber Line, ADSL), broadband wireless, cable modem, fibre to the premises (FTTH), and Integrated Services Digital Network (ISDN) (typically Basic Rate Interface). For customers with more demanding requirements, such as medium-to-large businesses, or other ISPs, DSL (often SHDSL or ADSL), Ethernet, Metro Ethernet, Gigabit Ethernet, Frame Relay, ISDN {BRI (Basic Rate Interface) or PRI (Primary Rate Interface)}, ATM, satellite Internet access and synchronous optical networking (SONET) are more likely to be used.

Just as their customers pay them for Internet access, ISPs themselves pay upstream ISPs for Internet access. An upstream ISP usually has a larger network than the contracting ISP and/or is able to provide the contracting ISP with access to parts of the Internet the contracting ISP by itself has no access to.

In the simplest case, a single connection is established to an upstream ISP and is used to transmit data to or from areas of the Internet beyond the home network; this mode of interconnection is often cascaded multiple times until reaching a Tier 1 carrier. In reality, the situation is often more complex. ISPs with more than one point of presence (POP) may have separate connections to an upstream ISP at multiple POPs, or they may be customers of multiple upstream ISPs and may have connections to each one of them at one or more point of presence. [1]

# CHAPTER 2: LITERATURE REVIEW.

## *2.1 History of Interconnection*

In order for us to understand the relationship between peering and transit, it is necessary to review the situation before the commercialization of the 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, 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 exchanging traffic with one another using the NSFNET as the backbone.

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 usersô traffic. The NSF decided to cease to operate the NSF backbone, which was replaced by four Network Access Points (NAPs). 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.

### *2.1.1 Network Access Points (NAPs)*

The role of the exchange was broadened with the introduction of the network access point (NAP) in the National Science Foundation (NSF)-proposed post-NSFNET architecture of 1995. The NAP was seen to undertake two roles: the role of an exchange provider between regional ISPs that want to execute bilateral peering arrangements and the role of a transit purchase venue, in which regional ISPs could execute purchase agreements with one or more of a set of trunk carriage ISPs also connected at the NAP. The access point concept was intended to describe access to the trunk transit service. This mixed role of both local exchange and transit operations leads to considerable operational complexity, in terms of the transit providers being able to execute a clear business agreement. What is the bandwidth of the purchased service in terms of requirements for trunk transit, versus the access requirements for exchange traffic? If a local ISP purchases a transit service at one of the NAPs, does that imply that the trunk provider is then obligated to present all the ISP's routes at remote NAPs as a peer? How can a trunk provider distinguish between traffic presented to it on behalf of a remote client versus traffic presented to it by a local service client?

We also should consider the issue that the quality of the purchased transit service is coloured by the quality of the service provided by the NAP operator. Although the quality of the transit provider's network may remain constant, and the quality of the local ISP's network and ISP's NAP access circuit may be acceptable, the quality of the transit service may be negatively impacted by the quality of the NAP transit itself.

One common solution is to use the NAP co-location facility to execute transit purchase agreements and then use so-called backdoor connections for the transit service provision role. This usage restricts the NAP exchange network to a theoretically more simple local exchange role. Such a configuration is illustrated in the figure 2.1.[2]

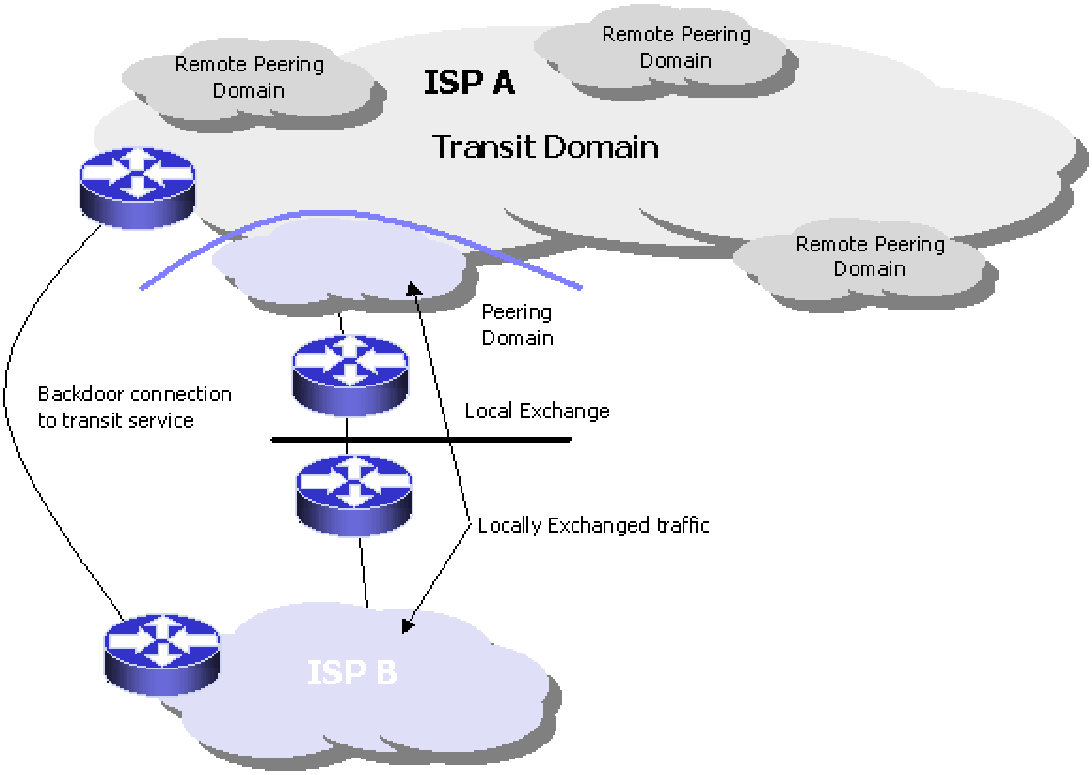

Figure 2.1: Backdoor connection

### *2.1.2 Brief History of internet development in Kenya.*

The Internet was introduced in Kenya in the early 1990s largely led by Kenyans returning from overseas studies, Western ex-patriots and NGO personnel. Commercial ISPs led by Formnet and Africa Online entered the Internet market by the mid 1990s primarily offering dial-up services and content services. The early adopters were the import/export sector, industries which had overseas operations and clients and the academic sector, with most of their users confined to Nairobi. The increasing number of ISPs and internet users created the need for an internet backbone and Jambonet was introduced in 1998. The challenges of the 1990s were the limited and high cost international internet bandwidth, the high cost of both dial-up and domestic leased lines, the limited penetration of PCs, limited capacity and poor quality fixed infrastructure, lack of an internet policy and regulatory environment and the lack of appropriate IT skills.[3]

The years 1999/2000 ï 2004/2005, were dominated by Telekom Kenya Limited (TKL) as a monopoly provider of telecommunication services, with internet bandwidth and leased line tariffs remaining high and unchanged. This trend is illustrated in table 2.1

| | 2000/01 | 2001/02 | 2002/03 | 2003/04 | 2004/05 | 2005/06 | 2006/07 |
|---|---|---|---|---|---|---|---|
| Number of licensed ISPs | 34 | 66 | 72 | 76 | 78 | 51 | 51 |
| No. Of Users (estimates) | 100,000 | 200,000 | 400,000 | 1,000,000 | 1,054,920 | 1,111,000 | 2,770,296 |
| TKLôs 64 Kbps leased line tariffs | 14,400 | 14,400 | 14,400 | 14,400 | 14,400 | 14,400 | 7,200 |
| TKLôs 2Mbps leased line tariffs | 96,477 | 81,457 | 81,457 | 81,457 | 81,457 | 81,457 | 40,728.5 |

Table 2.1 Key trends from 2000/01 ï 2006/07

The situation only changed after TKLôs monopoly came to an end in 2004 and Communication Commission of Kenya licensed new operators to compete in both internet backbone gateway and domestic licensed line services. Internet tariffs began to come down while international internet bandwidth increased.[3]

## *2.2 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.

### *2.2.1 Peering*

What is **Peering**?

***Peering*** is the situation where two or more autonomous networks interconnect directly with each other to exchange traffic. This is often done without charging for the interconnection or the traffic.

This can be of two types:

- ✓ Public Peering ï There is, in principle, one distinct point in each country in which all companies providing internet connectivity meet and interconnect their networks. Who connects to whom is public information. Public peering is most suitable for small, international ISPs.
- ✓ Private Peering ï This is a peering agreement based on common terms which are suitable for both parties. In private peering, only one operator is connected on each connection ï which means that the carrier has a 100 percent control of the connection. All major Tier 1 ISPs use private peering.

### *2.2.2 Transit*

What is **Transit**?

***Transit*** is the situation where one autonomous network agrees to carry the traffic that flows between another autonomous network and all other networks. The transit provider receives a "transit fee" for the service as its network has a higher value. It may for example provide access to a larger part of the internet or to a larger number of unique end customers.

Figure 2.2 illustrates Peering and Transit Internet Interconnection models between ISPs.

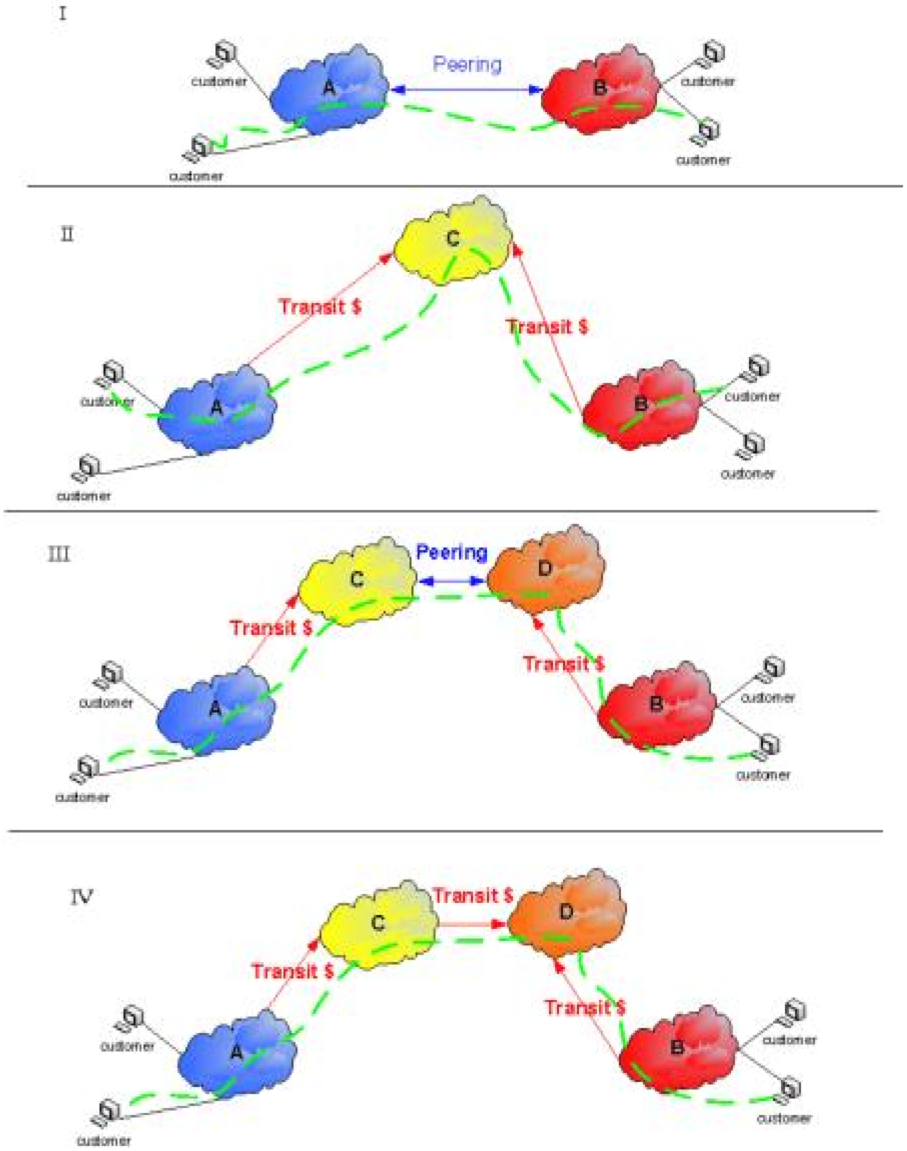

Figure 2.2: Peering vs. Transit

- *Diagram I: Peering between two networks.*
- *Diagram II: Transit over two networks.*
- *Diagram III: Transit over three networks where there is a peering arrangement between networks C and D. A and B both pay for transit.*
- *Diagram IV: A pays to C while B and C pay to D for transit.*

### *2.2.3 Peer or Client*

One of the significant issues that arises here is whether an objective determination can be made of whether an ISP is a peer to, or a client of, another ISP. This is a critical question, as, if a completely objective determination cannot be readily made, the question then becomes one of who is responsible for making a subjective determination, and on what basis.

This question is an inevitable outcome of the reselling environment, where the reseller starts to make multiple upstream service contracts with a growing number of downstream clients of the reselling service. At this point, the business profile of the original reseller is little distinguished from that of the original provider. The original reseller sees no unique value being offered by the original upstream provider and may conclude that it is in fact adding value to the original upstream provider by offering the upstream provider high volume carriage and close access to the reseller's client base. From the perspective of the original reseller, the roles have changed, and the reseller is now perceived as a peer ISP to the original upstream ISP provider.

This assertion of role reversal is perhaps most significant when the generic interconnection environment is one of a zero sum financial settlement, in which the successful assertion by a client of a change from client to peer status results in the dropping of client service revenue without any net change in the cost base of the provider's operation. The party making the successful assertion of peer interconnection sees the opposite, with an immediate drop in the cost of the ISP operation with no net revenue change.

The traditional public regulatory resolution of such matters has been through an administrative process of "licensed" communications service providers, who become peer entities through a process of administrative decree. In this model, an ISP would become a licensed service provider through the payment of license fees to a communications regulatory body. The license then allows the service enterprise access to interconnection arrangements with other licensed providers. The determination of peer or client is now quite simple: a client is an entity that operates without such a carrier license, and a peer is one that has been granted such an instrument. However, such regulated environments are quite artificial in their delineation of the entities that operate within a market, and this regulatory process often acts as a strong disincentive to large-scale private investment, thereby placing the burden of underwriting the funding of service industries into the public sector.

The regulatory environment is changing worldwide to shift the burden of communications infrastructure investment from the public sector, or from a uniquely positioned small segment of the private sector, to an environment that encourages widespread private investment. The Internet industry is at the leading edge of this trend, and the ISP domain typically operates within a deregulated valued-added communications service provider regulatory environment. Individual licenses are replaced with generic class licenses or similar deregulated structures in which formal applications or payments of license fees to operate in this domain are unnecessary. In such deregulated environments no authoritative external entity makes the decision as to whether the relationship between two ISPs is that of a provider and client or that of peers.

If no public regulatory body wants to make such a determination, is there a comparable industry body that can undertake such a role? The early attempts of the Commercial Internet eXchange (CIX) arrangements in the United States in the early 1990s were based on a description of the infrastructure of each party, in which acknowledgments of peer capability were based on the operation of a national transit infrastructure of a minimum specified capability. This specification of peering within the CIX was subsequently modified so that CIX peer status for an ISP was simply based on payment of the CIX Association membership fee.

This CIX model was not one that intrinsically admitted bilateral peer relationships. The relationship was a multilateral one, in which each ISP executed a single agreement with the CIX Association and then effectively had the ability to peer with all other association member networks. The consequence of this multilateral arrangement is that the peering settlements can be regarded as an instance of zero sum financial settlement peering, using a single threshold pricing structure.

Other industry models use a functional peer specification. For example, if the ISP attaches to a nominated physical exchange structure, then the ISP is in a position to open bilateral negotiations with any other ISP also directly attached to the exchange structure. This model is inherently more flexible, as the bilateral exchange structure enables each represented ISP to make its own determination of whether to agree to a peer relationship or not with any other co-located ISP. This model also enables each bilateral peer arrangement to be executed individually, admitting the possibility of a wider diversity of financial settlement arrangements.

The bottom line is that a true peer relationship is based on the supposition that either party can terminate the interconnection relationship and that the other party does not consider such an action a competitively hostile act. If one party has a high reliance on the interconnection arrangement and the other does not, then the most stable business outcome is that this reliance is expressed in terms of a service contract with the other party, and a provider/client relationship is established. If a balance of mutual requirement exists between both parties, then a stable basis for a peer interconnection relationship also exists. Such a statement has no intrinsic metrics that allow the requirements to be quantified. Peering in such an environment is best expressed as the balance of perceptions, in which each party perceives an acceptable approximation of equal benefit in the interconnection relationship in their own terms.

This conclusion leads to the various tiers of accepted peering that are evident in the Internet today. Local ISPs see a rationale to view local competing ISPs as peers, and they still admit the need to purchase trunk transit services from one or more upstream ISPs under terms of a client contract with the trunk provider ISP. Trunk ISPs see an acceptable rationale in peering with ISPs with a similar role profile in trunk transit but perceive an inequality of relationship with local ISPs. The conclusion drawn here is that the structure of the Internet is one where there is a strong business pressure to create a rich mesh of interconnection at various levels, and the architecture of interconnection structures is an important feature of the overall architecture of the public Internet.

### *2.3 Peering as an interconnection model*

In order to serve its customers, an ISP needs its own network to which customers connect. The costs of the ISP's network (lines, switches, depreciation, people, etc.) can be seen as fixed; costs don't increase when an extra bit is sent over the network compared to when there is no traffic on the network. Traffic that stays on the ISP's network is the cheapest traffic for that ISP. In fact, it's basically free. Peering costs a bit more, since the ISP will have to pay for a port and the line to connect to the other network, but over an established peering connection there is no additional cost for the traffic. As indicated earlier peering is the interconnection of two or more networks directly with each other to exchange traffic. This is done without charging a fee for the interconnection. Peering has emerged as one of the most important and effective ways of improving efficiency of service and operation. Peering is the interconnection mutual business arrangement between at least two Service Providers whereby each directly exchanges traffic to and from each other's clients. Peering relationships are sought primarily because peering reduces cost and reliance on purchased Internet bandwidth and/or transit.

Peering costs lie in the switches and the lines necessary to connect the networks; after a peering has been established, the marginal costs of sending one bit are zero. It then becomes economically feasible to send as much traffic between the two network peer as is technically possible, so when two networks interconnect at 1Gbps, they will use the full 1Gbps. But with transit, even though it is technically possible to interconnect at 1Gbps, if the transit-buying network has only bought 100Mbps, it will be limited to that amount. Transit will remain as a backup for when the peering connection gets disrupted. The money an ISP saves by peering will go into expanding the business.

In peering arrangements, especially when two ISPs of similar size want to interconnect it becomes a problem. The setting up of Internet Exchange Points (IXP), which is the neutral interconnection point of traffic exchange between peering ISPs has been a way to solving peering problems. An exchange point is a facility where networks interconnect, such as the [1]PAIX and Equinix facilities scattered throughout the US, the London Internet Exchange (LINX) in London, and many others. An exchange point is generally an Ethernet switch that

---

[1] PAIX, the Peering And Internet eXchange, is a neutral Internet exchange point operated by switch and data.

all the participants plug into and use to establish BGP sessions between their networks. Internet eXchange Points (IXPs) are high-speed (not less than 100mb) switch networks, with current physical configuration of today being a mix of FDDI/ATM switches. Many exchange points, or the collocation providers who host them, also offer private cross connects, cables going directly between networks in their facilities that the networks can use for interconnections. Private cross connects are useful when two networks have a large amount of traffic going between them, and donôt want to fill up the capacity of their exchange point switch ports.[4]

### *2.3.1 Sender Keeps All.*

The term ñpeeringò is sometimes used generically to refer to Internet interconnection with no financial settlement, which is known as a ñSender Keeps All (SKA)ò or ñBill and Keep.ò 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.

Sender Keep All (SKA) peering arrangements are those in which traffic is exchanged between two or more ISPs without mutual charge (an interconnection arrangement with no financial settlement). Within a national structure, typically the marginal cost of international traffic transfer to and from the rest of the Internet is significantly higher than domestic traffic transfer. In such cases, any SKA peering is likely to relate to only domestic traffic, and international transit would either be provided by a separate agreement or provided independently by each party.

This SKA peering model is most stable where the parties involved perceive equal benefit from the interconnection. This interconnection model generally is used in the context of interconnection or with providers with approximate equal dimension, as in peering regional providers with other regional providers, national providers with other national providers, and so on. Oddly enough, the parties themselves do not have to agree on what that value or dimension may be in absolute terms. Each party makes an independent assessment of the value of the interconnection, in terms of the perceived size and value of the ISP and the value of the other ISP. If both parties reach the conclusion that in their terms a net balance of value is achieved, then the interconnection is on a stable basis. If one party believes that it is larger than the other and SKA interconnection would result in leverage of its investment by the smaller party, then an SKA interconnection is unstable.

The essential criteria for a stable SKA peering structure is perceived equality in the peering relationship. This can be achieved in a number of ways, including the use of entry threshold pricing into the peering environment or the use of peering criteria, such as the specification of ISP network infrastructure or network level of service and coverage areas as eligibility for peering.

A typical feature of the SKA peering environment is to define a SKA peering in terms of traffic peering at the client level only. This definition forces each peering ISP to be self-sufficient in the provision of transit services and ISP infrastructure services that would not be provided across a peering point. This process may not result in the most efficient or effective Internet infrastructure, but it does create a level of approximate parity and reduces the risks of leverage within the interconnection. In this model, each ISP presents at each interconnection or exchange only those routes associated with the ISP's customers and accepts only traffic from peering ISPs at the interconnection or exchange directed to such customers. The ISP does not accept transit traffic destined to other remote exchange locations, nor to upstream ISPs, nor traffic directed to the ISP's infrastructure services. Equally, the ISP does not accept traffic, which is destined to peering ISPs, from upstream transit providers. The business model here is that each client of an ISP is contracting the ISP to present their routes to all other customers of the ISP, to the upstream providers of the ISP, and to all exchange points where the ISP has a presence. The particular tariff model chosen by the ISP in servicing the customers is not material to this interconnection model. Traffic passed to a peer ISP at the exchange becomes the responsibility of the peer ISP to pass to their customers at their cost.

Another means of generating equity within an SKA peering is to peer only within the terms of a defined locality. In this model, an ISP would present routes to an SKA peer in which the routes corresponded to customers located at a particular access POP, or a regional cluster of access POPs. The SKA peer's ability to leverage advantage from the greater level of investment (assuming that the other party is the smaller party) is now no longer a factor, because the smaller ISP sees only those parts of the larger ISP that sit within a well-defined local or regional zone. This form of peering is indicated in figure 2.3.

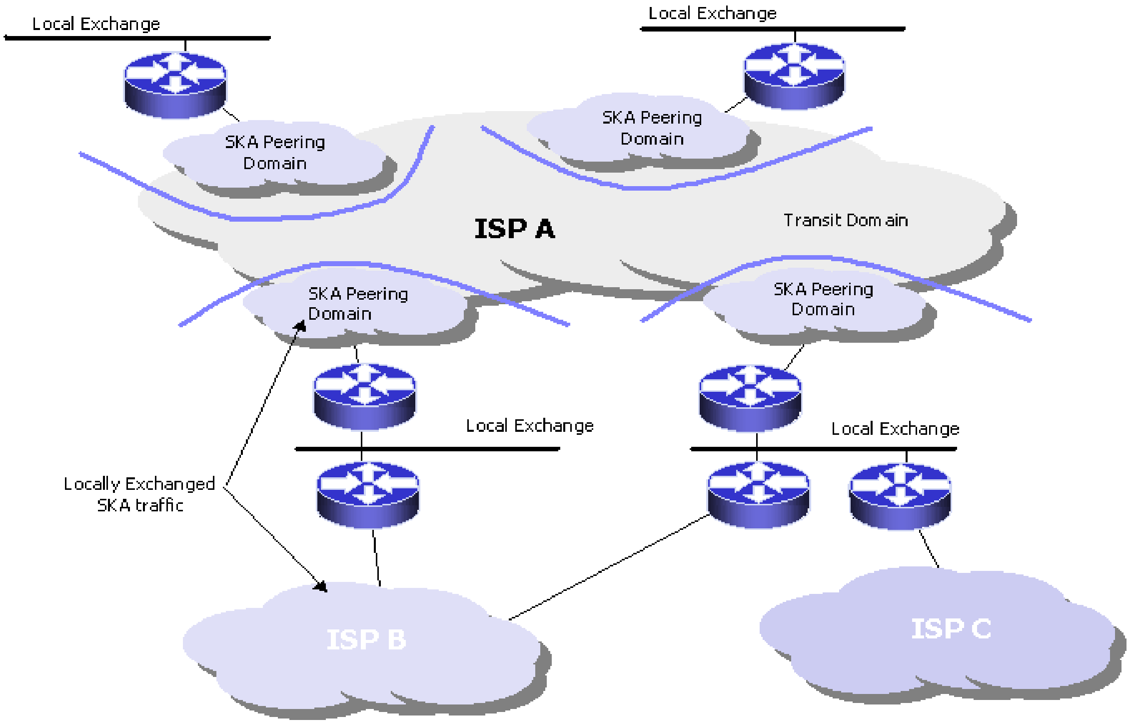

Figure 2.3: SKA peering using local cells

### *2.3.2 Characteristics of Peering.*

The original 4 NAPs are 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.

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.

The followings are the characteristics of peering:

(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 ñnon-transitive relationship.ò

(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 ñhot-potato routing,ò where an ISP will pass traffic to another backbone at the earliest point of exchange.

There are two conditions necessary for the 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 avoidance of 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. [5]

Peering benefits come mainly from the network externality. 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 is. Another motivation for peering is lower latency because peering needs only one hop to exchange traffic between peering partners.

### *2.3.3 Network Externalities*

Network externalities arise when the value, or utility, that a consumer derives from a product or service increases as a function of the number of other consumers of the same or compatible products or services. They are called network externalities because they generally arise for networks whose purpose it is to enable each user to communicate with other users; as a result, by definition the more users there are, the more valuable the network. These benefits are externalities because a user, when deciding whether to join a network (or which network to join), only takes into account the private benefits that the network will bring her, and will not consider the fact that her joining this network increases the benefit of the network for other users. This latter effect is an externality.

Network externalities can be direct or indirect. Network externalities are direct for networks that consumers use to communicate with one another; the more consumers that use the network, the more valuable the network is for each consumer. The phone system is a classic example of a system providing direct network externalities. The only benefit of such a system comes from access to the network of users. Network externalities are indirect for systems that require both hardware and software in order to provide benefits. As more consumers buy hardware, this will lead to the production of more software compatible with this hardware, making the hardware more valuable to users. A classic example of this is the compact disc system; as more consumers purchased compact disc players, music companies increased the variety of compact discs available, making the players more valuable to their owners. These network externalities are indirect because consumers do not purchase the systems to communicate directly with others, yet they benefit indirectly from the adoption decision of other consumers.

One unique characteristic of the Internet is that it offers both direct and indirect network externalities. Users of applications such as email and Internet telephony derive direct network externalities from the system: the more Internet users there are, the more valuable the Internet is for such communications. Users of applications such as the World Wide Web derive indirect network externalities from the system: the more Internet users there are, the more

Web content will be developed, which makes the Internet even more valuable for its users. The ability to provide direct and indirect network externalities to customers provides an almost overpowering incentive for Internet backbones to cooperate with one another by interconnecting their networks.

The effect that network externalities have on competitive forces in any particular market depends on demand and supply characteristics of this market. In Internet services the network effect (resulting from the number of people reachable via the network) is very strong. For successful market entry, ISPs need to offer their users *universal connectivity*, the ability to reach all other users and content connected to the Internet, irrespective of their home networks. ISPs achieve universal connectivity by direct and indirect network interconnection with other ISPs.[6]

A large ISP cannot abuse its high market share in attached customers. The opportunities to profit from strategic interconnection decisions (price increases or quality degradation) are restrained by the competitive forces in the market for Internet interconnectivity. To argue that larger networks have fewer incentives to interconnect than smaller rivals neglects important market characteristics of the Internet interconnectivity market, such as product differentiation between ISPs, low market entry barriers, low switching costs, and the possibility for side-payments in interconnection agreements among ISPs. In conclusion competitive forces in the Internet interconnectivity market effectively hinder large ISPs from discriminating against smaller ISPs.

### *2.3.4 Pay to peer?*

Would it be advisable to pay for peering? There has been significant debate on whether it is beneficial to pay for peering, but peering should typically be free. When two networks peer, they both save the same amount of traffic from transit.

The monetary benefits of not having to use transit depend upon the transit price that each network pays. The network that saves the least is the network that has the best transit deals. If, for both networks, a peering agreement is cheaper than buying transit, then the choice of who should pay for the peering agreement becomes completely arbitrary.

One could say that the network that saves more money should share the savings with the network that saves less, but on what basis? The peering in itself is already there. Paying money for it or sharing the benefits doesn't make it better. The only reason the smaller party pays more is because it is in a less fortunate position when it comes to buying transit. If, through renegotiation of transit contracts, it is all of a sudden better off, it would still be hard to convince the other network to reverse payments. Worse still, it would in fact be sponsoring the other network to attain even lower overall traffic costs. If the two networks at the same time compete for the same customers, it would now be sponsoring its competitor.

There might be situations where a peering might be beneficial to network A, but the savings are too little for network B. In such a case it might look good to A to pay B for a peering agreement to increase B's savings to such a level that both parties will profit. Though this might sound good at first, it could have unintended consequences for network A. If the traffic between the two networks grows to such a level that both parties benefit equally from the peering, B will still want to try to keep the payment for the peering; it's essentially free money. [7]

Another problem with pay to peer is that networks would have an incentive to understate their transit costs in order to become a receiving party. This makes it less likely that both parties would reach a peering agreement, because one party is lying about its benefits and the other is not willing to pay. This is hard to check for either party. The best thing a network can do is hope that when it's economical for this network to peer for free, it is the same case for the other network. If not, the transaction costs of other arrangements are probably too high.

### *2.3.5 Peering Decision-Making Process*

An interconnection strategy may be different according to its priority. If expense of interconnection is the number one issue, ISPs will try to find as many peering partners as they can and try to choose minimum combination costs among them. Or if performance is the top priority, they may prefer private peering or transit to public peering. All of interconnection decisions should start from the analysis of their own traffic. Then the ISP tries to find the available options and negotiates with their interconnection partners for interconnection methodology, interconnection line capacity, interconnection settlement, etc. This process will be explained below in detail.

*Phase I: Identification of Potential Peer: Traffic Engineering Data Collection and Analysis*
The costs of peering and transit vary according to the distance of the ISPsô POP (Point of Presence) and interconnection point.
Motivation: Why Peer?

**Lower Transit Costs.** Internet Service Providers (ISP) make choices that are often dominated by telecommunications cost issues. Highest among these costs is Internet transit service that provides the ISP with connectivity to the global Internet.

**Lower Latency.** As a side effect of interconnecting directly with peers, ISP customersô traffic has lower latency to the other ISPôs customers. ISPs highlighted a common concern: traffic destined for a competitors customer located across the street may need to traverse a couple of transit providers across great distances (with high latency) before interconnecting. The worst example was that traffic between the United Arab Emirates and Saudi Arabia must traverse an exchange point in Washington DC. Through direct interconnections (through direct circuits or regional exchange points) ISP customers realize better performance.

**Usage-based traffic billing.** Some ISPs charge customers based upon use of transit services. Since packet loss and latency slows traffic consumption, they benefit from a low latency, low packet loss Internet. It is in their interest to assure that customers use as much bandwidth as possible through effective traffic engineering.[8]

With whom do we peer?
So peering seems to make sense from a technical and financial perspective, but the question is, ñWho should we peer with?ò To identify potential peers, ISPs use a variety of criteria.

- **Quantities of traffic** distributed between networks often sets the pace of the negotiation; to quantify this, ISPs may systematically sample inbound and outbound traffic flows. Flows then are mapped to originating Autonomous System, and calculations are made to determine where peering (direct interconnections) would most reduce the load on the expensive transit paths. There is substantial work involved here, as this traffic sampling results in a large number of data. Alternative measurement methods include measuring port statistics.

- **Larger business arrangements** between ISPs may circumvent the peering negotiation phase expedite discussions directly to Phase III, the peering methodology negotiation phase.

- **Peering policies** range across a wide spectrum from ñopen peering policyò meaning ñwe will peer with anyoneò to ñif you have to ask, we wonôt peer with you.ò In many cases peering requires interconnections at multiple peering points, specifications for routing, etc.

The greatly simplified peer qualification decision tree looks something like this:

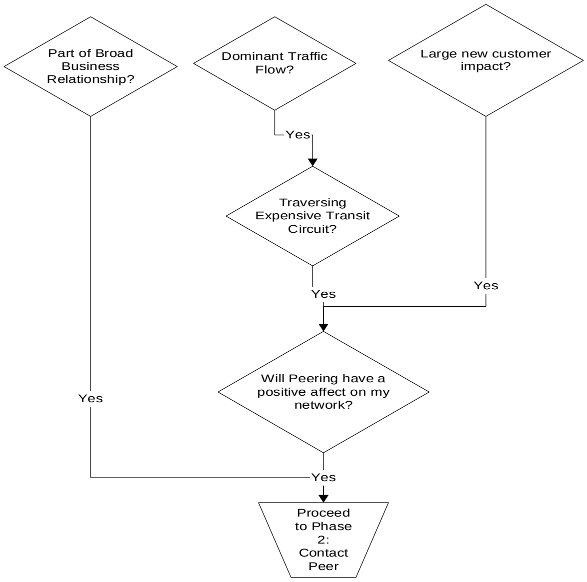

Figure 2.4: Peer qualification decision tree

Once the measurements have been made and analyzed, and it appears to be of benefit to peer, the ISP enters into Phase 2, Contact & Qualification, and Initial Peering Negotiation.

*Phase II: Contact and Qualification, and Initial Peering Negotiation.*

Internet Service Providers typically have a person or group specifically tasked with peering and traffic engineering issues. Some variations of the following steps lead to the parties either leaving the negotiation or proceeding to peering methodology discussions.

The first step is for one of the parties to initiate contact with the potential peer. This is usually via electronic mail, from contact list on an exchange point participant list or as part of a larger business transaction.

Second, mutual non-disclosures may be negotiated and signed, and a discussion of peering policy and prerequisites follow. Note that this is an optional step, and many ISPs do not require signed Non- Disclosure Agreements (NDAs) prior to discussions. Traffic engineering discussions and data disclosure may be used to justify the peering relationship. Each ISP typically has a set of requirements for peering that include peering at some number of geographically distributed locations, sometimes at public exchange points.

Traffic volume is usually a key determining factor. The decision rule hinges upon whether or not there is sufficient saving from peering to justify spending capital on a port on a router and/or a portion of the interconnection costs or augmenting existing capacity into an exchange point. A Bilateral Peering Agreement (BLPA) is the legal form that details each personôs understanding of acceptable behaviour, and defines the arms length interactions that each agreed to. Another motivation for peering to factor in includes lower latency and/or more regional distribution of traffic than existing connections allow.

After this initial discussion, either party may decide to walk away from peering discussions until certain criteria are met. If both parties agree that their requirements are met sufficiently to discuss methodology, and they both benefit from the peering relationship, they move onto Phase 3: Implementation Discussions. [7]

### *Phase III: Implementation discussions: Peering Methodology*

Since peering is of mutual benefit, both parties next explore the interconnection method(s) that most effectively exchange traffic to and from each otherôs customers. The primary goal is to establish mutual point(s) of interconnection, and secondarily detail optimal traffic exchange behaviour. For interconnections, ISPs face three options: Direct Circuit Interconnection, Exchange-Based Interconnection or some global combination thereof.

The preferred methodology depends on the number of peers participating in the region and bandwidth required for its regional interconnections. ISPs that expect to interconnect at high or rapidly increasing bandwidth within the region, or expect interconnections with more than five parties in the region often prefer the exchange-based solution. Those that do not anticipate a large number of regional interconnects prefer direct-circuits and typically decide to split the costs of interconnection with the peer by region.  On occasion the costs are covered in whole by one peer.

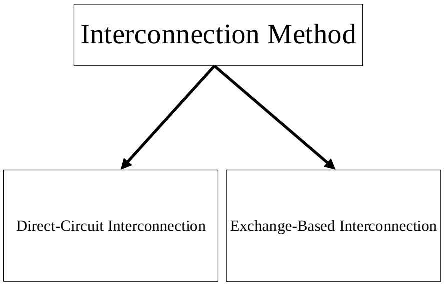

Figure 2.5: Interconnection methods.

For direct-circuit interconnects, key issues centre upon interconnection location(s) and who pays for and manages the interconnection. This becomes a material cost issue as traffic grows and circuits increase in size and cost.

In either case, ISPs generally have the following goals for establishing peering:

1. get peering set up as soon as possible,
2. minimize the cost of the interconnection and their transit costs,
3. maximize the benefits of a systematic approach to peering,
4. execute the regional operations plan as strategy dictates (may be architecture/network development group goal), and
5. Fulfil obligations of larger business agreement.

### *2.3.6 Peering Locations.*

Peering will happen at a location that is most convenient for both networks. When two networks decide to peer in one location, that location immediately becomes a valuable place at which to peer for other networks, too. This increase in value causes more and more networks to cluster together at certain locations. In the history of the internet, we can see that at first, these locations were at the sites where academic networks interconnected, and later on at large co-location facilities. In order to facilitate peering, Internet exchange points (IXPs) were established at those locations. In Europe these IXPs are typically not-for-profit associations, while in the USA they operate as private businesses.

Putting a single switch in between all the parties who want to interconnect makes it possible to reach all parties with one connection (public interconnect), instead of having to dedicate a line and a port on a switch for each interconnection. This does require IXP's to be neutral and uninvolved in the business of their customers; the process of peering and transit is up to the networks, and the IXP is just responsible for the technical functioning of the switch.

This doesn't mean, however, that peering will take place only through the IXP. There will still be direct interconnects that bypass the exchange (known as private interconnects), where the exchange can act as a backup for that interconnect (and a transit connection often acts as a backup for that backup).

When more and more networks roll out in the location of the Internet exchange point, this location becomes valuable not only for peering, but also for buying and selling transit. This will attract transit providers to the location in order to peer with other networks that sell transit and also to try and sell transit to networks needing it. The increase in transit providers will cause more competition and, therefore, a lowering of transit costs, which will, in turn, increase the attractiveness of the location for other networks through the combination of more peers and lower transit costs.

As networks grow, some of them will exchange more and more traffic with networks that are not yet present at the local Internet exchange. If the costs of buying a direct connection to another location where networks are present is lower than the costs of transit, then the network will expand toward the low-cost location. This is quite clear in Europe, where medium and large networks will almost always be present at the IXPs of Amsterdam, London, Frankfurt, and Paris. In these cities, there are many networks to interconnect with and the price of transit is at its lowest.

The irony is that in some cases, transit prices have dropped to such lows that it's no longer economical for some smaller networks to interconnect at an IXP, since the transit fee saved is lower than the monthly fee for the IXP.

In a nutshell, the economics of interconnection are:

- Peer as much as you can, to avoid transit fees.
- Use the savings from peering to expand your business and network.
- Use the expansion of your business and network to become more attractive for others to peer with and to reach those that are attractive to peer with.
- Establish IXPs in order to further lower the costs of peering, to bring together as many networks as possible, and

- To create locations where there is competition between providers of transit.

### *2.3.7 Advanced Peering.*

With the rapid growth of Internet traffic, larger retail ISPs (with traffic loads exceeding 1 Gb/s) are faced with the challenge of efficiently handling IP traffic increases. These companies, which include dial-up providers, DSL providers, RBOCs and cable companies, are evaluating the traditional Internet peering model as a way of achieving a leading cost structure and higher level of quality. This alternative approach is known as advanced peering.

It enables ISPs and content providers to use a shared, IP-based transport network to establish advanced peering links to business partners. It allows each provider to maintain its own AS network and achieve high quality and secure performance for all traffic types. And it does this while allowing the providers to avoid the cost and operational implications of the traditional model. The result is a more eloquent and cost-efficient option for Internet interconnection.

Because the traditional Internet peering model involves settlement-free peering and the achievement of Tier 1 peering status, it is viewed as a low-cost solution. However, the actual cost structure that can be achieved through the traditional Internet peering model is highly dependent on traffic volume and mix. Only the largest ISP backbones will achieve a cost structure that is equal or better than purchasing transit.

When taken to the extreme, the traditional Internet peering model results in reverse economies of scale that are detrimental to the industry as a whole. This is due in part to inefficiencies that slow the pace of technological innovation while stifling cost improvements. On the other end of the spectrum, a model based solely on the use of a transit provider fails to deliver the most efficient network architecture. Alternative models such as advanced peering create a robust networking environment coupled with the right cost structure.[9]

#### *2.3.7.1 Advantages of Advanced Peering.*

Advanced peering is much more efficient than traditional peering arrangements because it minimizes cost replication. By concentrating traffic across fewer networks, higher utilization levels are achieved. These efficiencies accelerate the development of high-bandwidth IP technologies. The combined effect of these factors is the acceleration of the IP unit cost reduction trend, which, in turn, fuels the growth of high-bandwidth applications. Advanced peering also exploits the advantages of [2]MPLS. The virtual links can be established at MPLS layers to ensure better service quality and security.

The advanced peering infrastructure can be used for multiple purposes and traffic types, including Internet transit traffic and the interconnection of non-contiguous properties. For example, a cable company could establish a voice or a video distribution network between its properties. Each of these links could use an MPLS layer that is optimized for voice or video. The cable company also could establish links for peer-to-peer traffic.

In addition, Advanced Peering would allow companies to establish links with their trading partners for non-internet traffic. One example would be to allow a media company to distribute video content to broadcasters or satellite up-link sites. Another would be to enable an interactive gaming network, such as Microsoft's X-Box, by establishing links between a cable company and the gaming provider's servers. In each of these examples, the virtual links would leverage the MPLS queue that is best suited for the service type.

One of the most intriguing aspects of the advanced peering solution, however, is its ease of implementation. To take advantage of advanced peering, a port would need to be homed to a MPLS edge switch instead of the Internet router. Initially, this would need to be a separate port from the Internet transit port. Within months, a shared port would be used. In the latter case, the incremental cost of enabling MPLS is trivial.

Immediate savings - The cost to support advanced peering traffic is lower than Internet traffic. Internet traffic often traverses peering links, which means that the provider of advanced peering will carry the cost for both origination and termination of the traffic, but will be compensated entirely by one customer. With advanced peering, the provider originates and terminates the traffic between two customers, who share the cost of the connection. Each customer benefits in the form of a lower per-megabit price.

---

[2] MPLS ï Multiprotocol Label Switching refers to a mechanism which directs and transfers data between Wide Area Networks nodes with high performance, regardless of the content of the data. MPLS makes it easy to create ñvirtual linksò between nodes on the network, regardless of the protocol of their encapsulated data.

Each time an advanced peering link is established, traffic that otherwise would be subject to transit pricing would be priced at a lower rate resulting in immediate savings. And, since aggregated volume drives price down, advanced peering relationships can be established between more and more trading partners. The network can be used for other applications. The hidden costs of traditional peering--metro links, co-location facilities, excess equipment and operational overhead--can be eliminated. All this adds up to long-term savings.

Advanced peering does not require that all ISPs and content companies agree on a single advanced peering provider. Vendor management should be used to drive pricing and performance levels over time, ensuring that the ISP and content communities benefit from the economic efficiencies of advanced peering. Over time, interoperability between advanced peering providers would become desirable.

### *2.3.8 Depeering.*

In 1996, a series of IBPs announced that they were ending peering with many of their previous peering partners and were no longer accepting peering arrangements from other networks whose infrastructure would not allow the exchange of a similar traffic level. Instead of peering, they would charge those smaller ISPs for transit. Finally, the large IBPs moved away from public NAPs to a series of private peering or maintained relatively small capacities in the NAPs and then placed themselves in a new hierarchy, so called top-tier IBPs. The top-tier IBPs donôt need transit service from others and they make peering arrangement with each other. The other IBPs make peering arrangements among themselves and simultaneously purchase transit services from the top-tier IBPs.

There are two types of cases for which peering is generally refused: (1) Regional IBPs which do not have a national backbone network and (2) content providers or web hosting companies, so called the web farms. The main reason for this refusal is a free-rider issue. Under the hot-potato routing rule (shortest exit routing), someone who does not have a national backbone network must transport its traffic on the othersô backbone networks. In addition to that, asymmetric traffic patterns, which occur in file transfer or web surfing, result in increased capacity costs without commensurate revenues.

***Solution:***

To overcome issues of free-rider and asymmetric traffic pattern under the current peering arrangement, new approaches are introduced: (1) Best Exit Routing and (2) Traffic Ratio-Based Peering. The peering burden upon the ISPsô networks is aggravated by the hot potato routing. The only solution to overcome this scenario is ñbest exit routing,ò which involves imposing responsibility on the web farm to carry the traffic to an exit point closest to the location of the IBPôs customers. To overcome the current free peering problem, a traffic-ratio based paid peering model is emerging. In this approach, peering is free until traffic asymmetry reaches a certain ratio, i.e., 4:1. At this point, the net source of traffic will pay the net sink of traffic a fee based upon traffic flow above this ratio.

## *2.4 Transit as an Interconnection model.*

Transit is an alternative arrangement between ISPs, 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 a Service Level Agreement (SLA), which describes outage and service objectives, and the financial repercussion for failure to perform. In a peering arrangement, there is no SLA to guarantee rapid resolution of problems. In case of an outage, both peering partners may try to resolve the problem, but it is not mandatory. This is one of the reasons peering agreements with a company short on competent technical staff are broken. In a transit arrangement it is a contract and customers could ask the transit provider to meet the SLA. Many e- commerce companies prefer transit to peering for this reason. 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. ISPs are not permitted to form transit relationship over public NAPs because these are designed as a neutral meeting place for peering. There is one exception: bypassing the public NAP switching fabric and running a backdoor serial connection between them. When purchasing transit service, ISPs will consider other factors beside low cost: performance of the transit providerôs backbone, location of access nodes, number of directly connected customers, and a market position. Figure 5.1 is an illustration of a transit relationship.

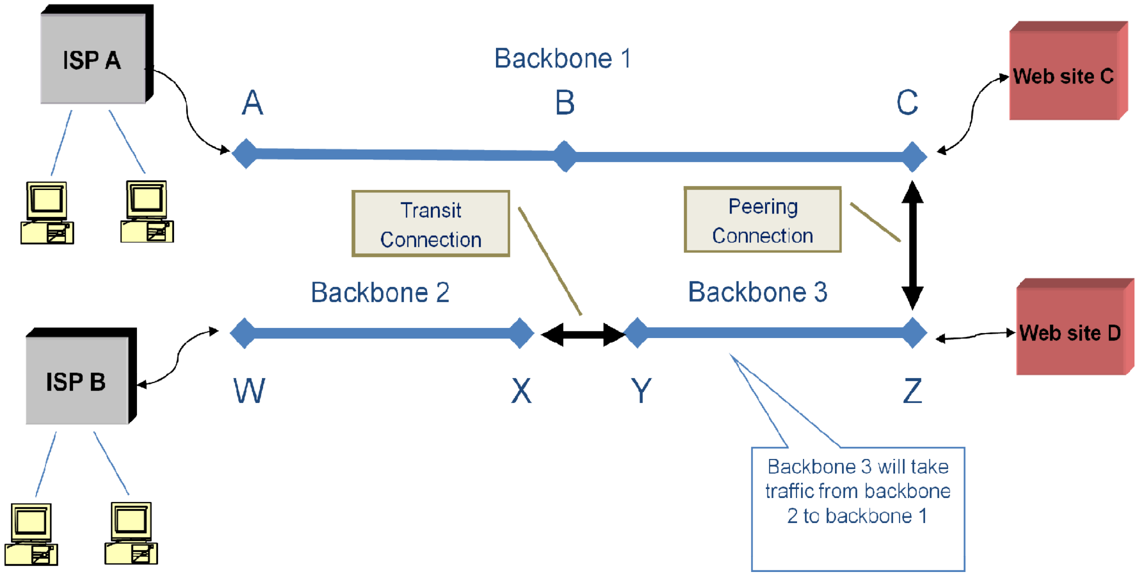

Figure 2.6: Transit Relationship

### 2.4.1 Transit economics

Transit traffic is the most expensive. The ISP will have to estimate how much traffic it needs, and any extra traffic will cost extra. If the ISP is faced with extra traffic, its first priority will be to keep the traffic on its own network. If it can't, it will then use peering, and as a last resort it will pay for transit.

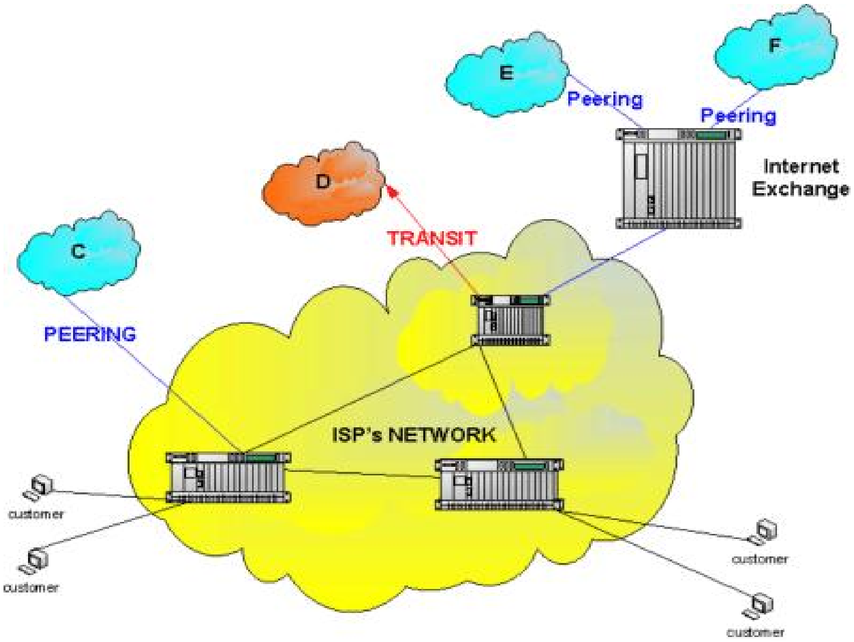

Figure 2.7: Peering and Transit

Every ISP will need to buy some amount of transit to be able to interconnect with the entire world, and to achieve resilience, an ISP will choose more than one transit provider. Transit costs money, and as the ISP grows, its transit bill will grow, too. In order to reduce its transit bill, the ISP will look for suitable networks to peer with. When two networks determine that the costs of interconnecting directly (peering) are lower than the costs of buying transit from each other, they'll have an economic incentive to peer.

Providing transit has its own rationales and economic mechanisms. Transit providers charge transit fees in order to recoup their investment in the lines and switches that make up their networks. The price of transit will be a combination of the costs of running the network, plus the amount of transit the transit provider has bought, minus (maybe) the traffic that is destined directly for peers and customers of the transit provider.

Being a pure transit provider with only Autonomous Systems as customers puts a network in a weird spot. Such a network's business case is built on being the intermediary in the flow of traffic, so it tries to charge all of the other autonomous systems for their traffic. The problem for a pure transit provider is that its customers are always looking at ways to lower their transit fees, and lower transit fees can be had by switching to a competitor or by not using the transit provider at all. So disintermediating the transit provider is standard behaviour for the transit provider's customers.

How can the transit provider prevent its customers from going to competitors or from cutting it out of the loop? The first way is to keep prices down. If a transit provider is the only provider of a link between Geneva and Amsterdam, it will have to be very aware that its price stays low. If it's too high, the customers may opt to cancel their transit contracts and either build their own links or compel a competitor to step into the market and start competing. The other trick is to actively work to keep competitors from entering the market. How do you persuade people not to enter the market? By keeping margins low, even as growth rises. Fibre is a fixed-cost investment, because traffic can be supported for little or no extra cost. Though it's tempting to let profits rise with the growth of traffic, the network will actually have to lower its traffic price every month in order for margins to remain the same, thereby keeping intact the barrier to entry for a competing network.

A couple of cooperating ISPs can also be dangerous to the business plan of a pure transit player. These networks could cooperate in creating a backbone between their networks in order to carry traffic to and from each other's systems. For instance, Dutch, Belgian, French, and Swiss ISPs could work together and bypass a Trans-European transit provider. So a pure transit play is under constant threat even from existing customers who resell traffic. An interesting tactic is that of a content-heavy hosting provider trying to buy transit from residential ISPs. ISPs have a high inflow of traffic; hosting providers have high outbound traffic. Because incoming and outgoing traffic are bundled into the same price, the hosting provider rightly had determined that there would be ISPs willing to resell upstream capacity they didn't use. For the pure transit player this might be seen as a loss of income.

In the end, pure transit is debatable as a real business model. An average end-user is bound to its ISP by numerous switching costs (change of e-mail address, lack of knowledge, time, hassle, etc.), but this customer lock-in just does not apply to transit. The Border Gateway Protocol propagates a change in transit provider within seconds, globally. Autonomous Systems can switch within seconds and there is little a transit provider can do to differentiate itself from rivals. Add to this the effect of competitors and mutually assured destruction, and one can understand that there is not much money to be had in this business.

### *2.4.2 Transit now regaining lost ground*

A few years ago, many ISPs chose to extend their network reach, mostly by establishing peering agreement with other parties, instead of utilizing the global Transit service as a platform for packaging customer Internet connections. The trend away from Transit was mainly the result of low global capacity prices. By purchasing enough additional capacity and signing peering agreements with each other, ISPs found a seemingly more cost-effective solution to Transit as a means to provide customers with international Internet connectivity.

Recently, however, IP Transit is coming back strongly. After evaluating their total peering costs, many ISPs are now turning back to Transit. Many of them have discovered that peering works fine so long as it is small-scale, but will become unacceptably expensive as the network grows. There are two main reasons why large-scale peering drives excessive costs:

I. Increased router costs

   While capacity prices have been stable or decreasing in most important markets, router prices have increased ï making capital expenditure the dominating risk factor.

The more peers, the more related equipment required, and the higher the capital expenditure.

II. Increased network management costs
Another burdensome task is managing these extended networks, as well as any additional related equipment. The implementation and management of new routers incurs new, not infrequently unexpected costs, including higher personnel costs.

In general, peering agreements pay off when the number of peers is few and the network coverage is low. In the end, no ISP will have enough traffic to justify too many peers covering all regions. Here is where Transit comes in as the most cost-efficient solution.

### *2.4.3 Tier 1 networks and ISPs*

Tier 1 networks are those networks that don't pay any other network for transit yet still can reach all networks connected to the internet. There are about seven such networks in the world. Being a Tier 1 is considered very "cool," but it is an unenviable position. A Tier 1 is constantly faced with customers trying to bypass it, and this is a threat to its business. On top of the threat from customers, a Tier 1 also faces the danger of being de-peered by other Tier 1s. This de-peering happens when one Tier 1 network thinks that the other Tier 1 is not sufficiently important to be considered an equal. The bigger Tier 1 will then try to get a transit deal or paid peering deal with the smaller Tier 1, and if the smaller one accepts, then it is acknowledging that it is not really a Tier 1. But if the smaller Tier 1 calls the bigger Tier 1's bluff and actually does get de-peered, some of the customers of either network can't reach each other.

If a network has end-users (consumers or businesses), it's probably in a better business position than a Tier 1 or a pure-play transit provider, since having end-users provides stability to a business. Autonomous Systems can switch within seconds, but end-users are stickier customers. Churn is less of a problem and revenues are therefore more stable and easier to base decisions on, since prices don't have to drop on a monthly basis. So an end-user business, combined with a bit of transit is, therefore, ideal for a network provider.

The simple approach has been to label a network tier 1 if it has large traffic volumes, large capacities, large customer bases, and large numbers of routes and if it supports many autonomous systems (ASs) inside the network. However, size and scale are not the only dimensions of tier 1 ISPs. The key attributes of tier 1 ISPs are as follows:

- They have access to the entire Internet routing table through their peering relationships.
- They have one or two Autonomous Systems per continent or ideally one AS worldwide.
- They own or lease international fibre optic transport.
- They deliver packets to and from customers and to and from peers around the world.

Global Tier 1 ISPs have two additional characteristics:

- They peer on more than one continent
- They donôt have to pay to have their traffic delivered through similar-sized networks.
- They own or lease transoceanic fibre optic transport to facilitate the best possible customer access experience in diverse markets on more than one continent.

Tier 1 ISPs own the operating infrastructure, including the routers and other intermediate devices (e.g., switches) that form the backbone, which is interconnected with other tier 1 ISPs via private peering in a "settlement-free" interconnection. This is also called free peering. They also interconnect at Internet Exchange (IX) points. Because a significant amount of todayôs Internet traffic is exchanged via private peering, tier 1 ISPs deliver the best network quality and throughput because they have the most direct control over the traffic that flows through these private peering connections. Other ISPs are completely dependent on tier 1 ISPs and their capabilities to properly manage the private peering infrastructure.[10]

Tier 1 ISPs make use of self-owned telecommunications circuits for those parts of their networks in which they have such an infrastructure. However, this may not be the case in every market in which tier 1 ISPs operate. Tier 1 ISPs may choose to make use of circuits provided by alternative carriers because of a number of factors, including lack of self-owned circuits, contractual arrangements (e.g., reciprocity), facility availability (a certain facility might be available from another carrier in a specific market before it is available from the carrier that owns the tier 1 ISP), or a desire to maintain some level of carrier diversity to ensure more stability in the network.

# CHAPTER 3: METHODOLOGY: Simulation of the Internet Interconnection Model.

The internet interconnection model, based on the quadratic monotonic increasing function, is used to explain the characteristics of internet traffic. [11] The model was simulated by developing an algorithm using MATLAB.

## *3.1 Assumptions.*

Several assumptions have been made to simplify the model:

(1) In the upstream backbone market, there is only one IBP and in the downstream Internet access market there are two ISPs. ISP-1 and ISP-2 sell the Internet connectivity to their customers. Since the IBP is the sole provider of the Internet backbone, interconnection to the IBPs network is the only way to provide internet connectivity. The IBP does not support customers directly.

(2) If the market share of ISP-1 is Ŭ, then that of ISP-2 is (1-Ŭ) because there are only two ISPs in the market (0<Ŭ<1). This market share is a unique factor in determining traffic volume and Ŭ is a parameter, which can be given by the downstream Internet access market.

(3) The total number of customers in the downstream Internet access market is N. If the market share of ISP-1 is Ŭ, the number of Internet subscribers of ISP-1 is N*Ŭ and that of ISP-2 is N*(1-Ŭ). Because of homogeneity of the service customers do not have to choose two ISPs at the same time.

(4) There are three kinds of traffic in each ISP, Tij, 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 other ISPôs network.
- The market share of an ISP determines the amount of local traffic. The larger the market share the greater the amount of local traffic compared to outbound traffic and vice versa.
- The amount of outbound traffic depends on the other ISPôs market share. The larger the market share of the other ISP, the greater the amount of outbound traffic.

- One ISPôs inbound traffic is the same as the other ISPôs outbound traffic because there are only two ISPôs in the market.
- The assumption of dependency of market share comes from the concept of network externality. An ISP with large customer base and many internet resources is less dependent on other ISPs than as ISP with small customer base and less internet resources.

(5) The average traffic generated per subscriber is assumed that 3 Gbits per month, which comes from the following assumptions and calculation:

- The two ISPs sell only 56 Kbps dial up modem internet connectivity.
- Average hours of internet usage is 90 hours per month.
- 1:6 bandwidth ratio is applied. The bandwidth ratio occurs because a user does not consume the whole 56 Kbps for the duration of the connection.
- 56 Kbps * 90 hours/month * 3600 seconds/hour * 1/6 = 3 Gbits per subscriber approximately.

(6) The number of subscriber and the average traffic per subscriber determine the traffic volumes such as T1 and T2.

- The total traffic generated by ISP-1 ($T_1$) is the sum of the local traffic ($T_{1L}$) and the outbound traffic ($T_{1O}$): $T_1 = T_{1L} + T_{1O}$ = 3 Gbits * Number of ISP-1ôs subscribers = 3 Gbits *(Ŭ*N).
- The total traffic generated by ISP-2 ($T_2$) is the sum of the local traffic ($T_{2L}$) and the outbound traffic ($T_{2O}$): $T_2 = T_{2L} + T_{2O}$ = 3 Gbits * Number of ISP-2 subscribers = 3 Gbits* (1-Ŭ) *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 can get a fixed monthly Internet access charge from its own users.

### *3.2 Traffic Function*

Since we are considering the case where there are only two ISPs, if one ISPs 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 share of the two ISPs is the same, that is

Ŭ= 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. From 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 ($f_{\mathrm{L}}$) is non-linear only if the number of servers on the network is non-linear with respect to the market share Ŭ. One of the main reasons for non-linear number of servers with respect to the market share Ŭ is mirroring and caching. Mirroring is the situation where content providers maintain duplicated web sites on a number of different servers to improve bandwidth efficiency and better service to the end user. Caching is basically the storing of copies of frequently retrieved web pages or data on servers that are geographically closer to end-users. As the number of subscribers increases, the mirroring servers and the caching servers increase more than linearly, which means that the local traffic also increases in a non-linear way. Also as the number of the mirrored and caching servers increases, the portion of local traffic within the network increases sharply.

From the above concept, the quadratic monotonic increasing function was used. Monotonic functions are functions that tend to move in only one direction as the x-axis component increases. A monotonic increasing function always increases as the x-axis component increases. The local traffic function ($f_{\mathrm{L}}$) and the outbound traffic function ($f_{\mathrm{O}}$) satisfying the above conditions are:

$f_{\mathrm{L}} = 2*\breve{U}^2$ : $0 < \breve{U} < 0.5$ (1)

$f_{\mathrm{L}} = -2*(1-\breve{U})^2 + 1$ : $0.5 < \breve{U} < 1$ (2)

$f_{\mathrm{O}}(1-\breve{U}) = 1 - f_{\mathrm{L}}(\breve{U}) = 1$ ï $2*\breve{U}^2$ : $0 < \breve{U} < 0.5$ (3)

$f_{\mathrm{O}}(1-\breve{U}) = 1 - f_{\mathrm{L}}(\breve{U}) = -2*(1-\breve{U})^2$ : $0.5 < \breve{U} < 1$ (4)

Figure 3.1 shows a graph of Local and Outbound traffic against the market share Ŭ.

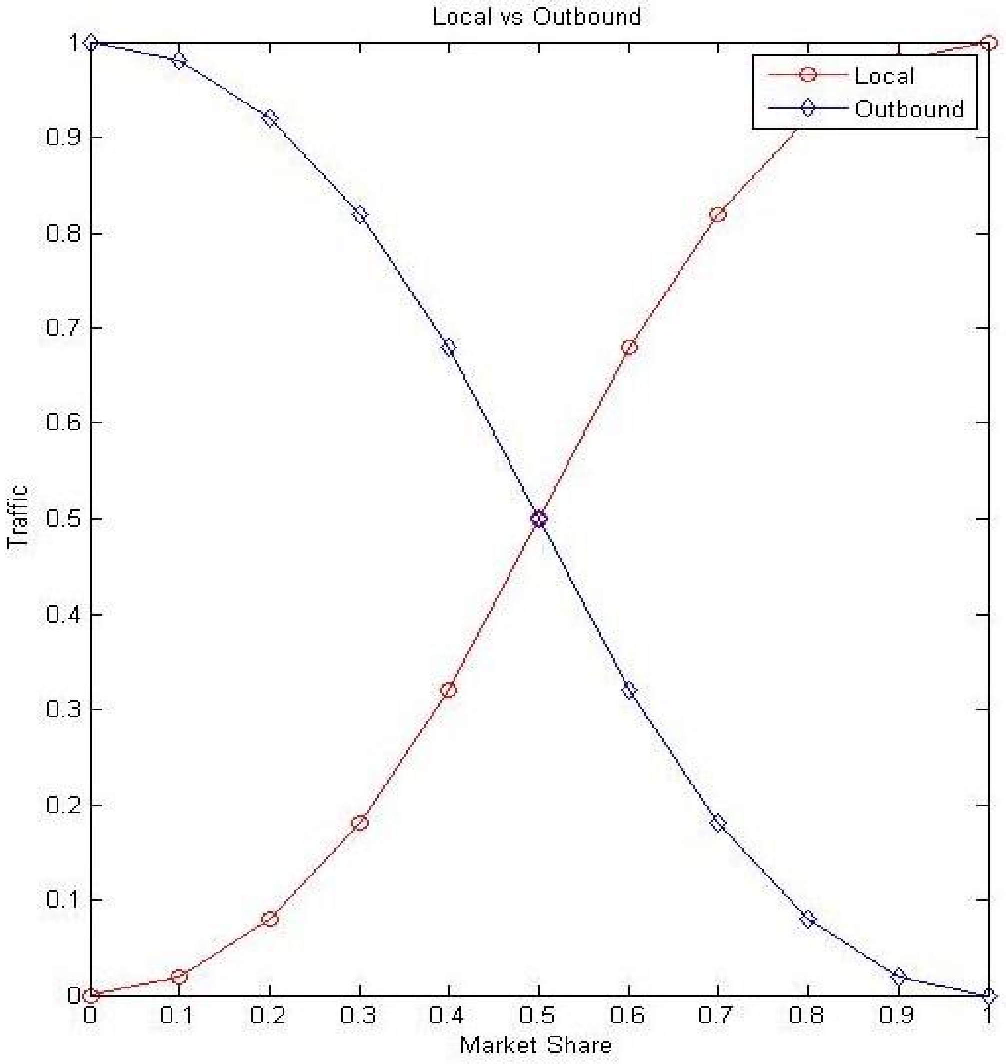

Figure 3.1: Graph of Local and Outbound Traffic.

### *3.3 Traffic supply for interconnection*

The traffic using ISP-1ôs network ($T_{1N}$) consists of three types of traffic:

(1) Local traffic only using ISP-1ôs network ($T_{1L}$)

(2) Outbound traffic generated by ISP-1 and forwarding to ISP-2ôs network ($T_{1O}$)

(3) Inbound traffic generated by ISP-2 and coming into ISP-1ôs network ($T_{1I}$).

For the traffic using ISP-1ôs network and ISP-2ôs network, we can write the following equations:

$$T_{1N} = T_{1L} + T_{1O} + T_{1I} \tag{5}$$

$$T_{2N} = T_{2L} + T_{2O} + T_{2I} \tag{6}$$

One ISPôs outbound traffic is the same as the other ISPôs inbound traffic. Therefore equations (5) and (6) change into equations (7) and (8):

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

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

From equations (7) and (8) we see that the traffic of one ISPôs network is composed 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 ISPôs outbound traffic, which can be traffic supply in this model.

### *3.4 Maximum outbound traffic criterion for settlement and traffic demand.*

Nowadays, 80%-85% of all ISP traffic is traffic generated by receiver requests, such as Web page retrieval or downloading files. In these cases, the request traffic is generally very small compared to the traffic of web pages or downloaded files. Therefore there is much more inbound traffic compared to the outbound traffic for each service request. Hence we 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 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 otherôs 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 ISPsô networks. Irrespective 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.

# CHAPTER 4: RESULTS AND ANALYSIS

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

$$
\begin{aligned}
\mathrm{Max}\ \{T_{1O}, T_{1I}\} &= \mathrm{Max}\ \{T_{1O}, T_{2O}\} \\
&= \mathrm{Max}\ \{f_O(\check{U})*T1, f_O(1-\check{U})*T2\} \\
&= \mathrm{Max}\ \{(1-f_L(\check{U}))*T1, (1-f_L(1-\check{U}))*T2\} \\
&= \mathrm{Max}\ \{(1-f_L(\check{U}))*\check{U}*3G\ bits*N, (1-f_L(1-\check{U}))*(1-\check{U})*3G\ bits*N\} \\
&= (-2\check{U}^3 + \check{U}) * 3Gbits*N, \text{ when } 0 < \check{U} < 0.5 \qquad (1) \\
&= (1-\check{U}) - 2*(1-\check{U})^3 * 3Gbits*N, \text{ when } 0.5 < \check{U} < 1 \qquad (2)
\end{aligned}
$$

The equations (1) & (2) consist of two parts: deterministic terms (3 Gbits *N) and variable terms that can be varied by the value of market share ($\check{U}$). Table 4.1 is made by the only variable part of the equations (1) and (2) when the market share of ISP-1 ($\check{U}$) increases from 0% to 100%.

| Market Share | | Local Traffic | | Outbound Traffic | | Inbound Traffic | | Max{$T_{1O}$, $T_{2O}$} |
|---|---|---|---|---|---|---|---|---|
| ISP-1 | ISP-2 | ISP-1 | ISP-2 | ISP-1 | ISP-2 | ISP-1 | ISP-2 | |
| $\check{U}$ | $1-\check{U}$ | $T_{1L}$ | $T_{2L}$ | $T_{1O}$ | $T_{2O}$ | $T_{1I}$ | $T_{2I}$ | |
| 0.00 | 1.00 | 0.000 | 1.000 | 1.000 | 0.000 | 0.000 | 1.000 | 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 | 1.000 | 1.000 | 0.000 | 0.000 |

Table 4.1: Max{$T_{1O}$, $T_{2O}$} with varying market share

Figure 4.1 shows a graph of Max{$T_{1O}$, $T_{2O}$} against market share $\check{U}$.

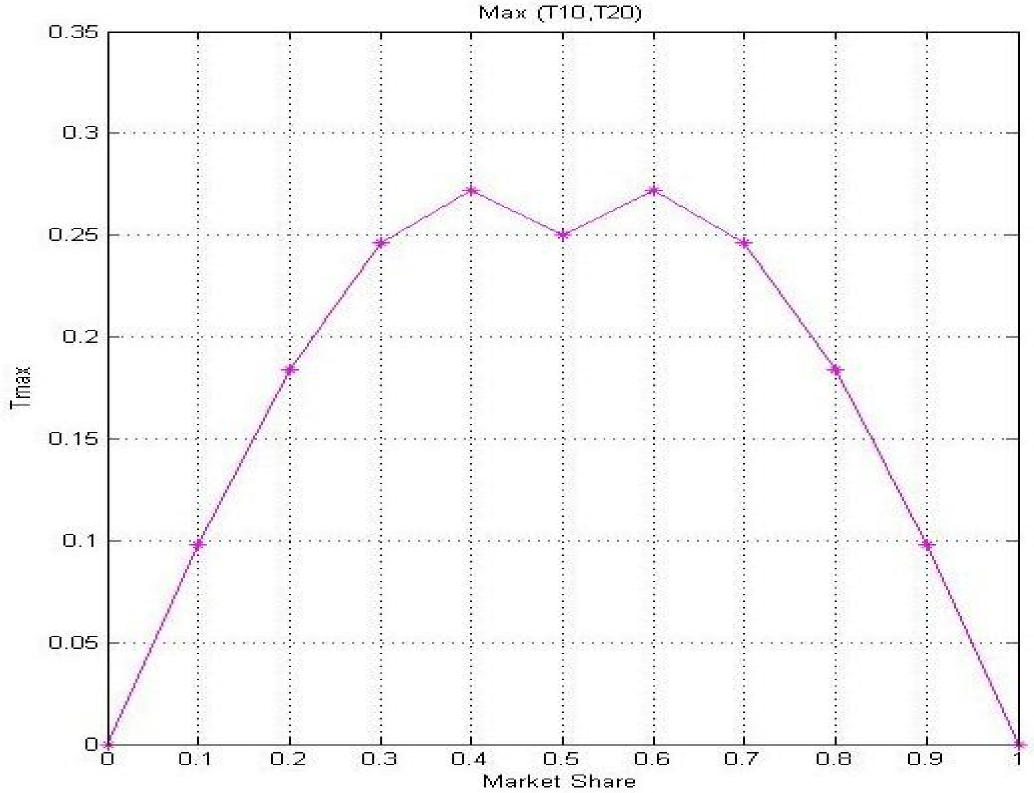

Figure 4.1: Graph of Max$\{T_{1O}, T_{2O}\}$

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 (Ŭ) = Max $\{T_{1O}, T_{2O}\}$

From table 4.1, we can draw the conclusion that the traffic demand for interconnection with the backbone provider depends on the market share Ŭ. And this demand is symmetric at 50%. Table 4.2 shows the traffic demand per month according to the market share Ŭ.

Note that in the table Traffic Demand = [(3Gbits* Max$\{T_{1O}, T_{2O}\}$)*N]

| Market Share (Ŭ) | Traffic Demand |
|---|---|
| 0.1 | 294Mbits*N |
| 0.2 | 552Mbits*N |
| 0.3 | 738Mbits*N |
| 0.4 | 816Mbits*N |
| 0.5 | 750Mbits*N |
| 0.6 | 816Mbits*N |
| 0.7 | 738Mbits*N |
| 0.8 | 552Mbits*N |
| 0.9 | 294Mbits*N |

Table 4.2: Traffic Demand.

The number of bits that can be accommodated by a single T-1 line in a month is 648,000 M bits per month {1.5 Mbps * (3600 second * 4 peak hours * 30 days)}, 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 648, 000 M bits. Table 4.3 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 Ǔ= 0.1, {294 M bits * 5,000}/ 648,000 M bits = 2.3 T-1 lines.

| Market share (Ǔ) | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|
| Number of T-1s | 3 | 5 | 6 | 7 | 6 | 7 | 6 | 5 | 3 |

Table 4.3: Number of T-1s needed for traffic demand.

The settlement is generally defined as a product of the traffic demand and 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 3 T-1 lines and the Internet interconnection T-1 transit price is Ksh.350,000[3] per month, then the settlement is Ksh.1,050,000 per month. The transit price is usually determined by the providerôs relative strength and level of investment in a particular area. The T-1 transit price is given by the market, which is equal to Ksh.350,000 per month. Table 4.4 shows the amount of settlement payment from each ISP to the IBP. This settlement is also symmetric at the mid-point of Ǔ= 0.5.

| Market Share (Ǔ) | Settlement |
|---|---|
| 0.1 | Ksh.1,050,000 |
| 0.2 | Ksh.1,750,000 |
| 0.3 | Ksh.2,100,000 |
| 0.4 | Ksh.2,450,000 |
| 0.5 | Ksh.2,100,000 |
| 0.6 | Ksh.2,450,000 |
| 0.7 | Ksh.2,100,000 |
| 0.8 | Ksh.1,750,000 |
| 0.9 | Ksh.1,050,000 |

Table 4.4: Settlement from ISP to IBP.

---

[3] Price obtained from Telekom Kenya Limited.

### *4.1 Internet Access User Price and Peering Incentive.*

Assuming 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 for the calculation of user price $P_1$ and $P_2$ of ISP-1 and ISP-2 under the assumption of ISP-1ôs market share 0 < Ŭ< 0.5.

ÅRevenue of ISP-1 = $P_1$ * (Number of Subscribers)
= $P_1$ * (Ŭ*5,000) (3)
ÅCost of ISP-1 = (Settlement to IBP)
= (No. of T-1 lines)*(T-1 transit price)
= (No. of T-1 lines)* Ksh.350,000 (4)
ÅProfit of ISP-1 = (3) ï (4)
= $P_1$*(Ŭ*5,000) - (No. of T-1 lines)* Ksh.350,000
= 5,000*{$P_1$*Ŭï (No. of T-1 lines)*(70)} (5)
ÅEquation (5) should be greater than ó0ô.
ÅUser Price $P_1$ > {(No. of T-1 lines)*(70)}/ (Ŭ) (6)
The logic used is applied to ISP-2 as well.

ÅRevenue of ISP-2 = $P_2$ * (Number of Subscribers)
= $P_2$ * ((1-Ŭ)*5,000) (7)
ÅCost of ISP-2 = (Settlement to IBP)
= (No. of T-1 lines)*(T-1 transit price)
= (No. of T-1 lines)* Ksh.350,000 (8)
ÅProfit of ISP-2 = (7) ï (8)
= $P_2$*((1-Ŭ)*5,000) - (No. of T-1 lines)* Ksh.350,000
= 5000*{$P_2$*(1-Ŭ) - (No. of T-1 lines)*(70)} (9)
ÅEquation (9) should be greater than ó0ô.
ÅUser Price ($P_2$) > {(No. of T-1 lines)*(70)}/ (1-Ŭ) (10)

From the equation (6) and (10) we can calculate the breakeven user price $P_1$ and $P_2$ for ISP-1 and ISP-2 to survive in the downstream market. Table 4.5 shows the user prices $P_1$ and $P_2$ according to the change of market share Ŭ from 0.1 to 0.9.

| ISP-1 | ISP-2 | ISP-1 | | ISP-2 | | IBP | ISP-1 | ISP-2 |
|---|---|---|---|---|---|---|---|---|
| Ŭ | 1-Ŭ | T-1s | Settlement Ksh. | T-1s | Settlement Ksh. | Revenue Ksh. | Breakeven $P_1$(Ksh.) | Breakeven $P_2$(Ksh.) |
| 0.1 | 0.9 | 3 | 1,050,000 | 3 | 1,050,000 | 2,100,000 | 2,100 | 233 |
| 0.2 | 0.8 | 5 | 1,750,000 | 5 | 1,750,000 | 3,500,000 | 1,750 | 438 |
| 0.3 | 0.7 | 6 | 2,100,000 | 6 | 2,100,000 | 4,200,000 | 1,400 | 600 |
| 0.4 | 0.6 | 7 | 2,450,000 | 7 | 2,450,000 | 4,900,000 | 1,225 | 817 |
| 0.5 | 0.5 | 6 | 2,100,000 | 6 | 2,100,000 | 4,200,000 | 840 | 840 |
| 0.6 | 0.4 | 7 | 2,450,000 | 7 | 2,450,000 | 4,900,000 | 817 | 1,225 |
| 0.7 | 0.3 | 6 | 2,100,000 | 6 | 2,100,000 | 4,200,000 | 600 | 1,400 |
| 0.8 | 0.2 | 5 | 1,750,000 | 5 | 1,750,000 | 3,500,000 | 438 | 1,750 |
| 0.9 | 0.1 | 3 | 1,050,000 | 3 | 1,050,000 | 2,100,000 | 233 | 2,100 |

Table 4.5: Breakeven user price of ISPs

If the Internet access market user price is set to Ksh.600 per month, then we can divide two regions according to the market share. In the region of (0.3 < Ŭ< 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 (Ŭ< 0.3 or Ŭ> 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. Table 4.6 shows each ISPôs dominant strategy according to its market share.

| ISP-1 | ISP-2 | ISP-1ôs Dominant Strategy | ISP-2ôs Dominant Strategy |
|---|---|---|---|
| Ŭ | 1 - Ŭ | | |
| 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 4.6: ISPôs Dominant Interconnection Strategy

In the peering arrangement, two ISPs can avoid expensive settlement payment to the IBP through bypassing an IBPôs 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 otherôs inbound and outbound traffic volumes because one ISPôs inbound (outbound) traffic is the other ISPôs outbound (inbound) traffic. Therefore Max

$\{T_{1O}, T_{2O}\}$ 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. In order to make a peering arrangement efficient, the cost of peering should be less than the lowest payment of settlement to the IBP.

# CHAPTER 5: CONCLUSION

The commercial Internet is one of the most important innovations in telecommunications and computing of the last 50 years. This ubiquitous data network based on low-level public technical standards has displaced well-established sophisticated high-level networks and has grown to reach a very large percentage of computers worldwide. At the core of the ability of the Internet to provide transport services lie the Internet backbones. The Internet backbone market has quickly grown to extremely high capacity of transmission and has surpassed the transmission capacity of the traditional long-distance network.

Global connectivity is largely provided to the ISPs by IBPs in exchange for a payment to carry the traffic. IBPs invest in, and maintain, backbone capacity, that is, typically large long-distant fibre optic cables with a huge capacity of data throughput. An ISP connects to the IBP, who charges a fee to the ISP for this connection. Such a fee may be flat for access, related to the capacity of the connection link, or may be usage dependent (whereby the traffic is metered and billed) or may be a combination of all three. This contractual relationship between the IBP and the ISP is called transit. It is the primary way in which ISPs provide their customers with access to web pages

The other way of providing access to web pages hosted by an ISP different from that of the end user is by means of peering agreements. Peering is a bilateral, reciprocal relationship in which two ISPs exclusively exchange their own end-customersô traffic directly with each other. Typically, these agreements are settlement free, that is, traffic and access are not billed, even though some networks have recently begun charging for peering, because the value proposition is unbalanced in some way.

The objective of the project was to carry out an investigation into the two interconnection modes and propose the best strategy for a particular ISP. This was done and a model developed for which an algorithm was written to determine the best interconnection strategy for an ISP. The main parameter in this study was market share of the ISP being considered. The model is based on a scenario in which the market at any one time has two major players in the market with a host of other smaller ISPs. Using a quadratic monotonic increasing function to model the traffic flow, the local, outbound, inbound and Max {inbound traffic volume, outbound traffic volume} traffic volumes of the two ISPs were determined. The traffic demand was then calculated using the Max {inbound traffic volume, outbound traffic volume} from which the number of T-1s and settlement was calculated. The breakeven price of ISP-1 and ISP-2 was then determined for particular values of market share. This was compared to the internet access market user price to determine the best strategy for either ISP.

Although the model can be used to determine whether to peer or transit based on traffic flows, other factors should be considered in determining the strategy to be adopted. Factors like the peering policy of the organisation and whether there will be mutual and equal benefit derived from the peering arrangement such as reduced transit costs and lower latency.

If the two ISPs make a peering agreement, the revenue of the IBP is ó0ô. Because any amount of settlement is better than ó0ô, 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:
(a) If one of ISPs cannot 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 IBPôs negotiation power will reduce, that is not desirable to the IBP.
(2) 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 ISPôs market share. Finally the total market size may shrink and revenues of the IBP also shrink, that is also not desirable to the IBP.

Even though the model developed 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 will find it 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.

In summary it can be seen that the best strategy for an ISP to adopt, be it peering or transit, is dependent on several factors.

i. Equality of the two ISPs in terms of geographic coverage, network capacity, traffic volume, size of customer base or a position in the market.
ii. High transit costs and the need to lower that expense.
iii. Peering policies of an ISP.
iv. Benefits to the customers of the ISP in terms of Network externalities.
v. The need for lower latency which reduces the likelihood of data loss.
vi. The relative importance of the interconnection. In case of a problem how fast is it corrected to prevent any losses both of data and money?

## APPENDIX A: Program codes

Code developed in Matlab:

```
a=0:0.1:1  %Declaring the range of market share.
b=1-a     %one minus Market share.
T1L=[];    %creating an empty vector to put T1L variables.
T2L=[];    %creating an empty vector to put T2L variables.
vect=[];  %creating an empty vector to put TMax variables.
for i=1:11 % Creating a row vector containing eleven
            %  elements with increments steps of 0.1.
  if  a(1,i)>=0 && a(1,i)<=0.5;  % Condition  if Market share greater
                             %than zero and less than or equal to 0.5
    val_a = a(1,i);       %Market share =corresponding vector element.
    fo=1-2.*immultiply(a(1,i),a(1,i));   %Expression for outbound traffic
                                      %in the range( 0<=Market share <=0.5)
 fl=2.*immultiply(a(1,i),a(1,i));        %Expression for local traffic
                                    %in the range( 0<=Market share <=0.5)
 Tmax=-2.*(a(1,i))^3+a(1,i);%Expression for maximum traffic volume traffic
                                    %in the range( 0<=Market share <=0.5)

T1L(i)=fl;              % Assigning local traffic elements to T1L vector.
T2L(i) = fo;          % Assigning outbound traffic elements to T2L vector.
vect(i)=Tmax;       % Assigning Tmax traffic elements to TMax vector.
  else               % Condition  if Market share greater
                             %than 0.5 and less than or equal to one.
 fo=2.*immultiply((1-a(1,i)),(1-a(1,i))); %Expression for outbound traffic
                                      %in the range( 0.5<=Market share <=1)
 fl=-2.*immultiply(1-a(1,i),1-a(1,i))+1;  %Expression for local traffic
                                      %in the range( 0.5<=Market share <=1)
 Tmax=(1-a(1,i))-2.*(1-a(1,i))^3;               %Expression for Maximum
traffic
                                      %in the range( 0.5<=Market share <=1)

T1L(i)=fl;              % Assigning local traffic elements to T1L vector.
 T2L(i) = fo;          % Assigning outbound traffic elements to T2L vector.
vect(i)=Tmax;           % Assigning Tmax traffic elements to TMax vector.
   end ;
   end;
   fl=T1L;      %Assigning all T1L elements to local traffic.
  T1L            % Displaying  all T1L elements on the output.
 fo=T2L;         %Assigning all T1L elements to local traffic.
T2L             % Displaying all T2L elements on the output.
T1O=1-fl      % Outbound Traffic volume of ISP-1 defined as 1 minus the
local traffic function
T2O=1-fo       % Outbound Traffic volume of ISP-2 defined as 1 - minus the
outbound traffic function
T1I=T2O     % Inbound traffic volume of ISP-1 is equal to the Outbound
traffic volume of ISP-2
T2I=T1O     %Inbound traffic volume of ISP-2 is equal to the Outbound
traffic volume of ISP-1
Tmax=vect;      %Assigning TMax to elements contained in vector vect.
Tmax % Displaying all  elements of TMax on the output.
N=5000;         %Assumed number of users.
G=1000000000;     %Gigabits (10^9).
M=1000000;        % Megabits (10^6).
TrafficDemand=(3*G*Tmax) %Expression for Traffic Demand.
 capacity=648000*M;  %Carrying capacity of each T-1 line.
T1lines= ceil((TrafficDemand*N)/ capacity) %Number of T-1 lines required to
                                         %handle Traffic Demand.
```

```
T1transitpricepm=350000; % current transit price (price obtained from
Telcom Kenya limited)
settlement=T1lines*T1transitpricepm  %Payement of each ISP to IBP.
Revenue=2*settlement                %Expression for Revenue.
g=[0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1];  % vector containing all
                                             % elements of market share
Breakeven_p1=imdivide((T1lines*70),g)  %expression for user price for ISP-
1.
Breakeven_p2=imdivide((T1lines*70),(1-g)) %expression for user price for
ISP-2.
subplot(1,2,1), plot(a,fl,'-ro',a,fo,'-bd')%subplot displays multiple plots
                                            %on the same window
title('Local vs Outbound')  %Title to first graph
xlabel('Market Share')%independant variable -Graph 1
ylabel('Traffic') %Dependant variable-Graph 1
legend('Local','Outbound')%Distinguishing the two plots-local and Outbound
subplot(1,2,2), plot(a,Tmax,'-m*') %Second plot
title('Max (T10,T20)')%Title to Second graph
xlabel('Market Share')%independant variable -Graph 2
ylabel('Tmax') %Dependant variable-Graph 2
grid on          % pinning grid to the plot
```

## LIST OF REFERENCES:

1. [1] http://www.wikipedia.com
2. [2] Huston, G. ñInterconnection, Peering and Settlementsò, March 1999
3. [3] http://www.cck.co.ke
4. [4] Steffen Lippert and Giancarlo Spagnolo, ñInternet Peering as a network of relationsò, Discussion Paper No. 191, November 2006.
5. [5] Norton, W. B. ñThe Art of Peering: The Peering Playbookò.
6. [6] Margit A. Vanberg, ñCompetitive effects of network externalities on interconnection incentives of ISPsò, September 2007.
7. [7] Gibbard Steven, ñEconomics of Peeringò, October 2004.
8. [8] Norton, W. B. ñThe peering decision treeò, white paper from Equinix: http:/www.equinix.com.
9. [9] Lisa King-Guillaume, ñAdvanced Peering: A better alternative to the traditional internet peering modelò, Jan 2003.
10. [10] Mark Winther, ñTeir1 ISPs: What they are and why they are importantò, IDC, May 2006, No. 201657.
11. [11] Weiss M. B and Shin SeungJae, ñInternet Interconnection Modelò, 2004.

# BIBLIOGRAPHY:

1. Kende, M. ñThe digital handshake: Connecting Internet backbonesò, OPP working paper, Federal communication commission. September 2000.
2. Huston, G. ñISP Survival Guideò.
3. Miller, R. ñThe economics of peeringò.
4. Little and Wright, ñPeering and settlement in the internet: An economic analysisò, Journal of regulatory Economics, vol. 18, 2000, 151-173.
5. Mauleg and Schwartz, ñCompatibility incentives of a large network facing multiple rivalsò, Journal of industrial economics, vol. 54, 527-567.
6. Norton, W. B. ñInternet service providers and Peeringò, white paper from Equinix: http:/www.equinix.com, 2001.
7. Economides Nicholas, ñHandbook of telecommunication economicsò, Volume 2, 2005, Chapter 9, pp. 375 - 407
8. Armstrong, M., ñNetwork interconnection in Telecommunicationsò, Economic Journal, vol. 108, pp. 546 - 564.
9. Daniel Roseman, ñThe digital divide and the competitive behaviour of internet backbone providersò, Technical paper, 2003, vol. 5, pp. 25 ï 37.
10. A. Feldmann, C. Lund, N. Reingold and J. Rexford, ñNetScope: Traffic Engineering for IP Networksò, IEEE Network Magazine, 2000.
11. J. Bailey, ñEconomics and Internet Interconnection Agreementsò, Journal of Electronic Publishing, May, 1996.