THE ECONOMICS AND COMPETITIVE PRICING OF CONNECTIVITY AT INTERNET EXCHANGES

Joseph Y. Hui, FIEEE, FHKIE
Department of Information Engineering
Chinese University of Hong Kong
Shatin, Hong Kong

Abstract With the emergence of Internet hubs, it is important to understand the history, the functions and the economics of the formation of Internet hubs and exchanges. These exchanges are often used for the multicasting of multimedia information, with quality of service control provided. This paper first delineates the history and types of Internet hubs. We then look at the economics of network interconnections with application to the development of Internet hubs. Such economics include aspects of increasing return and externalities, resource substitution, interconnection fee, price competition, and quality of service provisioning. We conclude by looking at policy and competition issues aimed at promoting Internet hubbing.

Keywords: Internet, network economics, bandwidth pricing, Internet exchanges

1. INTRODUCTION

Internet hubs have emerged as strategic facilities for economic developments. Traffic at these facilities typically grows at a compound rate which more than doubles every year [1]. It is anticipated that the importance of these facilities will increase as new applications such as Internet telephony, Intranets, and interactive Video on Demand services will employ Internet hubs for interconnection and facility location. These applications demand Quality of Service (QoS) guarantees for service delivery.

Foreseeing their emerging strategic importance, governments have indicated intention and issued policies to facilitate the emergence of Internet hubs within their jurisdiction [2]. These hubs not only serve the local economy and service industries, but also are set up competitively to attract traffic from the surrounding regions. Therefore, the emergence of Internet hubs and multimedia exchanges within cities reinforces their status as service and goods entrepot for their surrounding regions. These Internet hubs

D. H. K. Tsang et al. (eds.), *Broadband Communications*

naturally compete for traffic within the surrounding region. Given the increasing return or externality provided by a hub with large size, regional dominance of a hub is predicated by a head start in traffic buildup and liberal telecommunication policies.

This paper is organized as follows. In section 2, we shall first examine the historical development of Internet hubs. The many functions of these hubs are explained. In section 3, we look at the externality and economic benefits of a hub as a function of its size and other factors. In section 4, we form simple models of price competition for various modes of interconnection. In section 5, we draw simple conclusions from these models concerning means of achieving prominence of an Internet hub.

2. HISTORY AND FUNCTIONS OF INTERNET HUBS

The Internet was developed as a protocol for the internetworking of independently administered networks. Initially the network was funded by the US federal government for educational and government usage. As the network grew and usage became popular, access and backbone transport services are commercialized and are offered by large number of Internet Service Providers (ISP).

This explosive growth is a result of the low entry cost for setting up an ISP for the following reasons. First, the Internet Protocol (IP) is standardized, simple, and highly distributed. The IP switching equipment is relatively inexpensive and easy to operate compared with switching for the telephone network. Second, interconnection cost, which was based on a settlement free model to start with, is low and simple to administer. This offers a significant competitive advantage compared to the archaic, costly, and hardly competitive settlement system devised for the internetworking of telephony. Third, the transport facility of an IP network is built on top of the transmission facility of the telephony network, and therefore there is no expensive network investment. In addition, the global trend of liberalizing Public Switched Telephone Networks (PSTN) tends to drive down cost of subscriber access to ISP, and ISP access to the local and global Internet.

Internet hubs are developed for exchanging traffic among ISPs and for access to the global Internet. Internet hubs are termed Internet eXchanges (IX) or Network Access Points (NAP) [3]. In essence, Internet hubs are points of interconnections for Internet Access Providers (IAP), Content Providers (CP), and Internet Backbone Providers (IBP). In a region where there is no Internet hub or exchange, an ISP would have to buy global access using long distance transmission facilities to connect to a remote exchange point, often in the US. This was the case for most countries until recent years.

The development of IXs and NAPs is closely related to the development of the Internet in the US. Initially, the Internet is a backbone network funded by the Defense Department (DARPA) and by the National Science Foundation (NSF) of the US. As the Internet is commercialized, NSF established NAPs, called MAE, were turned over to commercial companies for operation. Later, major regional telephone companies in the US set up their own NAPs, providing Internet exchange functions using their own transmission facilities and switching centers. Still later, computer hardware and software companies entered the field. These Internet hubs focus not only on exchange functions, but also on the hosting of bandwidth intensive content.

The development of Internet hubs around the world is a logical necessity. Non-US ISPs market subscriber access in terms of the amount of dedicated bandwidth they use to connect to the US. As multiple ISPs develop within the local region, it is only natural for these ISPs to negotiate a local and preferably neutral point for themselves to exchange local traffic. The rationale is simply that local transmission facilities are much cheaper and of better quality in terms of delay and throughput than international transmission facilities. Thus we witness the emergence of one or more Internet exchanges within many countries in the Asian Pacific region.

While much of the Internet web content remains in the US, there is a common trend that both the volume and importance of local content are increasing. Also, mirror sites for non-local content are established locally in order to reduce international bandwidth consumption and for improved speed of retrieval. Consequently, local traffic volume is expected to approach the volume of international traffic.

The economics of these Internet hubs involves the tradeoff in the use of local bandwidth, international bandwidth, and storage at the hub for caching both local and international content. Also, global access can be provided at the hub, rather than having each ISP acquiring international bandwidth by itself. The sharing of international bandwidth at the hub itself is termed a transit service, which is cost effective due to sharing of a large international bandwidth. A good price discount is often obtained for a high capacity international link.

Internet hub could be seen as an example of the Internet information marketplace, where different players such as IAP, CP, IBP, etc meet, creating a vibrant market of services for each other. Such a market place allows players to flexibly acquire services from anyone they so choose. The market place allows these players to choose alternative service suppliers without a physical reconnection, provided the alternative suppliers are at the same hub.

3. THE ECONOMICS OF INTERNET HUBBING

The economics of Internet hubbing bears a certain resemblance to the hubbing of airline routes. The size of the hub brings about an externality (economic benefit), which is the ability to reach a large number of Internet sites efficiently. This externality in turn attracts more ISPs to connect to the hub. Therefore, the success of a hub depends strongly on achieving dominance early on.

To achieve dominance, the cost of accessing the hub must be low compared to other aspiring hubs. This is a common strategy in Internet product and service marketing, namely the use of low or even below cost introductory prices in order to achieve dominance early on, so that an increasing return is gained by signing on a large number of subscribers.

Consider the economics of two competing hubs for interconnecting N ISPs. Let us assume that each ISP generate an equal amount of traffic A, and this traffic is evenly distributed to the other $N-1$ ISPs. Suppose a fraction f of the N ISPs is connected to the first hub, leave the rest connected to the second hub.

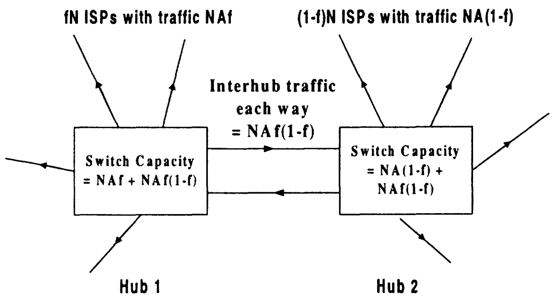

Figure 1. Traffic flow for two Internet Hubs

As seen in figure 1, a traffic volume of NAf is generated by ISPs connected to the first hub, out of which a traffic volume of $NAf(1-f)$ is destined for the second hub. This inter-hub traffic volume is symmetrical since similarly, a traffic volume of $NA(1-f)f$ is destined from the second hub to the first hub. Thus the use of two hubs requires an inter-hub transmission link which increases cost as shown in table 1.

Beyond increased transmission cost, switching cost is also increased. The first hub would require a switching capacity of $NAf + NAf(1-f) = NAf(2-f)$. Similarly, the second hub would require a switching capacity of $NA(1-f) + NA(1-f)f = NA(1-f\text{- }2)$. The total switching capacity required is then $NA(1+2f-2f\ 2)$.

Table 1. Switching and Inter-Hub Link Cost per ISP

	Switch Capacity		Inter-hub capacity	
	Total	Per ISP	Total	Per ISP
Hub1	$NAf(2\text{-}f)$	$A(2\text{-}f)$	$Naf(1\text{-}f)$	$A(1\text{-}f)$
Hub2	$NA(1\text{-}f^2)$	$A(1+f)$	$Naf(1\text{-}f)$	Af

Compare the cases of $f=1$ (one hub only) and $f=.5$ (two equal size hubs). We see readily that the case of two equal size hubs requires a total switching capacity of $1.5NA$, and an inter-hub transmission link of capacity $0.5NA$. This is a significant increase in cost compared to the case of one hub, which requires a switching capacity of NA and no inter-hub link.

If $f>0.5$, the first hub acquires a superior externality compared to the second hub, if we consider the per subscriber cost of switching and inter-hub transmission at each hub as shown in table 1. For the extreme case of f close to 1, namely that the first hub have a close to 100% dominance, we see that the switching cost per ISP of the second hub is twice that of the first hub, and the inter-hub capacity required per ISP is 0 for the first hub versus A for the second hub.

The placement of content at an Internet hub promotes the same externality as that generated by size. An Internet hub is an ideal place for the placement and caching of information for ISP connected to that hub. Placing content at the hub removes the need to set up a link to the hub. Any ISP connected to the hub enjoys fast one-hop retrieval for content placed at the hub. Therefore, Internet hubs may derive significant income via content co-location and facility management at these hubs.

Therefore, Internet exchanges can provide other services than simply traffic exchange, as shown in figure 2. Facility management provided at the hub reduces the operation cost of enterprises since managing networks may not be the core competency of most, and particularly the small and medium enterprises.

Another advantage of Internet hubbing is the provisioning of international Internet transit services. Many Asian ISPs maintain two links separately for local and international Internet access. International transit service allows an ISP to access the local hub via a single local link. At the hub, international traffic is sorted out and allowed to make transit onto shared international links. This sharing allows multiple ISPs to enjoy two types of economy of scale. First, together they may subscribe a larger capacity link and thereby enjoy a volume discount for the price of the link. Second, they may enjoy the economy of statistical multiplexing, which reduces the size of the link they may have to subscribe since their traffic patterns are not likely to peak at the same time.

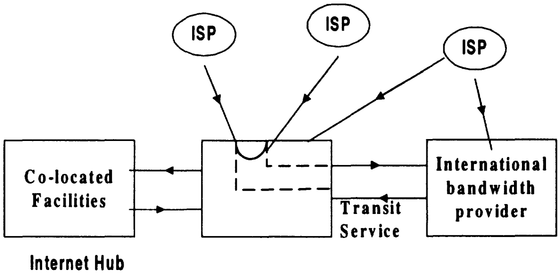

Figure 2. Services Provided at Internet Hubs

An Internet hub can achieve other intangible externalities besides the above externalities generated by the number of connected ISPs, the amount of co-located content, and the cost effectiveness of transit service. Value-added services provided at a hub make the hub more attractive for connection or service placement. It is often these services, rather than plan vanilla connectivity, which attract connectivity and service placement. Also, an open and flexible placement of services for the co-inhabitants of an Internet hub is by itself an attraction, since this kind of environment produces a vibrant information market place which safe-guards competition and consumer choice.

An important value added function for Internet exchanges is a multimedia exchange, which is a co-located storage of multimedia information at an Internet exchange for local Web based retrieval. This provides an open platform for Internet based VOD services. A multimedia exchange can also facilitate good quality of service provisioning, an externality for attracting connectivity to an Internet exchange.

4. PRICE COMPETITION FOR INTERCONNECTIONS AND QUALITY OF SERVICE

The competitive advantage of the larger hub depends strongly on the per unit cost of switching and transmission. If the inter-hub link is local, high bandwidth transmission can be obtained for inter-hub communication at very low per unit cost. Therefore, the competitive advantage of the larger hub is not particularly strong. Therefore, it could be argued that multiple hubs might be sustained within a locality, if smaller hubs can achieve substantial added values to their connectivity services.

If the two hubs are not in the same locality, inter-hub transmission is expensive. Also, the cost of an ISP connecting to a non-local hub can be very expensive. In choosing a hub to connect to for regional connectivity, an ISP is strongly influenced by the transmission cost to the hub. If a hub is situated in a region with an open and competitive market for international bandwidth, the region readily becomes a magnet for connectivity, and thereby its hub can readily become a dominant hub in the region.

The purpose of this section is to examine price competition for quality of service for various types of connectivity. A large literature concerning Internet economics can be found in [4]. We propose a new model concerning regional price competition of several network connectivity types as a non-cooperative game. The purpose of the analysis is to provide insights into collusive and competitive pricing practices for internetworking. This analysis can be applied to pricing access and network traffic exchange.

A network consists of a graph $G = (N,L)$ where N is the set of nodes n (where switches are placed for interconnections) and links l in the set of links L. To form a model of price competition, each link l is assigned ownership m_l , which is in the set M of service providers. Each service provider m owns a set of links L_m. Each service provider is interested in maximizing revenue, which is the product of price p_l and demand x_l , summed over all links l in L_m. A more general revenue model can also be assumed for non-linear pricing as a function of demand, as well as the incorporation of a demand dependent cost charged against revenue.

Naturally, traffic chooses the least costly connection for meeting an end-to-end demand. The cost per unit traffic for a link l depends both on the price p_l as well as the quality of service degradation cost $Cl(xl)$. This QoS cost may be a consequence of congestion induced by the traffic x_l on the link. To route traffic end-to-end, the total cost is given by the sum of the cost on the links in the end-to-end path. For an end-to-end traffic demand using more than one path, the cost of these paths must be the same, or else traffic could be shifted from the more costly path to the lest costly path.

We may assume two models concerning price-demand elasticity. The first model fixes demand for end-to-end service regardless of cost. The second model is cost elastic, which renders demand as a function of the lowest end-to-end cost.

This network of service providers with traffic seeking the least costly path is a non-cooperative game. Each service provider sets a price for each link it owns to attract traffic seeking the lowest cost paths. This non-cooperative game produces in a unique supply-demand equilibrium if the total cost suffers from a diseconomy of scale (i.e., the function $C_l(x_l)$ is a convex function).

We shall defer the solution of this competitive pricing model and the analysis of its properties for a later paper. In the remainder of this section, we analyze the simple networks shown in figure 3 to illustrate collusive and competitive pricing for internetworking.

In figure 3, we show three basic types of connectivity, namely the serial type, the parallel type, and the series-parallel type. Serial type connectivity consists of concatenation of two or more links. Parallel type connectivity consists of two or more links in parallel. Series-parallel type connectivity is formed by combining serial and parallel networks recursively.

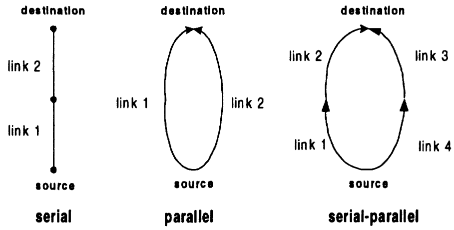

Figure 3. Types of Interconnection

We use these network types to illustrate collusive pricing for serial type network and competitive pricing for parallel type network. For a simple series-parallel network, we illustrate how a dominant network service provider can unfairly uncut its competitor.

For the sake of simplicity of illustration, we assume a linear congestion cost for each link. In other words, the total cost of using a link l is given by $y_l = p_l + c_l x_l$. We may assume further that cl is the same for all l.

We also assume a traffic demand of d between the source and the destination. This demand may be inelastic, in which case d is a constant. For elastic traffic demand as a function of the cost y, we may further assume a linear demand versus cost function $d(y) = f - ey$ for y between 0 and f/e, and $d(y)=0$ otherwise.

4.1 Competitive Pricing of Parallel Networks

Let us assume that the demand is inelastic, i.e. d is a constant. Let us assume traffic is split among the two links as x_1 and x_2 such that $x1 + x2 = d$. By symmetry, we have for optimal routing of traffic $x_1 = x_2 = d/2$. If the two links set prices competitively in order to maximize the revenue for each link, it can be readily shown that the optimal prices are $p_1 = p_2 = c$.

If there are k parallel competing links, it can be shown that each link would set a competitive price of $c/(k-1)$. In this case, revenue is driven to zero in an environment with many competing links .

If both links of the network belong to the same service provider, a monopoly exists and given an inelastic demand, the provider would set an exorbitant price with infinite revenue. If we assume a price elastic demand of $d(y) = f - ey$ for y between 0 and f/e, we can readily solve for the optimal monopolistic prices. Nonetheless, it can be readily shown that demand is suppressed and price is set high for the monopolistic case relative to the competitive case.

For the highly competitive Internet market where many service and route alternatives are available, significant allocative efficiency results from consumer choice and cost reduction. In that regard, the internetworking philosophy produces a highly efficient network economy.

4.2 Price Collusion for Serial Networks

Contrary to keen price competition for a parallel network of competing links, a serial network of competing links tends to produce collusive prices. For the case of inelastic demand, it can be readily seen that the two links of a serial network would raise prices indefinitely.

If we assume a price elastic demand of $d(y) = f - ey$, it can be readily shown that a serial network of competing links suppresses demand even more than the case of monopolistic ownership of both links.

An example of collusive monopolies is the provisioning of International Private Leased Circuit (IPLC). Two national and monopolistic PSTNs each owns a half-circuit for an IPLC. They tend to raise the price of their half-IPLC to levels which have no bearing with cost, thereby suppressing demand to an artificially low level.

The opening up of the IPLC market for International Simple Resale (ISR) of Internet and other value-added communication services is therefore an important step for development a vibrant information economy. Lowered IPLC cost will provide favorable conditions for the formation of a regional Internet hub.

4.3 Price Distortion for Series-Parallel Networks with Dominant Carriers

For series-parallel network, the existence of parallel alternative paths eases the collusive pricing effect of serial links. In the presence of a dominant carrier, significant price distortion and unfair competition may occur as shown by the following example.

For the series-parallel network shown in figure 3, suppose link 1 is owned by a non-dominant carrier, while links 2, 3, and 4 are owned by a dominant carrier. We may view link links 2 and 3 as local loops and the non-dominant carrier is purchasing local access from the dominant carrier.

The question then is how much should the non-dominant carrier pay the dominant carrier for local access. In both cases of elastic or inelastic demand, there is an incentive for the dominant carrier to charge excessive prices for link 2, so that demand would be redirected to links 3 and 4. The prices charged for links 2 and 3 would be different, even if the costs of these links are the same for the dominant carrier.

The regulation of the proper level of charges for access is difficult in this case. Improper determination may artificially suppress the demand for value-added services such as Internet access.

5. CONCLUSION

Many countries and cities aspire to become the Internet hub for the Asia-Pacific region. Similar to the creation of a hub for maritime, aviation, and ground transshipment of goods, a regional hub for Internet must achieve an economy of scale so that a significant sized induced externality is established.

There are a number of factors identified to create the conditions conducive to the establishment of a pre-eminent hub. First and foremost is an open and fair regime of interconnection. Second, local and international circuit cost must be low, as a result of a liberalized telecommunication market. Low cost local and international circuits attract connectivity and help build a large network infrastructure. A large traffic volume provides an attractive environment for the caching and further value-added processing of information. Third, promotion of value-added services further enhances the attractiveness of connecting to a hub.

In this paper, we modeled the economy of interconnection as a non-cooperative game among competing network service providers and service users. We identified network structures which produce competitive or collusive pricing practices. Examples of price distortion are given. Further work is being done to examine policies for promoting competition in the Internet.

References

[1] HKIX traffic statistics, http://www.hkix.net/hkix/stat/aggt/aggregate_new.html

[2] 1998 HK SAR Policy Address http://www.info.gov.hk/pa98/english/index.htm

[3] For a good list of NAPs around the world, see the link concerning exchange points in the page http://www.isi.edu:80/div7/ra

[4] The information economy home page organized by Hal Varian contains diverse discussion on pricing and policy, http://www.sims.berkeley.edu/resources/infoecon/