Unclassified **DSTI/ICCP/TISP(2005)11/FINAL**

Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development

05-Apr-2006

English - Or. English

DIRECTORATE FOR SCIENCE, TECHNOLOGY AND INDUSTRY
COMMITTEE FOR INFORMATION, COMPUTER AND COMMUNICATIONS POLICY

DSTI/ICCP/TISP(2005)11/FINAL
Unclassified

Working Party on Telecommunication and Information Services Policies

INTERNET TRAFFIC EXCHANGE: MARKET DEVELOPMENTS AND MEASUREMENT OF GROWTH

English - Or. English

JT03207049

FOREWORD

In December 2005 this report was presented to the Working Party on Telecommunications and Information Services Policy (TISP). It was recommended to be made public by the Committee for Information, Computer and Communications Policy (ICCP) in March 2006.

The report was prepared by Dr. Sam Paltridge of the OECD's Directorate for Science Technology and Industry. It is published on the responsibility of the Secretary General of the OECD.

This paper has greatly benefited from data and measurement of inter-networking from CAIDA and Tom Vest at Packet Clearing House as well as the work of Philip Smith at Cisco and Geoff Huston at APNIC in their ongoing reporting of Internet indicators, although interpretations, unless otherwise stated, are those of the author.

TABLE OF CONTENTS

Annex Tables

MAIN POINTS

In little more than a decade, following commercialisation, the Internet has become a critical and integral part of economic and social life. This has been made possible by the phenomenally successful growth of the Internet, as a network of networks. In 2005 more than 20 000 networks with independent routing policies provided connectivity for themselves and many millions of their customers' networks, supporting close to a billion users around the world.[1]

It is timely to re-examine the commercial relationships which enable traffic to flow between networks and have successfully supported access growth and service innovation. This report, in that respect, builds on previous work undertaken by the OECD. One reason for this work is to help inform discussions on 'Internet Governance". In the OECD's experience concerns raised in respect to Internet traffic exchange have disappeared as commercial solutions, enabled by liberalisation of telecommunication markets, have been applied. A commercial and competitive market based approach, for example, has also dramatically lowered the price of Internet access. In 1995 the average price for Internet access – a dial-up or permanent connection at 56/64 kbps – was respectively more than USD 100 and USD 1 000 per month in the OECD area. By 2005, high speed DSL and cable modem connections were widely available, for example, for less than USD 30.

This report discusses the existing structures for Internet traffic exchange and examines its applicability as a model for traffic exchange between convergent networks. New applications like Internet telephony and video services are proliferating. Inter-networking relationships are no longer confined to a relatively small group of homogenous telecommunication carriers but include a diverse set of carriage, service and content providers as well as the wider business community. The report discusses the economic incentives these networks have to co-operate and compete in delivering end-to-end services – and cautions that external regulation could harm the development of this market. It examines the recent evolution and performance to serve new users, underscoring the current system's flexibility and responsiveness to changing technological developments as well as market conditions.

There is an ongoing need for regulatory safeguards where there is insufficient competition. Many of the concerns expressed by some governments in developing countries, regarding Internet traffic exchange, mirror those of OECD governments prior to liberalisation. The lack of competitively available infrastructure (and co-operative infrastructure such as Internet Exchange Points) is a barrier to the benefits the Internet can bring for economic and social development. The report notes the tremendous development of communication access which has followed regulatory reform in a growing number of countries outside the OECD area. The adoption of new technologies, such as Internet telephony, in areas which previously did not have any telephone service is one example. There is also a pressing need to develop human capital, particularly inter-networking skills. Governments and industry need to support capacity building among the Internet's technical community in developing countries.

The need for indicators, for industry and policy makers, will grow as the Internet takes on an increasingly critical role in economic and social development. This is important for discussions on interconnection, network security and stability.

INTRODUCTION

The aim of this paper is to discuss, in broad terms, the existing structures for Internet traffic exchange, the reasons for their success in growing inter-networking and to suggest that this could be a model for allowing the market to determine the future direction of traffic exchange between convergent networks. The conclusion of this paper is that the existing model of Internet traffic exchange relationships is successful.

The development of the Internet stands in stark contrast to that of public switched telecommunication networks (PSTNs) in most countries. Some obvious differences include the technology – packet switched networks for the Internet and circuit switched networks for the PSTN – but also different regulatory treatment. Traffic exchange, between different networks on the Internet, has largely been commercially driven and free of regulation. As shown in the following sections, it is a model that has proved highly successful in its ability to scale and its openness to new entrants.

Internet networks emerged as an overlay to infrastructures which had been put in place to supply PSTN services. Accordingly, the development of the Internet was also influenced by the prevailing regulatory environment applicable to those infrastructures. In the United States, for example, the Computer Inquires regulations ensured that telecommunication carriers were open to overlay networks such as the Internet. Further the divestiture of AT&T in the 1980s created competition early on in the long distance telecommunications market. It is unlikely that the Internet would have developed, or at least exhibited the same pace of innovation, without telecommunication market liberalisation or without these open network regulations. The introduction of competition was fundamental to the successful growth of the Internet. Due to the legacy of monopolies regulatory safeguards were, of course, applied where there was insufficient competition, to some of the building blocks that were used to create the Internet such as leased lines.

Ongoing problems sometimes exist where monopoly carriers, or those with dominant market power in domestic markets, have constrained the ability of domestic Internet Service Providers to exchange traffic at a reasonable price. These problems are most acute in countries outside the OECD area with monopolies over the provision of infrastructure for international telecommunications or where liberalisation is relatively new.

In OECD countries the availability of alternative infrastructure is increasing due to liberalisation and the shift to convergent networks. In respect to convergence, the availability of Internet access is increasing on platforms, other than the PSTN, such as wireless as well as cable television networks. At the same time, the Internet Protocol (IP) is becoming the central enabler of communication over sometimes-called “next generation networks”. For its part liberalisation has brought tremendous new entry in backbone markets and increasingly, with the introduction of broadband platforms, in access markets. In respect to the Internet these players are known as Autonomous Systems, a term which is described further in the following sections, and their growth has been critically dependent on liberalisation.

A growing number and diversity of players

Historically, when telecommunication carriers met domestically or internationally to arrange traffic exchange, in the 20th century, they were a relatively small and homogeneous group. The Signatories to Intelsat, for example, which at its peak numbered around 140, were largely government owned telecommunication carriers with monopolies over domestic and international communication. Typically, these telecommunication operators owned or operated all equipment and the network identifiers necessary for circuit or packet switched traffic exchange to occur. The addressing scheme for X.25 networks is an example.[2]

The foregoing situation changed gradually as telecommunication markets were liberalised. PSTN liberalisation proceeded from deregulating the terminal equipment users could attach to the network, to liberalising the provision of so-called value-added services, through to full infrastructure and service competition. All these steps allowed the Internet to emerge and flourish as a network of independent networks. Along the way, an increasing number of networks took on characteristics akin to those that were once reserved for a relatively small number of players.

Two of the components necessary for routing packets over the Internet are IP addresses and Autonomous System Numbers (ASNs). Putting these resources into use, of course, takes much more including equipment, engineering skills and so forth.[3] That being said, an ever expanding number and variety of players are obtaining these identifiers for their own networks directly or as an adjunct to outsourcing their requirements to a third party network service provider (Box 1). Some are traditional players in the telecommunication and Internet markets. Others are obtaining identifiers to increase their networking flexibility and independence from any particular infrastructure provider. Both segments have been growing apace over recent years.

In late 2005 there were more than 20 000 Autonomous Systems in use – up from less than 3 000 at the close of 1997. This represented a compound annual growth rate (CAGR) of more than 28%. Autonomous Systems are networks with their own distinctive routing policies which appear in the Internet routing table.[4] These entities have a myriad of different commercial and internetworking relationships with each other. Some Autonomous Systems accept traffic from other networks and pass those packets on to third party networks. Others connect to multiple upstream or neighbouring networks but do not carry traffic between networks.

In May 2005, the number of Autonomous Systems carrying traffic between networks made up around 13% of the total. The number of Autonomous Systems in this category grew by a CAGR of 18% between July 2000 and July 2005. Their number was, however, outstripped by the growth in the total number of Autonomous Systems. This raises the question of the composition of the other 87% of Autonomous Systems. Some are from the original communities of the Internet (*e.g.* academic, military) but increasingly they are enterprises or organisations wishing to exert greater independence and flexibility over their networks. For example, Agence France Press, Colgate, the Cincinnati Children's Hospital, Michelin, Round Table Pizza and the Memphis Daily News use Autonomous System Numbers to define unique Internet traffic-handling policies. Some entities like eBay, even have multiple AS numbers to distinguish, for example, their Asian regional policy regime from their North American traffic handling policy. [5]

Box 1. Use and employment of address resources

Provider-independent IP addresses are a valuable resource to an Autonomous System because they do not have to reconfigure their network if they change upstream providers. Having an Autonomous System Number (ASN) can complement that independence in so far as, by controlling their own network identifier, any Autonomous System is in effect managing its own routing policy. By using an ASN a network is taking a decision that it will be multi-homed by being connected to more than one network. The manager of that network can give preference to which upstream network routes traffic as well as exchanging traffic directly with other networks.

To receive a delegation of resources that are 'provider independent', an entity must be able to demonstrate a "need" to a Regional Internet Registry (RIR).[6] A first step in this process is to become a member of an RIR. Members of RIRs are sometimes referred to as LIRs (Local Internet Registries). LIRs can apply for their own Internet resources, be it IPv4 address space, IPv6 address space, or an ASN. To obtain an ASN, an LIR needs to demonstrate that they will connect to at least two other autonomous networks. LIRs do not automatically qualify for an ASN simply because they are an RIR member.

In terms of independence, having provider-independent IP address space could be argued to be the most critical step. It could also be argued that having an ASN is not necessarily reflective of "independence" in that, at the most basic level of use, it simply proves that a network has a need to connect to at least two other autonomous networks. On the other hand, by taking the step to connect to two upstream networks, for example to provide redundancy, an operator is taking a step toward independence from any single network.

Why do entities use Internet address resources?

By employing Internet address resources and announcing them in the Internet routing table a network operator exercises greater independence and autonomy. These network operators can then decide to gain upstream access through one provider, or they may multi-home and use multiple networks. Most household (*e.g.* home wireless LANs) and business networks, of course, do not use identifiers such as AS numbers. Their Internet access may be provided by a single ISP which undertakes to manage their connectivity with the rest of the Internet.

This raises the question of why more than 20 000 Autonomous Systems connected to the Internet and visible in the routing table have taken this step. For many of the enterprise networks it may primarily be a matter of redundancy. If there is some form of outage of service, with one supplier, they have an alternative provider (*i.e.* multi-homing). Many Autonomous Systems may only have two upstream providers and beyond these two connections the rest of their traffic exchange is managed by the upstream providers. Typically, these networks would pay transit to the upstream providers (*i.e.* pay to have their traffic carried to and from the rest of the Internet). At the same time, once an entity has employed their own identifiers they also have a greater number of options in exchanging traffic.

If Autonomous Systems link to major Internet Exchange Points (IXPs), they not only have direct access to a large number of 'transit Autonomous Systems' willing to carry traffic, on a global basis, but they also have the ability to directly exchange traffic with any other Autonomous System at that IXP. As far as transit is concerned they have the ability to select the provider offering the best 'prices and service' as well as bypass those same providers where direct traffic exchange with another network is mutually beneficial. The important point is that presence at an IXP reduces transactional costs. If an Autonomous System wants to switch transit providers at an IXP, they can do so in a matter of hours and without physically intervening. In the past this may have involved the entity making the change, getting a new circuit installed to their premises as well as incurring significant waiting time and financial charges. This fluidity encourages co-operative behaviour by providers and disciplines prices.

In most cases the amount of traffic exchange between two networks may not justify a directly negotiated and managed relationship. In these instances it is simpler and more economical to purchase transit. When the amount of traffic is sufficient to establish a relationship two Autonomous Systems may agree to peer (*i.e.* directly exchange their own traffic rather than paying one or more upstream providers transit). It can be noted that some IXPs do not allow transit agreements. This may be counter productive in that it will discourage major transit providers from joining an IXP which is why the practice, never really common, is increasingly rare. Packet Clearing House (PCH) encourages IXP operators to eschew all restrictive membership and operational policies, other than those that are absolutely necessary for maintenance and security.[7] In their view this gives the IXP the greatest chance of sustainability over time, and enables it to have the broadest possible economic impact.

Players in the Internet traffic exchange market recognise that their interconnection arrangements can be a source of competitive advantage as well as reduced costs.[8] Take AS 15169, otherwise known as Google, by way of example. More than 30 networks exchange traffic directly with Google.[9] Some of the more widely known include Asia Netcom (China Netcom), KPN, TeliaSonera, AOL, IIJ, KDDI, TDC, Swisscom, Level3, Sprint, Reach (*i.e.* Telstra and PCCW), France Telecom, Teleglobe and Microsoft. Traceroutes from other carriers such as Cogent, Korea Telecom, BT, Singapore Telecom, Telecom Italia and so forth also show a direct relationship. All these networks connect directly to AS 15169 because of strong customer demand for access to Google and to make their own transit and peering services more attractive to other networks. These networks also connect directly to Google to bypass payments to each other for transit. At the same time Google minimises its own transit payments through direct exchange with these players. Transit may include termination on the network, to which payments are made, or carriage to a downstream network.

An example of a large content provider leveraging possession of their own address resources to minimise transit payments can be found in Australia. In that country the Australian Broadcasting Corporation (ABC) initially paid transit for delivering all of its content to the Internet. Other large ISPs in Australia accessed this content through their own peering arrangements with the ABC's network provider or, in the case of smaller ISPs, paid transit to access that content. New entrants and smaller ISPs were quick to point out that the ABC could reduce its transit payments, as well as their own transit payments, through direct peering relationships.[10] This also benefited smaller ISPs as they could then make this content unmetered to their customers.[11] The change represented a considerable saving for customers and a source of competitive advantage for the smaller ISPs over some of their large rivals.[12] The ABC (AS 9342) was able to do this because they had their own address resources including a 'provider-independent' IP address block.[13] The ABC's situation is little different from the one exemplified by Google. The key concept is that direct interconnection, lateral connections across the Internet's hierarchy, are a key cost-saving optimisation for any organisation large enough to want to carry the overhead cost of managing a least-cost routing policy.

Direct connectivity to popular content and services today is vastly different to 1997 when there were fewer than 3 000 autonomous networks.[14] At that time, most of the networks that today connect directly to popular content sites would have had traffic routed via other networks. In 1997 relatively few content providers had direct exchange relationships with anyone other than their one or two upstream provider(s). Liberalisation of infrastructure provision has played a fundamental role as telecommunication carriers could build or lease end-to-end infrastructure to bypass each other. At the same time, service and content providers could piece together their own 'backbones' or 'access links' to IXPs to exchange traffic directly with any Autonomous Systems present.

The same dynamics, evident with the large or attractive Autonomous Systems, are being played out countless times with regional or smaller players. The Internet is made up of thousands of Autonomous Systems agreeing to exchange traffic. To observe a table of such arrangements, at one of the world's largest IXPs, it is possible to look at the LINX Member's Peering Matrix. The table is not reproduced here because of its size but can be viewed at http://green.linx.net/cgi-bin/peering_matrix2.cgi. Each of the many hundreds of direct traffic exchange relationships shown in this matrix have been commercially negotiated and they all represent a mutually agreed outcome.

The traffic exchange relationships for Autonomous Systems, at an IXP such as LINX, are often part of a broader peering matrix for any particular ISP. Around half of all the Autonomous Systems which are connected to Euro-IX members exchange traffic at multiple IXPs.[15] A matrix showing which Autonomous Systems are located at multiple IXPs (for Euro IX members only) is available at: https://www.euro-ix.net/isp/choosing/search/ixpmatrix.php.

The importance of commercial negotiations

It can be surmised that each entity using a block of IP addresses and an ASN is making a logical decision about their best interests in terms of their network. They will act to strike the best commercial deal in terms of traffic exchange with other networks. Commercial negotiations have been shown to be the best way to deal with the many thousands of agreements which need to be transacted in order for the Internet to efficiently route traffic at the lowest unit cost for all parties.

The proof for the effectiveness of such arrangements is readily evident in the growth of traffic and direct traffic exchange. In August 2005, Internet traffic at LINX was over 82 gigabits per second at peak times – more than 33% higher than a year earlier – and LINX's membership has grown by more than 20% over the same period to a total of 180 organisations.[16] At the same time, due to the increase in use, LINX was able to cut the costs of key connection facilities – 1 gigabit and 10 gigabit Ethernet ports on its switches – by 15%.

This raises the question of what happens if two Autonomous Systems can not agree to exchange traffic.[17] The answer to this question is that traffic will still be exchanged between these networks but, instead of being direct, it will flow through one or more other networks via transit relationships. This is an extremely important point to bear in mind when considering Internet traffic exchange. To continue with the example of AS 15169, Deutsche Telekom, Telmex and many other large networks exchange traffic with Google via other networks.[18] If such players did not believe this met their needs they would negotiate a more direct relationship. At the same time, Deutsche Telekom and Telmex have many other exchange relationships which, in turn, make them attractive to partners who do provide connectivity to networks such as Google.

Like all commercial negotiations between different entities, reaching agreement may not always be easy. Some negotiations are anecdotally reported to be acrimonious. Others take place with relative ease and in convivial surroundings.[19] For a peering relationship to be established both parties must see mutual benefit. If a peering relationship ends after due notice has been given, and one party feels aggrieved, it is likely that they were receiving greater benefit from the arrangement. The system may not be flawless but it works well enough to have enabled millions of routes to be advertised between many thousands of Autonomous Systems.

It can be argued, of course, that not all networks have equal bargaining power in transit and peering negotiations. A small ISP or a small content provider, for example, may not always be satisfied with the deal they can strike with a major upstream network. On the other hand, smaller entities have many options to improve their situation. They can, for example, strike deals with multiple upstream providers and give routing preference to the one that provides the better deal to the extent they are not contractually required to route traffic to a particular provider. The market for Internet transit is extremely competitive in some OECD countries and increasingly competitive in most OECD countries. Moreover smaller Autonomous Systems can exchange traffic directly with others of equivalence (*e.g.* size and reach), thereby bypassing upstream providers.

All the available evidence from examining the use of address resources, is that this is exactly what has happened as the Internet evolved. Traffic exchange relationships between smaller Autonomous Systems have become richer and more diverse countering the perceived imbalance of bargaining power. Simply put, the seamless nature of the Internet offers the potential for entities to route around less competitive markets. Content providers, for example, sometimes find it more economical to host services outside their own country if the local market is less than competitive. This report notes examples from Nepal and New Zealand. One of the least recognised factors shaping the Internet, in terms of its original United States centric nature, was the ability for that country to act as a default market in the absence of competition in other countries.

How is this different from the PSTN?

It is worth contrasting traffic exchange on the Internet to the PSTN. As markets were opened to competition, with the PSTN, it became necessary to impose a regulated requirement to interconnect on incumbents in order to ensure that subscribers of new entrants could communicate with those of incumbent networks. Subscribers would not, of course, join a new network that could not communicate to all other networks. The dominance of incumbents in terms of subscriber lines and switches meant that they had little incentive to interconnect to a new entrant with few customers. The incumbent already had end-to-end connectivity and most of the traffic, as a result of the interconnection framework, passed through the incumbent's network.[20]

The Internet originated as a United States government sponsored project with the goal of interconnecting academic and research networks. It achieved this goal. By the time the Internet was opened to commercial network and traffic, interconnection between networks was the norm. The incentive of commercial networks at that time was to continue on with full Internet access which customers at that time demanded. In this historical environment, interconnection did not have to be imposed by regulation. Today, no two networks have to agree to direct traffic exchange for communications to occur between them. Communication between the users of two independent networks will still be carried, without a direct interconnection agreement between them, in so far as both networks have transit agreements with a third party network or networks.

Using regulation to intervene in Internet interconnection may well distort a market outcome which is currently delivering greater provider and network diversity. By its very nature the Internet would potentially provide participants with a much greater ability to manipulate traffic and so take advantage of an externally imposed framework for traffic exchange. Regulation may impose higher costs on operators in terms of auditing traffic exchange but this problem may also exist with poor selection of peering partners.[21] Notwithstanding the latter point, the current system of commercial negotiations among networks, with a high degree of flexibility and independence, has brought down the price of traffic exchange by encouraging all players to find the most economical partnerships or transit relationships for their traffic exchange.

Lower transit prices, for example, translate into less expensive communication for firms and less expensive retail prices for end users. This is not to understate the role of technological development in reducing costs and prices but to recognise that such benefits will not always be passed on to users if the market is not competitive. The latter phenomenon was typically the case with the international settlements system historically applied to circuit switched traffic.

Lyman Chapin has summarised the current state of Internet traffic exchange relationships:

> "Seamless Internet connectivity from any source to any destination is …. the net result of countless independent decisions by individual ISPs concerning whether and how to interconnect. This approach capitalizes on the strong business incentives for ISPs to interconnect; no single ISP's network can reach every corner of the globe, and the market has shown that an ISP's

> interconnections with others are an important source of business opportunity. As a result, the Internet as a whole is always fully interconnected — the customers of every ISP can communicate with the customers of every other ISP, whether or not any particular pair of ISPs is connected."[22]

In the United States the Network Reliability and Interoperability Council (NRIC), an advisory committee composed of members of the communications industry, has explored whether a potential problem could arise as a result of two ISPs not being willing to enter into a direct traffic exchange relationship. They also note that this is highly unlikely in a competitive market:

> "There is a potential problem if certain backbone ISPs fail to interconnect either by peering or transit. In principle, this could result in a loss of full connectivity in the Internet. Full connectivity between any two ISPs requires that the two ISPs either peer directly, that one of them obtains transit from the other, or that at least one of them obtains transit service from a third ISP. Up to now this problem has been resolved or avoided by business pressures: Any ISP which fails to offer full internet connectivity will receive considerable pressure from its customers, and up to now this pressure has been sufficient to motivate ISPs to provide full connectivity. Competition will force ISPs to interconnect, either directly or indirectly. ISPs are driven by market forces to have interconnection agreements (whether via shared cost peering, paid peering, or transit service) to serve their end users."[23]

It is true that temporary outages can occur if two networks 'de-peer' but experience has shown these to be relatively short in nature for the reasons highlighted by the NRIC. In addition commercial solutions are available to largely preclude outages that result from de-peering. Some instances of de-peering and their resolution are taken up later in this report by way of example. The key point is that even if two networks do not agree to directly interconnect their customers will still be able to communicate. It is conceivable that "rampant depeering" could be considered a problem, especially for those customers who are not aware or are not able to afford protection against it. On the other hand, the relatively rare instances of depeering do play a positive role by reminding market participants of the costs of such action.

Before further exploring what data are available that might inform policy makers in respect to how this market is evolving, it is worth looking at how Internet traffic is exchanged through commercial arrangements, such as peering and transit. In this respect the paper sets out to update, rather than repeat previous work undertaken by the OECD on Internet traffic exchange before looking at the measurement of traffic exchange and its implications for policy making.[24]

Classification of "Peering" and "Transit"

In terms of commercial arrangements ISPs exchange traffic in a variety of ways. The terms "Peering" and "Transit" are sometimes used to broadly indicate commercial arrangements. By agreeing to peer two Autonomous Systems will exchange traffic between each other and their respective customers.[25] They will not, as a general rule, carry traffic for each other to third party Autonomous Systems. The term peering is sometimes also used as shorthand to mean that the exchange of traffic occurs without payment. In the world of telecommunications this is generally known as "sender-keep-all" (SKA) or "bill-and-keep". Peering generally occurs between Autonomous Systems of similar size and equivalence or at least where both parties can see a mutual benefit.

For some a variation of SKA occurs when two Autonomous Systems agree to an arrangement known as "Paid Peering". The term paid peering is not, however, uniformly accepted in the Internet community. Many believe this arrangement is little different from purchasing transit, which is defined below, to a particular network. The term paid peering is, however, sometimes used when two Autonomous Systems agree that, on balance, one of the networks derives greater value from traffic exchange than the other. For example, ISP-A may have a lot of customers or attractive content. Under paid peering ISP-B agrees to pay ISP-A for its own customers to have direct access to the customers or content of ISP-A. ISP-A, however, does not agree to carry third party traffic for ISP-B. A network such as ADTN (AOL Transit Data Network) offers paid peering to other networks by advertising the benefits of direct access to AOL Time Warner content as well as their 35 million customers (so called "eyeballs" to use the industry term).[26]

Paid peering arrangements generally involve both Autonomous Systems agreeing in which direction benefits flow from direct interconnection of their networks. Autonomous Systems are free to determine which criteria to apply in forming such agreements but volume of traffic in each direction (*i.e.* akin to the bilateral PSTN settlements system) is unlikely to be foremost among them. In part this is because such arrangements are expensive to implement and monitor, easily "gamed" and highly risky for both parties. Many in the Internet community also believe that traffic ratios are a poor indicator of the relative value derived from any agreement to exchange traffic.[27] Nor do IXPs measure traffic between Autonomous Systems and apply a formulaic settlement system across an exchange. While this model has been tried in at least one country it has not gained the support of ISPs and was not continued in that form.

Transit is the term applied when one Autonomous System agrees to carry traffic for another Autonomous System to others or to the rest of the Internet. Whereas peering only offers connectivity between the customers and content of two Autonomous Systems, transit usually provides a predictable price for connectivity to the entire Internet.[28] Transit providers charge for their service and ancillary services they may provide such as Service Level agreements, installation support, local telecommunication infrastructure provisioning and Network Operations Centre support.

Autonomous Systems base their decisions on whether to peer with other networks or purchase transit from them, on a number of criteria. The NRIC has correctly pointed out that it is not technically possible for all Autonomous Systems to connect directly to all others (*i.e.* any to any interconnection of 10 000 ISPs would require 50 million connections – which is not technically feasible).[29] They also note that there are costs associated with each direct interconnection and the benefits of a direct relationship, such as by peering, must outweigh these costs. Some of the criteria Autonomous Systems use to determine whether they will peer or purchase transit include geographical coverage, customer mix, customer size, loyalty of installed base, service offerings, network quality (including operational support) and technology choices.[30] To this list Lyman Chapin adds "Blacklisted" behaviour. He notes that some Autonomous Systems may refuse to peer with a network that has been "blacklisted" for sponsoring spam or phishing attacks (or other misbehaviour).[31]

The commercial arrangements, which provide the framework for Internet traffic exchange, are countless bilateral arrangements between Autonomous Systems which find them mutually beneficial. They exist as efficient market responses with each participant trying to minimise their costs and maximise their performance in the delivery of services to their customers. When combined with competitive markets for communication infrastructure, a commercial framework for Internet traffic exchange leads to greater discipline on prices with all the economic and social gains which that entails. By way of contrast a regulatory framework which introduced 'certainty' for providers (such as who they should interconnect with and at what price) can be a barrier to efficient market outcomes which might otherwise develop. Moreover regulation could, and on past experience would, lead to gaming by providers rather than looking for the most efficient outcomes.

The Internet has proven to be very amenable to market entry as evident by the growth in the number of Autonomous Systems. If there is an imperfection it can be said that the current system does not prevent operators from discarding network announcements for small address blocks below a certain size (*e.g.* /24 or shorter). This is a technical necessity in that maintaining a routing table with many hundreds of thousands or millions of entries exceeds current technology and would be cost prohibitive.[32] This issue may need to be considered further in the future in terms of IPv6 deployment.[33] That being said exercising the right to “filter on prefix length” is fairly uncommon today. In part this is because operators remember the past “discrimination” and prudently forebear from parcelling up too many of their routing announcements into such small blocks. Larger transit providing ISPs are also generally more accommodating than in the past because the costs of router memory upgrades have fallen and the cost of losing a customer is high. In January 2006, for example, prefixes representing 256 or fewer IP addresses, and autonomous systems that originate 256 or fewer IP addresses in total, comprised more than 50% of the total.[34]

That the current system has permitted significant growth in Internet access and use by end users is evident from all available indicators. Consider, for example, that from the commercialisation of the Internet the number of hosts has grown from two million in 1993 to more than 353 million in 2005.[35] By some estimates the world is approaching one billion Internet users barely a decade on from commercialisation.[36] At the same time, the Internet’s commercial arrangements have continually acted to lower prices.

Measuring price trends

A commercial and competitive market has dramatically lowered the price of Internet access. In 1995 the average price across the OECD for a 64 kbps leased line connection to the Internet was USD 19 000 per annum.[37] This included the ISP fee (USD 13 600) and the cost of the leased line from a telecommunication carrier (USD 5 400). The average price for dial-up Internet access, including all applicable PSTN and ISP fees, was USD 1 290 per annum.[38] It is worth comparing those prices to ones that are readily available in 2005 across the OECD for DSL or cable modem Internet access. Price reductions have been made possible by access providers, in a competitive market, being able to find the best commercial relationship for traffic exchange for themselves and their customers. Packet Clearing House, for example, notes that wholesale rates have fallen dramatically. What might have cost USD 1000 per Mbps per month in 1995 may cost USD 15 per Mbps per month in 2005.[39]

Most available indicators point to continuing price declines for both the underlying capacity as well as the carriage of transit traffic though probably at a slower rate in 2005 than in recent years. Between 2001 and 2004 the price of 155 Mbps links in various regions around the world declined significantly each year (Figure 1). In 2004 links of 155 Mbps capacity decreased in price from between 10% to 40% depending on the region. This is as a result of the declining cost of the underlying technology and strong competition in backbone markets ensuring that the benefits are passed on to the market. In recent years many observers have pointed to “over-capacity” on some routes notably the trans-Atlantic. Price declines, in markets such as the United States, have also been attributed to a period of significant over building of fibre routes by most major transport providers. On many of these routes supply continues to be in excess of demand, though demand for capacity is also increasing. It remains to be seen whether price declines will continue once demand for capacity begins to approach available levels and in the face of increasing consolidation among some of the larger players in both the backbone and local transport markets.

Price declines in capacity have led to increasingly competitive transit pricing at major IXPs or at private peering points. In 2001 the average price for transit with a 155 Mbps connection was more than USD 500 per Mbps (Figure 2). By the second quarter of 2005 the equivalent port could be purchased for around USD 40 per Mbps. In the United States and Europe, transit prices well below USD 30 were generally available in 2005. On a regional basis, average transit prices in Asia are higher than inEurope and the United States, but all three regions continue to show declines (Figure 3). Packet Clearing House reports that, in 2005, transit prices well below USD 10 per Mbps were available in major cities around the world such as New York, Los Angeles, Hong Kong, Tokyo, London and Amsterdam.

Toward the close of 2005, Liberty Media, operating in multiple European markets, said that cable companies may pay an average transit price of USD 24 per Mbps – but based on volume discounts could pay an actual price of around half that amount (*i.e.* USD 12 per Mbps).[40] Liberty Media further stated that they had peering arrangements covering 92% of their traffic exchange. The figure given for the average cost of peering was USD 6 per Mbps.

In Europe the Yankee Group reports that prices for IP transit services have fallen by 65% to 75% between 2003 and 2005.[41] The Yankee Group say that the declines in pricing, while continuing, are tending to occur at a slower rate. They also observe that competition is starting to level out prices in areas where, not long ago, there were significant differences. For example, in 2003 a 100 Mbps port cost around USD 100 per month in Madrid and USD 70 in Frankfurt. By 2005, transit prices in both cities were around USD 35 per Mbps. Purchase of capacity at greater than 155 Mbps levels could bring larger volume discounts with prices as low as USD 25 per Mbps with a GigE port purchased with a 300 Mbps commitment.[42] The IXP charge to connecting ISPs is only a small part of this charge. The average cost to an ISP to use a 1 GigE port (excluding housing and transit) was USD 1 150 per month at the IXP members of Euro-IX in January 2005.[43]

It is worth noting that commercial IXPs such as "XchangePoint", operating at a number of locations across Europe, will showcase the prices transit providers have on offer for participants at their exchange.[44] These prices should be considered as the starting point for negotiations. Users are well aware of this and post the prices they have been able to obtain in online forums devoted to this subject.[45] Companies offering transit services at the European exchange points included Flag Telecom (India), Teleglobe (India), Interoute (Swiss), several resellers of Level3 (United States), NTT (Japan), PCCWBtN (Hong Kong; China), Deutsche Telekom (Germany) and Tiscali (Italy). Some operators also post list prices for transit services.[46]

Decreasing transit prices are not just evident on routes in the Northern hemisphere. William Norton, the Equinix Co-Founder and Chief Technical Liaison, made a presentation to the Australian Telecommunication Users Conference in March 2005 in which he noted that the average price for domestic transit in Australia had fallen by between 33% and 50%, depending on the volume purchased, in the previous 12 months (Figure 4). Norton went on to describe why this was occurring. In his view the primary reason for the reductions was that new players, such as Pipe Networks, had entered the market offering high capacity links to IXPs at far lower prices than existing players.[47] Once connected to an IXP, smaller players (so called Tier 2 ISPs) could then peer with each other or purchase global transit at competitive rates from international carriers such as MCI or Teleglobe (Figure 5).

The results of the developments described by Norton were lower costs for Australian ISPs. The benefits to Australian users, from the foregoing developments, are several and very practical. The competitive provision of infrastructure by companies such as Pipe Networks, has assisted the first Australian ISPs to begin offer to ADSL2 services at speeds up to 24 Mbps in some metropolitan areas.[48] There is also a trend towards much higher allowances for data transfer than were included in the original broadband offers of Australian ISPs. The inclusion of unmetered content, such as that of the ABC, is one example. By way of contrast, in countries where incumbents are still able to exercise monopoly power over domestic or international facilities broadband pricing continues to be the source of criticism from users and regulators.[49]

To explore further the dynamics of Internet traffic exchange it is necessary to take a step back from indicators such as price and look toward the number of players in the market and how it is evolving. To exchange traffic, along the lines described by William Norton, service and content providers need certain Internet identifiers (*i.e.* ASNs, IP addresses). If they are simply customers of upstream Internet access providers such entities do not require independent allocation of such resources. These indicators can be measured and used by policy makers to inform market developments.

Measuring the development and use of Internet identifiers used for traffic exchange

The Internet Corporation for Assigned Names and Numbers (ICANN) performs the Internet Assigned Names Authority (IANA) functions under contract with the United States Department of Commerce. These functions include performance of the administrative functions associated with root management, co-ordination of the assignment of technical protocol parameters, and the allocation of Internet numbering resources.[50] The United States Government has stated that it intends to continue to provide oversight to ICANN as it carries out these functions.[51]

Regional Internet Registries (RIRs) manage, distribute, and register public Internet Number Resources within their respective regions.[52] ICANN delegates Internet resources to the RIRs, which then allocate the resources within their regions. There are currently five RIRs: AfriNIC, APNIC, ARIN, LACNIC and RIPE NCC. Internet Number Resources (IP addresses and AS Numbers) are distributed in a hierarchical way. ICANN, in performance of the IANA functions contract, allocates blocks of IP address space to RIRs. RIRs allocate IP address space and Autonomous System Numbers to Local Internet Registries (LIRs), such as ISPs or enterprises, that assign these resources to the end users.

Statistics on the distribution of Internet resources are available from each RIR.[53] In addition, in 2003, the RIRs created the Number Resource Organization (NRO). The purpose of the NRO is to undertake joint activities of the RIRs, including joint technical projects, liaison activities and policy co-ordination. The NRO also publishes data on the allocation of IP addresses (IPv4 and IPv6) and Autonomous System Numbers collected from the RIRs.[54]

Aside from the distribution of Internet resources it is also possible to measure resources that are in use. Researchers at institutions such as Cooperative Association for Internet Data Analysis (CAIDA) use data gathered by the University of Oregon's "Route Views Project" to examine the utilisation of Internet resources.[55] Packet Clearing House also has a data-collection facility which enables research and analysis in this area. It is important to note that measurements of many aspects of the Internet are dependent on the view of the observer. The Route Views Project counters this by gathering data from the perspectives of several different backbones and locations on the Internet.

Autonomous System Numbers

An Autonomous System is one or more IP networks, under the same management, which have defined and coherent external routing policy. An Autonomous System Number (ASN), is a unique number, used in both the exchange of exterior routing information with neighbouring Autonomous Systems, and as an identifier of the AS itself.[56]

Defined as a 16 bit integer the number of ASNs is currently limited to 65 535 unique numbers.[57] Numbers 1 through to 64 511 are available for allocation to Autonomous Systems for use on the public Internet.[58] In mid 2005, some 39 000 ASNs had been allocated leading some experts to project that all the numbers in this space may be allocated by 2010, requiring the introduction of a new system with a larger numbering field.[59] Access to AS numbers, for entities with a demonstrated need, is an important goal in terms of preserving the openness of the Internet to new market entry. In this respect, it is important to note there is no shortage of AS numbers for entities with a demonstrated need and the Internet community has proposals to manage the extension of this resource in a timely fashion.[60] It should also be noted that not all ASN numbers which have been allocated to Autonomous Systems, or are in the pool from which RIRs assign them, are visible in the Internet routing table.

At any point in time, some allocated AS numbers are not visible because of the inevitable delay between allocation and activation.[61] Others may have been decommissioned for various reasons (*e.g.* following a merger of two firms or a firm exiting the market) but held for potential future use by recipients. It may be technically possible to determine some unused AS numbers but tracking down their original or current recipients could be problematic. It would impose a cost on RIRs, which may not easily be justified by reference to their traditional resource stewardship mandate or to their utility. Some previously used ASNs do get returned to RIRs but have limited utility. This is because they can not be reused without problems resulting from being associated with routing policies which continue to exist. That being said there may be good reason to review this policy based on other factors. Potential misuse of lapsed AS numbers, by those with malicious intent, for example, may engender security concerns.

While estimates of Internet growth and associated metrics provide valuable insight on changes associated with this important resource, it also begs the issue of what information should be accurately provided by ISPs to better and more accurately gauge competitive and other effects associated with the Internet. While one must acknowledge that poor regulatory policy could increase the “audit cost” of ISPs (as noted in this paper), it must also be recognised that a huge wealth of data is collected by ISPs for their daily operations and kept private, often for competitive reasons. It has also been noted that the information required and defined in simpler times, has sometimes been of limited value for determining important metrics regarding the Internet. As one example, it is not easily determinable which Autonomous System numbers are controlled by which companies, an issue that may be increasingly important with the market consolidation occurring among ISPs. For the future, it could be useful for researchers working with Internet metrics to examine what information should be key to viewing the dynamics of the Internet and how best to acquire such data.

In May 2005 there were 19 546 Autonomous Systems visible in the Internet Routing table (Table 1). This was up from just under 2 957 at the end of 1997. These data were compiled by Tom Vest, from Packet Clearing House, based on raw data from the University of Oregon’s Route Views Project. As part of his research, Vest has associated each AS with an ISO 3166 country code (by using the “Whois?” database) such that a time series is available for each country of the world.

In May 2005, some 77% of Autonomous Systems present in the routing table were in OECD countries. By far the largest share of Autonomous Systems have their origin in the United States though, of course, these networks may be offering service anywhere around the world. As might be expected, as the Internet develops outside its country of origin, the United States' share of the total number of Autonomous Systems in use is falling – down from 54% in November 1997 to 48% in May 2005 (Table 2). That being said the number of Autonomous Systems, in the United States, increased at a rapid pace from 1 608 in 1997 to 9 340 in May 2005.

The decreasing share of Autonomous Systems attributed to the United States mainly reflects catch-up growth in use of the Internet in the rest of the OECD. All other OECD countries increased their share of the total from 21% in November 1997 to 30% in May 2005. Meanwhile, over the same period, the rest of the world increased their number of Autonomous Systems from 725 to 4 409, though in total their share fell slightly. These data most likely suggest faster adoption by ISPs and business users in OECD countries than in non-OECD countries.

When weighted by population Iceland (4.8), followed by the United States (3.2), Switzerland (2.5) and Luxembourg (2.4) have the highest number of Autonomous Systems per 100 000 inhabitants (Table 3). Why some OECD countries create more Autonomous Systems than others, on a relative basis, is not entirely clear. Those countries with a large relative number of Autonomous Systems all have well developed Internet markets. However, some countries with a lower relative number also have well developed Internet markets.

The primary reason to obtain an ASN is for management of routing with multiple external networks. The most readily understood case is that of a transit network. Transit Autonomous Systems use ASNs because they wish to identify themselves in routing announcements with other networks. For example, ISP-B announces that it will accept traffic from ISP-A and carry that traffic to ISP-C.

Network owners obtain an ASN because they want to be multi-homed in terms of their connections with the Internet. A small ISP, for example, may rely on one or more upstream providers for global connectivity but also peer locally with similar sized ISPs. It should be noted that such a multi-homed network does not carry traffic on behalf of other networks as do transit networks. The small ISP simply uses the ASN to control its own routing policy and thereby benefit from any cost and performance advantages of direct traffic exchange. However, such an entity does not have to be an ISP. In such situations service and content providers (*e.g.* Google, BBC, ABC, eBay) obtain an ASN to facilitate direct connections to multiple ISPs. Alternatively, an entity with a private network, such as a bank or retail chain, may simply want to connect with several ISPs, to provide redundancy, in case one of those networks experiences downtime.

Tom Vest makes the observation that Autonomous Systems, needing ASNs to connect to at least two other networks, implies the use of wholesale telecommunication capacity or services (*e.g.* leased lines / private circuits or self-owned capacity).[62] The high level of competition in the United States market for Internet infrastructure and services, is a likely contributing factor in why that economy has been so successful in creating Autonomous Systems. Vest observes that provider diversity has a significant multiplier effect on the growth in utilisation of Internet resources such as IP addresses.

In Vest's schemata Autonomous Systems are akin to producers and routed IP addresses their output. These indicators have become more revealing over the past decade as more enterprises have deployed their own networks, and as stricter oversight of address resources has created a tighter link between routed IP addresses and actual Internet users, usage, and uses (content and services). What is at issue here is not just the number of 'transit Autonomous Systems', perhaps the most widely understood use of ASNs, but rather how many other enterprises and other organisations are employing ASNs and IP addresses to advance a great variety of commercial and institutional goals. Vest's research explores whether these "non-ISP" uses may be directly indicative of the mechanisms through which ICTs contribute to rising productivity and economic development more generally.

Routed IP addresses

An IP address is a numeric identifier for a device connected to the Internet.[63] Networks using the TCP/IP protocol route messages based on the IP address of the destination. The format of an IPv4 address is a 32-bit numeric address written as four numbers separated by full stops. Each number can be zero to 255. For example, 80.124.130.118 is one of the IP addresses used to route traffic to the OECD. Currently most routed IP addresses are IPv4 with the next generation of numbering (IPv6) being gradually introduced around the world.[64]

Routed IP addresses are the number of such identifiers that Autonomous Systems inject into the Internet routing table. In May 2005, there were around 1.6 billion routed IP addresses up from just over one billion in 1997 (Table 4). These data, compiled by Tom Vest at Packet Clearing House, may slightly overstate the actual number of routed IP addresses. Some Autonomous Systems inject IP addresses that are also visible as a part of larger IP prefixes injected by ASNs associated with a different country. This happens, for example, when one network receives some of its IP addresses from a foreign network operator, perhaps in conjunction with an IP transit service. Vest notes that in these cases the IP addresses will be counted as part of the "national Internet production" of both countries – *i.e.* double-counted – and as a result the worldwide sum of IP addresses counted at the national level is about 10-15% higher than the number which might be reported from other sources. The benefit from this approach, however, is that it allows an investigation of the growth in the use of IP addresses by country.

The OECD's share of globally routed IP addresses was 78% in May 2005. This was down from 83.6% in November 1997 (Table 5). The United States has by far the largest amount of routed IP addresses with 55.8% but this is down from just under 70% at the end of 1997. The next largest amount of routed IP addresses are attributable to Japan, Germany, Korea, Australia and Canada. Relative to their population the United States is the largest user of routable IP address with 311 per 100 inhabitants (Table 6). Other countries to record more than one routed IP address for each person are Iceland, Australia, Finland, Canada and Switzerland.

One caveat needs to be noted in respect to these data. In one or two places high fluctuations can be noted between the previous year and the following year. One such case is in the series for Turkey for 1 November 1998. Where this occurs it is generally the result of a configuration error by an Autonomous System which may or may not be an ISP. Another possible reason is an Autonomous System with a new allocation of IP addresses advertising them all instead of only those required for current needs. The data available, at the Oregon Route Views Project, allow researchers to identify which Autonomous System is responsible for such fluctuations. In this case the problem has been identified as a configuration error. Although a mid-point between the 1997 and 1999 would better represent the situation in Turkey the data have not been altered for that country.

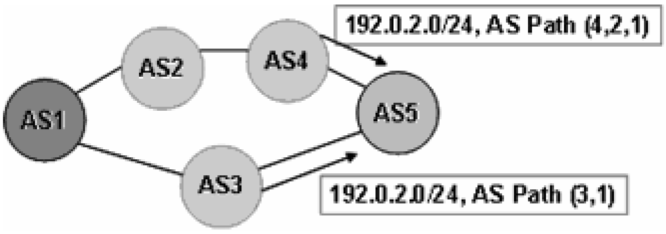
Placing one-off fluctuations aside, for the most part the available data show the average number of routed IP addresses per routed Autonomous System decreasing (Table 7 and Table 8). For the OECD as a whole the average number of IP addresses per routed Autonomous System fell from 392 821 in November 1997 to 83 595 in May 2005. Only seven OECD countries had a higher average in 2005 than in 1997. This is an outcome of more and more entities using ASNs and their own IP address blocks.

SyntheticpPrefixes

Prefixes are blocks of IP addresses announced to the Internet. A prefix would take the form of the one used by Geoff Huston to illustrate inter-domain routing in Figure 6 (*i.e.* 192.0.2.0/24).[65] Huston further explains:

> "As the routing advertisement is propagated across the inter-domain space each prefix accumulates an associated "AS Path". As a prefix advertisement transits each domain, the domain effectively "signs" the prefix advertisement by having its AS number prepended to the AS Path associated with the address prefix. At any point in the network the AS path describes a sequence of connected domains which forms a path from the current point to the originating domain. This is shown in Figure 6, where AS 1 originates an advertisement for the address prefix 192.0.2.0/24. At AS 5, the AS will receive two BGP [Border Gateway Protocol] advertisements for this prefix. One will have the AS Path (4,2,1), while the other will have the AS Path (3,1). In general the AS Path reflects the sequence of AS's through which the prefix advertisement has traversed to reach the current AS. And the general intention is that the AS Path reflects the sequence of transit AS's that a packet will traverse to reach the destination prefix…When a BGP speaker receives two or more advertisements for the same address prefix, the default selection mechanism is to prefer the advertisement with the minimal AS Path length. In the case of the example network in Figure 6, AS 5 will prefer to use the path via AS 3 to reach the originating AS 1, in preference to the longer path of (AS4, AS2, AS1)."[66]

Figure 6: Inter-domain routing with Autonomous System Nunbers and Prefixes



Source: Geoff Huston, 2005.

In summary, "…a BGP routing advertisement consists of an address range, a next-hop router address, and a list of the autonomous system (AS) numbers through which the advertised route will direct traffic."[67] Prefixes may have some value as an indicator of Internet growth as ISPs prefer to route as few as possible. Tom Vest notes that ISPs "…generally only add more when they go back to their upstream provider or RIR for more IP addresses, or when they need to "disaggregate" their existing prefixes, swapping out few/larger prefixes and replacing them with more/smaller prefixes covering the same unique IP addresses, to satisfy some technical or customer requirement."[68]

So-called 'synthetic prefixes' are a by product of the methodology Tom Vest uses to produce the routed Autonomous System series. Vest's methodology "…to calculate routed IP by originating ASN involves mathematically flattening the Internet routing space into a single numbers series (from 0 to 4 294 967 296), and then comparing individual routing table entries to find unique (routed IP, originating ASN) combinations. In this method, two unique prefixes that are numerically adjacent (*e.g.* 1-5, 6-10) and injected by the same ASN will get tabulated as a single entry, which is called a "synthetic prefix.".[69] While this approach does not necessarily correspond with the number of actual prefixes in the Internet routing table it does, once again, have the advantage of making a series available by country. The number of synthetic prefixes nearly tripled between November 1997 and May 2005 (Table 9). As might be expected, as the Internet develops around the world the share of synthetic prefixes for the OECD and for the United States are both decreasing in proportion to the global total (Table 10). In terms of the number of synthetic prefixes per 100 000 inhabitants the largest number can be attributed to Australian Autonomous Systems, followed by the United States, Canada, New Zealand and Finland (Table 11).

One further aspect of Autonomous System paths is worthy of note. The average length of visible Autonomous System paths has been reducing in recent years (Table 12). On a global basis the average length of Autonomous System paths reduced from 5.2 in July 2000 to 4.5 in July 2005. This number does not indicate the number of hops between routers but rather the number of Autonomous Systems traversed. This trend provides further evidence of more direct traffic exchange between networks at, what Geoff Huston has called, the edges of the network. For categorisations of traffic exchange in a hierarchical structure it provides evidence of greater inter-connectivity at the lower levels and potentially greater bypass of networks at higher levels.

Measuring Internet traffic exchange

While it is important to learn more about measuring the Internet, the available data present a variety of challenges, such as very specific assumptions and studies with limited time frames. In general, at this point in time, it must be recognised that researchers are still in the early stages of understanding how best to interpret the data. There is no central repository for the measurement of global Internet traffic exchange on or between networks. Even the view of the Internet routing table is dependent on the particular Autonomous System that is being used.[70] Many networks do, of course, measure traffic between themselves and other networks or 'on-net traffic'. On-net traffic is made up of packets exchanged between a network's own users or between the operator itself and its customers. The latter may represent a significant proportion of the traffic where an ISP is also a content provider. On the other hand, not all IP networks measure Internet traffic to the same degree as the PSTN. This is largely because the commercial arrangements can be such that they do not have the same need, even where such measurement is technically possible.

Service providers need to measure traffic in order to properly design and optimize their network, including peering and transit arrangements. The widespread use of Service Level Agreements by ISPs operating networks require that detailed traffic measurements be made. Mostly such arrangements are proprietary or non-standard methods of data collection.

The foregoing does not mean that there is not a broader public and private interest in such data being available at an aggregate level. There is a clear interest in supporting institutions which collect data in a neutral forum that can help inform policy makers on the overall performance of the Internet and the challenges it faces. The Cooperative Association for Internet Data Analysis (CAIDA), for example, is a collaborative undertaking among organisations in the commercial, government, and research sectors aimed at promoting greater co-operation in the engineering and maintenance of a robust, scalable global Internet infrastructure.[71] CAIDA provides a neutral framework to support co-operative technical endeavours. The University of Oregon's Route Views Project and Packet Clearing House are other examples of neutral data collection which can be used to inform policy makers and industry about Internet developments.

Where data are reported it is necessary to remember that Internet traffic exchange is far more decentralised than the situation which characterised the PSTN. Networks are generally not bound by regulation in terms of the locations between which they can carry traffic nationally or internationally. In contrast to the era typified by PSTN monopolies, no single network can be taken to represent a geographical area such as a country. Among OECD countries, perhaps only in Australia, where the Australian Bureau of Statistics undertakes an ISP survey, are national figures available on the amount of data downloaded by users.

While it is possible for individual networks to measure traffic exchange between and across networks or for IXPs to measure exchanges at specific points on the Internet, these data only represent the specifics of those particular exchanges. In a liberalised market there may be hundreds or even thousands of network operators in any given country each of which may establish one or more traffic exchange relationships. Indeed, some networks may have hundreds of such relationships. Against this background the number of networks entering into exchange relationships becomes a key indicator of the competitiveness of the market.

The number of Autonomous Systems present in the Internet routing table has increased substantially both in total and across each RIR region (Table 12). Origin Autonomous Systems present in the Internet routing table increased by a CAGR of 17% between July 2000 and July 2005. On a regional basis origin Autonomous Systems increased by a CAGR of 19.5% (APNIC), 15.5% (ARIN) and 26.3% (RIPE). The number of Autonomous Systems has also substantially increased in the LACNIC and AfriNIC regions though they have been in operation for a shorter period.

Autonomous Systems providing "transit service", present in the Internet routing table, can also be measured (*i.e.* transit Autonomous Systems). In this sense, transit does not imply a particular commercial relationship but rather that an Autonomous System provides connections to other networks with which it exchanges traffic. In other words ISP-B will accept traffic from ISP-A and pass to ISP-C. A network using an ASN for the sole purpose of multi-homing to different ISPs, as previously noted, does not carry third party traffic.

The number of transit Autonomous Systems has increased significantly over recent years. Between July 2000 and July 2005 the total number of transit Autonomous Systems present in the Internet routing table increased by a CAGR of 18.2%. On a regional basis, the number of transit Autonomous Systems increased by a CAGR of 16.9% (APNIC), 11.9% (ARIN) and 21.6% (RIPE) over the same period. Growth is also evident in the regions serviced by LACNIC and AfriNIC. Moreover many 'transit Autonomous Systems' operate in multiple regions adding to the level of competition in any particular market.

While the increase in transit Autonomous Systems suggests an increase in competition one caveat needs to be noted. If one network merges with, or takes over, another network there is no requirement to return an ASN to an RIR. If a network ceases trading entirely the ASN should, in the normal course of events, be returned to the RIR. Although there were a considerable number of acquisitions of financially troubled ISPs following the bursting of the Internet bubble, the annual increase in transit Autonomous Systems suggests significant levels of new entry continued in this market.

It could, of course, be argued that a relatively small network employing an ASN does not offset the merger of two larger networks in terms of competitive impact. It needs to be considered, however, that new entrants are free to exchange traffic directly with each other and bypass the larger players. Indeed, in many cases, this is may be precisely why they are using ASNs.

The decrease in the average Autonomous System path length also suggests that there are more direct traffic exchange relationships.[72] For the Internet as a whole, the average length of Autonomous System paths decreased by a CAGR of 2.9% between July 2000 and July 2005.[73] One reason for the decreasing length of Autonomous System paths is more direct traffic exchange between Autonomous Systems either bilaterally, at private points of inter-connection, or at IXPs.

The increase in the number of routes between the growing number of Autonomous Systems is evident in the Global Autonomous System Graphs produced by CAIDA (Figure 7). The thumbnail images replicated in this report clearly indicate the richer diversity of routes which have developed between 2000 and 2005. The full images, on the CAIDA Web site, reveal this trend in more detail. The Internet's ability to scale to this level is a result of "decentralised growth". One of the most important means through which this has been accomplished is by localised traffic exchange, particularly through the creation of Internet Exchange Points.

Measuring the growth and use of IXPs

The number of Internet Exchange Points (IXPs) has increased substantially in recent years. From the small handful of IXPs which were created in the transition from NSFnet to a commercial Internet, the number had grown to around 160 by 2004 (Figure 8). IXPs are "neutral" points at which autonomous systems can exchange traffic. Generally, the members of a not-for-profit IXP jointly share the cost of establishing and maintaining facilities, and are then free to interconnect to each other though commercial negotiations. There are also a small number of neutral but commercial IXPs such as those owned and operated by Equinix.[74] Some companies such as PacketExchange offer neutral IXP and their own transit services.[75] The exchange of traffic can also occur on a bilateral basis at so-called private peering points. While these locations are also a type of IXP they are generally not counted in the number of IXPs.

An example of a highly successful industry-driven not-for-profit IXP is the Seattle Internet Exchange (SIX) which operates solely on contributions from participants.[76] There are no IXP fees for using SIX and the exchange has attracted some of the industry's leading players.[77] Another example of a successful IXP is WAIX in the city of Perth in Western Australia. The distances from Perth to other cities in Australia or around the world are vast.[78] It is not surprising therefore to find that local ISPs have found it advantageous to exchange traffic locally. The WAIX also provides local ISPs with access to locally mirrored content from elsewhere in Australia and from around the world.[79] WAIX charges participants a quarterly fixed fee (plus setup charge) for connections.

A selection of IXPs in Europe, Asia/Pacific and North America is available (Table 13).[80] The traffic volumes should only be taken as indicative of the respective sizes in IXPs in relation to each other, at one point in time, as volumes have been increasing rapidly over recent years where data are available. For example, the members of Euro-IX had a total aggregated peak traffic of 280 Gbps in January 2005.[81] This was up from 155 Gbps in February 2004.

The increase in the number of IXPs reflects the desire of Autonomous Systems to improve performance for their customers and to reduce their costs in terms of transit. If two Autonomous Systems agree to exchange traffic at an IXP this will involve less hops between routers than if that traffic were to pass through one or more other networks. This tends to take on significance if that traffic would have otherwise had to travel long distances or traverse platforms with higher latency (*e.g.* satellite links). It generally makes little sense to transport traffic on international links when it can be exchanged locally.

The other major reason for the growth of IXPs has been the potential savings for Autonomous Systems to exchange traffic directly with each other rather than paying others to carry their traffic. A significant proportion of a small Autonomous Systems traffic may be local or regional. Peering with equivalent sized networks in the same area can mean a reduction in payments to upstream transit providers. On the other hand, establishing a presence at an IXP as well as creating and managing peering relationships also has a cost. In some cases, a competitive transit market may deliver lower costs for some traffic exchange than maintaining a presence at multiple IXPs. Accordingly, thousands of Autonomous Systems are continually making commercial judgements about the balance between peering, transit and the number of IXPs at which they participate.

IXPs can have a number of other advantages. In a country without an IXP, for example, content providers will tend to host their products and services in foreign countries.[82] In addition all domestic traffic will have to traverse international links which are generally more expensive than domestic links and, as previously noted, tend to have greater latency. Domestic IXPs also offer the opportunity for ISPs to connect directly to content and service providers and thereby use such arrangements to competitive advantage in attracting customers. In some cases content providers only make services available to providers interconnecting with them at local IXPs. They may, of course, still replicate content off-shore for foreign markets but this could generate a higher cost for ISPs rather than accessing content locally.

To see the range of benefits for a country to create an IXP it is worth considering a practical example. Packet Clearing House has assisted ISPs to create IXPs in a growing number of countries. One such facility is the Nepal Internet Exchange which is operated by its member ISPs. In October 2004, Steve Gibbard, from the PCH, set out the economics of having an IXP in Nepal.[83] In respect to costs he noted that 2 Mbps circuits to connect to the exchange were available to ISPs for USD 13 per month. He further reported that each circuit required about USD 1 000 worth of equipment to put into operation (*i.e.* USD 27 per month if spread over three years). As a member owned and operated facility the Nepalese ISPs were not, at the time he wrote, applying port charges. Gibbard noted, however, that the introduction of an annual fee of USD 800 was planned for 2005 to cover the cost of any additional equipment.

Based on the foregoing Gibbard calculated the total cost to connect to the Nepal IXP to be USD 107 per month for the first two Mbps, and USD 40 per month for each additional Mbps. Gibbard then contrasted the cost of the first month (*i.e.* USD 53 per 1 Mbps) with the cost of 1 Mbps of international satellite capacity and transit fees – some USD 5 000 per month. Gibbard continues in respect to the creation of the Nepal IXP:

> "This can be expected to have several outcomes. Peering in these areas should make connectivity for end users significantly cheaper, if a substantial portion of their traffic isn't leaving the area. Indeed, one of the broadband providers in Nepal allows its customers to send local traffic for free, while charging for international traffic. ISPs should be able to sell transit at considerably lower prices than those charged by foreign satellite operators, passing savings on even to networks that don't peer directly. Locally hosted content becomes attractive, both because the end users can get to it cheaply and because performance is improved significantly, improving business for local hosting companies. And, assuming there's local access to the DNS, the region becomes much better protected against external Internet outages."[84]

To reinforce Gibbard's observation about the benefits of locally hosted content it is worth noting that the peak in traffic exchange in Nepal for 2003 (5 Megabytes compared with an average of 2.5 Megabytes) was due to the release of high school results.[85]

It does, of course, take time for content providers to shift the hosting of their content once an IXP is created.[86] In addition an IXP is only one part of the equation. Content providers will also evaluate the price of local hosting and the reliability of service. They may also have paid for hosting services in advance in a foreign country. That being said an IXP is an essential step in promoting the local hosting of content. In addition e-mail traffic, which would be routed internationally without an IXP, can be exchanged locally. Local traffic exchange and hosting may also encourage the use of country code Top Level Domains. In Indonesia, following the creation of an IXP, the Internet community noted the rise in the use of **.id**.[87] They attributed this to content and service providers wanting to indicate to users that they were now hosting content locally and, as a result, they could expect better performance.

IXPs and regulatory frameworks

To work effectively IXPs need to be industry driven. Autonomous Systems connect to IXPs when they make a judgement it is in their interest do so. Regulation which compelled ISPs to connect to a particular IXP, or to exchange traffic with nominated providers at that location, could have a very adverse affect on the development of the market. It would significantly alter the dynamics of commercial negotiations in which each player makes a judgement on what is best for their network. Regulation of this type could provide incentives for Autonomous Systems to game-play the system or not to participate at IXPs.

More broadly, compelling a group of Autonomous Systems to exchange traffic could give them a certainty about each others actions that they would not otherwise obtain from commercial negotiations. They can use that knowledge to their advantage, and to the disadvantage of others, in negotiations with players beyond that group. In commercial negotiations "uncertainty" about third party relationships, between other networks, may lead to more competitive outcomes.

The creation of mandated traffic exchange can also discourage bypass which might otherwise have occurred with broader competitive benefits. If traffic exchange is mandated between the largest players in a market, it may create a gap between the chosen few and all other players in that market. By compelling the exchange of traffic between the largest player, such as in Australia in late 1998, in a market and the next three largest players, a regulator could be foreclosing actions the second, third and fourth operators would otherwise have taken to redress any perceived imbalance in respect to the actions of the largest player.[88] These actions might have included building bypass infrastructure or combining with each other or smaller players. Significantly, when the Australian Competition and Consumer Commission returned to review the Internet traffic exchange market some years later it decided against extending the regulation to include other ISPs.[89]

Traffic exchange relationships need to benefit both parties and this can be best determined by commercial negotiations. Geoff Huston has well captured the essence of this in respect to making it a peering or transit relationship:

> "…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."[90]

The assessment of peering relationships, and the benefits perceived by both parties can be a dynamic one. From time to time one Autonomous System in such a relationship will decide it should be terminated. In these situations there is generally an agreed period of notice during which both Autonomous System make arrangements so that their respective customers can continue to communicate. In the normal course of events, when de-peering occurs, the change over will be seamless. There have been, however, instances when such arrangements have not been put in place by the time de-peering occurs. In such instances the customers of both networks may not be able to communicate between each other until this is corrected. These cases, while rare, almost invariably raise the spectre for regulatory intervention.[91]

In theory, of course, notification of de-peering should give Autonomous Systems time to make alternative arrangements. Options include one Autonomous System paying transit to the other, or a third party, to carry traffic between both networks. In fact, for any Autonomous System which is multi-homed no outage should occur if they configure their network to take account of the change. In practice cases of de-peering can evolve, as in any commercial negotiation, into 'brinkmanship'. It is important to note that, in the absence of alternative arrangements, the customers of both networks suffer. As a result both networks will receive immediate pressure from customers to provide a solution. For this to work best a competitive market is needed such that customers have a choice of providers and alternative infrastructure. This may not always be the case in developing countries, particularly if a competitive market has not had time to develop or is constrained by restrictive regulation. The broader ISP community will also exert 'peer pressure' and express disapproval in that an ongoing argument might draw unwelcome attention from regulators. If one or both of the networks believes the other is more susceptible to such pressure they may hold off making alternative arrangements in the belief that the other will 'blink first'. This is not an unfounded belief as customer pressure virtually guarantees such outages are short-lived before one of the players makes alternative arrangements or re-peers.

Calls for regulatory intervention in such cases should be treated with extreme caution in a competitive market place. They rarely come from observers placing such instances in context. One reason for this is that commercial solutions are available to preclude such events (*e.g.* multi-homing). It is also the case that any 'de-peering', where alternative arrangements have not been put in place, impacts on a relatively small proportion of the Internet. In October 2005, in a well publicised case in the United States, two large backbone providers (Level3 and Cogent), de-peered.[92] Tom Vest, of Packet Clearing House, estimated at the time that this impacted on one-tenth of 1% of the theoretical United States connectivity total.[93] While it is, of course, a concern to customers that some part of the Internet is unreachable they quickly make this dissatisfaction known to their providers (*e.g.* the ISPs connecting to the backbone providers or to either of the Autonomous Systems concerned if they provide direct connectivity) and the outages are short lived. By way of contrast, regulatory intervention would alter the incentives such players have to look for commercial solutions. Indeed, they would have an equally strong incentive to game play the regulatory framework.

Users of the Internet demand "any to any" connectivity and therefore create tremendous pressure on ISPs to urgently remedy any instances where part of the Internet is unreachable due to circumstances within their control. If two networks do not agree to exchange traffic the nature of the Internet is such that purchasing transit means that their customers will be able to fully communicate. Should one network persist they are penalising their own customers which is why such instances are very rare and quickly resolved. It is worth exploring some recent cases by way of example.

Autonomous Systems and de-peering

What happens when two networks which have exchanged traffic under a peering relationship, for whatever reason, singularly or jointly terminate that agreement? In theory this should not disadvantage customers. Under such circumstances both networks should put in place other arrangements to ensure that the rest of the Internet is still reachable. This will usually be accomplished by one or both parties purchasing transit or utilising to a greater extent their other existing transit relationships. An increase in reliance on transit increases costs for both parties which is one reason instances of de-peering are relatively rare.

In one instance of "de-peering", in April 2005, France Telecom claimed Cogent had breeched some aspect of their agreed peering arrangements.[94] Cogent countered that the termination of the peering agreement had occurred because it was seen as an increasing competitive threat in Europe.[95] In the normal course of events peering agreements contain a clause specifying that if either party wishes to terminate the agreement they give notice to other. This permits both ISPs to make alternative arrangements in terms of transit so that their customers are not disadvantaged.

In this instance one or both of the players had not for whatever reason, put alternative arrangements into place. This impacted, for example, on the exchange of data between French users and Berkley University's Search for Extraterrestrial Intelligence (SETI) program.[96] Under this program users participate by running a free application that downloads and analyses radio telescope data. The problem was, however, short lived. The customers of both ISPs complained to their providers.[97] The broader operational community, for the Internet, also quickly becomes aware of such situations and their resolution creating 'peer pressure'.[98] A traceroute between both providers, after alternative arrangements had been put in place, showed traffic transiting via Verio (a company owned by NTT). The most likely explanation is that one of the players purchased transit via Verio to reach the routes provided by the other. This highlights another aspect of de-peering in that where the two parties do not reconcile it provides a business opportunity for someone else. In this case a Japanese company won new business from the de-peering of French and United States equivalents.

Content de-peering

Peering and transit relationships not only take place among ISPs but also between ISPs and other entities. Examples include the exchange of traffic between a backbone network and a service or content providers. ISPs peer with content providers, such as the BBC or Google, for several reasons.[99] One reason is to lower their own costs by not having to purchase transit from other backbone providers to reach these sites. A second reason is to make their own network more attractive in terms of sale of transit or peering to other networks. A third reason is to provide the highest level of service to their customers by exchanging traffic directly with such networks and to make their own networks more attractive for others to purchase transit. For this reason Internet content and service providers, with significant traffic exchange, have been increasingly employing their own ASNs and provider-independent IP addresses. Smaller content and service providers will generally use hosting that includes traffic exchange or host content themselves and purchase transit from their ISP to the rest of the Internet.

At the boundary between larger and smaller players, in both carriage and content, commercial negotiations will take place to determine if the content provider peers with a backbone provider or purchases transit. At the same time, some major content providers offer paid peering to ISPs. As the traffic flow will generally be in one direction the willingness of a backbone network or ISP to peer with a service or content provider will depend on demand from their customers and the level of competition in the market. Virtually all Autonomous Systems purchase transit but a popular content provider can minimise the cost of transit by peering with other Autonomous Systems. A popular content site such as Google will be multi-homed to several transit providers. But by peering with other Autonomous Systems, such as foreign backbone networks, they can both minimise their payments to those transit providers.

In a backbone market with a high degree of competition, such as the United States, there is a greater incentive to peer than a less competitive market. If an ISP believes they can enjoy the same advantages of direct connectivity through a transit arrangement with the content provider and get them to pay for that service, it is in their interest to do so. In a competitive market, however, the content provider will have many alternatives ranging from peering with other providers to paying a lower transit fee.

If negotiations on transit or continuing peering arrangements fail de-peering can occur. In New Zealand, in early 2005, TelstraClear de-peered at the Wellington Internet Exchange Point (WIX).[100] New Zealand's largest ISP, Telecom New Zealand's Xtra also declines to peer at the WIX exchange.[101] One of the service providers TelstraClear's de-peering impacted upon was "TradeMe". Trademe is New Zealand's largest online auction and classified advertisement site. Following the end of the peering arrangement between TelstraClear and TradeMe, customers accessing the TradeMe Web site found that packets, instead of being exchanged at WIX, were routed internationally. While TelstraClear's customers, and the customers of ISPs for which they provide transit, could still reach the TradeMe's site the latency increased with the additional international hops required to deliver the traffic.

This event caused considerable discussion in New Zealand in respect to the merits of each player's position as well as the bargaining strength of both parties and their options. Supporters of TelstraClear's actions stated that the carrier had every right to seek cost recovery for services rendered. Some observers noted that TelstraClear's actions were little different from "Tier 1" carriers in other parts of the world. In addition, there is a distinction which can be made between peering (*i.e.* carrying traffic to your own customers) and acting as a transit provider (*i.e.* carrying traffic to the rest of the Internet). An alternative view was that TelstraClear's customers were already paying for access to sites, such as TradeMe, and that the provider was taking advantage of an absence of strong backbone competition.

It is important to remember that, at least in the short term, this is essentially a "lose-lose" situation for all parties. From the perspective of TelstraClear's customers (direct or indirect via other ISPs purchasing transit), network performance is degraded for those who use TradeMe's Web site. This disadvantages the customers and TradeMe as the end service supplier. In addition, TelstraClear and TradeMe, as autonomous networks, both have to meet the additional cost of packets being routed through international networks if no domestic routes are available.

In the longer term, TelstraClear hoped the content or service provider (in this case TradeMe) would become a transit customer thus earning the carrier revenue and returning service performance to the previous level. For its part the end service supplier (TradeMe) hoped dissatisfaction from TelstraClear customers paying for Internet access and ISPs paying for transit from TelstraClear, would force the carrier to restore peering or improve its transit offer.

From a regulatory perspective it is important to note that alternatives are available to content providers. These include making peering arrangements with smaller players in the market. By doing this, content providers minimise their own costs and improve performance to the customers of these ISPs, thereby placing pressure on larger ISPs. They can also host content offshore such that they reduce their own transit prices and possibly increase those of ISPs refusing to peer. Of the two the performance for customers may be their stronger card to play as larger players tend to own capacity on international links mitigating any cost impact.

Streaming media peering

New Zealand also provides an interesting case of carriage and content providers testing each others strength in negotiations in relation to streaming media. In mid 2005, the state-owned public broadcaster Radio New Zealand made streaming audio content available for peering at a number of domestic IXPs. At that time, both Telecom New Zealand and TelstraClear declined to peer with Radio New Zealand at these IXPs.[102] The reasons given by both carriers were similar to the ones given in respect to TradeMe.

Separately, Radio New Zealand also had some of the same content hosted in California to serve listeners abroad. The benefit for Radio New Zealand of mirroring content offshore for foreign listeners, is that this reduces their cost for international transit payments. In other words multiple users would not haul the same content across the Pacific but rather access it locally within the United States. There were, however, differences in available content, for reasons of copyright, and the speed at which it was streamed.

Users accessing the New Zealand hosted content were able to access the full service at speeds of between 32-48 kbps for on demand content and 48-64 kbps for live simulcasts. By way of contrast, content hosted in California was streamed at 16 kbps and not all content was made available. So it can be observed that the customers of the large Autonomous Systems, such as TelstraClear, not exchanging traffic locally are the ones at a relative disadvantage. In a further example of content availability the customers of ISPs peering at New Zealand IXPs were able to view a webcast of the premier of the film “Lord of the Rings”.[103] This service was not available to ISPs not peering at the Citylink’s WIX exchange.

From a regulatory perspective it is important to note that exchanging traffic at IXPs can help small ISPs compete against larger ISPs. In addition, content providers have alternatives in a competitive market. By hosting services in California, New Zealand content providers decrease their own costs, in terms of serving overseas customers, and increase the costs of operators not peering with them locally (though this may be a relatively weak deterrent for carriers owning their own capacity). Regulatory intervention, on the other hand, could deter the development of alternative infrastructure and efficient market responses and commercial solutions.

VoIP peering and traffic exchange

Among the technical community there are a range of views on what the term “Voice over Internet Protocol (VoIP) Peering” entails and future directions for technological and commercial development.[104] IXPs and private bilateral peering points are part of the underlying infrastructure for IP traffic exchange at the network topology layer (*i.e.* Layer 3). VoIP, as an application like e-mail or the world wide web, utilizes Layer 5 in the OSI model.[105] There is no difference between the exchange of VoIP traffic and any other application at lower network layers.

It is, of course, possible to categorise several different types of VoIP services in respect to the commercial arrangements surrounding traffic exchange:

- Some VoIP services currently enable calls only between the users of the same application (*e.g.* GoogleTalk, Skype) and remain wholly on the Internet. These services may use open standards (*e.g.* GoogleTalk) or propriety technology (*e.g.* Skype). The VoIP traffic generated by these applications will be carried across the Internet just like any other application even when it involves peer to peer technologies.

- VoIP providers can also use standards such as Session Initiation Protocol (SIP) or the ITU approved H.323, to set up sessions between their applications on the Internet. For example, a Gizmo Project user can call a Gossiptel user. What distinguishes this category, from the one above, is that these providers may agree to a commercial framework for such exchanges. In terms of network layers lower than Layer 5 there is, however, no difference from the first category.

- Some VoIP services also enable users to communicate between the Internet and the PSTN. Examples of VoIP providers, enabling calls to and from the PSTN, include Gizmo Project, NetAppel, Vonage, YahooBB and SkypeOut. These services need commercial arrangements which allow them to exchange traffic with the PSTN.

The initiation of sessions between all VoIP services occurs at Layer 5 while the exchange of packets and transport over the underlying infrastructure occurs at lower layers. If a user of GoogleTalk, with a BT broadband connection, calls another user of GoogleTalk, with a Telstra broadband connection, the packets would be exchanged between BT and Telstra just as they would for any other IP traffic.

A service such as Skype enables its users to communicate with each other but not to call users of other VoIP providers. Skype uses proprietary technology rather than open industry standards. That being said the decision on whether to connect to other networks is more one of commercial policy than technology. Skype say their current service offering is based on customer demand and that they have not provided for calls to other services because their customers have not asked for this capability to be provided.[106] Some other providers, such as Wavigo, say they have built bridges to Skype services to enable calls between the two services.[107]

Skype does use open industry standards for the exchange of traffic between its service and the PSTN (*i.e.* SkypeOut). This can also include calls to VoIP providers, such as Vonage, which have given users a PSTN number. For the exchange of traffic with the PSTN, Skype partners with telecommunication carriers which have negotiated termination agreements with the operators of those networks or terminate the traffic directly on their own networks. These carriers include Cable and Wireless, COLT, B3G Telecom, iBasis, Level3, TDC Song, and Teleglobe which provide PSTN interconnections.[108] It is indicative of the high level of competition that Skype has at least seven carriers bidding for its business.

Skype's negotiations with these carriers and, in turn, the carriers' negotiations with others are commercial in nature. An indication of the potential differences between Skype's retail prices and the cost of termination might be inferred by looking at the rates on offer at commercial exchanges such as VPF (Voice Peering Fabric) or Arbinet.[109] In September 2005, for example, China Telecom was offering termination for USD 0.016 per minute in China at the VPF exchange but higher rates for other countries based on their own negotiated arrangements. China Telecom's price to terminate traffic in Greece, for example, was USD 0.027. At that time, Skype's rate to call China and Greece was the same – USD 0.021 per minute.[110]

SkypeOut's retail price needs to cover its own costs, those of its partner carriers and a margin for profit. Accordingly Skype's prices are dependent on the negotiated termination rates of its partner carriers. If a partner is terminating the traffic directly, as per the case of China Telecom, they may be able to offer a better deal than if they, in turn, need to negotiate arrangements with other parties. This may, apart from redundancy, be why Skype has seven suppliers such that it can select the least expensive option. The differences between SkypeOut retail rates and Arbinet termination rates, for a selection of networks in different countries with anonymous trading partners, range from 40% to 286% (Table 14).

Notwithstanding the need to pay network owners for termination some VoIP providers are experimenting with free calls to fixed PSTN networks. In September 2005, the France-based NetAppel was offering free calls to fixed networks in Belgium, Canada, France, Italy, the Netherlands, Portugal, Switzerland and the United Kingdom.[111] NetAppel's rates to most other OECD countries were priced at USD 0.012. Free calls could be viewed as promotional. On the other hand, with termination prices in the vicinity of USD 0.01 per minute and the cost of providing VoIP applications being very low compared to the PSTN, it is not difficult to envisage other business models being tested.[112] In France, the second largest broadband provider has begun offering free unlimited calls to fixed phones in selected foreign countries such as Australia, Canada, China, Germany, Italy, the United Kingdom and the United States.[113] Users pay a fixed monthly fee of USD 36 for 24 Mbps broadband access to the Internet, a package of television channels as well as free unlimited calls to fixed lines domestically and to 14 international destinations.

Carriers, such as the ones partnering with Skype, buy and sell minutes of termination at exchanges like Arbinet or VPF, in much the same way as any other traded commodity. Any carrier with a network capable of terminating traffic, or an entity which has negotiated rates with such carriers, can lodge an offer at such an exchange. For its part the exchange levies various charges for acting as the intermediary. The sales pitch to VoIP providers, over and above least cost routing and PSTN bypass, includes a range of services ranging from private ENUM databases to interoperability between different VoIP standards.[114] Some exchanges, such as Infiniroute, promise to bring "PSTN like quality" to the peering arrangements underlying VoIP traffic exchange.[115]

VoIP services which enable their users to communicate across different providers (*e.g.* a Gossiptel customer calls a Gizmo Project customer) have begun to create their own "VoIP Peering" arrangements. The XConnect Alliance provides one example.[116] XConnect enables, as do all such exchanges, their members to avoid the PSTN per-minute settlement model and the need to negotiate multiple bilateral agreements. Members of XConnect exchange traffic between themselves on a settlement-free commercial basis. Commercial exchanges are generally housed at so-called carrier hotels or by operators.[117] For example TelX hosts a wide array of Autonomous Systems alongside exchanges such as Arbinet and VPF.[118]

Some entities better known as backbone providers have also set up facilities to enable VoIP traffic exchange. In this respect they are acting much like exchanges such as VPF and Arbinet. Interoute's Arena service is one example and is described by them below.[119]

> "IP changes the game completely. Consider this. VNSL and any other carrier that rents a portal on a softswitch can swap VoIP traffic with all the other tenants within minutes of identifying a least cost route. The rental stays the same regardless of the amount of activity and traffic. There is no longer the need to make huge commitments to get the best price and trading relationships can be established and broken at will. Not everyone will survive in this lean environment where if one player won't agree to another's pricing demands, they are unplugged forthwith, but for the first time, trading activity will be able to react instantly to changes in this fluid market. This model is already working well in the US for Internet peering and is gradually being adopted in Europe, but it hasn't been deployed as a replacement for the old international settlement regime for telephony. Until now. Interoute has launched Arena, based on this Internet exchange model with VNSL as one of its first customers. As everything Interoute does is IP, a flat rent makes perfect sense, charging per minute doesn't. Nor does charging the end-user based on the constraints of time and distance that were the artificial creation of legacy technology and mindsets."[120]

The exchange of VoIP traffic is an emerging market and many different commercial models are being explored. There are a range of views on which models may survive or are necessary. Critics of the intermediary roles played by VoIP exchanges question their need and the value of the services on offer.[121] They point out that VoIP service providers, such as telecommunication carriers, could negotiate traffic exchange relationships among themselves without recourse to intermediaries.[122] Bill Woodcock, from Packet Clearing House, notes that the term "VoIP peering", over which there is no consensus in respect to definition, leads to confusion with IP peering. Successful VoIP providers, he points out, will be keenly aware of infrastructure requirements to exchange traffic but will not confuse these arrangements with those at higher network layers.[123]

IXPs can sometimes be best categorised by their membership. The GPRS Routing Exchange (GRX) which carries out traffic exchange for some mobile network operators is one such IXP. GRX says it offers a managed data network offering using IP based virtual private networks to support data services for mobile subscribers when they are roaming. GRX is operated under contract at the Amsterdam IXP (AMS-IX) using a separate VLAN (Virtual Local Area network) which GRX says enables them to offer enhanced services to their members. While GRX can be distinguished by its membership, like VoIP exchanges, it is conceptually little different from other IXPs.

It is not clear which business model will succeed for VoIP traffic exchange and there may continue to be a range of models on offer for entities which require additional services. On the other hand, as with IP traffic and the trend towards more entities employing independent Internet resources (*i.e.* ASNs, IP addresses) there will likely be increasing opportunities for bypass. Some observers believe this will extend to business users directly exchanging their own VoIP traffic. Hunter Newby, chief strategy officer at TelX expresses the view:

> "…that as corporates VoIP-enable their networks, they will look for ways to peer with each other without touching intermediate carrier networks, or the public Internet, at all…. Corporates today look like the dial-up ISPs of the 1980s and 90s and they will follow exactly the same pattern; they will want to offload traffic without paying for it so they will establish peering relationships with each other….Once enterprises start interconnecting their switches using SIP, and their ENUM directories, they will be able to send and receive calls between themselves for free….The winners in this scenario are Layer 2 Ethernet transport providers, like Exponential-e in the UK, Fastweb in Italy and BT with its 21CN network….And when corporates want international termination? …They will buy it at aggressive rates through…VoIP peering exchanges."[124]

For policy makers the important point is that the foregoing developments potentially lead to a more competitive environment for traffic exchange. As long as Autonomous Systems can avail themselves of infrastructure in a competitive market, to link their networks to IXPs, they will be able to take advantage of the new options technological developments enable.

Access to domestic and international backbone networks

Opening markets to facilities competition and the rapid development of technology have resulted in highly competitive backbone markets in most OECD countries. The development of geographically dispersed IXPs in larger countries has further assisted the development of a competitive market. These developments have been well documented.[125]

Increasing liberalisation – "at both ends of international circuit destinations" – also led to much greater availability of alternative international facilities and the provision of services on an end to end basis. While this has also been well documented, the costs of international interconnection still give rise to discussion in some fora. This has occurred most recently in discussions over Internet Governance. In these discussions there is not always a clear understanding of where the bottlenecks are in relation to reducing the cost of international connectivity and the commercial solutions which are available.

All OECD countries are connected by fibre optic cable and satellite networks. From the mid-1980s onwards, the economic advantages of using fibre optic cable for routes with significant amounts of traffic have made that the medium of a first choice for international transmission. For those countries sharing land borders there are generally multiple international cable routes and a high level of competitive availability of facilities. The number of international undersea cables and the amount of capacity they could deliver between OECD countries increased markedly in the 1990s. The largest increases came on East-West routes in the Northern Hemisphere across the Atlantic and Pacific. High capacity undersea cables also became available between Asia and Europe via the Indian Ocean.

At the same time significant increases occurred on North-South undersea cable routes connecting Latin America to North America and the West Coast of Africa to Europe and Asia. Alternative undersea cables also became available in Australia and New Zealand with connections to Asia and North America. By 2005, the most obvious gap in the international cable market was along the East Coast of Africa. It has been announced that a cable system will connect this region with deployment expected in 2006. Satellites continue to play an important role where fibre optic cables are not available for international transmission.

Diversity of national ownership and participation in major undersea cables has also increased markedly in recent years. Following the burst of the "dotcom bubble", Indian and Chinese telecommunication carriers have been particularly active in acquiring undersea cables or companies which own significant amounts of capacity on international routes. These facilities have been acquired at significant reductions compared to the cost of their construction. At the same time, Indian companies, in particular, have increased their participation in building regional and trans-continental cables. Traffic between India and China, which would once have passed via the United States or Europe, can now be exchanged directly between those two nations. In December 2005 India's Reliance Infocomm and China Telecommunications Corporation signed an agreement to provide direct telecommunication service, including a global hubbing service, to their customers.[126]

Greater numbers of undersea cables, passing more and more of the world's countries, have enabled far greater participation along these routes. If there is an ongoing problem for these countries it can be that all available international capacity is owned by the incumbent. In addition some members of cable consortia may sign non-compete clauses meaning that incumbents in the same region will not offer competitive access to facilities. In these cases the high cost of international connectivity is an ongoing concern and a barrier to the development of the Internet and broader communications market. The other clear requirement is a need for capacity building (*e.g.* developing networking skills) in these countries to take advantage of the competitive international bypass and domestic connectivity IXPs can enable. In the following sections examples are given from India, Sri Lanka, Bangladesh and Africa in respect to how liberalisation is assisting building communications connectivity.

The need for Liberalisation

The greatest cost barriers to any country connecting to global networks are not traffic exchange relationships, in competitive environments, but monopolists charging high prices in the absence of such competition. The experience of OECD countries is that the price of international connectivity fell dramatically following liberalisation and continues to decrease. Subsequent changes, at the retail level, were quickly evident in terms of lower prices for international telephony and dial-up Internet access. By the time broadband access began to be developed, in the OECD area, the international carriage of traffic had virtually disappeared as a consideration in the determination of retail pricing.

In those developing countries which have liberalised their markets the same trends are beginning to occur. India provides one example of where regulatory reform and the introduction of competition have vastly expanded access to communication services.[127] In the pre-reform years, from 1948 to 1998, India's tele-density (fixed plus mobile per 100 inhabitants) grew from 0.02% to 1.94%. Since then India has added more than 100 million telephone lines and by mid-2005 its tele-density exceeded 10% with a target of 23% by 2008. Competition has driven prices down to a level that the growing number of users find affordable but which still provides a return to operators. Mobile communication services are available in India for as little as USD 4 per month (average ARPU is around USD 9 per month). Morgan Stanley has calculated that Indian operators achieve a reasonable rate of return with ARPUs as low as USD 5 per month.[128]

The same competitive forces that have driven down the cost of telecommunication are now at work with broadband access to the Internet. Between the beginning of 2004 and mid-2005, average broadband prices fell 75% in India.[129] For example, a 256 kbps DSL connection with 400 Megabytes of data transfer included, is available from Bharat Sanchar Nigam Limited (BSNL) for less that USD 6 per month.[130] Faced with competition from mobile operators, fixed network operators in India are starting to bundle telephone lines with broadband services. Chennai Telephones, a BSNL operator in the city formerly known as Madras, offers rent free landline connections to broadband users on its “Liberty Plan 495” broadband access plan costing USD 11 per month.[131] Users on this plan only pay for telephony on a call-by-call basis.

Settlements and development

A number of commentators incorrectly attribute the sometimes high cost of Internet access to end users in some developing countries, as being the result of not imposing traditional settlements which applied to the PSTN, to the Internet. This is incorrect for a number of reasons.

From the outset, it is worth observing that the greatest expansion of access in developing countries has coincided with a decline in international PSTN settlement payments. Net out-payments from the United States to India, for example, have declined every year since 2000 (Figure 9). Net out-payments from the United States to Africa have declined every year since 1998. Notwithstanding this India and Africa have undergone an unprecedented expansion in access.

While some argue that settlements were used for development, though this was not their intended purpose, any benefit was more than outweighed by the monopoly regulation required to enforce this system. Opening markets to new suppliers, as occurred in Bangladesh with Grameen Phone successfully supplying services in rural areas on a profitable basis, is one case in point.[132] This was achieved without access to any international settlement payments by Grameen Phone (these payments were kept by the incumbent international operator).[133] By 1998 Grameen’s experience had led it to knock down many of the myths relating to telecommunication development.[134] This included the profitability of providing services in low income rural areas by adopting a commercial approach. Grameen experience showed that services in rural areas did not need to be subsidised to be successful and could be profitable on a stand-alone basis even without international settlements.

Sri Lanka also experienced rapid growth after introducing reforms to fixed and wireless telecommunication markets.[135] Competition in fixed services was introduced into Sri Lanka in 1996 with the two fixed wireless providers licensed to compete against the incumbent. Four cellular providers were also licensed in the mid-1990s. Between 1995 and 2004, Sri Lanka’s tele-density (fixed plus mobile penetration) leapt from 1.4 per 100 inhabitants to 16.6 per 100 inhabitants. Sri Lanka’s growth also coincided with declining net settlement payments which partly resulted from increased international telecom competition. By way of example, net out-payments from the United States to Sri Lanka amounted to the equivalent of USD 42 per subscriber line in 1996 (Figure 10). By 2003 this had been reduced to USD 4 per line. Whereas in 1996 net out-payments between the same two countries, represented the equivalent of USD 193 per new subscriber line added in Sri Lanka, by 2003 this was just USD 18 per new line added.

Nigeria provides another example of a country which has experienced decreasing settlements for the PSTN at the same time as unprecedented growth in access to telecommunication services. Between 1999 and September 2004 aggregate private investment in the Nigerian telecommunication sector grew from USD 50 million to more than USD 6 Billion (Figure 11).[136] This was at a time when the annual net settlement outpayments from the United States reduced from USD 100 million in 1998 to USD 15 million in 2003. Tele-density in Nigeria increased by a multiple of 20 between 1998 and 2004. The dramatic changes to the Nigerian market can be attributed to reform which opened the market to competition. The development of the market, including fixed and wireless infrastructure, has in turn benefited the Internet in Nigeria. Nigeria's Communications Commission say the number of users of the Internet increased from less than half a million in 2002 to more than 1.8 million in 2004.

As the Internet and overall communications market has grown it has become more attractive to develop international connectivity. The Nigerian Communications Commission reports that a new player in that market has announced plans for an additional international undersea cable connecting that country to the United Kingdom.[137] Elsewhere another proposal has been floated to build a fiber-optic cable from Portugal to nine West African countries including Nigeria.[138] The change in the African market can be attributed to the growing success of indigenous companies such as MTN and Econet.[139] MTN operates in nine African countries and recorded a profit of USD 1.1 billion in 2004. Econet, in addition to successfully operating in multiple African countries, is preparing to offer service in an OECD country (New Zealand).

The important point coming out of the experience of a growing number of developing countries is that reform to telecommunication regulation is the key to stimulating growth in access and the ability to attract investment. The inflow of private capital into a market such as Nigeria is much larger and has led to far greater development than occurred in the era characterised by monopoly provision of service and PSTN settlements. At the same time, greater access builds the capability for revenue to be raised domestically, to support further development, and makes the market more attractive in terms of international connectivity. All these developments are inextricably linked to the growth of the Internet as they assist in building the underlying infrastructure and provide a commercial environment for the delivery of services at increasingly affordable prices.

Commercial arrangements

The decreasing use of the traditional international settlements, in countries such as Sri Lanka, India and Nigeria did not occur because of the growing use of the Internet. It occurred because the system lost relevance as markets were liberalised. The traditional settlements system was not reliant for its existence on a particular technology but on the monopoly provision of infrastructure at one or both ends of an international link. Once carriers could build or lease infrastructure, on an end-to-end basis across national borders, the only applicable payments for interconnection, with the PSTN or mobile networks, have increasingly become those for local termination. This loss of relevance, for the traditional settlements system, would have occurred irrespective of the development of the Internet.

It is worth contrasting the prices nominated by a carrier such as China Telecom at the VPF exchange, for the termination of traffic in countries around the world, with those posted by the FCC for countries with which the United States still has international accounting rates.[140] With few exceptions the rates offered by China Telecom at VPF are significantly lower. The rate for Syria is USD 1.02 (FCC) versus USD 0.229 (China Telecom at VPF). The rate for the Central African Republic is USD 1.99 (FCC) versus USD 0.117 (China Telecom at VPF). This raises the question of why such deals are possible. One potential incentive is that termination is available in other countries such as China and the United States, by going outside the traditional system, at less than USD 0.02 per minute. To gain access to such low termination rates operators still using the traditional system are also willing to go outside it.

When multiple operators are permitted market access, and can invest in facilities, the cost of international connectivity quickly decreases. Using India as an example, the average cost of international capacity on various routes has fallen between 60% to 90%, depending on the amount of capacity purchased (*e.g.* 2 Mbps, 45 Mbps, 155 Mbps), between 2000 and 2005.[141] Prices are expected to decline further as the additional competitive pressure exerted by the new SEA-ME-WE-4 cable comes into play.

Driving increased connectivity and lower prices was the Indian Government's decision to open its market to international facilities competition. Following liberalisation, Indian telecommunication carriers acted quickly to build or buy international undersea cables. Videsh Sanchar Nigam Limited (VSNL) and Bharti Tele-Ventures are major investors in the new SEA-ME-WE-4 cable which commenced operations in late 2005.[142] The SEA-ME-WE-4 cable spans nearly 20 000 kilometres linking 14 countries from Singapore to France via Malaysia, Thailand, Bangladesh, Sri Lanka, India, Pakistan, the United Arab Emirates, Saudi Arabia, Egypt, Tunisia, Algeria and Italy.

BSNL, VSNL and Bhartii Tele-Ventures have completed or are building regional undersea cables to link to global networks.[143] Bharti Tele-Ventures and SingTel jointly own a cable which connects Chennai and Singapore (one of several such cables on that route owned by multiple operators). BSNL is completing an undersea cable to Sri Lanka which will link other cables landing in that country and are considering building a further cable on the India-Singapore route.[144] VSNL is a major investor in the SAFE cable which connects South Africa, Reunion, Mauritius, India and Malaysia.

Indian companies have been active in purchasing international telecommunication companies and facilities. In July 2005, VSNL purchased Teleglobe. At the time, VSNL said the acquisition would give it network access in 240 countries and territories, along with ownership interests or capacity in more than 80 undersea and terrestrial cables. Previous to this, in 2004, VSNL had purchased Tyco acquiring in the process over 60 000 kilometres of undersea cable network.[145] Reliance, one of India's largest communication companies, purchased FLAG Telecom in 2004.[146] FLAG owns and manages an extensive optical fibre network spanning four continents and connecting Asia, Europe, the Middle-East and the United States.

The key to India's success in bringing down international prices is allowing multiple operators to compete. Access to state-of-the art international cables would not necessarily have contributed to lower prices. While it is certainly true that the new cables have a much lower unit cost, how much these reductions are passed on to the market depends on the level of competition. Without effective competition the controller of the bottleneck international facilities uses this as a point to dictate downstream pricing structures and levels. By way of contrast, in a competitive market the cost of international carriage becomes a very minor consideration in the prices charged to end users. The provision of 265 kbps inexpensive broadband to Indian users, at less than USD 6 per month, is not only because international capacity is becoming less expensive and plentiful but more importantly because no single entity can exercise monopoly power.

Future challenges for traffic exchange in India

Although four IXPs exist in India they are underutilised for several reasons. In mid 2005, about 30 of India's approximately 180 ISPs connected to the IXPs. Some Indian ISPs still exchange traffic on the West Coast of the United States via foreign carriers even though domestic IXPs are available. Some observers believe that ISPs in India need to develop greater trust, in terms of co-operation over mutual traffic exchange. Like everywhere ISPs need to co-operate while still being active competitors. In India, ISPs operating at multiple locations across the country are not announcing all their routes since they believe others may enjoy a "free ride" on their backbone.

There is also a need to develop greater networking skills. This would enable better inter-networking and provide ISPs with the confidence they need to ensure that only traffic falling within their commercial arrangements is exchanged. The Internet community in the region is aware of this and the South Asian Network Operators Group (SANOG) aims to bring together the technical community for training and to build co-operation between ISPs.[147] The SANOG group comprises representatives of ISPs from the region, vendors such as Cisco Systems, APNIC and Packet Clearing House.

It may also be the case that local access circuits are expensive for small ISPs relative to paying transit. Part of the reason for the Indian Government providing seed funding for four IXPs was to make connecting to them more economical across the country. Without direct connections to the IXPs two relatively small ISPs, who are customers of the same upstream provider, may not be permitted to peer. This is understandable behaviour on the part of the larger provider wishing to sell transit. It is also currently the case that the largest provider of connectivity in India is also the largest hosting company with many of the most popular sites. This situation is the legacy of monopoly regulation and puts that player in a strong position in terms of commercial negotiations with smaller ISPs. Over time these issues can be addressed by competition, as has occurred in other countries, as more alternative infrastructure becomes available. One option available now is for smaller or regional ISPs to purchase transit only as far as an IXP to exchange traffic locally. This solution, however, relies on inter-networking skills being available to these ISPs.

International connectivity costs are still high in Africa

At the end of 2004, 1 Mbps of international capacity was available in some African countries for between USD 2 000 to USD 4 000 per month.[148] If an ISP for example, in Kenya or South Africa, purchased this capacity from the incumbent telecommunication carrier, they would have been charged in the vicinity of USD 20 000.[149] The prices paid by ISPs, in these two countries, had a built in mark-up of between five to ten times the best available African prices for international connectivity. The mark-up from the underlying cost is, of course, much greater.

If the ISPs in such cases were allowed to invest in their own facilities or to directly negotiate better wholesale connectivity rates, lower prices could be passed on to end users. This would, in turn, stimulate greater use of the Internet and greater volumes with which ISPs could negotiate even better rates.

Some observers mistakenly believe the high cost of links is the result of not imposing the traditional PSTN settlements model onto Internet traffic. In fact, of course, connectivity costs have always been high. Originally this was because of the high cost of provisioning international capacity but more recently due to monopoly providers not passing on the full benefits of reduced costs to users. The tremendous mark-up on international capacity in Kenya and South Africa is ample evidence of this fact. For those lamenting the demise of the traditional settlement model for international capacity, it should be remembered that this was an arrangement between two carriers, with monopolies at one or both end of the circuit, which were then free to extract monopoly rents. In those parts of Africa where monopoly power can still be exerted the mark-ups on international capacity are still very high.

The availability of capacity between countries is only as useful as the level of competition enables in terms of access to those facilities. The fibre optic SAFE cable provides transmission capacity between South Africa and Mauritius. At the end of 2004, a 1 Mbps connection to Europe cost an ISP in Mauritius USD 5 000 per month.[150] Global transit and the ability to peer with other ISPs in Europe were included in this price. To purchase the same amount of capacity between Mauritius and South Africa, at the same date, with no peering or transit included, cost USD 11 500 per month.[151] The result is that two geographical neighbours, with a state of the art fibre optic cable operating between them, exchange Internet traffic via North America and Europe.

A trace route between the two incumbent telecommunication carriers, in South Africa and Mauritius in June 2005, showed traffic traversing, among other places, Pretoria-Gauteng, New York, Paris and Saltzburg, before being delivered via satellite (with high latency for that hop). In other words not only did ISPs in both countries not exchange traffic directly but the incumbent telecommunication carriers which own the underlying capacity (and therefore have capacity available at cost) could obviously not agree to exchange traffic. This raises the question as to why this applies. One likely explanation is that there is simply no competitive pressure on either party to look for either higher performance or lower costs.

The same traffic exchange relationship, which is found between South Africa and Mauritius, appears to be the case for all countries on the West Coast of Africa connected to the SAT-3/WASC cable. Even though a state of the art fibre optic cable is available connecting Senegal, Cote d'Ivoire, Ghana, Benin, Nigeria, Cameroon, Gabon, Angola and South Africa, in all these countries for which trace routes were available, ISPs exchanged traffic via Europe or North America and in some cases both of these continents.

The route distance between Melkbosstrand (South Africa) and Douala (Cameroon) landing points on the SAT-3 cable is 4 886 kilometres with a latency of 24.4 ms.[152] In June 2005, a trace route between South Africa and Cameroon showed the traffic traversing North America and Europe (including a satellite hop) with a latency of more than 1 500 ms.

The lack of IXPs in some African countries is one barrier to regional traffic exchange. It is, however, not the only obstacle. By October 2005, IXPs existed in a 14 African countries.[153] Some of these countries were connected to the SAT-3/WASC cable, such as Ghana, Nigeria and South Africa. Private bilateral peering could be put into place relatively easily between incumbents, which own their own capacity on those routes, by them agreeing to exchange traffic even if monopoly pricing makes this prohibitive for independent ISPs.

A regional African IXP has been proposed.[154] The ownership arrangements surrounding the present SAT-3/WASC cable, however, may not readily facilitate attractive access to such an IXP even for those players owning a stake in the cable. If an operator does not own the capacity necessary to link to such an IXP they may face high charges such that they are better off exchanging traffic in Europe or North America. Consider, for example, the reason given by Botswana for investing in the EASSy undersea cable, along the East Coast of Africa, is to avoid "…paying exorbitant lease capacity fees in South Africa".[155] Instead of using state of the art cables, where available, AfrISPA is currently using satellite networks to provide some direct connectivity between African IXPs.[156]

While access to state-of-the art facilities like SAT-3/WASC cable or the proposed EASSy undersea cable has the potential to dramatically improve access to the Internet in Africa this will only be accomplished in a competitive market. Even then, experience in smaller OECD markets has shown it takes time for alternative infrastructure to be rolled out. In the case of Africa most existing capacity was provisioned at the time when monopolies applied. Even in the case of the EASSy cable its membership only includes 20 operators from 16 countries. This has led ISPs in countries such as Kenya, to suggest that even after the construction of EASSy they may not be able to access capacity at competitive prices.[157] They point to the failure of SAT-3 to lead to competitive pricing in South Africa. ISPs in Africa, such as Internet Ghana, also point to incumbents charging excessive prices for access to capacity, providing capacity to its own ISP at lower rates than competitors and acting anti-competitively in the delivery of capacity.[158]

The experience of SAT-3 is that a valuable resource for Africa's development, along the West Coast of the Continent, has been chronically underutilised.[159] For the main part this has been because of monopolies charging excessive prices. Access to such capacity at competitive prices, which still afforded an appropriate return to investors, would dramatically lower the cost of Internet connectivity to the rest of the world. It would give ISPs, and other communication providers in Africa access to competitive transit prices and allow revenues to be ploughed back into domestic development of Internet access.

There are positive signs that African governments are becoming increasingly aware of both the existing bottlenecks to Internet development and the opportunities and that new technologies can bring in a competitive market. In August 2005, the Communications Commission of Kenya (CCK) issued guidelines for the provision of VoIP.[160] Following the end of Telkom Kenya's monopoly some 39 licences in various categories have been issued including local loop, private data network, commercial VSAT, and Internet backbone and gateway operators. By encouraging the provision of VoIP, CCK aims to increase tele-density, particularly in rural areas, and reduce the cost of telephony services.[161] In South Africa the regulatory authority has called for lower prices for access to undersea cables and recognises that the current situation is a barrier to the development of Internet access.[162] What is additionally required, however, is vigorous competition in all parts of the market.

Not all of Africa's challenges in developing the use of the Internet can, of course, be attributed to the reticence of governments to liberalise. Capacity building in respect to networking capabilities is undoubtedly a key factor in developing greater Internet access and connectivity. Leading examples include the work of the AfriISPA, the African Network Operators Group and Packet Clearing House. That being said, liberalisation can bring the ability for new entrants to assist in expanding access including in those areas that did not previously have service.

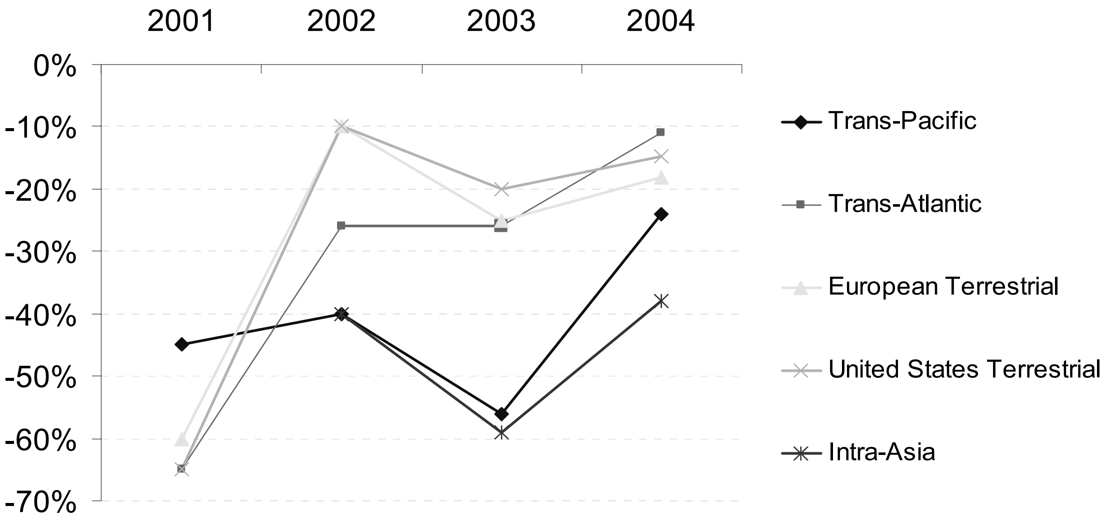
The adoption of new technology, including VoIP and new forms of powering network connections, has the potential to bring Internet access and telephony to areas where there was previously no PSTN access. One example is Inveneo's pedal and solar powered PC and communications system.[163] One hour of cycling can power the system for four hours of communication.[164] The first Inveneo system was deployed in Western Uganda, in rural villages with no power source, in June 2005.

> The stations provide computing and phone capabilities while operating with battery power charged from solar panels or bicycle generators. Wireless networking (WiFi / 802.11x) provides the communication between the various stations and the central hub. Voice over IP (VoIP) is used to transmit phone calls from the stations to the hub. The central hub provides the interface to the existing phone network (PSTN) and Internet. Through use of relay stations the reach of the wireless network can be extended to cover distances of up to approximately 60 km (37 miles) from central hub to the stations.[165]

In the second stage of the project It is planned to extend the first four connected villages, providing a service to 3 200 people, to 20. In terms of traffic exchange calls between the villages are free and charges levied when calls connect back into the PSTN over a satellite connection.[166] If call patterns in Uganda mirror those in other rural areas this is significant because the majority of outgoing calls are local.[167]

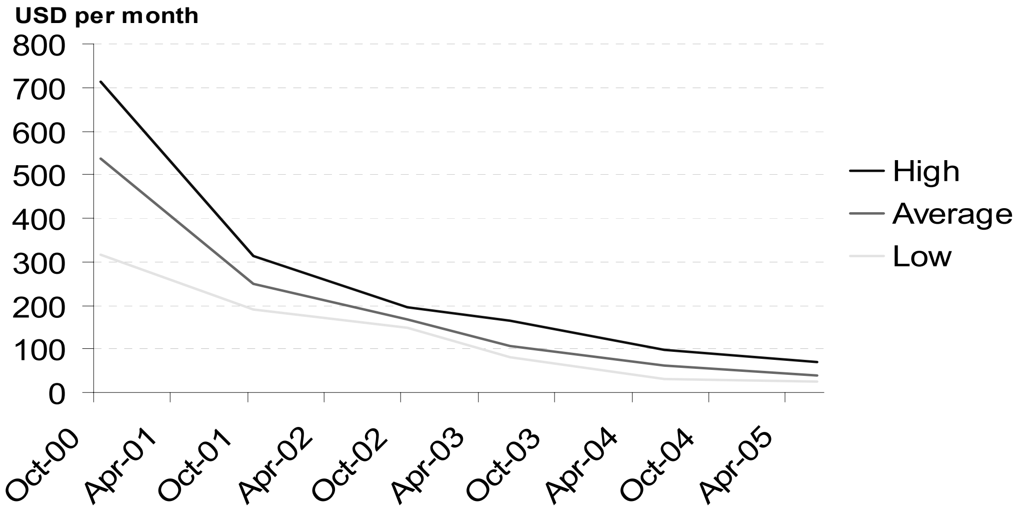
ANNEX FIGURES (1-5, 7-11)
(FIGURE 6, SEE PAGE 19)

Figure 1. OC-3/STM-1 Pricing trends, 2001-2004



Source: TeleGeography Research, © PriMetrica, Inc., 2005.

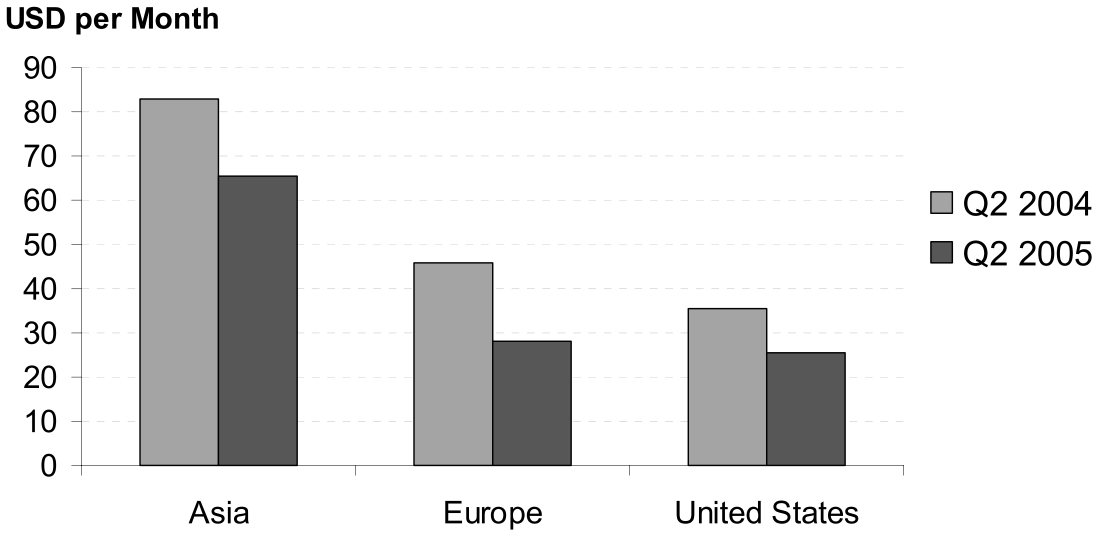
Figure 2. STM-1 IP transit prices in London



Note: Data prior to 2003 are based on the Band-X London IP Transit Exchange.

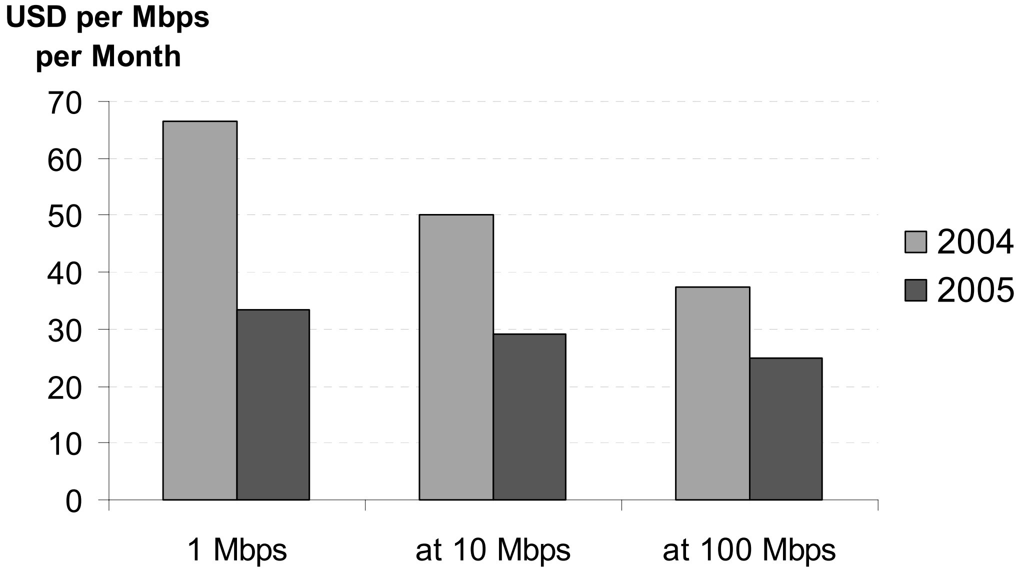
Source: TeleGeography Research, © PriMetrica, Inc., 2005.

Figure 3. Average GigE transit prices by region



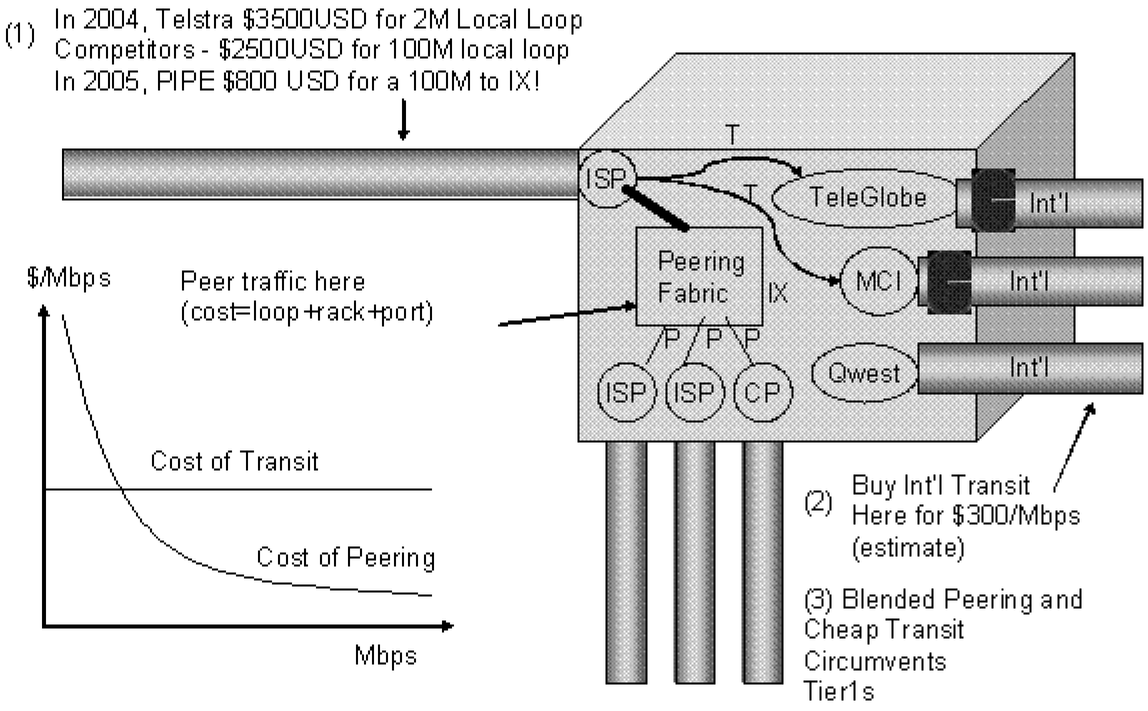
Source: TeleGeography Research, © PriMetrica, Inc., 2005.

Figure 4. Domestic transit prices in Australia



Source: William Norton, Equinix, Presentation at ATUG 2005.

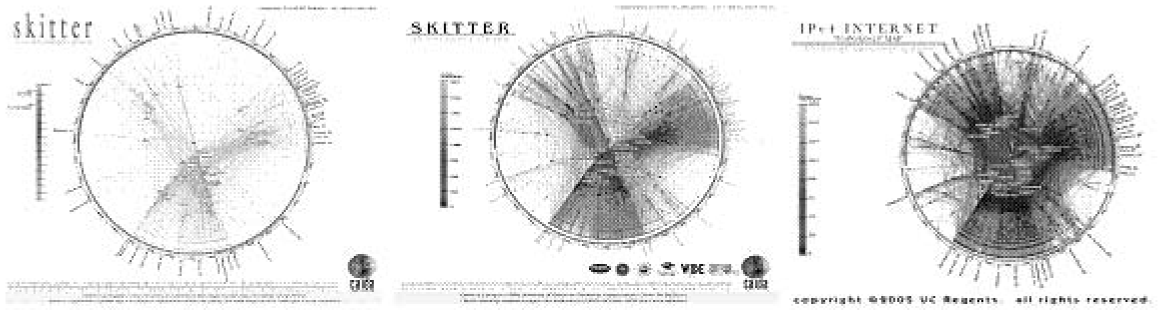
Figure 5. Competitive bypass and Internet traffic exchange in Australia



Source: William Norton, Equinix, Presentation at ATUG 2005.

For Figure 6, see page 19.

Figure 7. Autonomous system Internet graph January 2000 (Left), May 2003 (Middle) April 2005 (Right)



Source: CAIDA (www.caida.org/analysis/topology/as_core_network/historical.xml).

Figure 8. Number of IXPs in the world

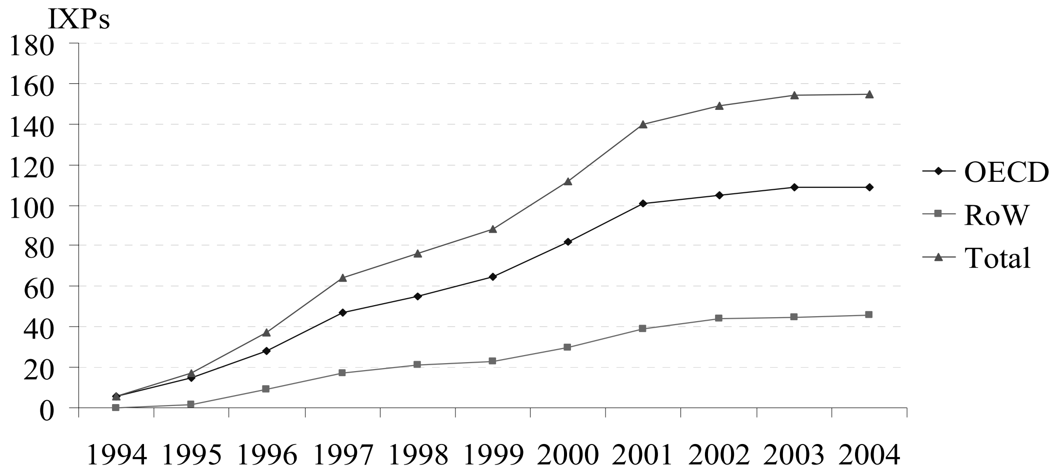
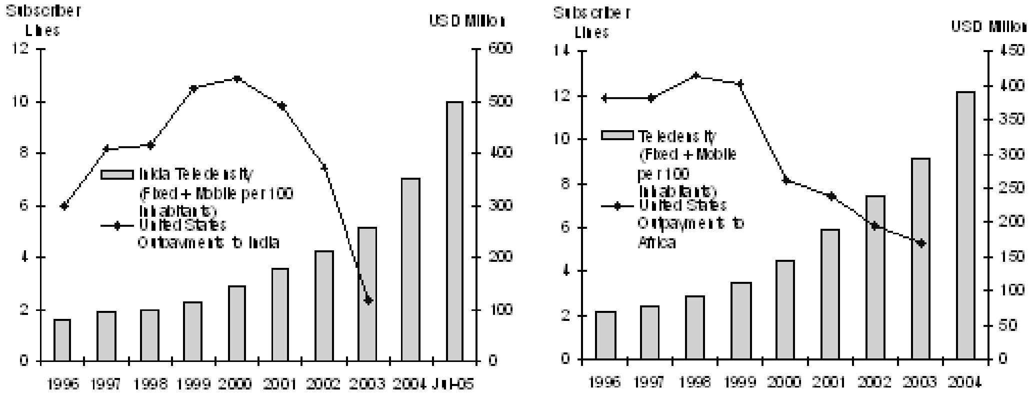
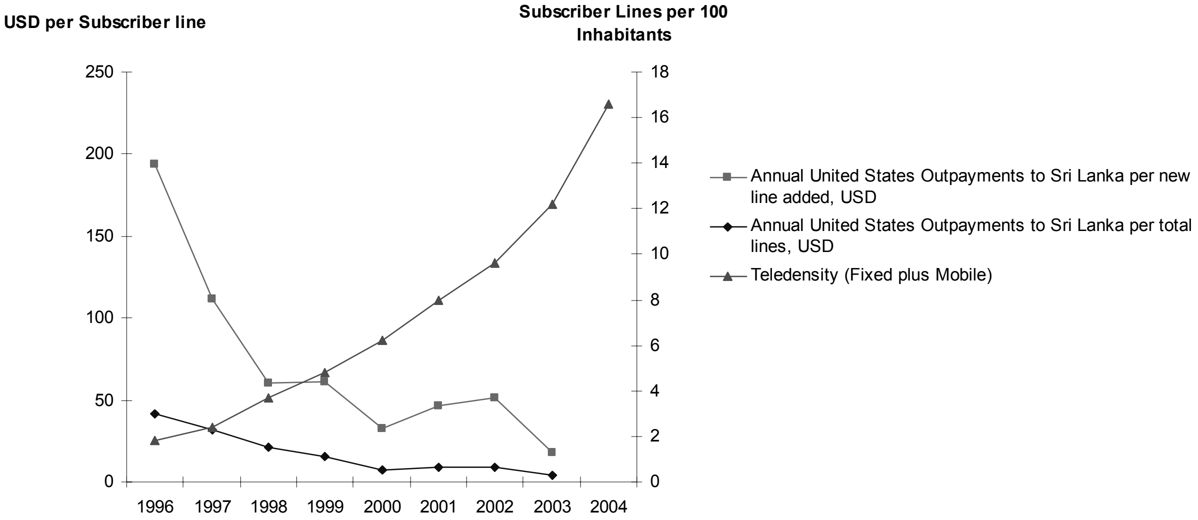


Figure 9. Access growth and decreasing PSTN settlements



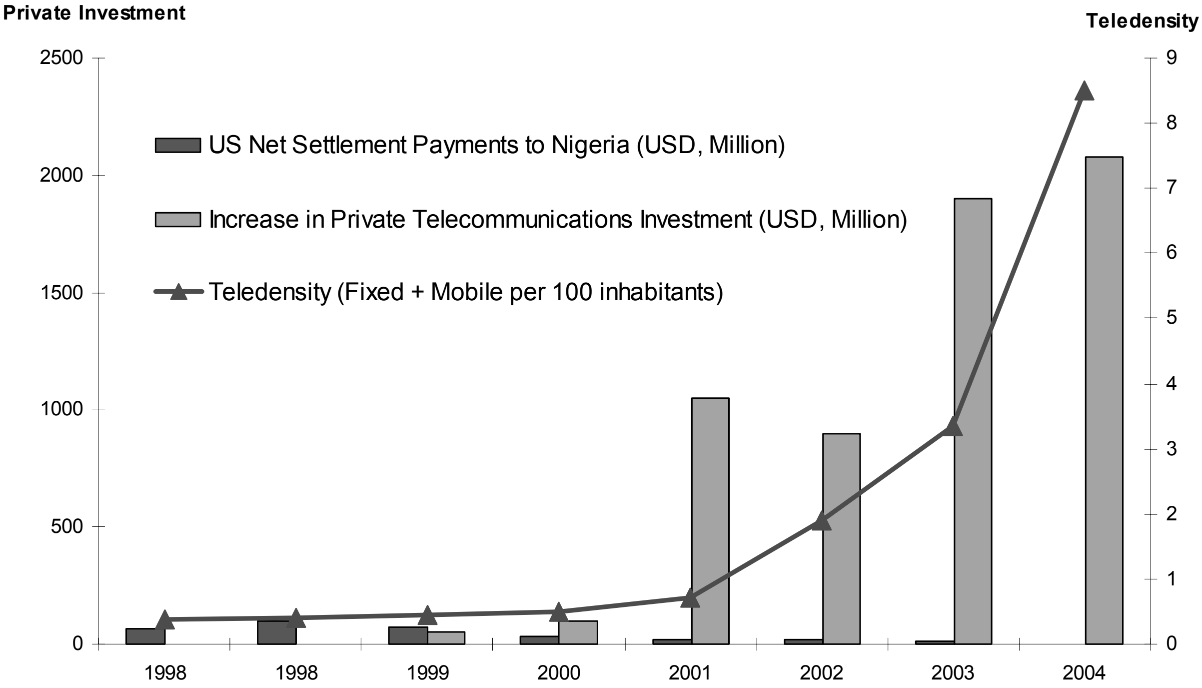
Source: OECD based on FCC, TRAI and ITU.

Figure 10. Sri Lankan telecommunication access development and settlement trends



Source: FCC and Telecommunications Regulatory Commission of Sri Lanka.

Figure 11. Nigerian telecommunication access development, investment and settlement trends



Source: FCC and Nigerian Communications Commission.

STATISTICAL ANNEX 2

Annex Table 1. Routed Autonomous Systems by country

	Nov-97	Nov-98	Nov-99	Nov-00	Nov-01	Nov-02	Nov-03	Nov-04	May-05	CAGR (Nov. 1997 - May 2005)
Australia	44	99	149	187	249	287	318	362	376	33.1
Austria	16	27	35	59	79	101	121	152	168	36.8
Belgium	7	9	15	23	30	31	48	58	62	33.8
Canada	92	103	136	192	257	313	370	438	457	23.8
Czech Republic	5	7	10	19	28	41	60	67	74	43.2
Denmark	6	6	13	28	36	37	48	60	63	36.8
Finland	8	10	16	22	31	40	50	61	65	32.2
France	26	46	82	111	160	178	205	219	236	34.2
Germany	44	90	179	304	433	491	558	647	703	44.7
Greece	11	23	32	50	56	62	64	71	74	28.9
Hungary	22	25	35	41	57	64	76	83	91	20.8
Iceland	2	2	1	4	5	7	9	14	14	29.6
Ireland	2	3	9	12	11	12	20	28	35	46.5
Italy	20	38	74	129	213	242	267	292	305	43.8
Japan	97	125	147	180	234	322	392	422	444	22.5
Korea	37	56	111	255	338	325	413	442	446	39.4
Luxembourg	1	3	5	6	7	9	11	11	11	37.7
Mexico	35	40	50	69	84	89	102	108	116	17.3
Netherlands	16	22	39	68	108	134	169	210	228	42.5
New Zealand	4	9	24	33	41	51	53	72	74	47.6
Norway	4	5	7	21	29	31	40	47	48	39.3
Poland	5	12	27	70	126	164	202	293	344	75.8
Portugal	3	6	14	24	24	24	26	32	35	38.8
Slovak Republic	8	11	12	15	22	26	31	34	40	23.9
Spain	7	8	27	56	100	120	143	165	170	53.0
Sweden	14	19	30	44	65	84	109	133	147	36.8
Switzerland	18	29	45	74	110	125	143	172	187	36.6
Turkey	6	22	27	49	73	86	98	118	130	50.7
United Kingdom	66	94	148	217	306	385	503	615	668	36.2
United States	1608	2204	3184	4683	6146	7150	8013	8939	9340	26.4
OECD	2232	3151	4682	7041	9453	11024	12653	14351	15137	29.1
Rest of World	725	1021	1335	1934	2518	3007	3434	4022	4409	27.2
Total	2957	4172	6017	8975	11971	14031	16087	18373	19546	28.6

Source : Tom Vest (Packet Clearing House www.pch.net) from raw data generated by the University of Oregon Route Views Project.

Annex Table 2. Routed Autonomous Systems as per cent of total

	Nov-97	Nov-98	Nov-99	Nov-00	Nov-01	Nov-02	Nov-03	Nov-04	May-05
United States	54.38	52.83	52.92	52.18	51.34	50.96	49.81	48.65	47.78
Germany	1.49	2.16	2.97	3.39	3.62	3.50	3.47	3.52	3.60
United Kingdom	2.23	2.25	2.46	2.42	2.56	2.74	3.13	3.35	3.42
Canada	3.11	2.47	2.26	2.14	2.15	2.23	2.30	2.38	2.34
Korea	1.25	1.34	1.84	2.84	2.82	2.32	2.57	2.41	2.28
Japan	3.28	3.00	2.44	2.01	1.95	2.29	2.44	2.30	2.27
Australia	1.49	2.37	2.48	2.08	2.08	2.05	1.98	1.97	1.92
Poland	0.17	0.29	0.45	0.78	1.05	1.17	1.26	1.59	1.76
Italy	0.68	0.91	1.23	1.44	1.78	1.72	1.66	1.59	1.56
France	0.88	1.10	1.36	1.24	1.34	1.27	1.27	1.19	1.21
Netherlands	0.54	0.53	0.65	0.76	0.90	0.96	1.05	1.14	1.17
Switzerland	0.61	0.70	0.75	0.82	0.92	0.89	0.89	0.94	0.96
Spain	0.24	0.19	0.45	0.62	0.84	0.86	0.89	0.90	0.87
Austria	0.54	0.65	0.58	0.66	0.66	0.72	0.75	0.83	0.86
Sweden	0.47	0.46	0.50	0.49	0.54	0.60	0.68	0.72	0.75
Turkey	0.20	0.53	0.45	0.55	0.61	0.61	0.61	0.64	0.67
Mexico	1.18	0.96	0.83	0.77	0.70	0.63	0.63	0.59	0.59
Hungary	0.74	0.60	0.58	0.46	0.48	0.46	0.47	0.45	0.47
Czech Republic	0.17	0.17	0.17	0.21	0.23	0.29	0.37	0.36	0.38
Greece	0.37	0.55	0.53	0.56	0.47	0.44	0.40	0.39	0.38
New Zealand	0.14	0.22	0.40	0.37	0.34	0.36	0.33	0.39	0.38
Finland	0.27	0.24	0.27	0.25	0.26	0.29	0.31	0.33	0.33
Denmark	0.20	0.14	0.22	0.31	0.30	0.26	0.30	0.33	0.32
Belgium	0.24	0.22	0.25	0.26	0.25	0.22	0.30	0.32	0.32
Norway	0.14	0.12	0.12	0.23	0.24	0.22	0.25	0.26	0.25
Slovak Republic	0.27	0.26	0.20	0.17	0.18	0.19	0.19	0.19	0.20
Ireland	0.07	0.07	0.15	0.13	0.09	0.09	0.12	0.15	0.18
Portugal	0.10	0.14	0.23	0.27	0.20	0.17	0.16	0.17	0.18
Iceland	0.07	0.05	0.02	0.04	0.04	0.05	0.06	0.08	0.07
Luxembourg	0.03	0.07	0.08	0.07	0.06	0.06	0.07	0.06	0.06
OECD	75.48	75.53	77.81	78.45	78.97	78.57	78.65	78.11	77.44
Rest of World	24.52	24.47	22.19	21.55	21.03	21.43	21.35	21.89	22.56

Source : Tom Vest (Packet Clearing House www.pch.net) from raw data generated by the University of Oregon Route Views project.

Annex Table 3. Routed Autonomous Systems per 100 000 inhabitants

	Nov-97	Nov-98	Nov-99	Nov-00	Nov-01	Nov-02	Nov-03	Nov-04	May-05
Iceland	0.7	0.7	0.4	1.4	1.8	2.4	3.1	4.8	4.8
United States	0.6	0.8	1.1	1.7	2.2	2.5	2.8	3.1	3.2
Switzerland	0.3	0.4	0.6	1.0	1.5	1.7	1.9	2.3	2.5
Luxembourg	0.2	0.7	1.2	1.4	1.6	2.0	2.4	2.4	2.4
Austria	0.2	0.3	0.4	0.7	1.0	1.3	1.5	1.9	2.1
Australia	0.2	0.5	0.8	1.0	1.3	1.5	1.6	1.8	1.9
New Zealand	0.1	0.2	0.6	0.9	1.0	1.3	1.3	1.8	1.8
Sweden	0.2	0.2	0.3	0.5	0.7	0.9	1.2	1.5	1.6
Canada	0.3	0.3	0.4	0.6	0.8	1.0	1.2	1.4	1.4
Netherlands	0.1	0.1	0.2	0.4	0.7	0.8	1.0	1.3	1.4
Finland	0.2	0.2	0.3	0.4	0.6	0.8	1.0	1.2	1.2
Denmark	0.1	0.1	0.2	0.5	0.7	0.7	0.9	1.1	1.2
United Kingdom	0.1	0.2	0.3	0.4	0.5	0.7	0.8	1.0	1.1
Norway	0.1	0.1	0.2	0.5	0.6	0.7	0.9	1.0	1.1
Korea	0.1	0.1	0.2	0.5	0.7	0.7	0.9	0.9	0.9
Poland	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.8	0.9
Hungary	0.2	0.2	0.3	0.4	0.6	0.6	0.8	0.8	0.9
Ireland	0.1	0.1	0.2	0.3	0.3	0.3	0.5	0.7	0.9
Germany	0.1	0.1	0.2	0.4	0.5	0.6	0.7	0.8	0.9
Slovak Republic	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.6	0.7
Czech Republic	0.0	0.1	0.1	0.2	0.3	0.4	0.6	0.7	0.7
Greece	0.1	0.2	0.3	0.5	0.5	0.6	0.6	0.6	0.7
Belgium	0.1	0.1	0.1	0.2	0.3	0.3	0.5	0.6	0.6
Italy	0.0	0.1	0.1	0.2	0.4	0.4	0.5	0.5	0.5
Spain	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.4	0.4
France	0.0	0.1	0.1	0.2	0.3	0.3	0.3	0.4	0.4
Japan	0.1	0.1	0.1	0.1	0.2	0.3	0.3	0.3	0.3
Portugal	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3
Turkey	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2
Mexico	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
OECD	0.2	0.3	0.4	0.6	0.8	1.0	1.1	1.2	1.3
RoW	0.02	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.08

Source : Tom Vest (Packet Clearing House www.pch.net) from raw data generated by the University of Oregon Route Views project.

Annex Table 4. Routed IPv4 addresses by country

	Nov-97	Nov-98	Nov-99	Nov-00	Nov-01	Nov-02	Nov-03	Nov-04	May-05
Australia	18 370 669	19 805 696	19 768 442	36 923 168	51 569 799	34 388 640	35 218 848	37 183 474	37 821 212
Austria	438 784	619 520	952 320	2 133 761	3 365 520	3 962 624	4 257 536	5 315 584	6 704 704
Belgium	274 688	306 944	164 864	419 840	625 664	866 560	1 155 840	1 403 936	1 942 464
Canada	42 962 370	26 787 970	28 816 228	32 330 112	32 918 700	34 264 860	34 873 922	36 978 480	37 185 104
Czech Republic	223 488	247 808	305 920	427 776	528 896	606 976	898 816	1 443 168	1 835 008
Denmark	809 216	924 416	1 125 377	1 367 424	1 745 600	1 990 272	1 810 688	2 146 816	2 364 928
Finland	4 110 336	4 485 888	4758 704	5 337 000	5 510 132	5 425 757	6 207 808	6 711 040	7 084 160
France	661 504	1 218 760	1 587 058	2 047 136	3 434 624	4 433 332	5 958 086	9 439 360	11 493 312
Germany	20 887 810	21 848 064	24 458 340	29 495 304	35 669 591	37 256 744	38 763 380	42 228 275	46 141 104
Greece	28 6976	523 008	546 304	796 160	982 784	1 103 104	1 042 432	1 252 608	1 158 144
Hungary	243 456	316 960	395 530	506 112	733 312	854 656	997 376	1 494 784	1 268 224
Iceland	6 144	16 896	82 944	185 600	341 248	386 304	412 160	510 464	559 360
Ireland	98 560	115 200	143 424	240 352	181 760	245 760	352 256	670 752	1 282 048
Italy	574 464	653 314	1 340 161	2563 840	3 900 992	4 737 280	5 095 936	5 987 840	5 771 520
Japan	31 566 986	32 132 368	33 708 692	36 152 688	47 150 765	58 249 075	65 652 003	93 658 320	84 002 608
Korea	6 865 664	7 821 824	10 335 684	18 060 064	23143924	26 664 161	33 066 605	36 911 766	38 033 214
Luxembourg	73 728	33 024	48 640	50 944	76 800	82 176	126 208	163 328	164 608
Mexico	3 796 736	4136 448	4728 960	5 186 548	5 556 224	5 816 192	6 295 144	6 825 176	7 688 100
Netherlands	929 824	771 072	1 411 352	3 243 825	5 666 664	6 716 832	8 684 320	11 755 904	11 034 880
New Zealand	2 798 096	2 578 432	2 690 262	2 841 600	2 992 793	3 152 293	3 281 152	3 505 152	3 547 904
Norway	3 129 088	3 211 008	1 106 944	1 422 848	1 424 896	1 697 536	2 204 160	2 766 080	2 932 736
Poland	500 224	1 524 736	1 799 936	2 363 136	2 933 760	3 555 584	4 032 000	6 742 384	7 026 176
Portugal	81 408	99 076	229 888	440 320	571 008	704 288	653 824	962 816	1 173 504
Slovak Republic	148 992	187 392	219 648	363 520	416 096	441 856	390 928	446 976	496 992
Spain	139 776	156 160	547 072	1 297 768	2 371 073	2 612 416	3 328 640	6 010 304	8 011 200
Sweden	527 616	702 784	777 984	1 319 064	2 237 417	3 175 680	3 563 788	5 132 576	6 012 655
Switzerland	2 452 480	2 520 320	3 065 344	4213 760	4 978 464	5 698 848	5 792 768	7 456 512	7 738 496
Turkey	560 896	17 874 432	1 246 208	1 503 232	1 596 928	1 809 920	2 284 288	2 552 064	3 315 200
United Kingdom	2 631 684	20 624 788	21 919 024	23 234 859	8 081 928	9 875 440	14 107 904	15 919 176	16 516 544
United States	729 648 985	710 724 831	713 653 964	787 552 495	835 721 606	802 161 037	862 812 515	917 859 405	905 630 405
OECD	875 794 504	88 2952 243	881 852 274	1 003 834 656	1 086 087 720	1 062 549 899	1 152 909 171	1 270 924 056	12 653 77 154
Rest of World	171 527 910	189 781 627	186 329 254	221 763 579	260 873 237	254 781 656	267 386 524	337 260 015	356 681 489
Total	1 047 322 414	1 072 733 870	1 068 181 528	1 225 598 235	1 346 960 957	1 317 331 555	1 420 295 695	1 608 184 071	1 622 058 643

Source : Tom Vest (Packet Clearing House www.pch.net) from raw data generated by the University of Oregon Route Views project.

Annex Table 5. Routed IPv4 addresses by country as percent of total

	Nov-97	Nov-98	Nov-99	Nov-00	Nov-01	Nov-02	Nov-03	Nov-04	May-05
United States	69.67	66.25	66.81	64.26	62.04	60.89	60.75	57.07	55.83
Japan	3.01	3.00	3.16	2.95	3.50	4.42	4.62	5.82	5.18
Germany	1.99	2.04	2.29	2.41	2.65	2.83	2.73	2.63	2.84
Korea	0.66	0.73	0.97	1.47	1.72	2.02	2.33	2.30	2.34
Australia	1.75	1.85	1.85	3.01	3.83	2.61	2.48	2.31	2.33
Canada	4.10	2.50	2.70	2.64	2.44	2.60	2.46	2.30	2.29
United Kingdom	0.25	1.92	2.05	1.90	0.60	0.75	0.99	0.99	1.02
France	0.06	0.11	0.15	0.17	0.25	0.34	0.42	0.59	0.71
Netherlands	0.09	0.07	0.13	0.26	0.42	0.51	0.61	0.73	0.68
Spain	0.01	0.01	0.05	0.11	0.18	0.20	0.23	0.37	0.49
Switzerland	0.23	0.23	0.29	0.34	0.37	0.43	0.41	0.46	0.48
Mexico	0.36	0.39	0.44	0.42	0.41	0.44	0.44	0.42	0.47
Finland	0.39	0.42	0.45	0.44	0.41	0.41	0.44	0.42	0.44
Poland	0.05	0.14	0.17	0.19	0.22	0.27	0.28	0.42	0.43
Austria	0.04	0.06	0.09	0.17	0.25	0.30	0.30	0.33	0.41
Sweden	0.05	0.07	0.07	0.11	0.17	0.24	0.25	0.32	0.37
Italy	0.05	0.06	0.13	0.21	0.29	0.36	0.36	0.37	0.36
New Zealand	0.27	0.24	0.25	0.23	0.22	0.24	0.23	0.22	0.22
Turkey	0.05	1.67	0.12	0.12	0.12	0.14	0.16	0.16	0.20
Norway	0.30	0.30	0.10	0.12	0.11	0.13	0.16	0.17	0.18
Denmark	0.08	0.09	0.11	0.11	0.13	0.15	0.13	0.13	0.15
Belgium	0.03	0.03	0.02	0.03	0.05	0.07	0.08	0.09	0.12
Czech Republic	0.02	0.02	0.03	0.03	0.04	0.05	0.06	0.09	0.11
Ireland	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.04	0.08
Hungary	0.02	0.03	0.04	0.04	0.05	0.06	0.07	0.09	0.08
Portugal	0.01	0.01	0.02	0.04	0.04	0.05	0.05	0.06	0.07
Greece	0.03	0.05	0.05	0.06	0.07	0.08	0.07	0.08	0.07
Iceland	0.00	0.00	0.01	0.02	0.03	0.03	0.03	0.03	0.03
Slovak Republic	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03
Luxembourg	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
OECD	83.62	82.31	82.56	81.91	80.63	80.66	81.17	79.03	78.01
RoW	16.38	17.69	17.44	18.09	19.37	19.34	18.83	20.97	21.99

Source : Tom Vest (Packet Clearing House www.pch.net) from raw data generated by the University of Oregon Route Views project.

Annex Table 6. Routed IPv4 addresses per 100 inhabitants

	Nov-97	Nov-98	Nov-99	Nov-00	Nov-01	Nov-02	Nov-03	Nov-04	May-05
United States	267	257	255	279	293	278	296	315	311
Iceland	2	6	30	66	120	134	142	176	193
Australia	99	105	104	192	264	174	176	186	189
Finland	80	87	92	103	106	104	119	129	136
Canada	144	89	95	105	106	109	110	117	118
Switzerland	34	35	43	58	68	78	78	101	105
New Zealand	74	67	70	73	77	79	81	87	88
Austria	6	8	12	27	42	49	53	66	83
Korea	15	17	22	38	49	56	69	77	79
Netherlands	6	5	9	20	35	42	54	72	68
Sweden	6	8	9	15	25	36	40	57	67
Japan	25	25	27	28	37	46	51	73	66
Norway	71	72	25	32	32	37	48	61	64
Germany	25	27	30	36	43	45	47	51	56
Denmark	15	17	21	26	33	37	34	40	44
Luxembourg	18	8	11	12	17	18	28	36	37
Ireland	3	3	4	6	5	6	9	17	32
United Kingdom	5	35	37	40	14	17	24	27	28
Spain	0	0	1	3	6	6	8	15	20
Belgium	3	3	2	4	6	8	11	14	19
France	1	2	3	3	6	7	10	15	19
Poland	1	4	5	6	8	9	11	18	18
Czech Republic	2	2	3	4	5	6	9	14	18
Hungary	2	3	4	5	7	8	10	15	13
Portugal	1	1	2	4	6	7	6	9	11
Greece	3	5	5	7	9	10	9	11	11
Italy	1	1	2	4	7	8	9	10	10
Slovak Republic	3	3	4	7	8	8	7	8	9
Mexico	4	4	5	5	6	6	6	7	7
Turkey	1	28	2	2	2	3	3	4	5
OECD	79	79	79	89	95	93	100	110	110
Rest of World	4	4	4	4	5	5	5	7	7
World	18	18	18	20	22	21	23	25	25

Source : Tom Vest (Packet Clearing House www.pch.net) from raw data generated by the University of Oregon Route Views project.

Anne Table 7. Average routed IPv4 addresses per routed autonomous system

	Nov-97	Nov-98	Nov-99	Nov-00	Nov-01	Nov-02	Nov-03	Nov-04	May-05
Australia	417 515	200 058	132 674	197 450	207 108	119 821	110 751	102 717	100 588
Austria	27 424	22 945	27 209	36 165	42 602	39 234	35 186	34 971	39 909
Belgium	39 241	34 105	10 991	18 254	20 855	27 954	24 080	24 206	31 330
Canada	466 982	260 077	211 884	168 386	128 088	109 472	94 254	84 426	81 368
Czech Republic	44 698	35 401	30 592	22 515	18 889	14 804	14 980	21 540	24 797
Denmark	134 869	154 069	86 567	48 837	48 489	53 791	37 723	35 780	37 539
Finland	513 792	448 589	297 419	242 591	177 746	135 644	124 156	110 017	108 987
France	25 442	26 495	19 354	18 443	21 466	24 906	29 064	43 102	48 700
Germany	474 723	242 756	136 639	97 024	82 378	75 879	69 468	65 268	65 635
Greece	26 089	22 739	17 072	15 923	17 550	17 792	16 288	17 642	15 651
Hungary	11 066	12 678	11 301	12 344	12 865	13 354	13 123	18 009	13 937
Iceland	3 072	8 448	82 944	46 400	68 250	55 186	45 796	36 462	39 954
Ireland	49 280	38 400	15 936	20 029	16 524	20 480	17 613	23 955	36 630
Italy	28 723	17 192	18 110	19 875	18 315	19 576	19 086	20 506	18 923
Japan	325 433	257 059	229 311	200 848	201 499	180 898	167 480	221 939	189 195
Korea	185 558	139 675	93 114	70 824	68 473	82 044	80 064	83 511	85 276
Luxembourg	73 728	11 008	9 728	8 491	10 971	9 131	11 473	14 848	14 964
Mexico	108 478	103 411	94 579	75 167	66 146	65 350	61 717	63 196	66 277
Netherlands	58 114	35 049	36 189	47 703	52 469	50 126	51 387	55 980	48 399
New Zealand	699 524	286 492	112 094	86 109	72 995	61 810	61 909	48 683	47 945
Norway	782 272	642 202	158 135	67 755	49 134	54 759	55 104	58 853	61 099
Poland	100 045	127 061	66 664	33 759	23 284	21 680	19 960	23 012	20 425
Portugal	27 136	16 513	16 421	18 347	23 792	29 345	25 147	30 088	33 529
Slovak Republic	18 624	17 036	18 304	24 235	18 913	16 994	12 611	13 146	12 425
Spain	19 968	19 520	20 262	23 174	23 711	21 770	23 277	36 426	47 125
Sweden	37 687	36 989	25 933	29 979	34 422	37 806	32 695	38 591	40 902
Switzerland	136 249	86 908	68 119	56 943	45 259	45 591	40 509	43 352	41 382
Turkey	93 483	812 474	46 156	30 678	21 876	21 046	23 309	21 628	25 502
United Kingdom	39 874	219 413	148 102	107 073	26 412	25 650	28 048	25 885	24 725
United States	453 762	322 470	224 138	168 173	135 978	112 190	107 677	102 680	96 963
OECD	392 381	280 213	188 349	142 570	114 893	96 385	91 117	88 560	83 595
Rest of World	236 590	185 878	139 572	114 666	103 603	84 730	77 864	83 854	80 899
Total	354 184	257 127	177 527	136 557	112 519	93 887	88 288	87 530	82 987

Source : Tom Vest (Packet Clearing House www.pch.net) from raw data generated by the University of Oregon Route Views project.

Annex Table 8. Index of average routed IP addresses per autonomous system

	Nov-97	Nov-98	Nov-99	Nov-00	Nov-01	Nov-02	Nov-03	Nov-04	May-05
Australia	100	48	32	47	50	29	27	25	24
Austria	100	84	99	132	155	143	128	128	146
Belgium	100	87	28	47	53	71	61	62	80
Canada	100	56	45	36	27	23	20	18	17
Czech Republic	100	79	68	50	42	33	34	48	55
Denmark	100	114	64	36	36	40	28	27	28
Finland	100	87	58	47	35	26	24	21	21
France	100	104	76	72	84	98	114	169	191
Germany	100	51	29	20	17	16	15	14	14
Greece	100	87	65	61	67	68	62	68	60
Hungary	100	115	102	112	116	121	119	163	126
Iceland	100	275	2 700	1 510	2 222	1 796	1 491	1 187	1 301
Ireland	100	78	32	41	34	42	36	49	74
Italy	100	60	63	69	64	68	66	71	66
Japan	100	79	70	62	62	56	51	68	58
Korea	100	75	50	38	37	44	43	45	46
Luxembourg	100	15	13	12	15	12	16	20	20
Mexico	100	95	87	69	61	60	57	58	61
Netherlands	100	60	62	82	90	86	88	96	83
New Zealand	100	41	16	12	10	9	9	7	7
Norway	100	82	20	9	6	7	7	8	8
Poland	100	127	67	34	23	22	20	23	20
Portugal	100	61	61	68	88	108	93	111	124
Slovak Republic	100	91	98	130	102	91	68	71	67
Spain	100	98	101	116	119	109	117	182	236
Sweden	100	98	69	80	91	100	87	102	109
Switzerland	100	64	50	42	33	33	30	32	30
Turkey	100	869	49	33	23	23	25	23	27
United Kingdom	100	550	371	269	66	64	70	65	62
United States	100	71	49	37	30	25	24	23	21
OECD	100	71	48	36	29	25	23	23	21
Rest of World	100	79	59	48	44	36	33	35	34
Total	100	73	50	39	32	27	25	25	23

Source : Tom Vest (Packet Clearing House www.pch.net) from raw data generated by the University of Oregon Route Views project.

Annex Table 9. Synthetic prefixes by country

	Nov-97	Nov-98	Nov-99	Nov-00	Nov-01	Nov-02	Nov-03	Nov-04	May-05
Australia	2 458	3 205	4 050	4 368	5 450	5 090	5 573	6 391	6 807
Austria	64	88	107	206	316	386	432	507	554
Belgium	14	23	22	41	79	97	166	226	276
Canada	4 581	4 604	4 242	5 683	5 025	6 197	9 679	6 066	6 278
Czech Republic	9	12	23	42	62	92	114	197	193
Denmark	52	57	60	74	99	94	127	159	185
Finland	1 071	823	530	555	625	631	653	685	637
France	221	380	437	598	587	676	970	1 421	1 575
Germany	467	629	950	1 475	2 070	2 072	2 526	2 906	2 861
Greece	27	79	79	108	142	156	144	202	240
Hungary	65	61	104	136	160	190	218	288	319
Iceland	23	3	4	11	16	18	23	28	29
Ireland	6	9	21	49	19	30	55	94	117
Italy	66	87	135	261	409	527	676	645	739
Japan	1 830	1 634	1 751	2 108	2 586	2 679	2 853	3 110	3 288
Korea	431	494	767	1 650	1 912	2 142	3 151	4 103	4 464
Luxembourg	2	5	10	15	16	22	44	47	49
Mexico	513	571	723	1 072	1 157	1 095	1 118	1 199	1 333
Netherlands	91	81	160	244	278	410	698	788	855
New Zealand	427	469	695	783	910	893	683	681	695
Norway	52	54	16	42	58	76	95	106	111
Poland	13	126	107	185	264	318	404	689	799
Portugal	18	25	24	46	51	50	54	75	96
Slovak Republic	10	20	26	53	59	59	79	85	92
Spain	10	11	45	189	235	346	433	642	741
Sweden	85	132	190	209	286	363	500	566	657
Switzerland	229	257	313	431	462	519	594	697	729
Turkey	240	276	75	142	176	216	346	526	599
United Kingdom	347	496	686	1 082	1 276	1 606	2 148	2 430	2 460
United States	34 556	30 302	37 270	53 807	60 670	65 913	78 658	85 672	88 014
OECD	47 955	45 010	53 618	75 654	85 439	92 945	113 191	121 203	125 763
Rest of World	9 561	10 244	12 958	18 718	22 823	24 738	29 407	36 221	40 679

Source : Tom Vest (Packet Clearing House www.pch.net) from raw data generated by the University of Oregon Route Views project.

Annex Table 10. Synthetic prefixes by country as percent of total

	Nov-97	Nov-98	Nov-99	Nov-00	Nov-01	Nov-02	Nov-03	Nov-04	May-05
United States	60.08	54.84	55.98	57.02	56.04	56.01	55.16	54.42	52.88
Australia	4.27	5.80	6.08	4.63	5.03	4.33	3.91	4.06	4.09
Canada	7.96	8.33	6.37	6.02	4.64	5.27	6.79	3.85	3.77
Korea	0.75	0.89	1.15	1.75	1.77	1.82	2.21	2.61	2.68
Japan	3.18	2.96	2.63	2.23	2.39	2.28	2.00	1.98	1.98
Germany	0.81	1.14	1.43	1.56	1.91	1.76	1.77	1.85	1.72
United Kingdom	0.60	0.90	1.03	1.15	1.18	1.36	1.51	1.54	1.48
France	0.38	0.69	0.66	0.63	0.54	0.57	0.68	0.90	0.95
Mexico	0.89	1.03	1.09	1.14	1.07	0.93	0.78	0.76	0.80
Netherlands	0.16	0.15	0.24	0.26	0.26	0.35	0.49	0.50	0.51
Poland	0.02	0.23	0.16	0.20	0.24	0.27	0.28	0.44	0.48
Spain	0.02	0.02	0.07	0.20	0.22	0.29	0.30	0.41	0.45
Italy	0.11	0.16	0.20	0.28	0.38	0.45	0.47	0.41	0.44
Switzerland	0.40	0.47	0.47	0.46	0.43	0.44	0.42	0.44	0.44
New Zealand	0.74	0.85	1.04	0.83	0.84	0.76	0.48	0.43	0.42
Sweden	0.15	0.24	0.29	0.22	0.26	0.31	0.35	0.36	0.39
Finland	1.86	1.49	0.80	0.59	0.58	0.54	0.46	0.44	0.38
Turkey	0.42	0.50	0.11	0.15	0.16	0.18	0.24	0.33	0.36
Austria	0.11	0.16	0.16	0.22	0.29	0.33	0.30	0.32	0.33
Hungary	0.11	0.11	0.16	0.14	0.15	0.16	0.15	0.18	0.19
Belgium	0.02	0.04	0.03	0.04	0.07	0.08	0.12	0.14	0.17
Greece	0.05	0.14	0.12	0.11	0.13	0.13	0.10	0.13	0.14
Czech Republic	0.02	0.02	0.03	0.04	0.06	0.08	0.08	0.13	0.12
Denmark	0.09	0.10	0.09	0.08	0.09	0.08	0.09	0.10	0.11
Ireland	0.01	0.02	0.03	0.05	0.02	0.03	0.04	0.06	0.07
Norway	0.09	0.10	0.02	0.04	0.05	0.06	0.07	0.07	0.07
Portugal	0.03	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.06
Slovak Republic	0.02	0.04	0.04	0.06	0.05	0.05	0.06	0.05	0.06
Luxembourg	0.00	0.01	0.02	0.02	0.01	0.02	0.03	0.03	0.03
Iceland	0.04	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
OECD	83.38	81.46	80.54	80.17	78.92	78.98	79.38	76.99	75.56
Rest of World	16.62	18.54	19.46	19.83	21.08	21.02	20.62	23.01	24.44

Source : Tom Vest (Packet Clearing House www.pch.net) from raw data generated by the University of Oregon Route Views project.

Annex Table 11. Synthetic prefixes by country per 100 000 inhabitants

	Nov-97	Nov-98	Nov-99	Nov-00	Nov-01	Nov-02	Nov-03	Nov-04	May-05
Australia	13.2	17.0	21.3	22.7	27.9	25.8	27.9	32.0	34.0
United States	12.7	11.0	13.3	19.1	21.3	22.9	27.0	29.4	30.2
Canada	15.3	15.3	14.0	18.5	16.2	19.8	30.6	19.2	19.8
New Zealand	11.2	12.2	18.0	20.2	23.3	22.5	16.9	16.9	17.2
Finland	20.8	16.0	10.3	10.7	12.0	12.1	12.5	13.1	12.2
Luxembourg	0.5	1.2	2.3	3.4	3.6	4.9	9.8	10.4	10.9
Iceland	8.5	1.1	1.4	3.9	5.6	6.3	7.9	9.6	10.0
Switzerland	3.2	3.6	4.4	6.0	6.3	7.1	8.0	9.4	9.8
Korea	0.9	1.1	1.6	3.5	4.0	4.5	6.6	8.6	9.3
Sweden	1.0	1.5	2.1	2.4	3.2	4.1	5.6	6.3	7.3
Austria	0.8	1.1	1.3	2.6	3.9	4.8	5.3	6.3	6.8
Netherlands	0.6	0.5	1.0	1.5	1.7	2.5	4.3	4.9	5.3
United Kingdom	0.6	0.9	1.2	1.8	2.2	2.7	3.6	4.1	4.1
Germany	0.6	0.8	1.2	1.8	2.5	2.5	3.1	3.5	3.5
Denmark	1.0	1.1	1.1	1.4	1.8	1.7	2.4	2.9	3.4
Hungary	0.6	0.6	1.0	1.3	1.6	1.9	2.2	2.8	3.1
Ireland	0.2	0.2	0.6	1.3	0.5	0.8	1.4	2.4	2.9
Belgium	0.1	0.2	0.2	0.4	0.8	0.9	1.6	2.2	2.7
Japan	1.5	1.3	1.4	1.7	2.0	2.1	2.2	2.4	2.6
France	0.4	0.6	0.7	1.0	1.0	1.1	1.6	2.3	2.6
Norway	1.2	1.2	0.4	0.9	1.3	1.7	2.1	2.3	2.4
Greece	0.3	0.7	0.7	1.0	1.3	1.4	1.3	1.8	2.2
Poland	0.0	0.3	0.3	0.5	0.7	0.8	1.1	1.8	2.1
Czech Republic	0.1	0.1	0.2	0.4	0.6	0.9	1.1	1.9	1.9
Spain	0.0	0.0	0.1	0.5	0.6	0.9	1.1	1.6	1.8
Slovak Republic	0.2	0.4	0.5	1.0	1.1	1.1	1.5	1.6	1.7
Mexico	0.5	0.6	0.7	1.1	1.2	1.1	1.1	1.2	1.3
Italy	0.1	0.2	0.2	0.5	0.7	0.9	1.2	1.1	1.3
Portugal	0.2	0.2	0.2	0.4	0.5	0.5	0.5	0.7	0.9
Turkey	0.4	0.4	0.1	0.2	0.3	0.3	0.5	0.7	0.8
OECD	4.3	4.0	4.8	6.7	7.5	8.1	9.8	10.5	10.9
Rest of World	0.2	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.8

Source : Tom Vest (Packet Clearing House www.pch.net) from raw data generated by the University of Oregon Route Views project.

Annex Table 12. Autonomous Systems (ASes) in the Internet routing table 2000 - 2005

	28-Jul-00	06-Jul-01	26-Jul-02	02-Aug-03	28-Jul-04	23-Jul-05	CAGR
Total ASes			13 448	15 616	17 668	20 129	14.4
Origin ASes	8 000	11 185	11 641	13 541	15 327	17 543	17.0
Transit ASes	1 122	1 520	1 807	2 075	2 341	2 586	18.2
Average AS path length visible	5.2	5.5	5.4	4.8	4.8	4.5	-2.9
APNIC Region origin ASes	949	1 289	1 578	1 872	2 086	2 312	19.5
APNIC Region transit	159	224	277	309	328	347	16.9
Average APNIC Region AS path length visible	5.1	5.8	5.3	4.9	4.9	4.5	-2.5
ARIN Region origin ASes	4 904	6 783	7 906	8 576	9 338	10 090	15.5
ARIN Region transit ASes	538	719	780	827	925	943	11.9
Average ARIN Region AS path length visible		5.3	5.3	4.6	4.6	4.3	-5.1
RIPE Region origin ASes	2 147	3 124	3 917	4 755	5 691	6 899	26.3
RIPE Region transit ASes	425	576	736	839	975	1 132	21.6
Average RIPE Region AS path length visible	5.8	6.3	5.9	5.4	5.4	5.2	-2.2
LACNIC Region origin ASes				343	386	626	35.1
LACNIC Region transit ASes				72	74	116	26.9
Average LACNIC Region AS path length visible				5.2	5.1	5.2	0.0
AfriNIC Region origin ASes					91	131	44.0
AfriNIC Region transit ASes					13	16	23.1
Average AfriNIC Region AS path length visible					4.8	4.6	-4.2

1. An additional category of Autonomous Systems are transit only.

Source : Weekly Routing Table Report (as seen from APNICs router in Japan).

Annex Table 13. Selected IXPs in Asia/Pacific, North America, Europe and Africa

	Established	Participants	Traffic Volume (Gbps)
London LINX	1996	191	76
Amsterdam AMS-IX	1997	238	114
Stockholm NetNod	1997	38	32
Vienna VIX	1996	87	9
Frankfurt DE-CIX	1995	166	50
Milan MIX	2000	57	10
Paris, Parix	2001	41	11
Prague NIX.CZ	1996	55	10
London XchangePoint	2001	165	12
London, LoNAP	1997	49	1
Dublin, INEX	1996	18	0.44
Oslo, NIX	1993	59	11
Helsinki, FICIX	1993	22	11
Budapest, BIX	1996	50	18
Zurich, TIX	1999	57	3
Madrid, ESPANIX	1998	28	56
Lisbon, GIGAPIX	1995	21	1
Brussels, BNIX	1995	48	6
Athens, AIX	1997	14	0.52
Rome NaMeX	2001	22	2
Palo Alto PAIX	1994	180	
Ashburn Equinix	1999	72	
Seattle SIX	1996	90	6
Miami NOTA	2001	89	5
New York IIX	1998	80	
Los Angeles LAAP	1995	75	
Chicago Equinix	2001	36	
San Jose Equinix	2001	37	
Portland NWAX	2002	15	
San Jose MAE-West	1994	100	
Seoul	1996	148	168
Tokyo	1996	252	75
Hong Kong, China	1995	69	13
Perth (WAIX)	1997	52	0.5
Beijing	2000	8	50
Jakarta	1997	70	50
Osaka	1998	30	5
Wellington	1996	123	
Singapore	2001	12	0.5
Chinese Taipei	1998	77	2
Auckland	2000	48	
Johannesburg JINX	1996	15	0.045
Nairobi KIXP	2002	11	0.003
Maputo MozIX	2002	7	0.004
Kinshasa PdX	2002	4	0.001
Cairo CR-IX	2002	9	
Ibadan	2003	2	0.0002
Kampala UIXP	2003	5	
Dar es Salaam TIX	2004	10	0.001
Mbabane SZIXP	2004	3	0.000128
Kigali	2004	6	0.0004

Source : Bill Woodcock, "Economic Trends in Internet Exchanges", Packet Clearing House, January 2005. European entries updated from Serge Radovik – Euro-IX 15 December 2005.

Annex Table 14. SkypeOut rates compared to Arbinet termination rates

Destination	Arbinet Termination Rate per minute	SkypeOut per minute (excluding tax)	Difference
Cambodia, Mobile	0.144	0.260	81%
Iran, Tehran	0.045	0.133	196%
Nigeria, Lagos	0.030	0.117	286%
Pakistan, Proper	0.118	0.265	126%
Saudi Arabia, Mobile	0.128	0.245	91%
Senegal, Proper	0.129	0.234	82%
Ukraine, Mobile	0.096	0.134	40%
United Kingdom, Mobile - Orange	0.084	0.253	203%
Zimbabwe, Proper	0.046	0.089	95%

Source : OECD based on Arbinet, SkypeOut rates (13 September 2005).

NOTES

[1] The figure of 20 000 autonomous systems is an approximation based on the Internet Weekly Routing Table (Annex Table 12) and work undertaken by Tom Vest at the Packet Clearing House (Annex Table 1).

[2] X.121 is the ITU-T standard describing an addressing scheme used in X.25 networks. X.121 addresses are sometimes called IDNs (International Data Numbers). http://www.itu.int/ITU-T/inr/forms/files/dnic-1508-en.pdf For examples of the identifiers in ITU Operational Bulletin, from August 2005, refer to http://www.itu.int/dms_pub/itu-t/opb/sp/T-SP-OB.842-2005-TOC-HTM-E.htm.

[3] Tom Vest, "IP Address Allocation vs. Internet Production 1: Understanding the Relationship, and the ifferences", Circle ID, 28 April 2005 http://www.circleid.com/posts/ip_address_allocation_vs_internet_production_i_understanding_the_relationsh/

[4] An Autonomous System is one or more IP networks, under the same management, which have a defined and coherent external routing policy. A more precise definition can be found in IETF RFC 1812. Refer to section 2.2.4 at http://www.arin.net/reference/rfc/rfc1812.txt

[5] AS 10806 is Agence France Press, AS 14074 is Colgate, AS 17089 is the Cincinnati Children's Hospital, AS 26960 is Michelin, AS 27478 is Round Table Pizza, AS 30439 is the Memphis Daily News. AS 11643 is eBay and AS 24331 eBay Asia. Many thousands of additional ASNs have been allocated but are not yet in use.

[6] There are several reasons that ASNs are not given out on demand. The current system is finite with 65 536 possible values. Although a new version could be introduced this would have cost such that the Internet community prefers to manage the resource. In addition, restricting the number of ASNs to entities demonstrating need helps to minimise the size of the routing table and therefore the load placed on the memory of routers.

[7] Correspondence with Tom Vest of the PCH.

[8] Lyman Chapin, "Declaration of Lyman Chapin", Before the Federal Communications Commission in the Matter of Developing a Unified Intercarrier Compensation Regime, CC Docket No. 01-92, Washington, 2005.

[9] http://www.fixedorbit.com/AS/15/AS15169.htm.

[10] Phil Sweeny, "ABC to peer with PIPE", Whirlpool, 6 July 2004. http://whirlpool.net.au/article.cfm/1284.

[11] Internode, "Internode unmeters content from the ABC", Press Release, 29 July 2004. http://www.internode.on.net/about/news/news-29-07-2004.htm.

[12] Ibid. After the change Internode commented: "This means an Internode ADSL customer on any plan, including the $29.95 Internode Starter Plan, can leave NewsRadio playing 24 hours a day if they want to at no extra cost. On BigPond's $29.95 plan, it would cost more than $900 extra." Notwithstanding a user

would, of course, choose a different plan with Telstra if they wanted unmetered access to ABC content the change did represent a considerable saving.

[13] A traceroute tool displaying ASN numbers is available at http://logbud.com/visual_trace The ABC's Web site is at www.abc.net.au

[14] The Internet standard that mandated multi-homing as a prerequisite for securing an ASN was published in 1996. http://www.faqs.org/rfcs/rfc1930.html

[15] In September 2005 48% of ASes, in this category (the European Internet Exchange Association members), connected at multiple IXPs. http://www.euro-ix.net/isp/choosing/search/ixpmatrix.php.

[16] LINX, "LINX cuts prices as traffic grows - May help ISP broadband price competition", Press Release, August 2005 https://www.linx.net/www_public/press_events/press_releases/pr122.

[17] Bill Woodcock in "Internet Topology and Economics" Packet Clearing House, Version 1.0, January 2003 has a number of diagrams that assist in understanding the difference between peering and transit particularly pp 3-4. Refer to http://www.pch.net/resources/papers/topology-and-economics/Topology-and-Economics.ppt

[18] In the case of Deutsche Telkom and Telemex at least in as far as traceroutes from their networks show traffic being exchanged with Google via other networks.

[19] LINX, the largest IXP in the world, organised a three-day cruise between 4-7 March 2005 for network operators to discuss and negotiate peering arrangements. Refer to "HotLinx", Summer 2005 https://www.linx.net/www_public/press_events/publications/newsletter9/hotlinx-9.

[20] In the United States interconnection between independent long distance carriers and the Bell System was always possible. Independent long distance carriers interconnected to the Bell System via loop (now known as Feature Group A) interfaces. However, regulation was required for such independent carriers to get "equal access" (Feature Group D) interfaces. Thus prior to regulation, the incumbents were dictating the terms of interconnection. This changed after regulation was introduced.

[21] Paul Milgrom, Bridger Mitchell and Padmanabhan Srinagesh "Competitive Effects of Internet Peering Policies", The Internet Upheaval, Ingo Vogelsang and Benjamin Compaine (eds), Cambridge: MIT Press (2000):175-195. http://www.stanford.edu/~milgrom/publishedarticles/TPRC%201999.internet%20peering.pdf. The authors of this work claim that in seeking to reduce transport costs, entities can game the system causing "core ISPs" to incur auditing costs. The reference goes on to claim that proper choice of interconnecting ISPs can lessen the chance of 'gaming' and therefore ISPs can economise on monitoring interconnection agreements. Regulatory effects may or may not complicate this, but would depend on the specifics of the case in point.

[22] Chapin, Op.cit. It might be suggested that Chapin understates the case in that he characterises interconnection as "an important source of business opportunity," whereas it could be viewed as the sole source of the good which is being sold.

[23] NRIC, "Service Provider Interconnection for Internet Protocol Best Effort Service", Focus Group 4 Final Report Appendix B, www.nric.org/pubs/nric5/2B4appendixb.doc

[24] Earlier work included OECD, "Internet Traffic Exchange and the Development of End to End International Telecommunication Competition", March 2002 http://www.oecd.org/dataoecd/47/20/2074136.pdf and OECD, "Internet Traffic Exchange: Developments and Policy", 1998, http://www.oecd.org/dataoecd/11/26/2091100.pdf.

[25] NRIC, Op.cit.

[26] http://www.atdn.net/paid_peering.shtml.

[27] William Norton, "The Folly of Peering Ratios", Post to Nanog, 2 November 2005. http://www.merit.edu/mail.archives/nanog/2005-11/msg00072.html

[28] NRIC, Op.cit.

[29] Ibid.

[30] Ibid and Chapin, Op.cit.

[31] Chapin, Op.cit. Blackholing is a technique ISPs generally reserve for dealing with incidents such as denial of service attacks or other network abuse. It involves advertising a false route which redirects traffic away from its intended destination to a 'sink point'. France Telecom, for example, reserves the right to blackhole parties they deem to using OpenTransit Internet's Systems, Products and Services for prohibited or illegal uses. http://vision.opentransit.net/docs/AUP-FranceTelecom.html. Refer also to Geoff Huston, "Securing Inter-Domain Routing", March 2005. http://www.potaroo.net/ispcol/2005-03/route-sec-2-ispcol.html.

[32] "For reference, consider that the public Internet today is composed of almost exactly 1.5 billion "Internet resources" (unique public IP addresses), and instructions for reaching all of them are summarised into at most 180-200k sets of instructions (*i.e.* prefixes). By contrast, managing all of that in /24 (256 IP) increments would necessitate accommodating a set of routing instructions 6 million lines in length." (Tom Vest, Email Correspondence with the Author, February 2006).

[33] RTI, "IPv6 Economic Impact Assessment", Planning Report 05-2, October 2005. http://www.nist.gov/director/prog-ofc/report05-2.pdf The authors of this report note additional memory will be needed in forwarding hardware pieces to continue current network performance given the larger size of IPv6 (128 bits versus 32 bits in IPv4).

[34] Routing Table Report, Saturday 28 January, 2006. https://www.apnic.net/mailing-lists/bgp-stats/archive/2006/01/msg00027.html

[35] http://www.isc.org/index.pl?/ops/ds/.

[36] In the OECD area the number of fixed network Internet subscribers was around 275 million at the end of 2004. Each subscription in workplaces or households can, of course, be used by multiple users. The ITU reports an estimated 873 million Internet users, a figure which includes mobile Internet access, for 2004.

[37] OECD, "Information Infrastructure Convergence and Pricing: The Internet", Paris, 1996 http://www.oecd.org/document/27/0,2340,en_2649_34225_25496027_1_1_1_1,00.html.

[38] Ibid.

[39] Bill Woodcock, Packet Clearing House, E-mail with author, February 2006.

[40] Tony Werner, CTO of Liberty Media quoted in "Future of TV.net", Newsletter, May 17, 2005.

[41] Tony Marson, "Wide-Area Peering Could Be New Internet Paradigm", 18 April 2005. The Yankee Group, http://www.yankeegroup.com/public/products/decision_note.jsp?ID=13005.

[42] Ibid.

[43] Radovcic, Op.cit. http://www.apnic.net/meetings/19/docs/sigs/ix/ix-pres-serge-euroix-update.pdf.

[44] See for example: http://www.xchangepoint.net/news/transit_promotions.php and the transit providers available at NLix http://www.nl-ix.net/marketplace.html#globaltransit.

[45] See for example posts on mnet prices (reselling Level3) compared to list prices at: http://www.forum2.co.uk/forums/archive/index.php/t-4497.html Post by forum member: "Mnet (http://www.mnet.net.uk) sell Level3 transit in SOV and are an official direct reseller. If you're looking for 10Mb/s, the pricing is around £25-£35 per Mb/s, 100Mb/s could probably get you under the £20 per Mb/s level. 29th May 2005".

[46] For example: http://www.kewlio.net/kewlio.net-extended-pricing.k.

[47] http://www.pipenetworks.com/.

[48] Pipe networks'"Dark Fibre Accelerates Internode ADSL2+ Rollout", 27 June 2005; http://www.pipenetworks.com/docs/media/05_06_27_Internode_Fibre.pdf.

[49] "ICASA wants AU subsea cable price cut", *Mining Weekly*, 12 October, http://www.miningweekly.co.za/?show=75642.

[50] http://www.icann.org/general/.

[51] Department of Commerce, "U.S. Principles on the Internet's Domain Name and Addressing System", June 2005: http://www.ntia.doc.gov/ntiahome/domainname/USDNSprinciples_06302005.htm

[52] http://www.ripe.net/info/resource-admin/index.html.

[53] The RIR statistics can be found at: ftp://ftp.afrinic.net/pub/stats/afrinic and http://www.apnic.net/info/reports and http://www.arin.net/statistics and http://www.lacnic.net/en/est.html and http://www.ripe.net/info/stats See also: http://www.aso.icann.org/stats/.

[54] http://www.nro.net/statistics/index.html.

[55] http://www.routeviews.org/.

[56] http://www.apnic.net/info/faq/as_faq.html.

[57] Geoff Huston, "Exploring Autonomous System Numbers", August 2005: http://ispcolumn.isoc.org/2005-08/as1.html.

[58] Refer Ibid. AS 0 is reserved, and may be used to identify non-routed networks. The largest value, AS 65 535 is also reserved. The block of AS numbers from 64 512 through to 65 534 is designated for private use.

[59] Geoff Huston, "AS Number Consumption", September 2005:. http://ispcolumn.isoc.org/2005-09/as2.html.

[60] Geoff Huston, "4-Byte AS Numbers", October 2005: http://ispcolumn.isoc.org/2005-10/as3.html

[61] Tom Vest, E-mail Correspondence with the Author, February 2006.

[62] Tom Vest, "The Wealth of Networks", Packet Clearing House, Version 1.1, 16 March 2005: www.pch.net. Forthcoming at www.thewealthofnetworks.org

[63] http://www.webopedia.com/TERM/I/IP_address.html.

[64] http://www.webopedia.com/TERM/I/IPng.html.

[65] Geoff Huston “Exploring Autonomous System Numbers”, August 2005: http://ispcolumn.isoc.org/2005-08/as1.html.

[66] Ibid.

[67] http://www-dsg.stanford.edu/papers/contentrouting/node6.html.

[68] E-mail with author.

[69] Each entry may or may not exactly match a real unique routed prefix using this methodology. Based on e-mail correspondence with the author, July 2005.

[70] Geoff Huston and others have pointed out there is no single view of the Internet routing table. Each AS view will have some local specifics attached to it.

[71] http://www.caida.org/

[72] Geoff Huston, “Routing Table Status Report”, Policy SIG, APNIC 19, Kyoto, Japan, February 2005: http://www.apnic.net/meetings/19/docs/sigs/routing/routing-pres-info-huston-routing-table.pdf See also Geoff Huston, “Internet BGP Table Analysis”, Telstra, December 2000: www.caida.org/outreach/isma/0012/talks/huston/huston.ppt. Recently Geoff Huston has noted that the density of AS interconnection is increasing at a rate roughly proportional to the number of ASNs being added.

[73] As measured in the Weekly Routing Table Report as seen from APNIC's router in Japan.

[74] http://www.equinix.com/about/aboutus/index.htm.

[75] http://www.packetexchange.net/content.plm/44.

[76] http://www.seattleix.net/.

[77] http://www.seattleix.net/participants.htm.

[78] http://www.relocationswest.com.au/page9.html.

[79] http://waix.bur.st/.

[80] Bill Woodcock, “Economic Trends in Internet Exchanges”, Packet Clearing House, January 2005: http://www.apnic.net/meetings/19/docs/sigs/ix/ix-pres-woody-tour-world.pdf.

[81] Serge Radovcic, “Euro-IX Update”, APNIC 19, January 2005.: http://www.apnic.net/meetings/19/docs/sigs/ix/ix-pres-serge-euroix-update.pdf.

[82] Srinath Beldona and Philip Smith, “Internet Exchange Points (India Specific)”, Cisco, 2001: http://www.nixi.org/pdf/IXP_basics_design.pdf.

[83] Steve Gibbard, Economics of Peering, PCH/Steve Gibbard Consulting, October 2004: http://www.stevegibbard.com/peering-economics.htm.

[84] Ibid.

[85] Gaurab Raj Upadhaya, CEO and technical Chair, Nepal Internet Exchange, APNIC Open Policy Meeting, 20 August 2003: www.apnic.net/meetings/16/programme/ sigs/docs/ix/ix-pres-gaurab-ixes-south-asia.ppt.

[86] Sumon Ahmed Sabir, BDIX Updates, February 2005: http://www.apnic.net/meetings/19/docs/sigs/ix/ix-pres-sabir-bdix.pdf.

[87] Johar Alam, "Indonesian Internet Exchange": http://www.iix.net.id/library/Iix_history.pdf.

[88] Paul Montgomery, "Regulator Tries to Fix Australian Peering", 21 February 2000: http://www.internetnews.com/bus-news/article.php/307251. Mongomery argues: "The issue of peering came to a head 18 months ago when the four largest ISPs in Australia - Telstra, Cable & Wireless Optus, AAPT (then Connect.com.au) and Uunet (then OzEmail) - were forced by the ACCC to enter into peering agreements with each other. However, the benefits to the 800 other ISPs in Australia which the ACCC said at the time it hoped would "trickle down", were not passed on."

[89] "ACCC rules against increased peering", CRN, 20 January 2005: http://www.crn.com.au/story.aspx?CIID=21314.

[90] Geoff Huston, "Peering and Settlements": http://www.cisco.com/en/US/about/ac123/ac147/ac174/ac201/about_cisco_ipj_archive_article09186a00800c83a5.html

[91] CBR Staff Writer, "Peering dispute reprieve, regulatory threat", Computer Busienss Review Online, 10 october 2005: http://www.cbronline.com/article_news.asp?guid=86029C2F-723D-4D45-B365-504F3C6562F9.

[92] See for example "ISP spat blocks Net for thousands", 7 October 2005: http://money.cnn.com/2005/10/06/technology/isps.reut/?cnn=yes.

[93] Tom Vest post to the CyberTelecom list 8 October 2005.

[94] Robert W. Smith, "France Telecom severs all network links to competitor Cogent", 21 April 2005: http://www.heise.de/english/newsticker/news/58835.

[95] A long discussion on this topic occurred at NANOG following the depeering between the two networks: http://www.merit.edu/mail.archives/nanog/2005-04/msg00484.html.

[96] http://forum.folding-community.org/printview.php?t=11936&start=0.

[97] In these instance users generally communicate quickly between each other and protest to their respective providers. Refer, for example, to: http://www.iantighe.com/boincers.htm.

[98] http://www.merit.edu/mail.archives/nanog/2005-04/msg00683.html.

[99] The economic advantages of peering with large service content providers such as Yahoo and Google are describered here: https://ecc.equinix.com/peering/why.htm.

[100] Reuben Schwartz, "Depeering move 'Balkanisation' of the net" Stuff.co.nz, 28 february 2005: http://www.stuff.co.nz/stuff/0,2106,3201079a28,00.html and Adam Gifford, "TelstraClear pulls internet plug", *New Zealand Herald*, 4 March 2005: http://www.nzherald.co.nz/section/story.cfm?c_id=5&objectid=10113474.

[101] Ibid.

[102] Reuben Schwarz, “Telecom, TelstraClear hold back from Radio NZ peering”, Stuff.co.nz 18 July 2005: http://www.stuff.co.nz/stuff/0,2106,3348056a28,00.html.

[103] Juha Saarinen: “Paying the price of peer pressure”, *New Zealand Herald*, 1 June 2004: http://www.nzherald.co.nz/category/story.cfm?c_id=55&objectid=3569738.

[104] “VoIP Peering and Interconnect BOF”, IETF 63, Paris, July-August 2005: http://www3.ietf.org/proceedings/05aug/slides/voipeer-1/sld1.htm and other presentations in this session at: https://datatracker.ietf.org/public/proceeding_interim.cgi?meeting_num=63 See also Caroline Chappell, “VoIP peering in an IP World”, *Capacity*, Vol 5, Issue 6, July/August 2005 http://www.thevpf.com/txt/Capacity%20-%20Voice%20Peering%20-%20JulAug05.pdf.

[105] Bill Woodcock, “PCH’s operational experience with VoIP peering”, August 2005.
http://www3.ietf.org/proceedings/05aug/slides/voipeer-5.pdf and
http://www.webopedia.com/quick_ref/OSI_Layers.asp.

[106] Niklas Zennström, one of the founders of Skype, made this comment in a Webcast, London, 13 September, 2005: http://investor.ebay.com/calendar.cfm.

[107] http://www.wavigo.com/sbridge.html.

[108] Skype Fact Sheet, September 2005: http://investor.ebay.com/downloads/Skype_FactSheet-3843hd.pdf.

[109] http://www.arbinet.com/ and http://www.thevpf.com/.

[110] http://www.thevpf.com/index.php?action=minutes_search_now&rt=dod.

[111] http://www.netappel.fr/fr/index.html.

[112] . Internet advertisers, for example, are prepared to pay high rates for ‘click through’ advertising. Overture’s tool for advertisers to bid on keywords, for example, shows a range of between USD 0.30 to more than USD 1.00 on OECD country names.

[113] Iliad, “Free Phone Calls to the Most Frequently Called Countries with Freebox”, 15 December 2005: http://www.iliad.fr/actualites/cp_151205_eng.pdf

[114] Charlotte Wolter and Khali Henderson, “Peering Links More, Diverse VoIP Islands”, June 2005: http://www.phoneplusmag.com/articles/551carrier01.html.

[115] http://www.infiniroute.com/solution/solution.php.

[116] http://www.xconnect.com/.

[117] RCN for example hosts VPF at some locations: http://www.thevpf.com/?action=about_locations.

[118] http://www.telx.com/carriers.cfm.

[119] http://www.interoute.com/products_arena.html.

[120] Jim Kinsella, “New Retail Model will Triumph in the Telecoms Arena”, 27 July 2005: http://www.tmcnet.com/usubmit/2005/Jul/1167601.htm.

[121] Sean Michael Kerner, “VoIP Peering Fabric a 'Stealth' Business”, 30 June 2005: .http://www.voipplanet.com/solutions/article.php/3516826 and Woodcock Op.cit.

[122] Chappell, Op.cit: and R. Scott Raynovich, "VOIP Peering: Incumbent Killer?", 16 June 2005: http://www.lightreading.com/document.asp?doc_id=75881&site=lightreading&WT.svl=news1_1.

[123] Woodcock, Op.cit. http://www3.ietf.org/proceedings/05aug/slides/voipeer-5.pdf.

[124] Chappell, Op.cit.

[125] OECD, "Internet Traffic Exchange and the Development of End to End International Telecommunication Competition", March 2002: http://www.oecd.org/dataoecd/47/20/2074136.pdf.

[126] Reliance Infocom, "Reliance Infocomm and China Telecom sign agreement for telecom services", Press Release, Mumbai and Beijing, 12 December 2005: http://www.relianceinfo.com/webapp/Infocomm/jsp/media/PressRelease.jsp?id=172

[127] TRAI, "Indicators for Telecom Growth", Study Paper 2/2005, 30 June 2005:http://www.trai.gov.in/ir30june.pdf.

[128] Morgan Staley cited by TRAI. Ibid.

[129] Joji Thomas Philip, "Tariff cuts bad news for dial-ups", ZDNet India, 12 August 2005:http://www.zdnetindia.com/news/national/stories/366,126925.html.

[130] http://www.bsnl.in/bsnlnews.asp?intNewsId=52880.

[131] http://chennai.bsnl.co.in/News/Liberty.htm and NT Bureau, "Free landline with broadband connection", 3 August 2005: http://newstodaynet.com/03aug/rf11.htm.

[132] TeleCommons Development Group, "Grameen Telecom's Village Phone Programme:: A Multi-Media Case Study", March 2000 http://www.telecommons.com/villagephone/contents.html.

[133] Ibid. http://www.telecommons.com/villagephone/section2.html.

[134] Grameen Phone, "Annual Report", 1998: http://www.telecommons.com/villagephone/gpar98.pdf.

[135] Rohan Samarajiva, "Sri Lanka's telecom revolution" *OECD Observer*, February 2001: http://www.oecdobserver.org/news/fullstory.php/aid/487/Sri_Lanka%92s_telecom_revolution.html. Published: February 2001

[136] Nigerian Communications Commission, "Trends in Telecommunication Markets in Nigeria 2003-2004", 2005: www.ncc.gov.ng

[137] Ibid

[138] "Fiber-optic Cable Wires Africa", *Red Herring Magazine*, 21 November 2005. http://www.redherring.com/Article.aspx?a=14560&hed=Fiber-optic+Cable+Wires+Africa

[139] www.econetwireless.com and www.mtn.co.za/

[140] China Telecom's prices are at: http://www.thevpf.com/index.php?action=minutes_search_now&rt=dod The FCC data can be found at: http://www.fcc.gov/ib/pd/pf/account.html.

[141] "Bandwidth prices may fall by 20%", rediff.com, 1 August 2005: http://inhome.rediff.com/money/2005/aug/01band.htm.

[142] www.seamewe4.com/.

[143] "BSNL's undersea cable to be operational by April next", *Business Line*, 2 August 2005:http://www.thehindubusinessline.com/blnus/15021705.htm.

[144] ENS Economic Bureau, "VSNL offers its undersea cable to BSNL", *The Indian Express*, 9 August 2005:http://www.indianexpress.com/full_story.php?content_id=75921.

[145] "VSNL plans more acquisitions", 1 August 2005: http://inhome.rediff.com/money/2005/aug/01vsnl.htm.

[146] http://www.flagtelecom.com/.

[147] http://www.sanog.org/.

[148] Alan Levin, "Creating National and regional Internet Exchange Points in Africa", Presentation to ICANN GAC, Regional Forum, Cape Town, 31 November 2004.

[149] Ibid.

[150] Ibid.

[151] Ibid.

[152] This can be tested here: http://www.safe-sat3.co.za/Configuration/Configuration.asp.

[153] "Ghana launches Internet Exchange", *News In Ghana*, 20 October 2005:http://www.newsinghana.com/general.php?story=328.

[154] Levin, Op.cit.

[155] "Telecommunication system to be modernised", 8 September 2005: http://www.gov.bw/cgi-bin/news.cgi?d=20050908&i=Telecommunication_system_to_be_modernized.

[156] AfriISPA, "Africa Online and Transtel Selected as Regional Carriers by AfrISPA", Press release, 7 April 2005: http://www.afrispa.org/NewsDetail.asp?ItemID=9.

[157] Richard Bell, "Submarine Cable Should Not be Commercially Driven", 7 September 2005:http://allafrica.com/stories/200509070792.html.

[158] CEO of Internet Ghana, A speech delivered in South Africa, 2005: http://www.internetghana.com/ceo.htm.

[159] Harry Goldstein, "Surf Africa", *Spectrum, IEEE* Volume 41, Issue 2, February 2004.

[160] "Kenya to allow telecom operators to transmit phone calls via Internet", 11 August 2005: http://www.cck.go.ke/html/news.asp?newsid=132&area=new.

[161] AFP, "Kenya to allow telecom operators to transmit phone calls via Internet", 11 August 2005: http://www.todayonline.com/articles/66044.asp.

[162] "Icasa appeals to AU to cut undersea cable costs", By *BusinessDay*, 13 October 2005:: http://mybroadband.co.za/nephp/?m=show&id=943.

[163] Inveneo's Web site is at: http://www.inveneo.org/?q=pedalnetwork.

[164] This recalls the use of pedal radio in the early days of Australia's School of the Air and Royal Flying Doctor Service in remote areas of that country: http://www.questacon.edu.au/html/school_of_the_air.html.

[165] Inveneo, http://www.inveneo.org/?q=pedalnetwork.

[166] Cyrus Fariva, "VOIP Phones Give Villagers a Buzz", *Wired*, 12 September 2005: http://www.wired.com/news/technology/0,1282,68796,00.html?tw=wn_6techhead.

[167] http://www.telecommons.com/villagephone/section2.html.