Chapter 5: Issues for consultation

Q1. Is there a need to mandate IP interconnection? If so, what should be the time frame for implementation of the same? Please comment with justifications.

Cisco: The Internet Protocol (IP) has steadily gained widespread global acceptance as the preferred protocol not just for data traffic, of which the tremendous growth of the Internet traffic is in itself a primary example, but also for carrier voice transport. The share of international carrier traffic routed as VoIP has grown from 11% in 2002 to 36% in 2013 [1], and global service providers are steadily migrating their network infrastructure to IP. While the significance of circuit switching (TDM) is reducing globally, many established service providers still rely on their legacy TDM networks. Given the trends in the growth of internet data traffic, the IP-fication of the mobile radio access network (4G-LTE mobile technology is fundamentally based on an IP-core), and the growth of data centers and cloud computing, application & services have propelled service providers to adopt and migrate to IP networks. In India, most Service providers have to a large extent curtailed investing on the TDM-based network infrastructure and network expansions are being predominantly planned with NGN Voice over IP network. However, as it appears today, it is only due to requirements of regulatory compliance, that IP is being converted into TDM in the Media gateway at the POI.

Hence, given the global trends, emergence and acceptance of IP as the preferred protocol for data and voice traffic, this is the right time to consider and permit IP interconnection in communication networks. Also, given the rapid adoption and growth of IP-based traffic, <u>the time line for IP interconnection enablement should be 'as soon as possible'.</u>

[1] Reference: Telegeography Report (2013) (Enclosed)

Q2. Whether both TDM and IP interconnection should be allowed to coexist? If so, whether the existing regulation i.e. 'Reference Interconnection Offer dated 12th July 2002' addresses the requirements of IP interconnection also? Please comment with justifications.

Cisco: Most service providers today are investing and expanding their IP NGN infrastructure, given that capital outlay required to transition to new generation IP networks and converged services is significantly lower compared to TDM-based infrastructure, and this is complemented and accentuated by the service provider's requirement to support convergence and burgeoning data and voice traffic growth, including those originating from OTT players. It is also becoming imperative for mobility services providers to evolve their RAN infrastructure to IP, and evolve the end-to-end network architecture to natively support IP-based 4G services. However, service providers have already made significant investments on TDM-based network infrastructure in the past, and these investments also need to be protected while transitioning from TDM to all-IP that will require both financial investment and time To begin with, the increase capacity and also the new POIs shall use IP Interconnection. We expect on a long term, the traffic over IP interconnect will increase and TDM will reduce to very small. Hence, we recommend for coexistence of both TDM and IP interconnections.

Q3. In case IP interconnection is mandated in India, whether the enforcement of interconnection agreements should rely on

(i) Bilateral agreements and dispute resolution; or

(ii) Mandatory reference offer

Cisco: No comment.

Q4. In an IP based network scenario, which mode of interconnection is preferable to carry traffic:- peer-to-peer, Interconnect Exchange or combination of both? Please comment with justifications.

Cisco: Technically both models are feasible and have their own advantages. Telecom service providers (Operators) should be permitted to access direct interconnect (peer-to-peer) traffic, as well as at the Interconnect Exchange. The interconnect exchange could simplify and reduce overall cost for Telecom service providers for POI interconnect. The Interconnect exchange needs to be designed with carrier grade reliability and availability. ISOC (The Internet Society) has published a detailed document [2] "The Internet Exchange Point Toolkit and Best Practices Guide" which discusses several technical and economic issues related to maximizing the effectiveness of network interconnection. It is suggested that this document may be considered and reviewed in part to the answer to this question. It is also suggested that technical documents from the International Interconnection Forum for Services over IP (i3 Forum) that is supported by global service providers, may also be considered and reviewed in part to the answer to this question [3].

Potentially, multiple interconnect exchange could be planned across India for redundancy and also for supporting higher voice service quality by reducing network latency and jitter.

[2] Reference: ISOC document "The Internet Exchange Point Toolkit and Best Practices Guide" Published February 2014. (Enclosed)

[3] Reference: www.i3forum.org

Q5. In case an Interconnect Exchange is required, should such Exchange be placed within each licensed service area or a single Interconnect Exchange will be adequate for the entire country? Please comment with justifications.

Cisco: Interconnect Exchange(s) should be planned at every licensed Service area. Having peering at multiple interconnect exchange could increase reliability, help reduce latency, control jitter, and increase quality of service. The interconnect at every interconnect exchange should be made optional if an operator is able to manage same service levels with peering at few interconnect exchange and also by having direct peering (Peer to peer). References [2] and [3] suggested in response to Q4 may also be relevant to be considered and reviewed in part to answer to this question.

Q6. Whether any regulatory intervention is required to mandate the locations and structure of points of interconnection (POI) for IP based network architecture? Please comment with justifications.

Cisco: Regulatory could provide some guidelines in proportion to the traffic being handled by the POI. Link Speed, QOS, Redundancy / High availability etc. This will help the service providers to better plan for POIs.

Q.7 what are your views on the migration from the existing interconnection regime-measured in terms of minutes of traffic to an IP interconnection regime replaced by measures of communication capacity? Please comment with justifications.

Cisco: Between Service providers, Current measurement methods (Minutes) based shall continue with IP interconnect as well.

Q.8 In an IP interconnection between networks, comment on the type of charging principles that should be in place-

(a) Capacity based in terms of Mbps.

(b) Volume based in terms of Mbps.

(c) QoS based.

(d) A combination of the above three.

Cisco: Interconnect exchange could follow combination of Capacity, Volume and QoS for charging. However, between service providers, the charges shall be based on Voice minutes.

Q9. What should be the criteria to estimate the traffic minutes in IP environment if interconnection charges continue to be minute based? Please provide justification in support of your answer.

Cisco: This depends on the Voice Codec, Sample interval, MOS for every call. Giving below a links for estimating the IP/Ethernet bandwidth per voice calls for different Voice Codec.

http://www.cisco.com/c/en/us/support/docs/voice/voice-quality/7934-bwidth-consume.html

Q10. In addition to the above, any other modifications or components of IUC which are required to be reviewed in the IP based network scenario? Please provide all relevant details?

Cisco: Carrier grade redundancy, Bandwidth/Links Scaling, High availability features to be considered. Also, the Network management system shall be planned for monitoring the KPI.

Q11. Do you envisage any interconnection requirement for application & content service providers? If so, what should be the charging mechanism? Please provide all relevant details justifying your comments.

Cisco: Yes, the same interconnect infrastructure could also be used to connect telecom service providers with Application & Content providers. They could reach to their customer through same infrastructure. However, there must be interconnecting agreement for application and Content service providers to avoid any dispute.

Reference [2] ISOC paper gives some useful pointers in this direction, and hence may be considered and reviewed in part to the answer of this question.

Q12. Whether the existing regulatory framework for measuring and reporting quality of service parameters as defined for PSTN/PLMN/Internet may continue to apply for IP based network services? Please comment with justifications.

Cisco: Guidelines on Quality of service is very critical. Each operator may have different marking to classify the voice as priority traffic on their network. At POI level, honoring other operator marking and remarking is essential to prioritize the voice traffic.

Documentation from Reference [3] is relevant here in part to the answer of this question.

Q13. In the context of IP based network Migration, if the parameters in the existing QoS regulation are required to be reviewed immediately then please provide specific inputs as to what changes, if any, are required in the existing QoS regulations issued by the Authority. Please comment with justification.

Q14. In case new QoS framework is desirable for IP based network, do you believe that the QoS be mandatory for all IP based network services. If yes, what should be QoS parameter and their benchmarks?

Q15. What should be the mechanism for monitoring the parameters for end to end QoS in IP based network environment? What should be the reporting requirement in this regard? Please comment with

justification.

Cisco: Monitoring Voice quality end to end is very complex. Various network parameters like Packet loss, Latency, Jitter require monitoring. It is also possible to have the MOS value as part of the CDR which could also be monitored. The IP network elements support Voice probe supports for regular or periodic measurement of voice quality within the IP/network.

There is automated voice quality measurement systems/solution available to measure the end to end voice quality measurement for both Wired and Mobile. These equipment play reference voice files from one location to another location and the results are captured by central servers for estimation of voice quality with different POI or destinations.

Q16. Should sharing of the IP based core and Access network element by different telecom service providers be allowed in IP based network scenario? What are the challenges, opportunities and problems of such sharing? Please comment with justifications.

Cisco: Sharing of IP Core & Access network should be permitted. The IP based transport network uses MPLS Technology for secure VPNs while sharing. This could help service providers to reduce the overall Capex and Opex budget. This will provide higher bandwidth availability for small service providers who do not have fiber reach across all locations and there by increased service quality.

The Current technologies like 2G/3G/4G demand high bandwidth per base station. The current Microwave backhaul will not be able to provide required bandwidth and quality of service. Extending fiber to all base stations is also not economical for service providers. Hence, sharing core and Access network will help to drive broadband growth in India.

We do not see any technical challenges in sharing the core and Access network between different telecom service providers.

Q17. Do you see any issues concerning the national numbering plan with regard to the migration towards IP based networks?

Cisco: We do not see any issues with current fixed line and also with mobile services. However, if IP end points are going to be permitted (ex. SIP Phones or VOIP from a PC), then this aspect perhaps require further study and recommendations.

Q18. Do you believe that ENUM has to be considered when devising the regulatory policy for IP based networks as it will provide essential translation between legacy E.164 numbers and IP/SIP (Session Initiation Protocol) addresses.

Cisco: Translation shall be part of Service provider infrastructure. We do not see any challenge in this.

Q19. Which type of the ENUM concept should be implemented in India? What should be the mechanism for

inter-relationship between number and IP addressing, and how it will be managed?

Cisco: No comment.

Q20. Is there a need to mandate Emergency number dialling facilities to access emergency numbers using telephone over IP based networks platform? Please give your suggestions with justifications.

Cisco: No comment

Q21. How will the issues, of Caller location delivery and priority routing of calls to the emergency centre in IP based networks environment, be handled? Please comment with justifications.

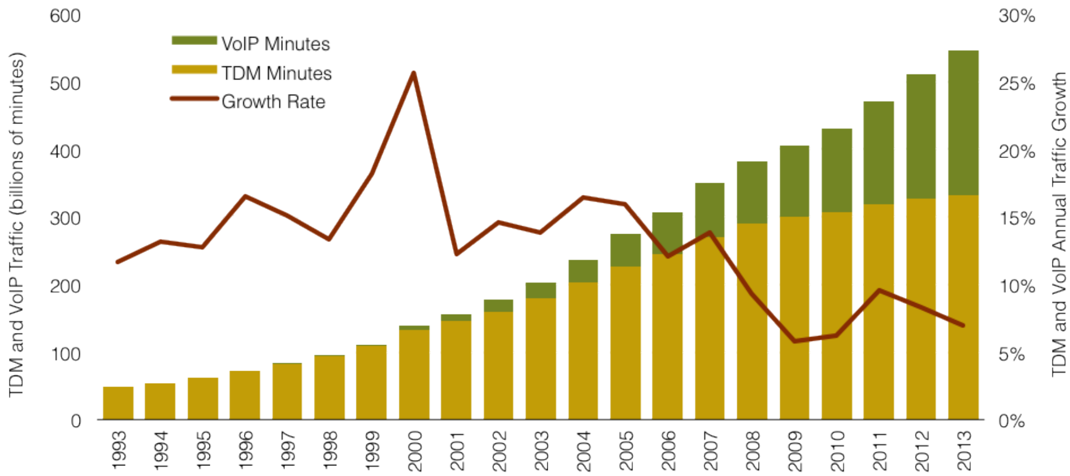
Cisco: No comment

Executive Summary

Few industries have experienced more wrenching changes than the international long-distance business. Over the past two decades, service providers have weathered market liberalization, the enormous telecom market bubble and its aftermath, intense competition, rapid technological innovation, and non-stop price declines. Throughout these years of market turbulence, continuous double-digit traffic growth helped the industry to eke out modest revenue gains in most years. However, even greater challenges lie ahead: traffic growth is slowing, just as telcos must come to grips with competition from software based computer and smartphone applications, such as Skype and Google Voice, and make difficult decisions about investments in new infrastructure. The *TeleGeography Report* analyzes and quantifies the state of the international long-distance industry and assesses the factors that will shape it in the years ahead.

FIGURE 1

International Call Volumes and Growth Rates, 1993-2013



Notes: Data for 2013 are projections. VoIP traffic reflects international traffic transported as VoIP by carriers, and excludes PC-to-PC traffic.

Source: TeleGeography

Traffic

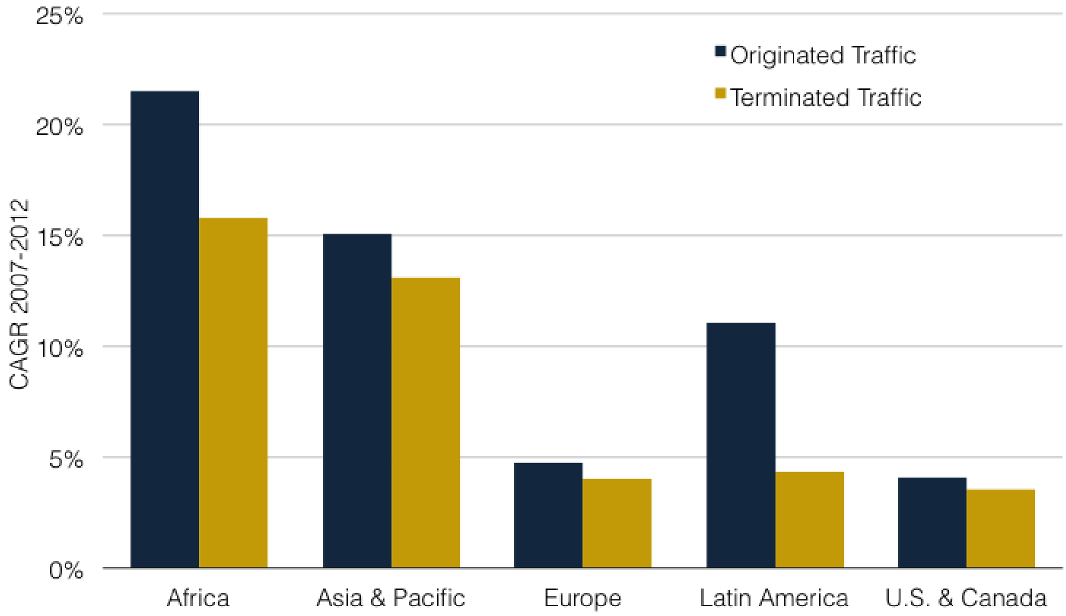
Over the past 20 years, international voice traffic has grown at a compounded rate of just over 13 percent annually. Growth was especially rapid during the late 1990s and early 2000s thanks to a wave of market liberalization, the global proliferation of mobile phones, and the emergence of pre-paid phones and calling cards, all of which brought telecommunications services to billions of people in developing countries previously without.

Traffic growth peaked at 25 percent in 2000 before returning to growth rates of 12-16 percent annually, in line with historical trends. Volume growth slowed to 9 percent in 2008, and has remained below 10 percent annually since (see Figure: International Call Volumes and Growth Rates, 1993-2013). Total international voice traffic grew 8 percent in 2012, to 511 billion minutes. Traditional time division multiplexed (TDM) international traffic grew 2 percent, to 326 billion minutes, while traffic carried as Voice over IP (VoIP) grew 21 percent, to 184 billion minutes.

Major markets in Asia and Africa have generated much of the volume growth in recent years. Asian countries now generate 80 billion more minutes per year than they did in 2007, roughly equivalent to the volume of new traffic generated in all other world regions, combined. Between 2007 and 2012, traffic to and from Western Europe and the U.S. & Canada grew at a compounded rate of 4-5 percent annually, while traffic to Africa 16 percent, and traffic from Africa grew 21 percent annually. Despite this rapid growth, aggregate volumes remain very small for so large a region: all the countries of Africa combined generated less traffic than France alone.

FIGURE 2

Compounded Annual Traffic Growth Rate by Region, 2007-2012



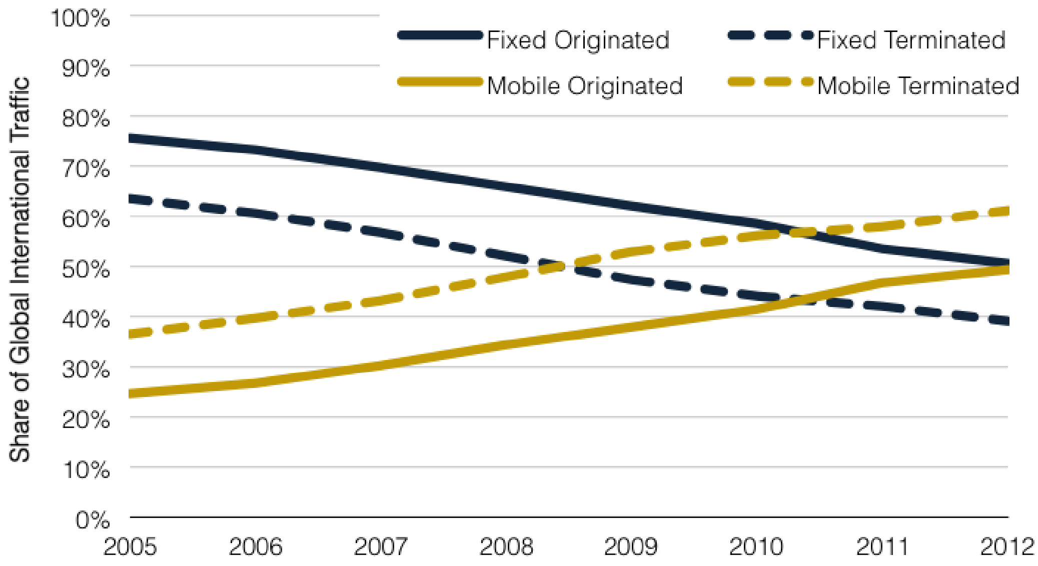
Notes: Data include traffic routed via TDM and VoIP.

Source: TeleGeography

Mobiles have provided a key engine of growth for the international long distance market. In 2012, mobiles accounted for 84 percent of global phone lines, 49 percent of originated international calls, and 61 percent of terminated international calls (see Figure: Fixed and Mobile Share of International Traffic, 2005-2012). Mobiles play a particularly important role in the wholesale market. In 2012, mobile-terminated calls accounted for 65 percent of wholesale traffic, and 84 percent of wholesale carrier revenues. Mobiles contribute to a disproportionately large share of wholesale revenues because mobile network interconnection rates (the per-minute fees carriers pay to destination network operators to terminate calls on their networks) are often several times higher than fixed-network termination rates. The high cost of mobile interconnection has attracted the attention of regulators, which are requiring mobile operators in many countries to reduce their network interconnection rates to levels more in line with fixed-network charges.

FIGURE 3

Fixed and Mobile Share of International Traffic, 2005-2012



Source: TeleGeography

Wholesale

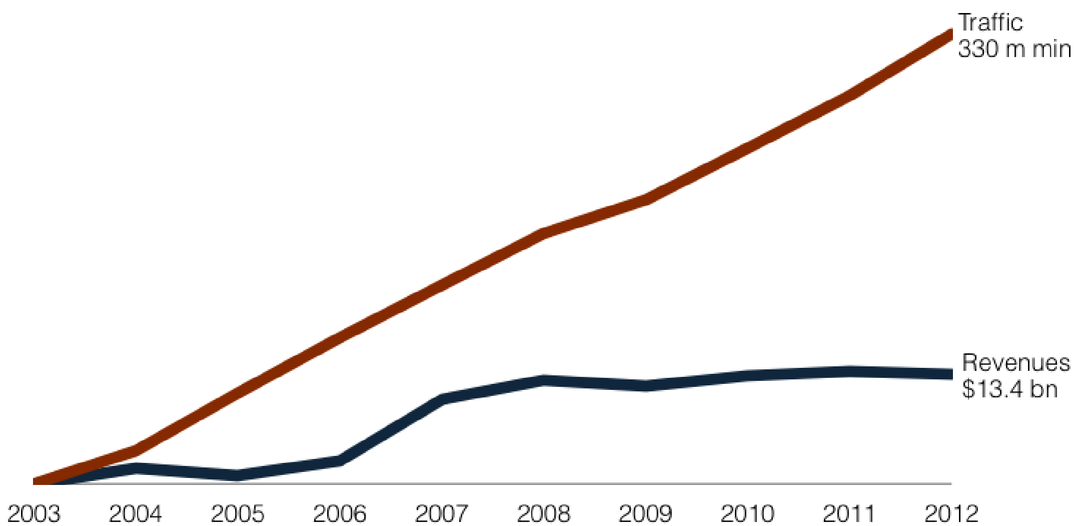
A mature international wholesale voice market has emerged over the past decade, greatly increasing its efficiency. Traffic terminated by wholesale carriers grew 11 percent in 2012, to 330 million minutes. Wholesale traffic has consistently expanded faster than aggregate traffic. The share of global traffic transported by wholesale carriers has grown from 45 percent in 2003 to 65 percent in 2012.

Traffic increases to emerging market countries have particularly fostered wholesale market growth, and wholesale carriers account for a disproportionate share of traffic terminated to many emerging market destinations. For example, in 2012, wholesale carriers handled four out of five calls to Sub-Saharan Africa, to South America, and to Central Asia. Conversely, just 36 percent of traffic to fixed lines in western Europe was terminated by wholesale relationships.

Unsurprisingly, sharply declining wholesale rates to high volume destinations in South Asia, and the rapid reduction in mobile interconnection rates, have affected wholesale carrier revenues. While wholesale traffic has grown nearly 50 percent since 2008, revenues have remained stubbornly flat, and declined modestly in 2012, to $13.4 billion (see Figure Wholesale Traffic and Revenues, 2003-2012).

FIGURE 4

Wholesale Traffic and Revenues, 2003-2012



Source: TeleGeography

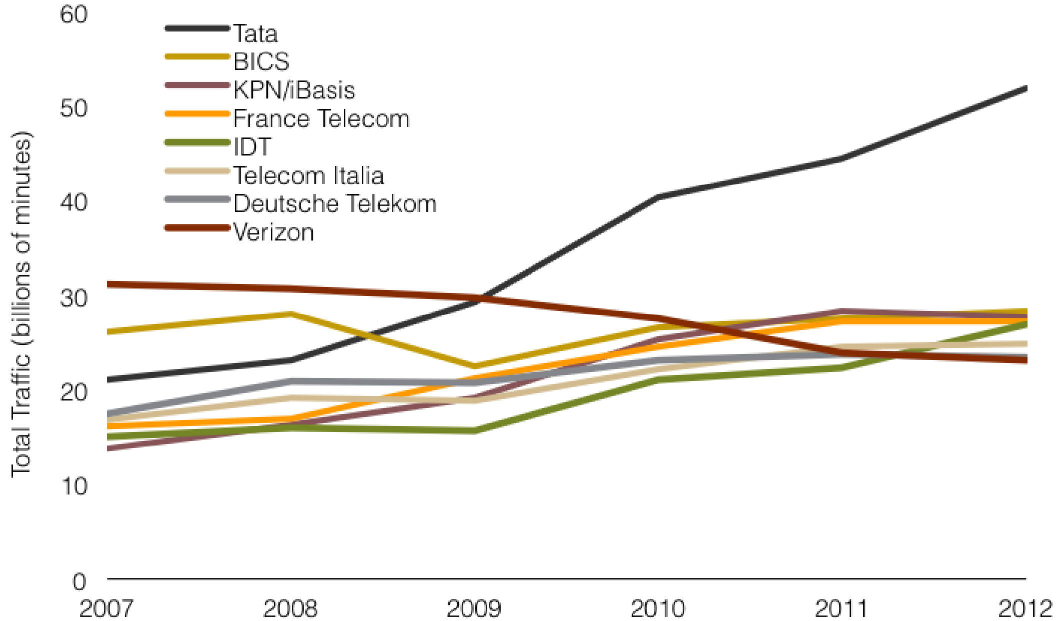
Carriers

As prices have declined relentlessly, a handful of carriers have pursued a strategy of volume growth, expanding their wholesale operations and acquiring or combining their operations with those of other carriers to increase the scale of their business. The figure “Traffic Volumes of Top Carriers, 2007-2012” presents a ranking of some of the world’s largest international carriers. In 2012, nine carriers in TeleGeography’s ranking transported more than 20 billion minutes of traffic, compared with only three in 2007.

Among the largest voice carriers, Tata Communications now occupies a tier of its own. Tata has built its voice business through a combination of acquisitions, outsourcing agreements, and aggressive business development. In 2012, Tata terminated 51.8 billion minutes of traffic, 80 percent more than its closest competitor. Not all carriers are pursuing volume growth. Verizon, which was long the world’s largest voice carrier, has taken the opposite approach, deliberately allowing volumes and gross revenues to decline in pursuit of higher margins. If present trends in the international voice market continue—and TeleGeography believes they will—a growing number of carriers can be expected to follow the example of Verizon and opt for a strategic retreat from the international voice market.

FIGURE 5

Traffic Volumes of Top Carriers, 2007-2012



Source: TeleGeography

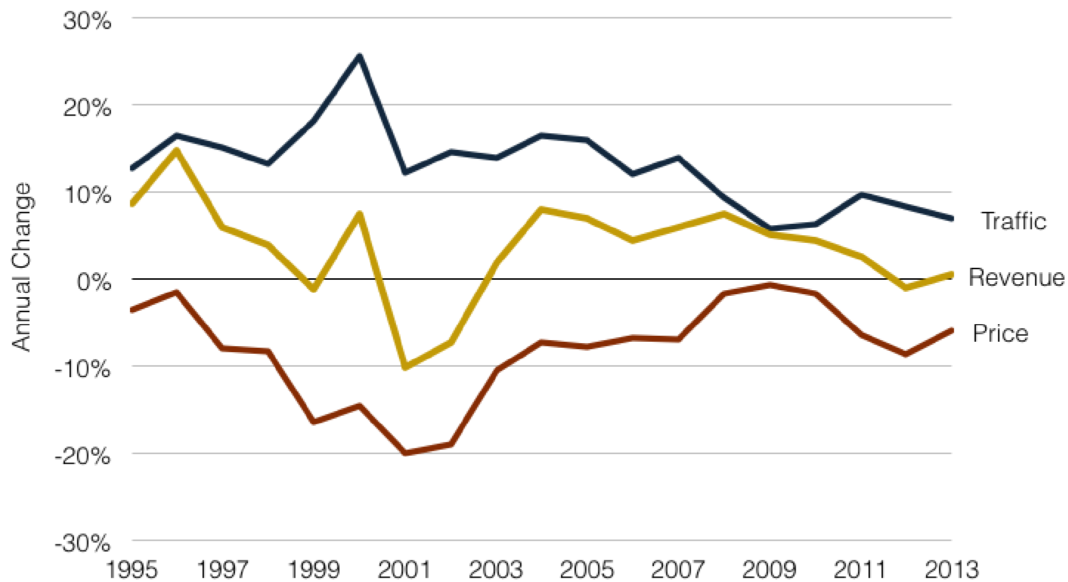
Prices & Revenues

Retail service prices have fallen continuously since 1992. The pace of price declines accelerated sharply in the late 1990s, peaking in 2001, when global retail prices dropped 20 percent, resulting in a 10 percent decline in global retail revenues. Price erosion has moderated since, and in most years, traffic growth has been sufficient to offset price declines, allowing global retail revenues to eke out small gains. This precarious balance was upset in 2012, as price declines accelerated to 8.6 percent, causing global retail revenue to fall 1 percent, to $95.6 billion.

If over-the-top communications services take a larger bite out of traffic growth, or if retail service providers (particularly mobile operators) are no longer able to maintain prices, revenues will fall (see Figure: Global Traffic Rate of Price Decline versus Volume Growth, 1995-2013).

FIGURE 6

Global Traffic Rate of Price Decline versus Volume Growth, 1995-2013



Notes: Data reflect both TDM and VoIP volumes. Periods where volume increases outpace average price declines mark a period of revenue growth. When price declines outpace volume increase, revenue declines. Data for 2013 are projections.

Source: TeleGeography

Outlook

While the international voice market has seen more than its fair share of turbulence over the past 20 years, even greater challenges, and difficult decisions, lie ahead for international service providers.

The era of double-digit traffic growth is over. The key drivers of growth over the past 20 years were price declines, brought about by competition and mobile termination rate cuts; the expansion of mobile phone service to developing countries, which connected billions of people to the PSTN for the first time; and, innovations such as prepaid services, which helped to make telecom services available to lower income users. However, after two decades of continuous price reductions, and with global mobile penetration approaching 90 percent, the incremental effectiveness of further price cuts or mobile subscriber growth is wearing off. These factors are compounded by the fact that OTT services are siphoning off at least a share of international voice traffic.

Revenues are fragile. Retail and wholesale calling prices have declined continuously over the past 20 years, and there is no end in sight. While much of the decline can be attributed to reduced interconnection charges and improvements in carriers' cost structures, the relentless erosion in service prices makes it ever harder for international carriers to identify and exploit profitable market niches.

TeleGeography projects that retail prices will fall an average of 6 percent annually between 2013 and 2018, outstripping traffic growth, and causing global retail revenues to decline by about 2 percent annually. At this pace, global traffic would increase 26 percent by 2018, to 688 billion minutes, while retail revenues would fall 8 percent, to $88.8 billion.

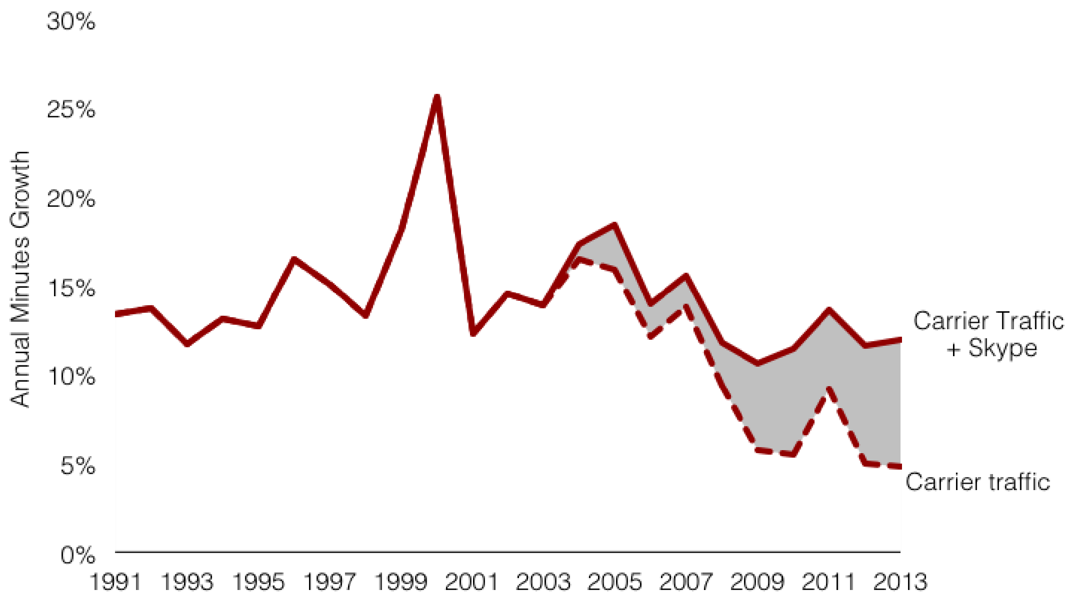
The wholesale market stands particularly exposed to the danger of price decline. Only five sub-regions (northern Africa, Sub-Saharan Africa, the Middle East, Central Asia, and the Caribbean) experienced revenue growth in 2012. Revenues from termination to all other markets declined, often dramatically. The small number of healthy wholesale markets suggests that carriers not serving these select regional markets are already facing significant challenges.

Carrier voice transport is migrating to IP. While the share of international carrier traffic routed as VoIP has grown from 11 percent in 2002 to 36 percent in 2013, many established service providers still rely on their legacy TDM networks. The capital outlay required to transition to new generation IP networks is a small fraction of what most of these companies spent to deploy their TDM networks, but many carriers have been operating their international voice business with a view to maximizing cash flow. Such operators could find it difficult to justify CAPEX in a market segment that is now in decline, and opt to exit the business, or to rely on wholesale or other arrangements for their voice transport and termination requirements.

OTT is a siphon. Hundreds of millions of people now use “over-the-top” (OTT) voice, video, and text communications on their computers and mobile devices for a growing share of their calls. Skype, which launched its service in 2003, has long been the bellwether of this market. TeleGeography estimates that Skype’s on-net international traffic grew 36 percent in 2013, to 214 billion minutes. While the volume of international telephone traffic remains far larger than international Skype traffic, Skype’s traffic is growing far more rapidly. Skype added approximately 54 billion minutes of international traffic in 2013, 50 percent more than the combined volume growth of every carrier in the world, combined. Given these immense traffic volumes, it’s difficult not to conclude that at least some of Skype’s growth is coming at the expense of traditional carriers. If all of Skype’s on-net traffic had been routed via traditional telcos, global cross-border telephone traffic would have increased 12 percent in both 2012 and 2013, much closer to historical growth trends. This finding suggests that demand for cross-border communications has not declined, but that an ever-growing number of callers have chosen to take telcos out of the equation.

FIGURE 7

Where Did the Missing Traffic Go?: The Skype Effect



Notes: Telephone traffic volumes for 2013 are projections. Skype traffic reflects on-net (Skype-to-Skype) cross-border traffic only, and excludes calls originated via Skype but terminated to the PSTN.

Source: TeleGeography

Moreover, while Skype is the most established competitor, it is far from alone in this segment. Messaging services are among the most popular smartphone applications, and several, including Skype, WhatsApp, Facebook Messenger, Viber, Line, Tango, Google Hangouts, and Samsung's ChatOn, have been installed more than 100 million times from just Google's online Play app store.

The PSTN is not going away (soon). While the use of OTT services will grow, and the number of international carriers will decline, the PSTN will be around for many years to come. No other communications or social networking service can match the global reach or ubiquity of the PSTN. While Facebook has approximately 1.2 billion monthly users, at year-end 2013, the PSTN connects just over 8 billion fixed and mobile subscribers.

Consolidation is coming. Industry participants have been predicting consolidation in the international voice market for years, and have been complaining about the slow pace of consolidation for almost as long. While the process has been slow, and its timing remains difficult to predict, consolidation is inevitable. The international voice market is crowded, offers narrow margins, presents no easy growth opportunities, and holds the prospect of a longer-term decline.

Consequently, a growing number of retail service providers, including many incumbents, will choose to get out of the business of transporting and terminating international voice traffic. Others will seek to steadily reduce their involvement in this market. The availability of an efficient and highly competitive wholesale international voice market means that telcos can provide international voice services to their retail customers without actually operating their own international voice network.

The process of consolidation has been slow, but the inexorable decline in per-minute prices and revenues make consolidation inevitable. While the international calling market will be around for many years to come, the number of participants must contract.

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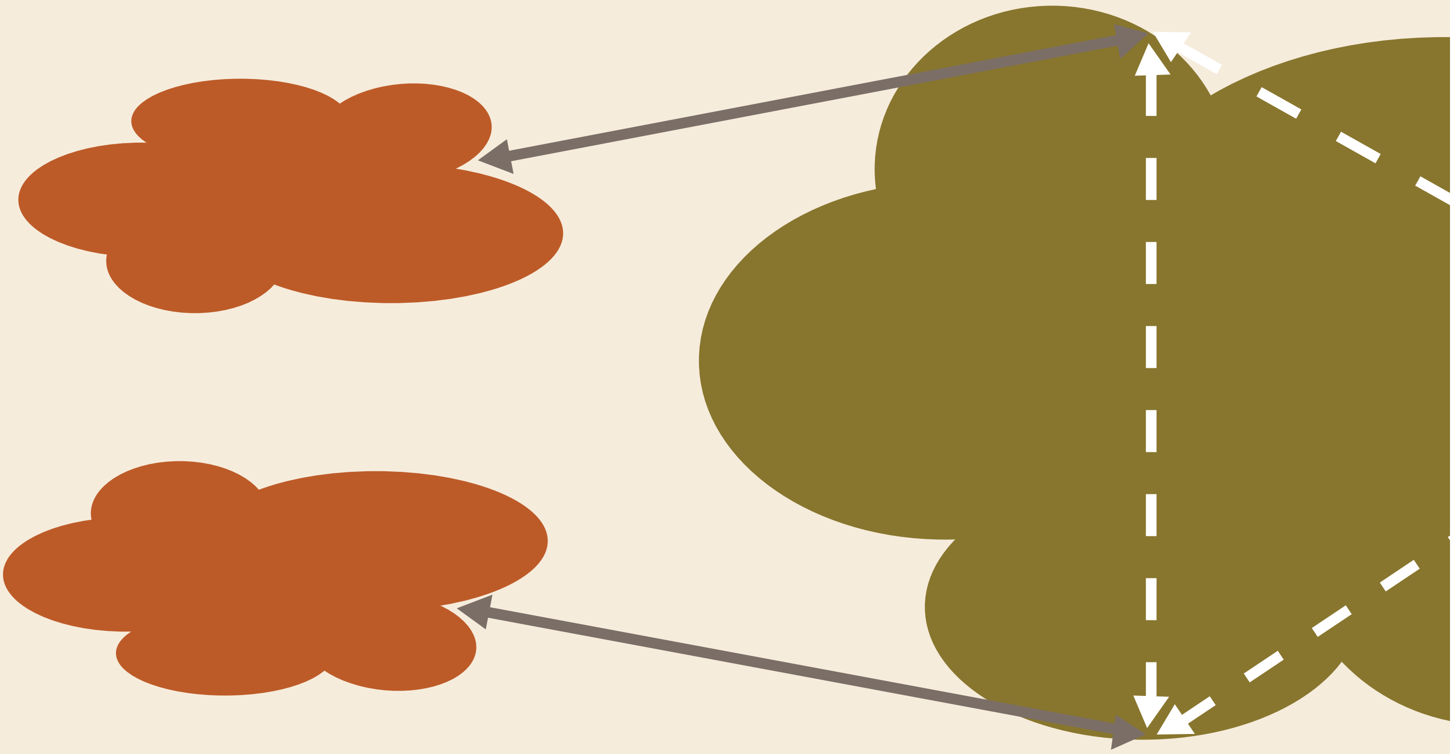
Collaborative Draft

The Internet Exchange Point Toolkit & Best Practices Guide

How to Maximize the Effectiveness of Independent Network Interconnection in Developing Regions and Emerging Markets

February 2014



Internet Society

Author final: February 2014

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Table of Contents

Executive Summary

THE BENEFITS OF MAXIMISING LOCAL TRAFFIC via independent Internet exchange points (IXPs) is well-recognised as essential for facilitating a robust domestic Information and Communication Technology (ICT) sector. From a public policy perspective, ensuring the presence of local IXPs has become an increasingly important priority in order to make sure that online services are equally accessible to all local users, as well as to enhance competitive opportunities, and generally improve the quality and affordability of Internet services.

So far IXPs have only emerged in about half the countries in the world, and these vary greatly in scale and effectiveness. To help accelerate the development of new and existing IXPs this Toolkit has been created to describe best practices for setting up and supporting the growth and enhancement of these crucial Internet facilities.

Ideally, IXPs are needed in every region in which different networks need to exchange local traffic. Deployment of IXPs are, however, sensitive to a variety of local constraints, and initiating and ensuring their efficient operation is not as simple as it would appear, especially in emerging markets (where IXPs are rare). Nevertheless IXPs are not a universal solution to a country's Internet and Internet access challenges. IXPs can and often do complement and improve the functioning of a local Internet ecosystem, but they cannot gloss over problems such as lack of competitively priced international or local capacity, nontransparent regulation, or poor energy supplies.

Research into the experiences of IXPs around the world was compiled for this report and the variety of case studies and data about IXPs presented in Section 6 amply demonstrate that: IP interconnection is still relatively new and there are a wide variety of fees, institutional models, business models,

IXPS ARE IDEALLY NEEDED IN EVERY /'CITY WHERE DIFFERENT NETWORKS NEED TO EXCHANGE LOCAL TRAFFIC. THEY ARE, HOWEVER, SENSITIVE TO A VARIETY OF LOCAL CONSTRAINTS, AND INITIATING AND ENSURING THEIR EFFICIENT OPERATION IS NOT AS SIMPLE AS IT WOULD APPEAR,.

policy rules, and technical strategies adopted by IXPs across the world. Some of the choices made may have constrained growth in interconnection; in other cases, alternative IXPs have emerged to fulfil needs unmet by the existing IXPs.

As a perusal of the case studies will show, IXPs vary immensely in scale (from a few 100Kbps of traffic to many Tbps), in pricing and in institutional models — from free to use, to nonprofit cost-recovery, to for-profit. There are few geographic trends that can be deduced aside from the commercial/noncommercial divide between the US and the rest of the world; but even this is now blurring with three European IXPs recently launching neutral membership-based services in the United States.

Nevertheless, in broad terms, three main models for operating an IXP have emerged:

1. the for-profit carrier neutral data centre as typified in the United States;
2. the neutral nonprofit member-owned organisation operating on a cost recovery basis, with infrastructure often hosted at a commercial data centre; and
3. the sponsored IXP, supported either by a ccTLD manager, a regulator, an NREN, or a large network operator.

In the last two years, there has been a notable surge in the number of IXPs in secondary cities, particularly in Argentina, Brazil and Indonesia, but also in secondary cities around the world, including Arusha, Adelaide, Buffalo, Cork, Durban, Edinburgh, Grenoble, Leeds, Lyon, Manchester, Manitoba, Mombasa, Port Harcourt, Saint Etienne, Toulouse, Turin, Winnipeg, and Zurich.

This trend reflects increasing local content consumption, decentralisation of content redistribution, and overall growth in bandwidth demand built on the steady extension of high bandwidth cable and wireless networks. While most of this growth has so far been in more developed economies, the same trends are becoming evident in emerging economies.

In addition, aggregating outbound traffic and avoiding tromboning is likely to be more critical in smaller secondary city markets where local ISPs typically face higher transit costs and longer routes to the desired content.

At the same time, the scale, reliability, and geographic scope of existing IXPs is growing. Many IXPs now offer multiple sites, remote peering, and 'partnership programmes,' often called service-provider or reseller plans. Such programmes leverage the benefits of the remote peering model and low cost national or regional backhaul, minimising technical support needs for the IXP and taking advantage of link aggregation.

Regional extension of networks is also being encouraged in countries where the IXP may operate its own links to a neighbouring city or country. In France, members of France-IX may freely use up to 100Mbps of connectivity between Paris and Lyon, Toulouse, Luxembourg, and Italy, after which they need to purchase their own links.

Global expansion of IXP presence is also a noteworthy recent trend. For example, Dutch IXP AMS-IX now operates an IXP in Curacao and Hong Kong, and is collaborating with KIXP to manage the Mombasa exchange in Kenya, while DE-CIX operates the UAE-IX, the Dubai exchange and DE-CIX New York. While increasing economies of scale and attracting new members are some of the motivations for this, demand for the skills and expertise developed at leading exchanges is another.

MANY IXPS HOST REGULAR SOCIAL, TECHNICAL, OR INDUSTRY EVENTS TO HELP BUILD THE LOCAL COMMUNITY OF PEOPLE INVOLVED IN PEERING.

Another feature of many IXPs is the presence of domain-name server mirrors for a variety of gTLDs and ccTLDs. However, surprisingly few IXPs offer a wider variety of shared services such as time servers, CERT, and software mirrors.

It is also noteworthy that policies that promote multilateral peering are present among a significant number of IXPs on either mandatory terms or incentivised through discounts on the port fee for the invited party. The majority of IXPs, however, also offer bilateral peering and VLAN services and of late, a few are beginning to offer VoIP or GRX type services.

Many IXPs also host regular social, technical, or industry events to help build the local community of people involved in peering and add another membership benefit. Twinning programmes (programmes in which experienced IXPs partner with developing IXPs) to support emerging IXPs have also been adopted by some of the larger exchanges such as those in London, Amsterdam, and Stockholm. Some IXPs also have created positions for policy staff in order to inform and educate local and global policymakers.

A significant number of IXPs are still operated without charge; however, the majority of IXPs have pricing for participation ranging from simple joining free to charges almost equalling the cost of transit. We have seen that there is great variability in fees, especially for smaller emerging country IXPs, many of which may have donated space and equipment, and so are able to minimise fees to attract members before moving on to achieving a cost recovery position.

A SIGNIFICANT NUMBER OF IXPS ARE STILL OPERATED WITHOUT CHARGE; HOWEVER, THE MAJORITY OF IXPS HAVE PRICING FOR PARTICIPATION RANGING FROM SIMPLE JOINING FREE TO CHARGES ALMOST EQUALLING THE COST OF TRANSIT.

The most important variable in IXP pricing is port speed. This may need to be balanced against membership fees (if any) or setup fees (if any) as well as the backhaul costs of getting to the IXP and the availability of link aggregation and discounts for second ports to allow smoothing the costs as network needs grow (for example, a network needing 1.2Gbps could cost the same as 2X1Gbps ports or 1x10Gbps port without link aggregation).

In analysing the current costs for use of IXP services, 1Gbps and 10 Gbps ports are the most commonly available. A minority of IXPs have 100Gbps services and below 1Gbps, ports may not be available or may even be free. (See page 27, figure 4.6, for the annualised port cost for 1 and 10Gbps ports at a variety of IXPs in different locations around the world.) There is greater variability and inconsistency in charges for 10Gbps ports.

The case studies and data samples provided in this report draw on information from a variety of sources, including the IXP websites, national ICT market profiles, and personal interviews for this study with IXP managers. In the course of gathering this data, researchers found little consistency in the presentation of basic information on IXP websites. Few IXP websites in emerging markets provide the three main data points: pricing, membership policies, and peers lists. Traffic statistics are also missing from many sites while some may show disaggregated data with the traffic history of each network connected to the exchange. In other cases, information may be buried in a hard to find web link or may not be current. Overall, only a small minority of IXPs operate websites that fulfil the basic requirements of a prospective peer for up-to-date, easily accessible information.

Further case study information and additional materials can be found on the IXP Toolkit portal at **http://www.IXPToolkit.org**.

* Note about releasing this “Collaboration Draft” of the Toolkit and Portal. We plan to enhance and amplify many areas of the Toolkit in April, when we release v.1.0 of the Toolkit. Thus, the release of the *IXP Toolkit & Best Practices Guide,* now, as a “Collaboration Draft.” More input from the community is essential. The Toolkit Portal (**www.ixptoolkit.org**) is meant to be a more detailed resource, and we also are asking for continuous feedback and information from the community. Feedback about the Toolkit and Portal can be sent to **feedback@ixptoolkit.org**.

Acknowledgements

THIS DOCUMENT WAS DEVELOPED BY A long list of individuals and from consultations with many experts. We will cite proper acknowledgments upon release of v.1.0 in late April. For now, we offer a preliminary "thank you" to everyone we have spoken with, worked with, and may come back to for more data.

Introduction

An Internet Exchange Point (IXP) is simply a physical location where different IP networks meet to exchange traffic with each other with copper or fibre cables interconnecting their equipment, usually via one or more Ethernet switches. They keep local traffic local.

The benefits of access to these local traffic exchange facilities are many, and are described in detail further below. IXPs are now well recognised as a vital part of the Internet ecosystem,[1] essential for facilitating a robust domestic ICT sector. From a public policy perspective, ensuring the presence of local IXPs has become an increasingly important priority in order to make sure that online services are equally accessible to all local users, as well as to enhance competitive opportunities, and generally improve the quality and affordability of Internet services.

IXPS ARE ONLY PRESENT IN ABOUT HALF OF THE WORLD'S COUNTRIES, AND EVEN WHERE THEY ARE PRESENT, MANY ARE NOT FUNCTIONING TO THEIR FULL POTENTIAL.

Nevertheless IXPs are only present in about half of the world's countries,[2] and even where they are present, many are not functioning to their full potential. Most cities could benefit from the presence of an IXP, but even large, highly industrial

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[1] See for example, the OECD's recent report on Internet Traffic Exchange: http://www.oecd-ilibrary.org/science-and-technology/internet-traffic-exchange_5k918gpt130q-en

[2] https://prefix.pch.net/applications/ixpdir/summary/

countries such as Canada only have a handful of IXPs. It turns out that IXPs are actually quite sensitive to a variety of local constraints. Initiating them and ensuring their efficient operation is not as simple as it would appear based on their evident benefits, especially in emerging markets (where IXPs are rare).

However IXPs are not a universal solution to Internet challenges in a country. They can complement and improve the functioning of other parts of the Internet ecosystem such as by providing a more competitive environment for purchasing capacity and offloading traffic from congested international links, but they cannot address problems such as lack of competitively priced international or local capacity, non-transparent regulation, or poor energy supplies. For further details on such issues, see the Internet Society report entitled *Lifting Barriers to Internet Development in Africa.*[3] To help accelerate the development of IXPs this Toolkit has been created to describe best practices for setting up an IXP and supporting the growth and enhancement of existing IXPs.

IXPS ARE NOT A UNIVERSAL SOLUTION TO INTERNET CHALLENGES IN A COUNTRY. THEY CAN COMPLEMENT AND IMPROVE THE FUNCTIONING OF OTHER PARTS OF THE INTERNET ECOSYSTEM SUCH BY PROVIDING A MORE COMPETITIVE ENVIRONMENT FOR PURCHASING CAPACITY, AND OFFLOADING TRAFFIC FROM CONGESTED INTERNATIONAL LINKS, BUT THEY CANNOT ADDRESS PROBLEMS SUCH AS LACK OF COMPETITIVELY PRICED INTERNATIONAL OR LOCAL CAPACITY, NONTRANSPARENT REGULATION, OR POOR ENERGY SUPPLIES.

To improve understanding of IXP dynamics, the Toolkit aims to address the following key themes and issues:

- How IXPs make countries and regions more economically and technically autonomous, including the role IXPs play in improving regional interconnection, fostering development of local content and culture and improving information security.
- The role of IXPs as 'nerve centres' of the networks that comprise the Internet that help accelerate the spread of Internet services, and improve access to critical Internet resources.
- Learning from well-established IXPs in both developed and developing countries with a view to localising, and replicating the most effective strategies for IXP development in other, often smaller and less developed countries and cities.
- Identification and explanation of the policy and regulatory environment needed to ensure the viability and efficient functioning of IXPs. This includes analysis of the role played by the main stakeholders – the Internet industry, government, civil society and the public.

A key part of the Toolkit is a methodology that is intended to assist in guiding strategy for establishing new IXPs and benchmarking the progress of existing IXPs. A key aspect is to identify constraints that IXPs commonly face in growing. In this respect the Internet Society hopes that others will join in the process of improving the Toolkit and that the document will generate debate about how IXPs can best reach the next 'level' in order to fully benefit from the impact of maximal interconnection.

The Toolkit makes extensive use of case studies and IXP data that provide an illustrative survey of different types of IXPs from around the world. These case studies and basic data are presented at the end of the document. Development of the Toolkit has taken place in consultation with IXP experts, network operators, and other relevant practitioners who were provided with early drafts for review and comment. The intention is that this will be a living, iteratively refined document and that reader comments will be used to refine it.

The benchmarking methodology developed and outlined in detail in the document is to be tested with twelve selected IXP initiatives. Wider testing will take place if other IXPs choose to participate in the online self-assessment opportunity. We welcome comments and feedback on the IXP Toolkit, the methodology found in this Toolkit, and the IXP Toolkit Portal (www.ixptoolkit.org). Send your feedback and comments to **feedback@ixptoolkit.org**.

The Toolkit is aimed at all parties interested in IXPs (ICT market regulators, network operators, IXP managers, and content providers) and is designed for those who may not have deep technical knowledge of the intricacies of Internet traffic exchange.

Examples of specific products and services mentioned in this document do not imply endorsement by the Internet Society or the authors of the Toolkit.

[3] http://www.internetsociety.org/doc/lifting-barriers-internet-development-africa-suggestions-improving-connectivity

1. The Role of Internet Exchange Points

THE INTERNET IS NOT A SINGLE ENTITY, BUT is made up of tens of thousands of independent networks[1] that communicate with each other using a common protocol (TCP/IP). As such, the key task of a network operator is to ensure that its users are cost-effectively, rapidly, and securely interconnected with any other point on the Internet – be it a website on their own network or a user connected to another network in the same city, or in a distant part of the world.

In the quest for the shortest (fastest) and lowest cost routes between two local points on the Internet, the most effective strategy for networks that exchange traffic is to set up direct physical links between each other. When many networks are in the same location, however, establishing direct links would be an expensive process, both in terms of capital and human resource costs for maintaining separate links to each network. This constraint has led to the emergence of shared hubs, usually called Internet Exchange Points,[2] through which local networks are able to connect with each other simply by establishing a single physical link to the exchange point (figure 1.1, following page).

To illustrate this further, we can use the following example. As shown in figure 1.2 (following page), three local networks connected to the Internet are able to pass traffic between each other via the 'upstream' Internet.

But if two of the networks are close to each other in the same city or country, it is usually better to use a separate connection

[1] ASN data indicate that there were over 44,000 active autonomous networks in mid-2013. See http://www.potaroo.net/tools/asn32/. Networks generally use ASNs to communicate with each other, and are critical to certain Internet protocols. ASNs are assigned by regional Internet registries (RIRs).

[2] While there is no formally agreed naming convention, the most commonly used terms are *IXP, IX,* or *exchange point,* often shortened to *exchange.* IXPs are also called *INXs, Network Access Points (NAPs), Peering Exchanges, PIC, PIT,* and *PTT.*

for local traffic between the two networks rather than pay for transit and international links, as shown below for ISP A and B in figure 1.3.

However, when there are at least three[3] local networks that exchange traffic with each other, it is more efficient to set up a hub (the IXP) to which each network can connect. Figure 1.4 shows how three ISPs would use a local IXP to route their local traffic. An IXP can thus be viewed as the centre of a group of local networks that makes it possible for local traffic to traverse through a single connection from each network to the hub.

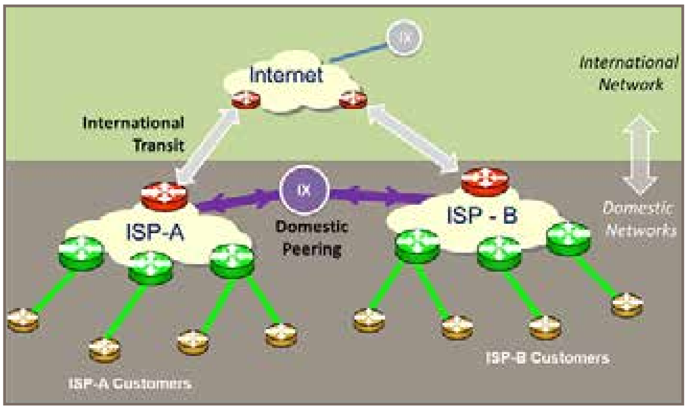

Figure 1.1. Internet Exchange Point Model 1 (*Source: http://mobileapps.gov.kn/?q=node/14)*

IN THE QUEST FOR THE SHORTEST (FASTEST) AND LOWEST COST ROUTES BETWEEN TWO LOCAL POINTS ON THE INTERNET, THE MOST EFFECTIVE STRATEGY FOR NETWORKS THAT EXCHANGE TRAFFIC IS TO SET UP DIRECT PHYSICAL LINKS BETWEEN EACH OTHER.

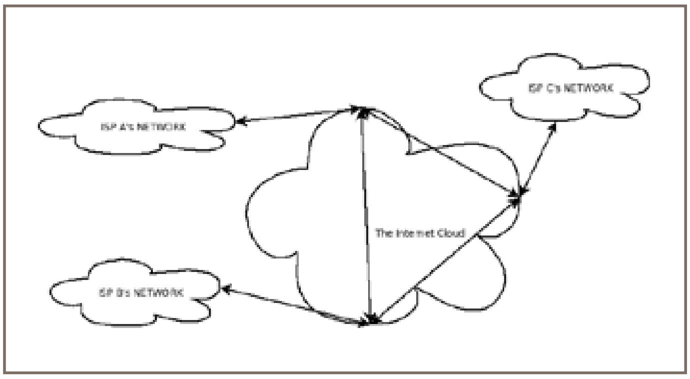

Figure 1.2. Internet Exchange Point Model 2 *(Source: Mike Jensen, 2013)*

This connection to the hub speeds up local traffic by minimising the number of network hops needed to reach other local networks, avoiding costly multiple direct links being set up between each network. Connections between local networks become much more responsive because of the reduced latency (often up to 10 times) in the traffic which has to make fewer hops to get to its destination, dramatically improving the end-user experience when interacting with local networks. This is similar to the development of airport hubs where many different airlines are served. At these locations, airlines exchange passengers between flights in much the same way that networks exchange traffic across the IXP.

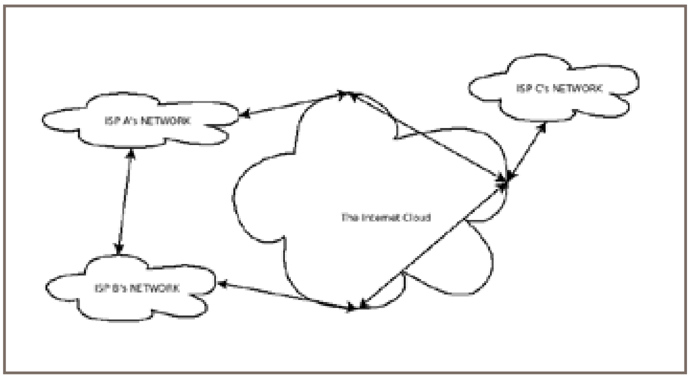

Figure 1.3. Internet Exchange Point Model 3 *(Source: Mike Jensen, 2013)*

In this respect, the primary roles of an IXP are to improve network performance by keeping local Internet traffic local and to reduce the costs associated with traffic exchange between networks. This creates a 'virtuous circle,' resulting in several important benefits and spinoffs from the IXP:

1. More bandwidth becomes available for local use because of the lower overall costs of local capacity.
2. Expensive (and often congested) international capacity is freed up when the local traffic is offloaded from the link,

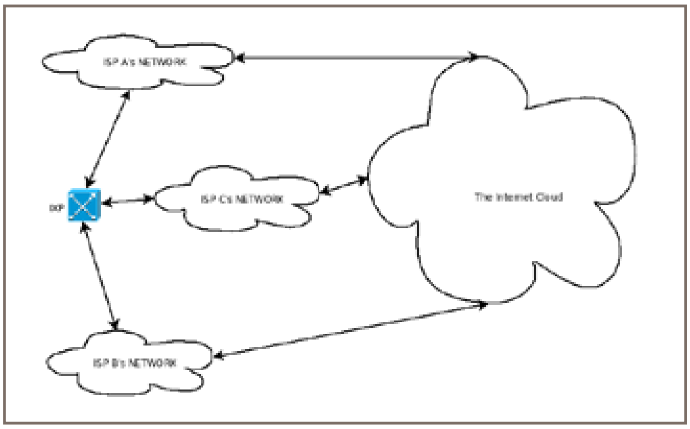

Figure 1.4. Internet Exchange Point Model 4 *(Source: Mike Jensen, 2013)*

[3] The precise number of local networks needed before an IXP makes sense depends greatly on the relative size of the individual networks, the overall size of the market, the local infrastructure available, and thus the amount of local traffic generated by each network. But if there are five networks present, an IXP can almost always be justified. In small island economies, just two access provider networks may be sufficient in order to reduce long-haul traffic costs and to promote traffic exchange with local content networks.

improving international access for local users (and vice-versa for foreign networks connecting into the country).

3. Networks can make substantial cost savings by eliminating the need to put all traffic through more expensive long-distance links to the rest of the world. Networks can pass on these cost savings to their users and/or use the savings to reinvest in improving and growing their networks.

4. National economies benefit by reducing the export of capital offshore because local networks pay less to international providers for traffic. From an economic development perspective, this means more capital is available to be invested locally to develop the domestic economy.

5. Increasing the critical mass of the local Internet sector present at the IXP means that international and national providers are encouraged to build their own links to the IXP due to the larger market resulting from aggregation of traffic at the IXP from different networks; this local aggregation also further reduces off-shore capital flows.

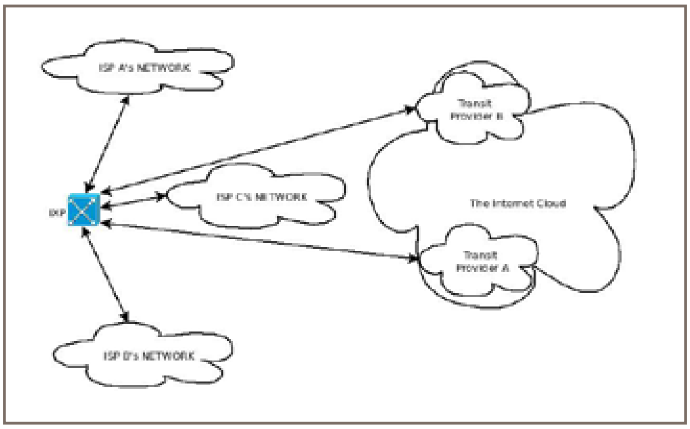

Figure 1.5. Internet Exchange Point Model 4 *(Source: Mike Jensen, 2013)*

As a result, IXPs can also become a location for local networks to source their international capacity, thus eliminating the need for multiple physical links between local and international suppliers (figure 1.5). In this respect, IXPs help to encourage the development of local telecom infrastructure such as national and international fibre cables.

6. When multiple international carriers are present at the exchange, the Internet also becomes much more reliable for local users because the connecting local networks can spread their international capacity needs across more than one link or quickly switch providers if one goes down.

7. International and regional transit capacity unit costs are also minimised because of the more competitive market that is created when multiple off-shore operators are present at the IXP. Evidence has shown that more choices in transit suppliers available locally results in a more competitive transit market. An additional advantage in the IXP environment is that it substantially reduces transactional costs in switching suppliers. Although there may be constraints on switching suppliers contained in service contracts, if a network operator decides to switch transit providers at an IXP, this can be accomplished in a matter of minutes and without physical intervention, simply by changing a setting on the router. Without the IXP, such a switch would involve having a new physical circuit installed, thereby incurring significant waiting time and additional financial charges. This market fluidity that is made available through the use of an IXP encourages greater price competition among transit providers, further driving down costs for provision of Internet access.

NETWORKS MAKE SUBSTANTIAL COST SAVINGS BY ELIMINATING THE NEED TO PUT ALL TRAFFIC THROUGH MORE EXPENSIVE LONG-DISTANCE LINKS TO THE REST OF THE WORLD.

8. Development of new local content and services that benefit from higher-speed low-cost connections become more attractive to establish. Download speeds for websites improve dramatically, when they are connected to the IXP rather than hosted internationally creating greater confidence in the ability of local networks to deliver content; this improvement can result in new or existing businesses expanding from the increased value in delivering local content. There are also benefits gained from the increased economies of scale and the larger markets created by the broader user-base available via the IXP. In addition, more advanced local services that require low-latency connections, such as VPNs, multimedia streaming and VoIP, become more viable. Mobile operators that run local traffic through IXPs see speeds increase almost immediately after an IXP has been set-up. When links between local networks rely on satellite connections (as is the case in some developing countries, especially outside the major cities), many of these services cannot be provided with acceptable quality. As a result, a local terrestrial interconnection point is critical to ensuring their availability to users.

9. With sufficient levels of participation at the IXP, a variety of shared services also become viable to host at the IXP. These include:

   - Caches/mirrors of bandwidth-intensive international content, such as YouTube (via its own Google Global Cache) and other sources through third-party content delivery networks such as Akamai. Such caching acts to reduce international bandwidth requirements and costs.[4] Software caches and other types of static content can also be hosted at the exchange to further reduce the loads on long-distance links.
   - DNS servers (root name servers and ccTLD name servers) also increase the responsiveness of the network to local users and improve resilience in the case of international connectivity interruptions.
   - A variety of shared administrative and technical facilities for network operators, such as time servers, routing and traffic measurement facilities, and public key infrastructure (PKI).
   - The staff from different networks that interact through the IXP often share experiences formally and informally online and during meetings hosted by IXP participants. Technical human-resource development potential in this respect has been notable at many IXPs around the world.
   - The circle of technical experts across regions grows and "human networks of trust" are established among experts, establishing a virtuous circle of experts who train and reinforce each other. These human networks should not be underestimated as they provide the basis for collaborative interaction, in which experts are able to troubleshoot, find communities, and solve problems within their circle. Face-to-face introductions are critical in the IXP community. Many of the first Internet connections in developing economies were established through these human technical networks, and experts continue to give back to the community.

[4] For example, Google estimates that up to a 70% reduction in bandwidth requirements for accessing Google services can be achieved by implementing the Google Global Cache. locally. This further reduces off-shore capital flows and improves the end-user experience when accessing this content (through lower latencies).

1.1. Patterns of IXP Distribution, Membership, and Geographic Scope

ONCE A NATIONAL EXCHANGE POINT HAS BEEN established, additional exchanges might then be set up to serve smaller geographic areas where it is cost effective to keep traffic within the local area. Another reason to establish exchanges to serve smaller areas may be to deal with deficiencies in national infrastructure, such as high cost, lack of network reliability, or dependency on satellite-based links. This can be particularly relevant in developing countries where national backbone infrastructure is poorly developed, congested, or costly — a common situation when cities are still connected via satellite links or when monopoly pricing is in force. As a result of such factors, IXPs are often useful in secondary cities as well.

According to Packet Clearing House,[1] in mid-2013 about 45 countries had more than one IXP and nine countries had 10 or more IXPs — in order of rank: United States, Brazil, France, Japan, Russia, Australia, Germany, the United Kingdom, and Argentina. As can be seen from most of the countries on this list, these are generally the larger or more densely populated countries with mature Internet infrastructure markets, although there are some notable absences in the list, such as Canada, China, India, and Mexico.

[1] https://prefix.pch.net/applications/ixpdir/summary/

Region	Country	City	Exchange Name	Number of Participants
Europe	Netherlands	Amsterdam	Amsterdam Internet Exchange	472
Europe	Netherlands	Amsterdam	Amsterdam Internet Exchange	472
Europe	United Kingdom	London	London Internet Exchange	407
Europe	Russia	Moscow	Moscow Internet Exchange	344
Europe	Germany	Frankfurt	Deutscher Commercial Internet Exchange	325
Europe	Netherlands	Amsterdam	Netherlands Internet Exchange	294
North America	United States	Los Angeles	One Wilshire Any2 Exchange	216
Europe	Poland	Warsaw	Polish Internet Exchange	204
Latin America	Brazil	São Paulo	Ponto de Troca de Tráfego Metro	167
Europe	United Kingdom	London	XchangePoint London IPP	166
North America	United States	Seattle	Seattle Internet Exchange	151
Africa	South Africa	Cape Town	Cape Town Internet Exchange	150
Europe	Germany	Frankfurt	KleyReX Internet Exchange	138
North America	United States	New York	New York International Internet Exchange	137
Europe	France	Paris	Paris NAP	133
Europe	Switzerland	Zurich	SwissIX	132
Asia-Pacific	Japan	Tokyo	Japan Internet Exchange	125
North America	Canada	Toronto	Toronto Internet Exchange	116
Europe	United Kingdom	London	London Network Access Point	114
Europe	France	Paris	Free-IX	106
Asia-Pacific	Australia	Sydney	PIPE Networks Sydney	105
Europe	Austria	Vienna	Vienna Internet Exchange	105
Asia-Pacific	China	Hong Kong	Hong Kong Internet Exchange	104
Europe	Italy	Milan	Milan Internet Exchange	102

Table 1.1. IXPs with more than 100 Members *(Source: ADD)*

As shown in the figures 1.6 and 1.7 (following page), more than 350 IXPs are now operational worldwide.[2] In general, at least one well-functioning IXP is likely to be needed in each country; however, only 99 countries have established operational IXPs so far. As would be expected, developing countries have generally lagged behind the rest of the world in establishing IXPs, and Africa is the region with the fewest (only 21 of the 53 nations have them as of the end of 2013).

[2] https://prefix.pch.net

The number of participants at an IXP varies greatly, but the 11–30 member IXP is the most common size (figure 6.8, following page).

Table 1.1 lists the 23 IXPs with more than 100 participant networks. They are mainly located in Western Europe and North America although a few of these also exist in some cities of other regions, namely CapeTown, Hong Kong, Moscow, Sao Paulo, Sydney, Tokyo, and Warsaw. If the membership of the three London IXPs is combined, London and the UK constitute the location with highest absolute levels of IXP participation.

ONLY 99 COUNTRIES HAVE ESTABLISHED OPERATIONAL IXPS SO FAR. AS WOULD BE EXPECTED, DEVELOPING COUNTRIES HAVE GENERALLY LAGGED BEHIND THE REST OF THE WORLD IN ESTABLISHING IXPS, AND AFRICA IS THE REGION WITH THE FEWEST.

Figure 1.6. Map of IXPs around the World *(Source: Telegeography)*

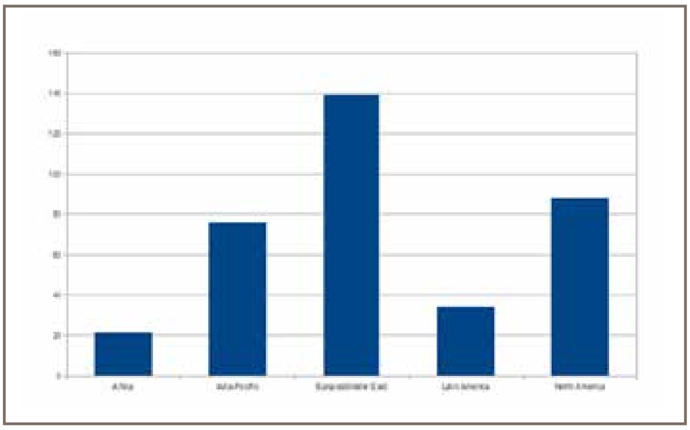

Figure 1.7. Regional Distribution of IXPs *(Source: PCH)*

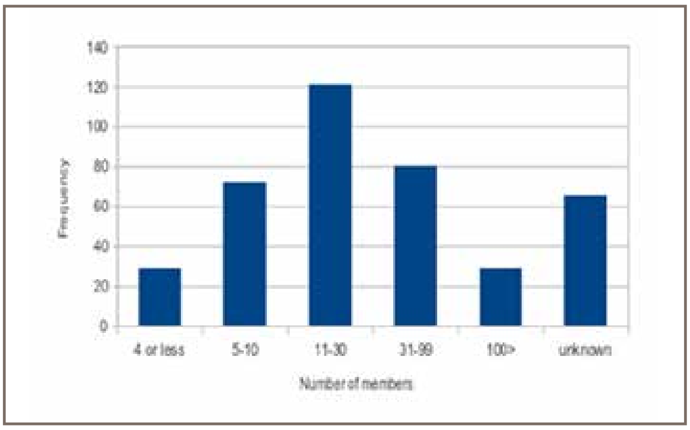

Figure 1.8. IXPs by Number of Members *(Source: PCH)*

2. How IXPs Are Managed: Institutional and Operational Models

A VARIETY OF INSTITUTIONAL AND OPERATIONAL models have been adopted to manage IXPs; these fall roughly into five categories:

1. Not-for-profit independent organisation
2. Industry association of ISPs
3. Operator-neutral commercial/for-profit company
4. University[1] or government agency
5. Informal association of networks

Except for the United States, where the for-profit commercial model largely prevails, the most common of these models today are IXPs operated either by a nonprofit independent organisation or an industry association of ISPs. The former is particularly common in Europe where many IXPs are typically mutual, not-for-profit organisations whose members collectively 'own' the facility. Operating costs are shared among members who usually pay a one-off joining fee and a monthly, quarterly or annual port fee. The fee may be determined by the capacity of their connections to the IXP or less commonly, by the volume of traffic that is passed across the exchange.

Commercial IXPs are more prevalent in the United States and are operated by specialized peering exchanges or data centre companies such as CIX, Any2, and Equinix. These types of specialist companies are almost always provider-neutral and do not compete with networks in providing services to end users.

[1] The role played by National Research and Education Networks (NRENs) and universities has been extremely important for IXP, local technical capacity, and university network development. We plan to provide more information about the role of universities and NRENs in the next iteration of the Toolkit. See www.nsrc.net as an example of assistance to the development of NRENs and IXPs, as well as excellent background information about the development of the Internet in some countries.

A small number of IXPs may also be "free to use," with no port fees for participants, simply relying on donations of premises, equipment and staff from large sponsors. The largest such example is SIX in Seattle, Washington. This practice is also common in the initial stages of IXP formation where founding members are trying to gain critical mass, such as the Calgary IXP (YYCIX), which has just been formed and is offering free services to operators for the first year.

Carrier/incumbent IXPs are often called "phony IXPs" where the dominant Internet or telecom operator provides local exchange points in one or two major cities. In these cases, the IXP is more a marketing term used by the commercial transit provider as it is really no more than a router offering peering as a means of marketing local and/or international transit services. These types of IXPs are unlikely to scale as few other major carriers are likely to be interested (or encouraged) to participate. These "phony" IXPs can be fairly easily identified because they charge for traffic volume exchanged or levy a price per port that approaches international transit costs.

University run IXPs are often tied to NRENs and run by a team of technical experts. These IXPs are an excellent incubator for technical assistance and for knowledge sharing. VIX in Vienna and MOZ-IX in Mozambique are examples of University run IXPs.

Operational and Routing Policies

Operating policies are relatively uniform across most IXPs in terms of the type of traffic that is allowed, although there may be some variations that reflect local conditions. In order to connect to an IXP, networks may be required to be recognised legal entities and must be licensed to operate (if a license is required).

Increasingly, any entity that needs to exchange traffic with other IXP members is allowed to join. This option allows the operators of private networks that provide public services (such as hosting providers, government departments or banks) to take advantage of the benefits of being present at an IXP. In some cases, allowing large end-user-networks to peer at the IXP can be a sensitive issue for corporate Internet-access providers present at the IXP who may feel that the IXP is competing with their services. However, the value of an Internet Exchange is proportional to the number of members, so the more 'non-licenced' networks that join, the greater the benefits to all in terms of performance, resiliency and cost of international capacity required by individual members.

There have been two common models for IXP operation. The older, now deprecated model is that the IXP exchanges all traffic between participating networks inside a single router. This is usually called a Layer 3 IXP. The most common current model is the Layer 2 IXP in which each network provides its own router and traffic is exchanged via an Ethernet switch. The Layer 3 model may be less costly and simpler to establish initially, but it is less scalable and limits the autonomy of its members who have less control over with whom they can peer and who are dependent on a third party to configure all routes correctly and keep routes up-to-date. The latter requires greater technical skills from the IXP staff. The Slovenian IXP (SIX) is hosted at the Slovenian Advanced Research and Education Network (ARNES) and is an example of a Layer 2 IXP. Members connect their remote routers via fibre. The latter is cost-effective for both SIX and its members. Colocation requirements are much less demanding, as there is no need for remote hands, and out-of-band access. This model, however, demands a secure Layer-2 infrastructure. Remote equipment should not put the IXP in jeopardy, and all ports should be configured with appropriate port security mechanisms.

MULTILATERAL PEERING IS AN EFFICIENT AND COST-EFFECTIVE METHOD OF REACHING MULTIPLE PEERS AS NO TRAFFIC CHARGES APPLY AND ROUTE-SERVERS MAKE IT EASY TO CONNECT WITH NETWORKS THAT HAVE AN OPEN PEERING POLICY BECAUSE IT IS NOT NECESSARY TO MAKE INDIVIDUAL AGREEMENTS WITH EACH MEMBER OF THE IXP.

Requirements for traffic-routing agreements between IXP members varies depending on the IXP's institutional model and other local policies. A few IXPs require mandatory multilateral peering, in which anyone who connects with the IXP must peer with everyone else who is connected. Perth IX is one of the few examples of this model that usually creates a disincentive for large access providers to interconnect because these usually wish to only peer with other large operators

Multilateral Versus Bilateral Peering

Multilateral peering is an efficient and cost-effective method of reaching multiple peers as no traffic charges apply and route-servers make it easy to connect with networks that have an open Peering Policy because it is not necessary to make individual agreements with each member of the IXP. Since multilateral peering allows networks to interconnect with many others through a single port, it is often considered to offer less capacity than bilateral peering. However, the benefit of multilateral peering is that it can provide access to a considerable number of other networks.

Many smaller networks, or those networks that are new to peering, find multilateral peering at exchange points an attractive way to meet and interconnect with other networks. Larger networks may also utilise multilateral peering to aggregate traffic with a number of smaller peers or to conduct temporary low-cost trial peering. Other networks may also enter private peering arrangements with each other where a separate physical link (outside the IXP) is established directly between the two networks.

MANY SMALLER NETWORKS, OR THOSE NETWORKS THAT ARE NEW TO PEERING, FIND MULTILATERAL PEERING AT EXCHANGE POINTS AN ATTRACTIVE WAY TO MEET AND INTERCONNECT WITH OTHER NETWORKS.

Some IXPs require each network to enter into bilateral peering arrangements with each of the other network members (discrete Border Gateway Protocol (BGP) sessions across the exchange fabric). Other IXPs may also limit the use of the facility for transit traffic. Most IXPs, however, provide the option of either multilateral or bilateral peering or a mixture of the two and do not restrict the nature of the transit or peering arrangements made between members.

Flexible peering policies, which permit the coexistence of multilateral and bilateral peering arrangements, allow peers at an IXP to enter into separate bilateral peering or transit agreements. It is also usually acceptable for IXP members to restrict (filter) traffic originating from or destined for any member's network in accordance with the member's policies. Multilateral peering also allows small- and medium-sized networks in many emerging markets to operate on a level-playing field rather than be 'allowed-in' because of the size of their network. See the case study on BIX Hungary on page 68 (6. Case Studies and IXP Facts by Country).

Other important policies and strategies that IXPs and their member networks normally adopt include:

- Payment for the cost of and management of the link between the network and the IXP, including a redundant link if required, is usually the responsibility of the member. However, some IXPs have adopted policies to level these costs so that each member pays the same amount to access the IXP. This flat rate helps to ensure that commercial operators that happen to be located closer or are co-located in the same building as the IXP do not have an unfair advantage. JINX in Johannesburg had this policy in effect for some time, but found that it was ultimately constraining growth. Instead, JINX elected to charge an annual "hosting fee" to the network that hosts the exchange to balance the advantage.
- Passing traffic to the IXP destined for networks that are not members of the IXP is usually not acceptable unless transit is allowed and specific agreements with the IXP and the members providing transit are made.
- Monitoring or capturing the content of any other member's data traffic which passes through the IXP is limited to data required for traffic analysis and control; members usually agree to keep this data confidential.
- Mandatory provision of routing information and looking-glass sites.
- Routing and switch-port information can either be made public or restricted to members.
- Security response provisions for infrastructure failures, routing equipment failures, and software configuration mistakes.
- IXPs do not normally compete with their members. They normally do not provide transit facilities, for example, although in the case of interlinked IXPs, they may do this at low speeds. See the France-IX case study on page 65 (6. Case Studies and IXP Facts by Country).

The pros and cons of the different IXP business and operating models are discussed further starting on page 34 (5. Benchmarking IXPs: A Methodology for Assessing Performance).

MULTILATERAL PEERING ALSO ALLOWS SMALL- AND MEDIUM-SIZED NETWORKS IN MANY EMERGING MARKETS TO OPERATE ON A LEVEL-PLAYING FIELD RATHER THAN BE 'ALLOWED-IN' BECAUSE OF THE SIZE OF THEIR NETWORK.

3. Getting Started

This section provides a 'how to' operational guide to setting up an IXP, drawing on the case study examples and providing a checklist/summary table of requirements. This section will be amplified via additional outreach and feedback on the report. A simple checklist is provided at the end of this section.

First Steps

The first step in considering the establishment of an IXP is determining the need. This determination is based on a provisional assessment of the number of providers (most likely at least three) that are willing to support and use the IXP, the amount of traffic that would be exchanged, and the likely cost of setting up and connecting to the IXP. A meeting of local network operators and technical advisers should be sufficient to establish this. It is worth noting here that setting up an IXP is "80% human and 20% technical" — without an environment of cooperation between ISPs, an Internet exchange will not be successful.

Building community support and expertise

If the outcome of the assessment proves positive, the next step is to build support for the project among all stakeholders and identify potential policy problems or market barriers to the establishment of an IXP. Such problems and barriers usually arise from either the potential members themselves or as a result of inappropriate government policies.

The establishment of a local IXP is often seen as a threat by competing commercial providers who may not be aware of the full advantages of collaboration and local traffic exchange. It may be important to engage local policy/regulatory officials to obtain their support or understanding of the benefit of the IXP. The latter was a successful tactic in Lesotho.

There can be other factors as well: lack of trust, a fear of making business less costly for (or even subsidizing) competitors, and concerns that *interconnection* means stealing of customers. Experts have suggested an anonymous survey as one way to manage this process. These issues will need some time to be managed, supported by awareness raising on the role of IXPs, before all the relevant parties may be in full support of the IXP. This stage can take months or even years in some cases. The average start-to-finish of community-building is a 2–3 year process.

There may also be outstanding issues regarding participation in the IXP when there is a dominant commercial Internet service provider in the market. Dominant providers may be resistant to participation or they may participate, but severely under-provision the link to the IXP. This under-provisioning is known as the "Thin Pipe Stratagem." In such a strategy, the customers of competing ISPs encounter slow connections to dominant provider's customers and understandably, the customers of the competing ISP fault their provider for the poor connection. This creates a strong incentive for users to switch to the dominant service provider. If unsolvable by other means, this problem may be cause for regulatory intervention, such as through infrastructure sharing or Significant Market Power (SMP) determinations. Opening the market to greater competition may be the most-effective long-term approach.

CONTINUED LOBBYING OF GOVERNMENT POLICY MAKERS AND REGULATORS CAN ULTIMATELY HELP TO OPEN MARKETS AND RELAX RESTRICTIONS ON NEW MARKET ENTRANTS.

Some network operators may also be concerned that IXPs could be overly complicated compared to their needs. This is especially the case for small network operators with only one connection to the rest of the Internet who may not have the technical expertise to implement multipath routing. This view may be amplified by contact with large developed-country IXPs that may have much more sophisticated switches and powerful routers. Equipment marketing agents can also contribute by proposing equipment that may not be appropriate for the needs of a small IXP.

To address these issues, further awareness raising and training activities may be necessary. At a minimum, potential members will need a staff member familiar with BGP used for routing between networks, and each network will need to have a publicly registered ASN for their traffic exchange, obtained from the relevant Regional or National Internet Registry (RIR/NIR). In view of the switch from IPv4 to IPv6 that is currently taking place, familiarity with IPv6 configuration and IPv6 capable equipment is also desireable.

Regulatory Issues

In most markets, IXPs are not regulated by any government policy. Most activity within an exchange is considered private and is free from government regulatory oversight. In many developing countries, however, government policies restrain the establishment of an IXP in both direct and indirect ways.

Because IXPs only exist where there are ISPs that need to exchange traffic, in many countries the presence of a monopoly service provider is probably the major reason for the lack of an IXP. Alternatively, the lack of an IXP may indicate the existence of a single player with monopoly power over certain infrastructure or rights of way, such as international gateways. If low levels of competition exist, networks may have little choice but to exchange domestic traffic via the dominant player rather than directly between themselves.

In the immediate term, there may be little that can be done by potential IXP members to address problems related to monopoly market power. However continued lobbying of government policy makers and regulators can ultimately help to open markets and relax restrictions on new market entrants. Without this type of activity, the dominant operator(s) will have little incentive to lower prices or improve services, and to have a fair chance of entering the market, new operators need fair access to the existing networks.

Aside from working to improve the enabling policy environment generally, the regulatory body can also play a more active role in assisting the establishment of IXPs. For example, in Lesotho and Serbia, approval for the IXPs was necessary through regulatory determinations to 'allow' them, while in Uganda the regulator assists in hosting the exchange.

Even where the market is open to more competition, incumbent telecom operators may still resist establishment or participation in an IXP. Unfortunately, the incumbent operator's views often carry great weight with regulatory authorities for a variety of reasons (such as close personal relationships, state shareholding in incumbent telecom operators or even outright corruption). The market position of the incumbent operator also influences many developing-country policymakers whose governments are often dependent on revenues from state shareholding in the operator. As a result, policymakers may be reluctant to sanction activities that are thought to limit the incumbent's profits, taking advantage of statutory or other licensing requirements that might arguably be applied to IXPs.

More often, the regulatory authority is, at least initially, unfamiliar with the technical and economic aspects of Internet facilities and ISP traffic exchange. IXP founders need to address this and ensure that policymakers, regulators and incumbent operators are aware that reducing the cost of Internet connectivity for domestic consumers will generate greater investment, more users, and greater international leased line revenues.

In view of these factors, some governments have made it mandatory for networks to use a common peering point (e.g., Chile, see www.nap.cl). While this may superficially seem to be a good policy, it may actually hinder growth by removing the incentives for a commercial network operator to competitively expand its connections beyond a single exchange.

Other government policies that may need examination for their dampening effect on strategies for the establishment of an IXP include any limitations on self-provisioning of links between network members and the IXP. Such policies may also include limitations on use of radio frequencies, on use of space on telephone poles, or on rights to dig up streets and lay cables (i.e., use of rights-of-way, way-leaves, and easements).

Defining the IXP's operational and management structure

Once the IXP's founding members have addressed the issues above, it will be necessary to decide on the appropriate management structure and policies as described earlier. This is most likely to be based on a form of independent nonprofit company, but local conditions will likely determine the precise structure. After deciding on the most appropriate institutional structure for the IXP, the required technical expertise will need to be identified and a technical committee established to design the IXP, assess costs, and find the most appropriate location to host it. An anonymous survey may be useful to help determine where to "host." Some members may not want to discuss this in a group setting, and an anonymous survey provides a way to do this.

IXP Site Selection

Deciding on a location likely will include an assessment of existing facilities that could be used, and then comparing the potential location options to the cost and effort involved in setting up a new independent facility. In many countries, costs associated with leasing space, financial resources, and hiring staff can be high. Hosting the IXP in an existing datacentre or carrier facility can substantially reduce start-up and operating expenses. Existing facilities that might be considered include the premises of telecom operators, the facilities of university networks (particularly suitable as neutral locations), carrier-neutral datacentres or facilities that support city emergency services.

The most important features of potential sites that would need to be examined are:

- *The location to host the IXP.* All involved parties must agree; without such agreement any of the other points below are moot. (If potential IXP members are at an impasse, an independent expert may be brought in to visit sites and provide an opinion.
- *Proximity to the networks of the potential members.* This may also depend on whether the IXP is to be centralised in one room, located in a campus of adjacent buildings or more widely dispersed across a broader area, such as by using fibre channel switched fabric.
- *Availability of electric power, including backup supply or generator.*
- *Availability of air-conditioning.*
- *Availability, capacity, and reliability of telecommunication links to the site.*
- *Access to fibre facilities.*
- *Ability to build antenna towers or dig trenches for fibre – access to rights-of-way.*
- *Ease of access.* Independent 24/7/365 access for IXP member staff is highly desirable.
- *Quality of security.* CCTV, 24-hour monitoring, fire and break-in detection is highly desirable.
- *Availability of ancillary equipment and services, e.g., equipment cabinets and telephones, and so forth.*

Business Plan Development and Financing

Once the design of the IXP and the site(s) have been identified, a more detailed business plan can be developed which covers set-up and maintenance costs, proposed revenues, and cost recovery projections.

To help establish IXPs where they do not exist in developing countries, financial support may be available from appropriate development agencies or donors. The World Bank and the Latin American Development Bank already have track records in this area. Since the financial assistance needed for the start-up costs of an IXP are relatively modest compared to the potential long-term economic benefits, a strong case usually can be made for development assistance. As the majority of IXPs are nonprofit facilities, financial aid can assist the growth of the market without distorting its natural development.

As the majority of the expenditure needed is on the initial training of staff to establish and maintain the facility, donor objectives in local capacity building can easily be met. A more severe problem with development financing from donors is excess funding, which can result in 'gold plating' the exchange — using high-end equipment with more capacity than needed and costly energy needs, making the IXP less sustainable in the long run. Estimates range for start-up from US$100.00 for an Ethernet switch and a free host site to $15,000.00–$30,000.00 with donated equipment, power costs, hosting, and other fees. Once the IXP is off the ground and exchanging traffic, then it can be steadily enhanced with additional services and facilities, and via staff training.

3.1. Summary of Best Practices in IXP Development

THIS SECTION SUMMARIZES BEST PRACTICES from the point of view of the primary stakeholder groups: the IXP itself, national policy makers and regulators, ISPs, CDNs, and end users.

The following national ICT policy-level support policies increase competition in order to drive down prices and improve the level of investment in local, national and regional infrastructure:

1. Mandating local loop unbundling and related facilities leasing.
2. Mandating provision of access to dark fibre and related connection conditions, notably pricing.
3. Imposing limitations on the market power of incumbent operators (often termed “Significant Market Power”).
4. Allowing self-provisioning of infrastructure by licensed network operators.
5. Reducing the cost and conditions of operator and spectrum licenses (such licenses often increase barriers to entry and, ultimately, costs to the end user).
6. Eliminating special revenue-raising taxes (these increase end-user costs and therefore reduce demand, e.g., sales taxes on communications and import taxes/custom duties on communication equipment).
7. Eliminating content-provider, foreign network (no local operations except exchanging traffic at the IXP), and IXP licenses where these are in place or being considered.
8. Mandating the sharing of essential facilities, telecommunication infrastructure, civil works and access to alternative infrastructure provided by transport and energy operators, especially for land-locked countries.
9. Addressing issues that limit the ability of infrastructure developers and Internet service providers to cross borders, particularly the need for harmonisation of regulations between neighbouring countries and the lack of clarity from governments about permissions for use of cross-border ROWs and areas designated as “no-man’s land.”
10. Promoting awareness of the need for all local carriers, ISPs and content providers to connect to IXPs so that the development of local content is encouraged and the aggregation of traffic is enabled, thus allowing developing regions to become locations to which the international providers wish to connect rather than continuing to be the ‘client’ regions where providers must pay all of the costs of connecting to global backbones.
11. Recognising the important role of the public sector in financing infrastructure development in remote and less population-dense areas that may not be initially profitable for private operators. Related to this consideration is the need for financing of redundant infrastructure in these areas to improve the reliability of service provision.
12. Increasing the support for information sharing and multistakeholder consultation to understand and address concerns of all affected parties in policy development and to build relationships and trust between the various players.
13. Increasing the level of support for relationship building, technical training, and skills development to ensure that network operators can more effectively use existing IXPs and quickly implement IXPs in the countries where these are not yet present.
14. Promoting awareness at the top levels of leadership within government, in regional governmental agencies, and in the international development assistance community, of the importance of IXP-related issues and of implementing policy changes necessary to promote IXP and Internet ecosystem development. National regulators also need special focus and specific awareness raising events to help build internal awareness about the importance of IXP development. These events could be attached to existing fora such as the regional regulatory association meetings.

For network and IXP operators, among the most important best practices include:

1. Holding forums, meetings, mentoring sessions and training workshops to build human capacity and especially to develop social networking and personal relationships between the staff of different network operators in order to build communities of trust. Such activities are particularly needed to bring in additional network operators who have not participated in information-sharing events and to promote the recruitment of volunteers and “champions” for the IXP.
2. Ensuring there is a staff position designated as ‘peering coordinator’ (within network operators) to ensure that network traffic is properly analysed for identifying peering needs and opportunities, evaluating potential peering locations, developing appropriate peering policies and negotiating the best peering terms.
3. Aggregating as much traffic as possible at IXPs to build critical mass, leverage economies of scale, and attract content providers.
4. Adopting simple IXP policies and fees that maximise potential membership. For example, IXPs that have mandatory multilateral peering policies are less likely to be successful due to the limited interest of international transit and content providers in participating in these exchanges.
5. Taking advantage of the benefits of using IXPs for voice interconnection between networks as the overall communications environment moves toward IP-based networks for both voice and data.
6. Promoting special peering relationships and transit traffic agreements with academic networks in order to help encourage human capacity development.
7. Adopting the use of tools such as PeeringDB and sFlow to help identify peering opportunities, potential peers, and peering locations.

SEE PAGE 76 (ANNEX 3) FOR A GENERIC LIST OF IXP TECHNICAL AND EQUIPMENT RECOMMENDATIONS. IXPS THAT HAVE BEEN IN OPERATION FOR SOME TIME MAY CHOOSE TO SEE EURO-IX’S IXP WISHLIST AT HTTPS://WWW.EURO-IX.NET/IXP-WISHLIST.

4. The Economics of IXPs

THE GENERAL BENEFITS OF THE PRESENCE OF IXPs have been described earlier in the Toolkit, however the economic incentive for network operators is often the most tangible benefit, and thus usually the initial motivation to join an IXP, or to assist in their establishment where there are none. Documenting the cost savings that can be achieved by exchanging local IP traffic within the country is often vital for making the argument to network operator decision-makers to make the investments needed to join or help set up the IXP.

Joining an IXP will be attractive if the cost of exchanging traffic locally is cheaper than purchasing international bandwidth (IP transit) from an upstream provider for routing the traffic overseas. Given that international bandwidth can comprise a significant portion of operating expenses for ISPs in developing nations,[1] an IXP can significantly reduce costs, resulting in lower Internet access subscription charges for users, provision of more bandwidth and making the costs saved available for increased network build-out.

The financial attractiveness of an IXP is influenced by several factors such as market structure and the volume of local traffic. Due to market structure, a significant amount of traffic may stay within an ISP's network (i.e., "on-net" traffic). In this case, typical of environments where only a few ISPs dominate the market, there may be little incentive to participate in an IXP. Another situation would be where most Internet traffic is destined to users or websites overseas. An IXP would be unlikely to ameliorate the necessity for international IP

[1] Historically developing nations have had to pay for the full cost of the circuit to overseas PoPs and addressing this has long been part of the Internet governance agenda.

transit, at least in the short run. It could be argued that these situations are characteristic of domestic market weaknesses, and untreated, are likely to impact the long-run sustainability of national Internet ecosystems. A healthy and competitive Internet market is critical for affordability and innovation. The Internet market will never be deep rooted until there is significant local content available. The establishment of an IXP can therefore be a trigger to financial viability for smaller or new ISPs, resulting in greater market competition and stimulation of local content development.

Whether an IXP makes financial sense for ISPs can be analyzed by comparing the cost of IP transit to the cost of domestic peering.[2] An example based on actual 2010 values for the German Internet Exchange (DE-CIX) illustrates this calculation.[3] It is based on the assumption that all traffic is destined for local termination although in reality this is rarely the case. The cost of peering is calculated based on three distances to DE-CIX: local, nearby and far. The cost of IP transit has been estimated at US$3.50 per Mbps based on interviews with several ISPs. Peering costs include the variable transport charges to the IXP depending on location as well as the common costs for a 10G port in the IXP, collocation fees and router amortization (figure 4.1).

Table 4.1 shows the level of traffic required for the IXP to be a cheaper alternative than IP transit ("break-even point") for the various scenarios based on the IP transit cost of US$3.50 per Mbps. The break-even point is dependent on the volume of traffic and the ratio of local vs. international traffic. Given the higher transport costs for ISPs that are further away, they also require a higher level of traffic to break-even.

Note that some national fibre backbones and submarine links have relatively distance-independent pricing, which can affect this part of the calculation. In addition, the local peering/IXP fees may be much lower in a developing-country context (for example, in Ecuador, the cost is about US$1/Mbps/month). Table 4.1 also shows the minimum cost of using the IXP on the assumption that 70% of the 10G port will be utilized.

The key factor influencing the decision to peer in this example is the volume of traffic. As the volume increases, the per-unit cost of peering decreases. If the ISP has sufficient traffic, then peering will be a less expensive option than IP transit. Figure 4.2 (following page) illustrates this, showing the different break-even points depending on the distance from the IXP.

Help us improve this report!
Future iterations of this report will contain examples from a range of emerging markets where IXPs are either just starting out or have been operating for only a few years. Obtaining data to conduct analyses is not easy due to a lack of basic published data. Keeping track of basic traffic measurements or deploying open source software like INEX's[4] IXP Manager software is a simple way for an IXP to generate data.

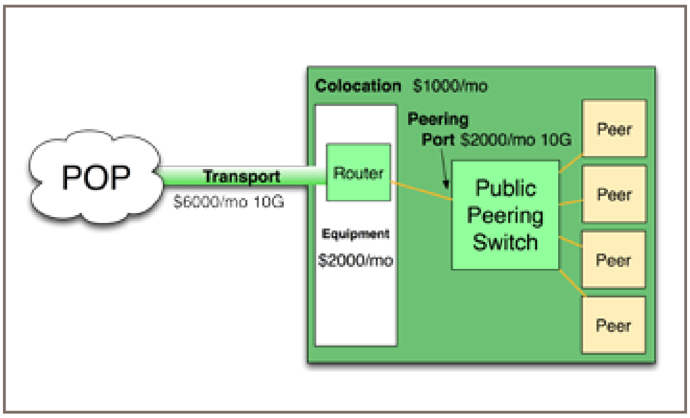

Figure 4.1. Peering Cost Elements *(Source: "The Business Case for Peering," DrPeering International. Accessed 26 November 2013. http://drpeering.net/core/ch5-Business-Case-for-Peering.html)*

	Far	Near	Local
Transport into IX	$6,000	$4,000	$2,000
Colocation Fees	$1,000	$1,000	$1,000
Peering Fees	$2,000	$2,000	$2,000
Equipment Costs	$2,000	$2,000	$2,000
Total Cost of Peering	$11,000	$9,000	$7,000
IP Transit Price (US$/Mbps)	$3.50	$3.50	$3.50
Peering Break-even Point (Mbps)	$3,143	$2,571	$2,000
Minimum Cost for Traffic Exchange (US$/Mbps) (assuming 70% utilization of 10G port)	$1.57	$1.29	$1.00

Table 4.1. Break-even Points for Hypothetical Peering Example per Month in US$. *Assumes all traffice is destined for local termination. (Source: Adapted from "The Business Case for Peering." DrPeering International. Accessed 26 November 2013. http://drpeering.net/core/ch5-Business-Case-for-Peering.html)*

2 A simple spread-sheet or web application could easily be created to allow IXPs or prospective IXP founders to make the calculations of savings based on local conditions — all that would be needed is the cost of domestic and international capacity, number of links, and volume of traffic. Revenue angles that IXPs should consider will be included in the next iteration of this report.

3 "The Business Case for Peering," DrPeering International. Accessed 26 November 2013. http://drpeering.net/core/ch5-Business-Case-for-Peering.html. Also see http://www.ripe.net/ripe/meetings/regional-meetings/dubrovnik-2011/presentations/IXP%20Workshop%20Part%20I%20-%20Daniele%20Arena.pdf.

4 INEX is the Internet Neutral exchange located in Dublin, Ireland, www.inex.net. INEX developed and collaborates with IXPs around the world to improve its free software, IXP Manager, which enables IXPs to keep track of data, manage IXP members, and provide more services to members. See the presentation by Nick Hilliard, INEX CTO, at http://www.internetsociety.org/events/serbian-open-exchange-%E2%80%93-ixp-workshop.

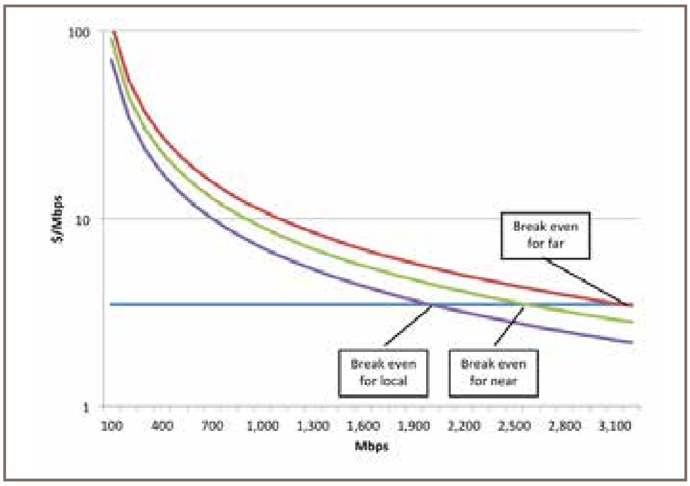

Figure 4.2. Peering Versus Transit Break-Even Point *(Source: Adapted from "The Business Case for Peering," DrPeering International. Accessed 26 November 2013. http://drpeering.net/core/ch5-Business-Case-for-Peering.html)*

A quick rule of thumb for determining the break-even traffic point is dividing the monthly cost of connecting to the IXP by IP transit costs (per month per Mbps). In many developing regions, the cost of IP transit remains high so the amount of traffic required to make an IXP financially attractive is normally low. The key price breaker is the connectivity cost to get the ISP's traffic to and from the IXP. These domestic transport costs can often exceed the pure peering costs (port and colocation charges), particularly as the distance to the IXP increases.

In the following list, the economy-wide impact of the savings from domestic peering has been quantified for four developing countries. Note that the savings reflect the estimated cost of IP transit if current IXP traffic had to be routed overseas. (Kende and Jurpy 2012, Galperin 2013)

Argentina (2013)
Savings: US$12.3 million
The wholesale cost savings associated with local traffic exchange at the new IXPs can be estimated as follows. Before the establishment of IXPs in other cities, NAP Buenos Aires was exchanging around 2Gbps during peak traffic. Today traffic peaks are as high as 12Gbps. Assuming this additional 10Gbps of traffic was previously exchanged between local operators over transit agreements, and assuming a very conservative transit cost estimate of US$100 per Mbps per month, the new IXPs are generating wholesale savings of US$12.3 million per year. Even discounting transport costs to the IXP (which as explained below aggregate traffic from large geographical areas), IXP fees and related equipment costs, the savings are very significant, and tend to be higher for operators in less developed markets.

Ecuador (2013)
Savings: US$7.2 million
NAP.EC currently exchanges about 6Gbps during peak traffic. International transit costs in Ecuador hover around US$100 per Mbps per month. By contrast, local traffic can be exchanged at NAP.EC for as little as US$1 per Mbps per month. Assuming that in the absence of NAP.EC operators would exchange local traffic through international transit routes (i.e., assuming no bilateral peering agreements), the additional wholesale costs for local ISPs would be US$7.2 million per year.

Kenya (2012)
Savings: US$1.4 million
ISPs credited all of their local traffic exchange to the impact of KIXP – stating that without the KIXP all of their traffic would trombone. This means that without the IXP, the entire current 1Gbit/s peak traffic exchanged through the IXP would be carried over international transit connections. In terms of the cost of those circuits, there are a wide variety of values ranging from US$90–250 per Mbit/s of traffic per month for wholesale service. The differences in values reflect a number of variables, including traffic volume, use of self-owned capacity, and routing; one source suggested an average value of US$120 per Mbit/s for international transit. Using that relatively conservative value, the wholesale savings of exchanging 1Gbit/s at KIXP instead of using international transit to trombone the traffic is US$1,440,000 per year.

Nigeria (2012)
Savings: US$1.1 million
ISPs today are typically paying in the range of US$250–400 per Mbit/s of traffic/month for international transit (the differences in values for wholesale services reflect a number of differences between buyers such as traffic volume, route, and use of self-owned capacity). Using an average cost of US$300 per Mbit/s for international connectivity, the wholesale savings of exchanging 300Mbit/s at IXPN instead of using international transit to trombone the traffic is US$1,080,000 per year.

In addition to the quantifiable financial benefit, IXPs increase competition in the market by providing another option for exchanging traffic. This should put downward pressure on IP transit prices. Another distinguishing feature of IXPs compared to IP transit, is that the former are much more transparent by generally publishing their connectivity pricing and traffic levels.

Given that the financial benefits of an IXP include saving expenditure and providing a competitive alternative to IP transit, it may seem surprising that there are still more than 100 countries without one. Reasons include a lack of cooperation among domestic ISPs, policy and regulatory issues, as well as market structure. In the latter case, some ISPs dominate the market, accounting for a significant portion of domestic IP traffic that they may exchange within their own

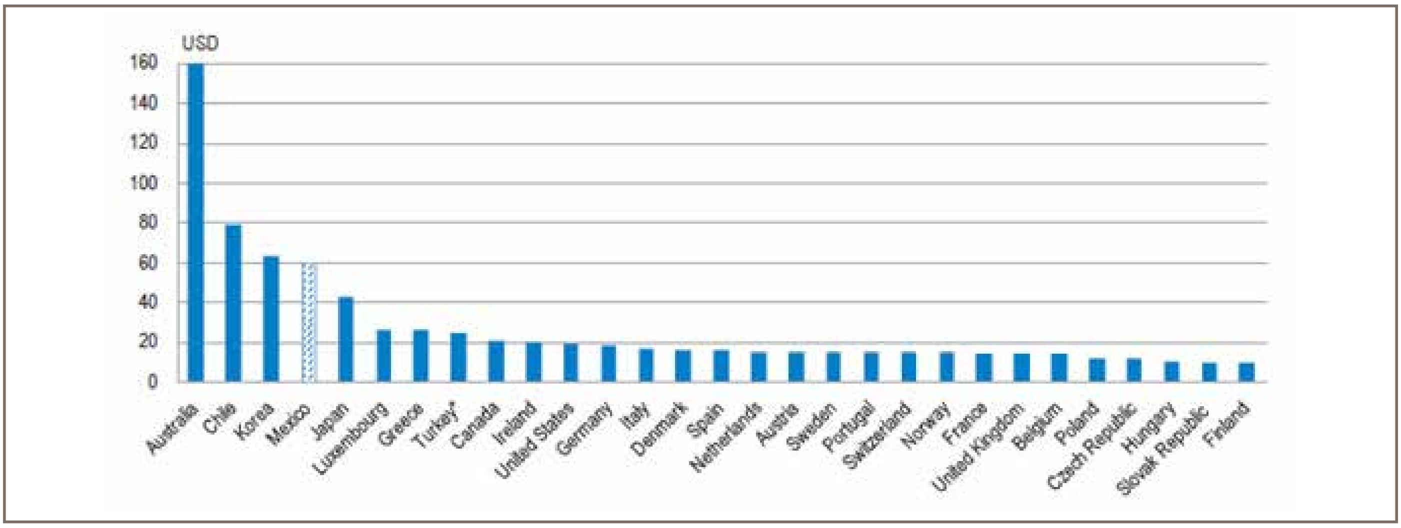

Figure 4.3. IP Transit Prices in US$, Mbps/Month, 2011. Based on a full-port STM-1/OC-3 (155 Mbps). *(Source: OECD)*

network (i.e., “on-net”). Larger ISPs often have their own IP backbone arrangements, generally through participation in a global telecommunication group.

Such ISPs do not see a financial gain from open peering at an IXP since they would likely be receiving much more traffic than they send. Take the case of Mexico, which at the end of 2013, was the largest country (and only OECD member) without an IXP. It has significantly higher IP transit costs than other OECD countries, all of which do have IXPs (figure 4.3). One reason cited for Mexico’s lack of an IXP is resistance by the incumbent telecommunication operator that already generates significant on-net traffic and wants domestic ISPs to use its IP transit services.[5]

Despite the competitive impact on IP pricing and potential for lowering Internet access prices for consumers, it is somewhat surprising that many countries are not more supportive of IXPs. This is even more puzzling considering international consensus encouraging IXPs.[6] Governments can foster an enabling environment for IXPs through various steps, such as supporting community-based IXP development; nurturing consensus-building among industry stakeholders; promoting local content; lowering or eliminating taxes for computer hardware and software; stimulating competition in national and international IP transit markets and other pro-Internet policies. A light handed regulatory approach is favored so as not to affect incentives to expand the market.[7]

Community-based IXP development as noted has been an extremely successful IXP model. Bringing stakeholders together is no easy matter in some countries and regions, but the importance of community-building to create a sustainable environment can not be underestimated. It may take years to build both trust among competitors and a sustaining environment, but this process is integral. From Ecuador to Malawi this process has led to the development of an IXP, and created a strong community of practice around the IXP and in the technical community.[8]

IXP Finances

Although IXPs share the basic function of exchanging traffic among members, they vary widely in business models, operations, scope, and size. A key difference is market orientation in terms of private versus cooperative ownership and the setting of prices for price maximization versus cost recovery.

Another difference is that IXPs vary tremendously in size, a function of the level of Internet market maturity as well as geography and population (figure 4.4, following page). These factors influence the range of services provided, operational performance, and pricing that impact IXP finances.

Regardless of the institutional set-up, even nonprofit-oriented IXPs need to recoup costs to achieve sustainability. Therefore revenues need to be sufficient to cover expenses plus an allowance for reinvestment. In deciding how to price services, IXPs need to ensure that they are a competitive alternative to IP transit, bearing in mind the transport costs ISPs incur

5 Toward Efficiencies in Canadian Internet Traffic Exchange, Bill Woodcock and Benjamin Edelman. p. 10. OECD. *OECD Review of Telecommunication Policy and Regulation in Mexico,* 2012. http://www.oecd.org/sti/broadband/50550219.pdf.

6 For example, the 2013 International Telecommunication Union’s (ITU’s) World Telecommunication and Information and Communication Technology Policy Forum adopted “Opinion 1 on Promoting Internet Exchange Points (IXPs) as a long-term solution to advance connectivity.” See https://itunews.itu.int/En/4140-Promoting-Internet-exchange-points-to-advance-connectivity.note.aspx.

7 ITU. “Internet Exchange Points (IXPs).” WTPF Backgrounder Series, May 2013.

8 In our next iteration, we plan to highlight the key roles individuals have played in starting IXPs. In some countries, the volunteer efforts of one or two people and/or the support of technical experts from the network operator group community and national research and education community have catalyzed the development of the IXP and IXP community of practice.

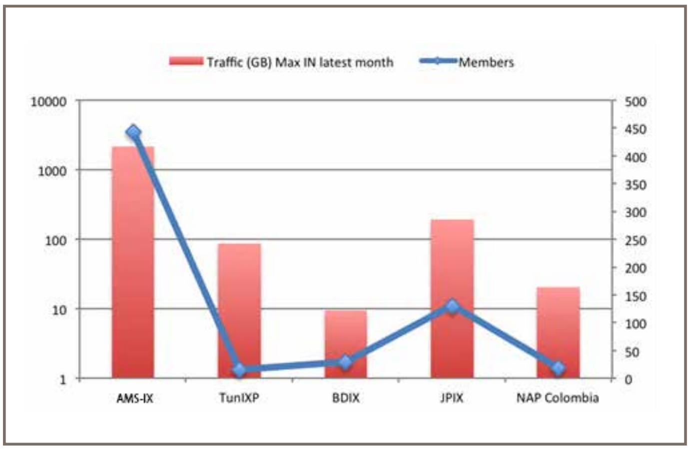

Figure 4.4. Peak Traffic and Members of Selected IXPs, 2013. Logarithmic left scale *(Source: Adapted from IXP websites)*

to connect to the exchange. Otherwise, peering at the IXP will not be financially attractive for ISPs.[9] For this reason it is crucial for IXP sustainability that there is a competitive market in national capacity to reach the exchange.

IXPs earn income through a variety of fixed and variable charges. Fixed charges can include membership fees; port charges (also known as usage charges) are variable. Some also earn revenues from charging for colocation, operating a CERT, or providing other services.

Some ccTLD registrars support IXPs through the significant source of revenue derived from domain name registrations. For example the National Internet Exchange of India earned two thirds of its revenue from registrations for the .IN TLD in its fiscal year ending March 2010 (NIXI 2010).

Many IXPs recoup a significant portion of their costs via usage charges (by specifically charging for a port of a specific capacity at the exchange) and via membership fees. While we are not suggesting that this is a common practice among IXPs, following are additional policies specific to port charges on which we were able to find data:

- In India, in addition to port charges, there are also traffic payments with the National Internet Exchange of India (NIXI) settling the amounts between ISPs based on net traffic flows. Content providers (i.e., having outgoing traffic more than five times incoming traffic) are charged proportionally more.[10]
- At the Hong Kong Internet Exchange (HKIX) there are no port charges and instead participants provide their own equipment.[11]
- In addition to port charges, the Malaysian Internet Exchange (MyIX) also charges for the volume of traffic.[12]
- The Internet Service Providers' Association (ISPA) of South Africa exchanges (CINX, DINX, and JINX) have different port charges for members and nonmembers. In addition, members must be of the Large category to lease 1Gbps or 10Gbps ports and at least in the Medium category to lease a 100 Mbps port. The categories are determined by fees paid. Nonmembers are not allowed to lease 10Mbps ports (table 4.2).[13]

There are several port capacities on offer at IXPs around the world. Smaller IXPs offer capacities as low as 10Mbps whereas some of the larger IXPs are starting to provide 100Gbps ports. Knowing what port sizes to offer requires the IXP to monitor usage, particularly when members are leasing multiple ports due to the lack of higher capacity ports. This must be balanced against the requirements of members that could be disadvantaged if small port capacities are not available. One way of matching capacity to ISPs needs is to allow members to resell extra capacity. Also of note here is that some IXPs offer port aggregation and/or fractional port charges to smooth the upgrade costs from one speed to the next.

IT IS CRUCIAL FOR IXP SUSTAINABILITY THAT THERE IS A COMPETITIVE MARKET IN NATIONAL CAPACITY TO REACH THE EXCHANGE.

The lease price logically increases with the size of the port but on a per bit basis, the larger ports are significantly less expensive. For example a 100Gbps port on the Amsterdam Internet Exchange costs 10 times more than a 1Gbps port, e.g., the monthly per Gbps charge of a 100Gbps port is US$64, compared to US$643 for the 1Gbps port (figure 4.5, following page). Therefore scale is critical since marginal costs come down significantly with each increase in port size.

There is a large variation in port charges among IXPs. A review of 1Gbps port charges shows that the least expensive offer differs from the most expensive by a factor of over four (figure 4.6, following page), not taking into account IXPs that do not charge for ports, but earn income in other ways. The

[9] In Kenya, the revenues outweighed the cost savings 4:1. Connecting to the exchange was more cost effective compared to the cost of joining and connecting to the exchange.
[10] http://nixi.in/en/routing-and-tarrif-policy
[11] http://www.hkiz.net/hkix/policies.htm
[12] See "MyIX Subscription Form" at http://myix.my/services/
[13] http://ispa.org.za/inx/inx-policy/

variation is even greater among 10Gbps port offers where the price magnitude between the least and most expensive is eight. Port charges can vary due to the price of equipment in the national market, the quality of the equipment, taxes and labor costs. There may be 'off-list' prices negotiated with larger networks to encourage them to join. Optional membership fees also influence port charges (e.g., in the case of South Africa, nonmembers of the IXP pay significantly more than members).

The volume of an IXP's traffic does not seem to have significant influence on the price. The Amsterdam exchange has by far the highest traffic among the IXPs studied yet port pricing falls into the middle range. The average price for a 1Gbps port was US$6,921 per year and US$18,763 for a 10Gbps port among the IXPs studied.

An IXP must pay careful attention to operating expenses to reduce costs for members and ensure that it remains a viable alternative to IP transit. Personnel, energy and premises form a significant proportion of operating expenses for IXPs. Many IXPs may be able to obtain premises at low cost or free, such as via a university, government office (the regulator), or a data centre that sees value in an IXP for attracting other tenants.

Some of these costs can be mitigated through the cooperative nature of many IXPs. For example members could defray some personnel costs by carrying out some activities and there may be scope for bringing in interns willing to work for less or free in exchange for the experience. Similarly some IXPs can lower their building rental by locating in data centres that see their presence as an attraction for other customers.

A further example of how member-led IXPs can help reduce costs is through cross-connect pricing. These are the charges to provide fibre-based connectivity between peering equipment in the exchange. The cost of cross connects are significantly lower in Europe where the model of cooperative IXPs is prevalent compared to North America (figure 4.7, following page), where for-profit companies typically provide exchange services, and in some markets there are "veritable monopolies."[14] Some IXPs have noted that the difference in cross-connect pricing is a function of the competition in the colocation market in a specific city.

Depreciation is also a significant expense item. Given the technological nature of IXPs, it is critical to ensure that sufficient funds are set aside for reinvestment in hardware, software and services. Estimates of the capital expenditure

[14] Higginbotham, Stacey. "With Help from Netflix, a Internet Exchange That Can Change the American Bandwidth Landscape," *Gigaom,* 3 December 2013. http://gigaom.com/2013/12/03/with-help-from-netflix-a-internet-exchange-that-can-change-the-american-bandwidth-landscape/.

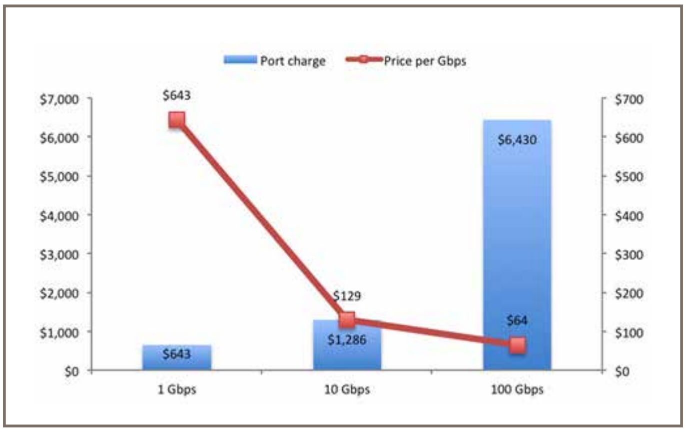

Figure 4.5. Monthly Port Charges in US$ on the Amsterdam Internet Exchange. Converted to US$ using 2012 annual average exchange rate. *(Source: Adapted from AMS-IX information)*

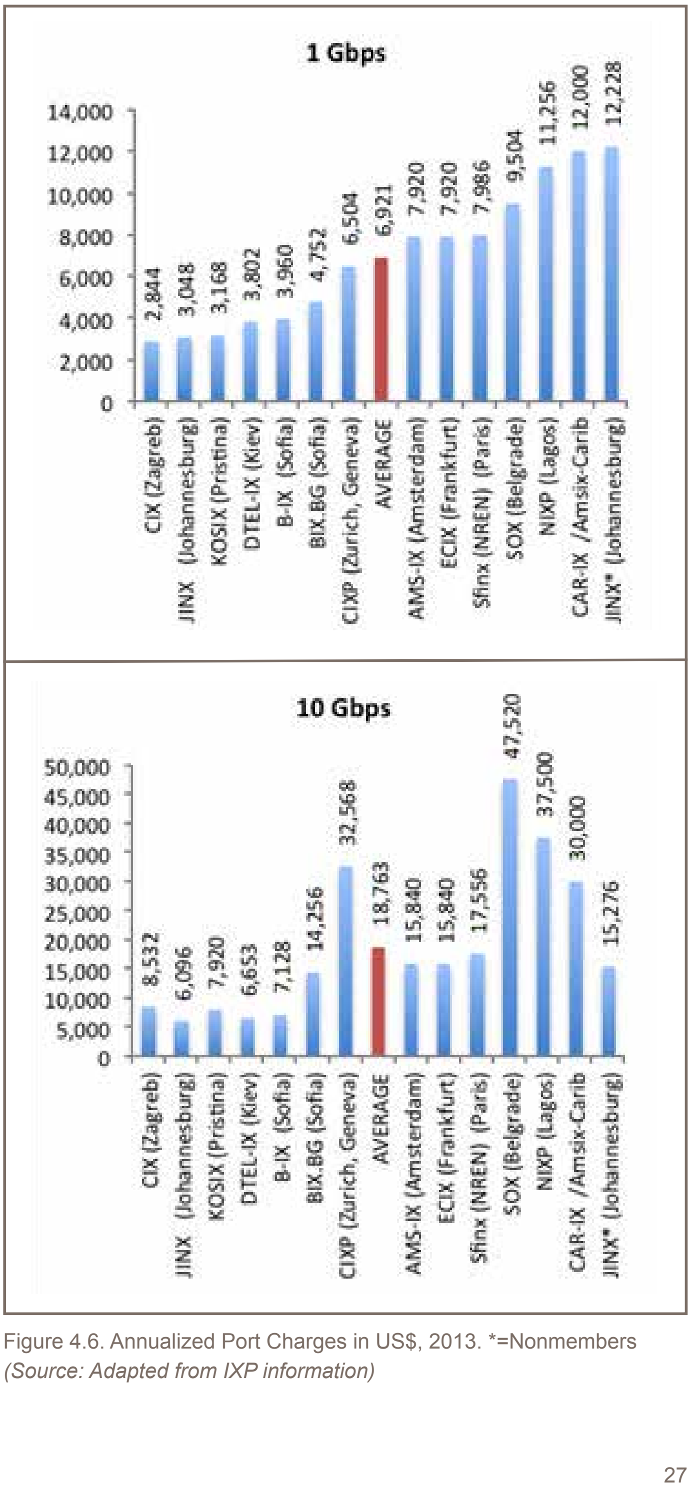

Figure 4.6. Annualized Port Charges in US$, 2013. *=Nonmembers *(Source: Adapted from IXP information)*

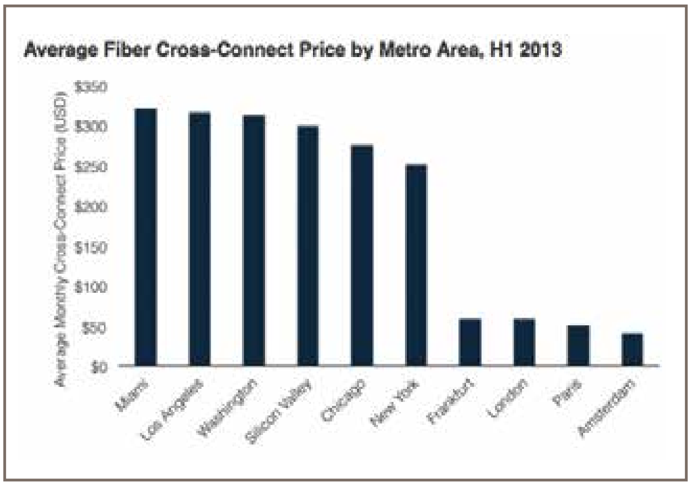

Figure 4.7. Average Fibre Cross-Connect Price in US$ by Metro Area, H1 2013 *(Source: Telegeography, http://www.telegeography.com/press/press-releases/2013/09/24/u-s-europe-colocation-pricing-models-vary-significantly/index.html)*

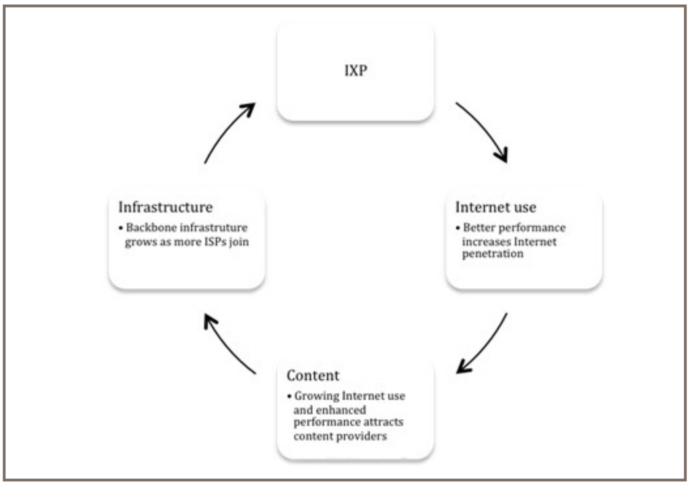

Figure 4.8. IXPs and the Virtuous Circle *(Source: Author)*

for launching an IXP vary, particularly as organizations like Cisco, the Internet Society, the Network Startup Resource Center (NSRC), and PCH can provide donated equipment at startup and as an IXP "levels-up." One source estimates the investment for starting an IXP at between US$40,000–100,000, an amount that could be recouped fairly quickly provided there is sufficient traffic (Woodcock and Edelman 2012).

Few IXPs publish traditional annual reports containing income statements, balance sheets and other financial and operational information[15]—in carrying out the research for this report only three could be found (AMS-IX, Czech IXP, and NIXI (the last being somewhat dated (2010)). Given that few IXPs formally disclose financial and operational data, it is difficult to analyse revenues, cost recovery, and investment strategies for the overall industry. Tracking and making operational and financial metrics publicly available would benefit the global IXP community by providing data for comparable industry benchmarking.

IXPs and the National Internet Ecosystem

As IXPs expand, they trigger a virtuous circle for national Internet ecosystems (figure 4.8). By keeping domestic IP traffic local, IXPs enhance performance. This in turn makes content, services and applications more attractive to use, growing the Internet market. In addition, prices are lowered since costly IP transit is avoided, saving money for consumers and increasing Internet penetration. The growth in Internet use, coupled with faster access to local websites, attracts content providers. They benefit from better response times to their services, which generates additional income. Growing traffic at the IXP spurs investment in national backbone infrastructure in order to connect other parts of the country to traffic exchange services. These factors, coupled with important human capacity gains as technical skills become enhanced, contribute to the sustainability and expertise of the IXP, allowing it to offer additional services and assume an important public policy role for the industry.

[15] This refers to neutral multilateral peering IXPs. There are private companies that provide IXP like services but more commonly provide hosting type services for participants to interconnect.

Internet Use

The speed and latency requirements for various cloud-based Internet services can be classified into basic, intermediate and advanced (table 4.3, following page). In order to use the most advanced services, a latency of less than 100 milliseconds (Ms) is required. This requirement provides an important impetus for the creation of IXPs. By keeping local traffic local, they dramatically reduce latency.

High latency impacts the Internet user experience. Telecom equipment manufacturer Nokia estimates that latency is more important than access speeds for applications such as VoIP, music downloading and gaming (NSN 2009). Users are becoming more sensitive to latency and will stop using applications that take too long to load. On the other hand, when applications load quickly, they are more attractive and drive demand and increase penetration.

Routing IP packets overseas via long-haul traffic routes implicitly doubles latency since a round-trip is required. With an IXP, traffic does not have to travel abroad and then return. As a result users can enjoy applications that they would not have been able to use before because latency was too high. This should help to drive higher Internet take-up. The reduction in latency from the establishment of an IXP has been

BASIC	INTERMEDIATE	ADVANCED
Download: 750 kbps Upload: 250 kbps Latency: 160 ms	**Download: 751–2,500 kbps Upload: 252–1,000 kbps Latency: 159–100 ms**	**Download: >2,500 kbps Upload: >1,500 kbps Latency: <100 ms**
Single Player Gaming Text Communications (Email, IM) Stream Basic Video/Music Web Conferencing Web Brownsing VoIP (Internet Telephony)	ERP/CRM HD Video Streaming Multiplayer Gaming Online Shopping Social Networking (Multimedia/Interactivity) Video Conferencing	3D Video Streaming HD Video Streaming Stream Super HD Video Connected Education/Medicine Group Video Calling Virtual Office

Table 4.3. Levels of Cloud Sophistication and Related Quality of Service Requirements. Note that concurrent and multiples instances of applications will require faster a network. *(Source: Adapted from http/:www.cisco.com:en:US:netsol:ns1208:networking_solutions_sub_sub_solution.html)*

documented in a number of studies. For example, the creation of the Kenyan Internet Exchange Point (KIXP) reduced latency from 200–600Ms to 2–20 (Kende and Hurpy 2012).

In addition, since IP transit is avoided for domestic traffic, the cost of supplying Internet access is reduced. As a result ISPs can offer cheaper Internet access packages to consumers. Some ISPs charge lower prices or offer higher or no caps on user Internet charges for domestic traffic.[16] The lower prices help to stimulate demand for the Internet and increase penetration.

HIGH LATENCY IMPACTS THE INTERNET USER EXPERIENCE. TELECOM EQUIPMENT MANUFACTURER NOKIA ESTIMATES THAT LATENCY IS MORE IMPORTANT THAN ACCESS SPEEDS FOR APPLICATIONS SUCH AS VOIP, MUSIC DOWNLOADING AND GAMING (NSN 2009).

Growing local traffic also increases revenue for ISPs. In Kenya, ISPs offering mobile data services saw their traffic increase by at least 100Mbit/s due to the presence of the IXP. This triggered an estimated US$6 million increase in revenue, as the ISPs charge by the MB for data (Kende and Hurpy 2012).

Content

The improved latency provided by the IXP coupled with the growth in Internet use and neutral peering attracts other players to join. They include domestic companies, government, the educational sector, the banking sector, international content providers and Content Data Networks (CDNs).

As we noted earlier in this report, lower latency helps to foster the development of domestic content and services. National websites that had previously been hosted abroad will find it more attractive to connect to the IXP if most of their customers are local. In Colombia, although adequate international bandwidth to the United States results in latency of about 45ms, for local traffic it is only 3Ms, providing a strong justification for hosting content in the country (Galperin 2013). Not only will access to domestic sites improve, but local companies also can save on overseas hosting and transit charges. Thru Vision, a Malaysian web development company is hosted in the same datacenter with the Malaysia Internet Exchange (MyIX) and notes the benefit to local websites of the extra redundancy of having multiple ISPs in the same facility.[17] In Malawi, local banks have begun discussions with the IXP as the IXP can provide a more stable and reliable environment.

Hosting a country's top level domain (ccTLD) and generic top level domain (gTLD) root servers at the IXP enhances quality through faster domain name resolution and increases resiliency for websites using those domains. The root server for Kenya's ccTLD (.ke) is connected to the Kenyan Internet

[16] In South Africa, Telkom does not have a data cap for its ADSL packages when accessing servers hosted in the country. http://residential.telkom.co.za/broadband-internet/broadband_services/adsl/cost_dsl_cost.html

[17] http://www.thruvision.com.my/resources/benefits-web-hosting-hosted-malaysia-internet-exchange.html

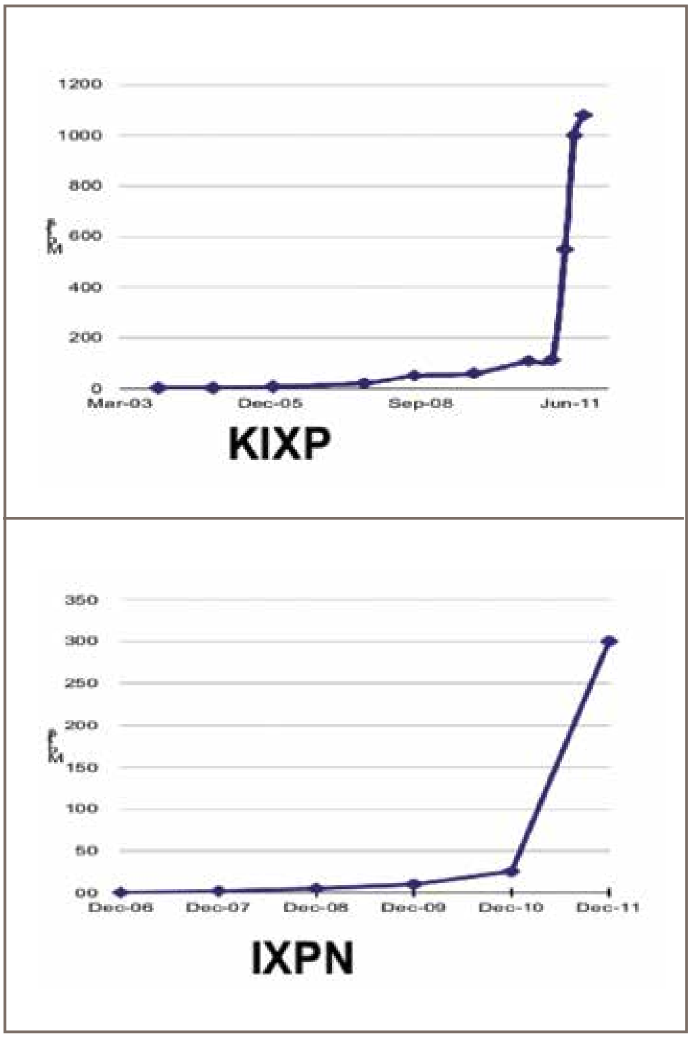

Figure 4.9. Traffic Impact of Google Caches in Kenya (KIXP) and Nigeria (IXPN) *(Source: Mwangi, 2012)*

Exchange Point (KIXP), helping it to become the most widely used TLD in the country (Weller 2012). There are other synergies between the ccTLD and IXP. Some IXPs also are responsible for the ccTLD, and income from registrations can help sustain operations as is the case in Armenia. ccTLD registrars also recognize the importance of improving the performance of local sites since many will be using the country's domain name. The Canadian Internet Registration Authority (CIRA), responsible for the .ca Internet domain, promotes the development of more IXPs throughout the nation via Town Hall meetings and bottom-up Internet community led support: "This is about improving security, speed and network resilience, while maximizing the amount of traffic that stays within Canada for the benefit of all Canadians."[18]

The improved quality of service and growing Internet market is appealing to international content and service providers. Revenues from the service offerings of large Internet companies such as Amazon, Google and Microsoft are particularly sensitive to response times (NSN 2009), giving them an incentive to take advantage of reduced latency.

Google's Global Cache (GGC) program places servers in IXPs to improve performance and typically can handle between 70–90% of its traffic.[19] Experiences from Latin America demonstrate the impact from GGC. In Ecuador, the installation of GGC at the IXP increased the importance of peering for other networks. Latency for local content is reported at about 20Ms, compared to 150Ms for content located abroad (Galperin 2013). In Argentina, Google is estimated to account for over half the country's Internet traffic. Since GGC was installed at the Cabase Buenos Aires NAP in October 2011, latency to YouTube and other Google properties is estimated to have dropped by a factor of ten (Galperin 2013). Similarly traffic has exploded in Kenya and Nigeria following the introduction of Google caches at KIXP and IXPN. After the installation in 2011, Google traffic soared making up around half the IXP traffic in both countries (figure 4.9).

Similar to content providers, CDNs also benefit from the open peering and improved performance available at the IXP. Akamai, one of the world's largest providers of web-based third party content joined France-IX to reach a large number of ISPs through a single connection and to avail itself of better optimization. Since joining in 2010, Akamai has quadrupled its port capacity to 40Gbps,[20] the largest on the exchange along with Numericable, a fibre optic Internet access and streaming video provider. Other companies with large port capacities on France-IX include multinational cloud services companies such as Amazon, Facebook, and Google.[21] In Malaysia, Amazon, Facebook and Microsoft joined the country's Internet exchange (MyIX) in 2013 to reduce latency for users and lower international connectivity costs.[22] The growing number of "eyeballs" (an Internet marketing term referring to people who look at web pages) in Malaysia, fueled by exploding smart device use, are a big attraction for web content firms.

IXPs play a critical role in enabling online public services. Given that most e-government users are resident in the country, it is logical to locally host servers and exchange data for citizens. Security is heightened since the traffic stays within the country and subject to national privacy laws (Woodcock and Edelman 2012) and availability is enhanced with immunity

18 Canadian Internet Registration Authority (CIRA). "CIRA to Act as a Catalyst for a Faster, Better Performing Internet." News Release, 28 June 2012. http://www.cira.ca/news/news-releases/ixp/

19 https://peering.google.com/about/ggc.html
20 https://www.franceix.net/media/cms_page_media/823/Case-study_Akamai_member-of-France-IX(september-2012).pdf
21 https://www.franceix.net/fr/members-resellers/members/
22 "MyIX Peers with Three Global Internet Brands." Press Release. 7 February 2013.

to disruptions on international circuits. The Kenya Revenue Authority (KRA), responsible for collecting the nation's taxes, has benefitted by connecting to KIXP. Income tax forms and trade documents can be filed online with significant increases in data traffic as deadlines approach (Mwangi 2012). Savings to the private sector from having access to KRA online services has been estimated at US$45 million.[23]

Infrastructure

The growth of the IXP reduces traffic exchange costs, lowers latency, enhances redundancy, and attracts domestic and global content providers. This increases the appeal of connecting other parts of the country to the exchange. Building out domestic networks increases a country's infrastructure assets, reduces access costs for users and shrinks digital gaps within the nation.

There are different strategies for connecting regional ISPs to IXPs. One is for the IXP to increase its geographic reach by establishing additional nodes in other locations. A second strategy is to build out domestic backbone connectivity so that different parts of the country can reach the IXP. In practice, both approaches are often followed since it may not be feasible to put an IXP node in every location.

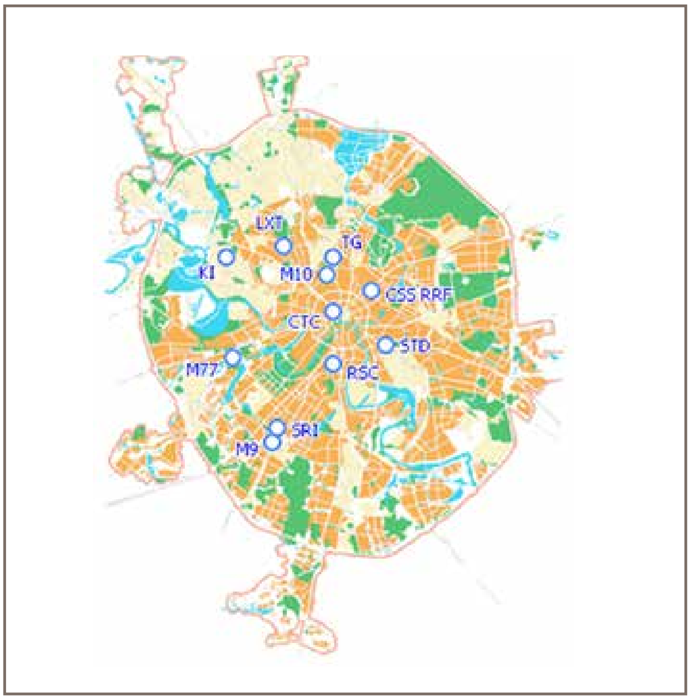

Figure 4.10. Moscow Internet Exchange Nodes *(Source: Moscow Internet Exchange, http://www.msk-ix.ru/eng/where.html)*

A number of countries, particularly of large geographic size, have created additional IXP points of presence, referred to by some as virtual IXPs. For example, NIXI, the Internet Exchange of India has seven locations, PTT of Brazil has 24 locations, while the Moscow Internet Exchange (MSK-IX) is interconnected to eleven sites in the capital as well as eight other Russian cities (figure 4.10).

In countries where there is only one physical IXP, ISPs located in other areas would need to obtain a backhaul link in order to connect. The high cost or lack of high-speed national backbone connectivity has been a deterrent to connecting ISPs to the IXP. In some cases the cost of domestic connectivity is higher than international IP transit (particularly when charged on a distance rather than traffic basis). For example, it is cheaper to send traffic via submarine cable from Capetown to Johannesburg versus sending traffic completely overland via terrestrial fibre. This also is an issue where there are multiple IXP nodes since they will not reach every population center.

THE GROWTH OF THE IXP REDUCES TRAFFIC EXCHANGE COSTS, LOWERS LATENCY, ENHANCES REDUNDANCY, AND ATTRACTS DOMESTIC AND GLOBAL CONTENT PROVIDERS. THIS INCREASES THE APPEAL OF CONNECTING OTHER PARTS OF THE COUNTRY TO THE EXCHANGE.

Given the benefits of connecting to the IXP, countries are encouraging the deployment of national telecommunications infrastructure through a variety of strategies. In some cases, governments are promoting domestic backbone connectivity using a variety of policies. This includes developing national fibre networks through public private partnerships. The latter is an option where the costs of construction are too high and the private sector is not convinced of the return on investment. Another strategy for encouraging fibre deployment is through regulatory tools such as price controls on operators with significant market power in the domestic wholesale bandwidth market or encouraging infrastructure sharing among operators. One of the simplest solutions is simply to allow a competitive wholesale bandwidth market. This will attract domestic and foreign investors as well as utilities such as power companies and railroads with their own fibre optic networks.

Kenya has pursued a number of these strategies. The government has funded the National Optic Fibre Backbone Infrastructure (NOFBI) network extending thousands of

[23] http://www.itu.int/ITU-D/finance/work-cost-tariffs/events/tariff-seminars/Egypt-13/documents/Session10_Ibrahim.pdf

THE GROWTH IN DOMESTIC IP TRAFFIC CAN ATTRACT INTERNATIONAL BANDWIDTH PROVIDERS, AND CAN BE PARTICULARLY IMPORTANT FOR LANDLOCKED COUNTRIES. ONE OPTION FOR A LANDLOCKED COUNTRY IS FOR INTERNATIONAL IP-TRANSIT PROVIDERS TO ESTABLISH A POP OPERATING AS A VIRTUAL LANDING STATION.

kilometers throughout the country. In addition, the backbone fibre market is liberalized with several providers including the country's power utility. In fact the latter, Kenya Power and Lighting Company, has emerged as the largest wholesale fibre operator in the country. These developments have lowered the cost of domestic IP transmission, facilitating ISPs connecting to KIXP. Fibre networks are built to the borders of several neighbouring countries which has reinforced KIXP's attractiveness as an East African hub; a second IXP has been established in Mombasa, site of the undersea cable landing stations. This has attracted international operators to the exchange. In 2011, over half of the Autonomous Systems Numbers (ASNs) routed through KIXP originated from more than a dozen foreign countries (Mwangi 2012).

In Argentina, ISPs outside large cities have high domestic transport costs exacerbated by limited competition. ISPs and citizens in these areas pay higher wholesale and retail costs than those in main urban centers, impacting the growth of the Internet market. The Argentine Internet Chamber (CABASE) an association of ISPs that operates the IXP NAP Buenos Aires spearheaded an initiative to connect these regions. Connecting regions in Argentina allowed them to exchange local traffic and interconnect through NAP Buenos Aires, forming a virtual IXP with national reach. The first node was established in 2011 and to date, nine regional IXPs are operational, connecting over 80 network operators through a central routing hub in Buenos Aires. By aggregating outbound traffic at the IXP, small network operators were able to negotiate better contract terms with upstream transit providers. Prices in the national transit market have declined to about US$40 per Mbps per month (Galperin 2013).

The growth in domestic IP traffic can attract international bandwidth providers, and can be particularly important for landlocked countries. One option for a landlocked country is for international IP-transit providers to establish a POP operating as a virtual landing station. Such is the case in East Africa where SEACOM, an undersea fibre optic cable company, has established POPs in Rwanda and Uganda.

An additional infrastructure trend is the globalization of IXPs as they expand their services outside their home countries. The Amsterdam Internet Exchange (AMS-IX) is at the forefront of this trend, billing itself as the most international IX in the world with over three quarters of its connected networks coming from outside the Netherlands.[24] AMS-IX helped established the Caribbean Internet Exchange (CAR-IX) in Curacao in 2008, and assimilated into the AMS-IX global network in 2013. AMS-IX has created a POP in Hong Kong, the first such platform allowing remote peering from Asia into Amsterdam. AMS-IX is also partnering with the Kenya Internet Exchange Point (KIXP) and undersea cable provider SEACOM to establish a regional exchange for East Africa that will also support virtual peering to Amsterdam (AMS-IX 2013). The Dutch exchange recently announced plans to set up several exchanges in the United States as part of the Open-IX initiative. This aims to introduce neutral multilateral peering in order to reduce costs for major content providers such as the video streaming company Netflix.[25]

THE LONDON INTERNET EXCHANGE (LINX) HAS A STRONG OUTREACH PROGRAM REPRESENTING ITS MEMBERS ON IMPORTANT PUBLIC POLICY ISSUES. IT NOTES: "BY DOING SO, WE ARE NOT ONLY WORKING TOWARDS THE GOOD OF OUR MEMBERS, BUT THE INTERNET AS A WHOLE."

Expanded IXP Services

As IXPs grow, they often evolve from a basic switching and routing service to become centers of Internet expertise in the country. This know-how allows them to begin to provide other services, supplementing the critical Internet infrastructure that has been put in place. Examples include IPv6, network security (e.g., CERT), mobile peering, and root servers. In addition, IXPs can play a catalytic role promoting and nurturing the country's Internet industry assisted through cooperative partnerships with other IXPs, regional Internet registries and international organizations.

The strong technical bond between the IXP and its members can be leveraged into industry promotion to the benefit of the

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[24] https://www.ams-ix.net/connect-to-ams-ix/benefits-of-connecting/

[25] Amsterdam Internet Exchange. "Netflix Signs On To New York Open Internet Exchange." News, 2 December 2013. https://www.ams-ix.net/newsitems/124.

Sector	Impact	Reason
Overall economy	Increase in GDP	Investment in network infrastructure. A number of studies have demonstrated the impact on economic growth from investment in telecommunications.[27]
Overall economy	Increase in GDP	Increase in broadband access. There is growing research citing the relationship between broadband penetration and economic growth.
ISPs	Lower costs	Exchanging traffic domestically is generally cheaper than IP transit.
ISPs	Increased revenue	Triggers additional domestic traffic increasing revenues (Kende and Hurpy 2012)
Consumers	Lower costs	Reduction in Internet access fees and/or increase in speeds due to lower ISP costs.
Content providers	Increased revenue	Lower latency increases revenue (Nokia 2009). According to a Latin American study faster broadband speeds from IXPs would have a GDP impact of US$915 million (Telecom Advisory Services 2013).
Government	Lower costs	Greater efficiency through online public services (e.g., KRA)
Local computer equipment and software suppliers	Increased sales	Growing domestic Internet market triggered by IXP will generate higher sales of computer hardware and software.

Table 4.4. Economic Benefits of IXPs

national Internet ecosystem. This is particularly important in countries that lack strong Internet associations. Given the importance of the Internet in any society, it is critical to have a group lobbying for sustainable and progressive policies. The London Internet Exchange (LINX) has a strong outreach program representing its members on important public policy issues. It notes: “By doing so, we are not only working towards the good of our members, but the Internet as a whole.”[26]

IXP Economic Impacts

The direct financial benefits for ISPs of an IXP have been demonstrated above. In addition, IXPs offer benefits beyond the measurable financial advantages. Although these spill-over impacts are often not precisely calculable, the improvement in quality and reduction in cost generate significant gains for ISPs, consumers, content providers, governments and others. National technical human capacity is also raised with IXPs helping to make the Internet more sustainable (table 4.4).

[26] https://www.linx.net/about/index.html
[27] http://mddb.apec.org/Documents/2010/EC/SEM1/10_ec_sem1_002.pdf

5. Benchmarking IXPs: A Methodology for Assessing Performance

THIS SECTION DESCRIBES A SET OF BASIC benchmarking measures that have been designed to assess the potential of an IXP to improve performance and to help identify bottlenecks to delivering maximal interconnection. It is set up as a template for a spreadsheet or online form that can be filled in by IXP stakeholders. In addition, part of the template can be used to describe the conditions in a location where no IXPs currently exist in order to identify the bottlenecks and potential viability of a new exchange.

The template is based on data derived from case studies, best practices, and findings from field studies/training. It categorises IXPs into three types — Basic, Intermediary and Advanced — based on the type of services provided, and analyses these according to the following benchmarks:

- Participation levels of local networks and CDNs
- Geographic scope
- Scalability and sustainability

The benchmarking methodology will be tested in the field with selected IXPs and after testing, will be further refined. The methodology also can be used to create a self-assessment tool to enable field and self assessments and to compare and contrast that data.

The template is shown on the following pages without description and commentary about the variables so that the overall structure of the benchmarking process can be more easily understood. Notes on the relevant sections are reproduced following the template (table 5.1).

IXP Basic Details

1. Full name
2. Abbreviation

3. Website/URL
4. ASN
5. Host organisation name
6. Region (seven options: Africa, Asia-Pacific and South-Asia, Europe, Middle East, North America, Latin America and the Caribbean, CIS)
7. Country or territory
8. City
9. Date information collected

Location Setting

1. Country population (2012)
2. Country level of development (GNI/Capita – World Bank Atlas method definition 2012)
3. Number of neighbouring countries or island states
4. Number of neighbouring countries with cross-border telecom links to IXP country
5. Number of international fibre links landing in country (interregional)
6. Number of submarine fibre links landing in country (intercontinental)
7. Number of national fibre backbones in country
8. Cost of intercontinental/submarine fibre capacity – STM-1 ($/Mbps/month)
9. Cost of cross border capacity – STM-1 ($/Mbps/month)
10. Cost of national backbone capacity – STM-1 ($/Mbps/month)
11. Number of national fixed and mobile operators in country
12. Presence of a National Education and Research Network (NREN)
13. Number of ISPs operating in the country
14. Number of ASNs assigned to the country
15. Number of Internet users in country
16. IXP city population
17. IXP city rank
18. Other IXPs in same city

IXP Size and Physical Connectivity

1. Number of members
2. Number of ASNs visible at IXP
3. Number of IP prefixes announced at IXP
4. Peak traffic (Gbps)
5. Number of national fibre networks present at IXP
6. Percent of national fibre networks present at IXP
7. Percent of international fibre links at IXP (interregional and intercontinental)
8. Number of physically separate locations
9. Size of premises (sq. m)
10. Number of rooms
11. Average power consumption (kW)

IXP Policies and Neutrality: Governance and Business Model, Peering, Fees

1. Operating model (options: Commercial, Nonprofit, Volunteer, Public Sector, NREN-hosted)
2. Host organisation type (options: ISP, ISP/Telco Association, Independent nonprofit, government, regulator, neutral for-profit company, informal project)
3. Relationship with other IXPs (options: parent/subsidiary, partnership, twin)
4. Neutrality of premises location (options: Independent site, ISP/Telco site, NREN, Government
5. Membership categories
6. Member-type exclusions (e.g., only licensed ISPs, etc.)
7. Peering policy (options: only multilateral, only bilateral, both)
8. Private peering policies
9. Competition with member services
10. Only certain member types allowed to peer
11. Board of directors — yes/no
12. Constitution
13. Public accounts
14. One-time joining/setup fees (US$)
15. Annual membership fee (US$)
16. Annualised 10Mbps port fee (US$)
17. Annualised 100Mbps port fee (US$)
18. Annualised 1Gbps port fee (US$)
19. Annualised backup 1Gbps port fee
20. Annualised backup 10Gbps port fee
21. Other fees (US$)

IXP Services and Facilities

Basic IXP

1. Peering Policy Document
2. Number of 10Mbps ports
3. Number of 100Mbs ports
4. Route Server(s)
5. IPv4
6. IPv6
7. Member traffic statistics
8. Human Resources — number of volunteers, number of employees
9. Staffing description
10. Email and telephonic point of contact
11. Remote hands (part time)
12. Equipment backups/duplication
13. Manual Access security
14. Power backup
15. Cooling/air conditioning
16. Basic SLA available
17. ccTLD host/mirror
18. Administrative LAN
19. Website
20. Aggregated traffic statistics on website
21. Individual member statistics available to members
22. IPv6 statistics
23. Historical Data statistics (5–10 years)
24. Route Server statistics
25. Member application form on website
26. Membership details on website (names of members, URLs)
27. Entry in global peering databases (PeeringDB, etc.)

Intermediary IXP

1. 1Gbps Ethernet ports
2. Fractional 1Gbps Ethernet ports
3. Looking glass server
4. NTP server
5. DNS server mirror(s)
6. Route-views server
7. Link aggregation
8. Remote peering
9. Multicast
10. Real-time, broadcast, and multicast traffic statistics
11. 24/7 telephonic technical support desk
12. 24/7 authorised member access control
13. High-end SLA
14. Text message alert system for members
15. Human resources — number of FTE staff
16. Staffing description
17. Cable distribution system/management, false floor, etc.
18. Fire protection
19. Additional cooling/air conditioning
20. Quarantine VLAN
21. Port security features
22. Private peering via VLAN
23. Configuration backups
24. Governance document and agreement
25. Site duplication at other locations

Advanced IXP

1. 10Gbps Ports
2. Fractional 10Gbps Ethernet ports
3. 100Gbps ports
4. MPLS/VPLS
5. Jumbo frames
6. Out-of-band management network
7. Number of of DNS root servers
8. Spam filtering
9. VoIP Federation
10. Automated site access security
11. Automated provisioning and billing
12. Human Resources – number of FTE staff
13. Staffing description
14. Partner/Reseller programme
15. IPX/GRX peering and statistics
16. Blackholing
17. Other statistics
18. Additional power backup and customer supply

Benchmarking Analysis

Participation levels of local networks and CDNs

1. Largest telecom operator exchanging all local traffic at IXP
2. Percent of fixed and mobile operators present at exchange
3. National Participation Density (member ASNs visible / ASNs allocated to country) x 100 (percent)
4. Nontraditional local member participation (number of local content providers, nonprovider or noneyeball networks/ total members) *100 (percent)
5. Number of external CDNs present (e.g., GGC, Akamai)

Geographic scope of IXP

1. International scope (number of out-of-country ASNs present/total ASNs present) (percent)
2. Internationality (number of foreign ASNs x number of countries those ASNs are from)
3. "Continentality" (number of ASNs from same continent x number of countries those ASNs are from)
4. Subregionality – (neighboring country ASNs x number of neighboring countries)

Scalability and sustainability

1. Peak traffic/Capacity of switch (percent)
2. Total traffic on links / total capacity of links
3. Number of ports in use/number of ports available
4. Percent of rack space available
5. Percent of floor space occupied
6. Scarce resource policy
7. Rack space utilisation policy
8. Cabling policy

Variable	Discussion Points, Comments, and Issues
IXP BASIC DETAILS	
Full Name	
Abbreviation	
Website/URL	
ASN	It is not obligatory for an IXP to have an ASN, but many do so to provide access to shared services provided by the IXP, and to facilitate BGP.
Host Organisation Name	
Region *(six options: Africa, Asia-Pacific & South-Asia, Europe, Middle East, North America, Latin America& the Caribbean)*	
Country or Territory	"Territory" is used to designate locations such as Reunion (part of France), or Western Sahara (disputed)
City	
Date Information Collected	
Location Setting	
Country Population *(2012)*	
Country-level of Development *(GNI/Capita–World Bank Atlas method definition 2012)*	Low income, US$1,035 or less; lower middle income, US$1,036–$4,085; upper middle income, US$4,086—$12,615; and high income, US$12,616 or more. Project focus on all except high income
Number of neighbouring countries or neighbouring island states	To measure the extent of subregional connectivity

Table 5.1. Benchmark Table

Variable	Discussion Points, Comments, and Issues
Number of neighbouring countries with cross-border telecom links to IXP country	A filter on the above
Number of international fibre links landing in country (interregional)	Source: AM or Telegeography (not including submarine cables which are included below).
Number of submarine fibre links landing in-country (intercontinental)	(I.e., not local coastal festoon systems) Potential data source: AM or Telegeography. IXPs can attract international membership when they are situated where competitively priced international fibre-optic links are available. Networks from other countries may be generating sufficient traffic with members of the foreign IXP to warrant the cost of a direct international link versus paying another network for transit. For example, LINX, an IXP in the UK, has members from more than 50 countries.
Number of national fibre backbones in country	Source: AM or Telegeography.
Cost of intercontinental/submarine fibre capacity – STM-1 ($/Mbps/month)	In a number of developing countries, local capacity may cost more than international or intercontinental capacity. For example in Nigeria, the cost to send traffic between Abuja and Lagos is greater than between Lagos and London. Similarly in South Africa, the cost to send traffic between Johannesburg and Cape Town is greater than between Cape Town and London. This disparity between cost and distance is usually caused by immaturity and lack of competition in the local market when multiple international submarine cables land in each country, providing competitive prices for international connectivity. This disparity severely hampers the viability of local IXPs by making exchange of traffic locally more expensive than sending it via an exchange in another country.
Cost of cross border capacity – STM-1 ($/Mbps/month)	
Cost of national backbone capacity – STM-1 ($/Mbps/month)	
Number of national fixed and mobile operators in country	Source: AM or Telegeography
Presence of a National Education and Research Network (NREN)	
Number of ISPs operating in the country	For level of participation measures
Number of ASNs Assigned to Country	Source: NRO For level of participation measures: http://www.nro.net/wp-content/uploads/apnic-uploads/delegated-extended
Number of Internet Users in country	Source: ITU
IXP City population	Source: World Almanac
IXP City Rank	To identify secondary city IXPs
Other IXPs in same city	Although IXPs usually do not compete with each other, when traffic volume grows in larger urban areas, there may be market-driven reasons for competition between IXPs. Competition also helps

Table 5.1. Benchmark Table (continued)

Variable	Discussion Points, Comments, and Issues
	keep IXPs 'honest,' efficient, and meeting member needs, but too many competing IXPs could mean that none reach critical mass and none are successful or sustainable. Striking the balance between the advantages of competition and disadvantages of duplication of resources may not be a simple matter and due to local conditions, there may be different groupings of networks supporting different IXPs. Particularly common are commercial IXPs competing with each other in the US and Canada or commercial IXPs competing with nonprofit IXPs, including National Research and Education Networks NRENs. In some cases, there may be a different function assigned to the IXP – national vs. local/citywide exchange. Examples of IXPs in the same city include: Latin America/Caribbean: Panama (Intered, NAP Panamerico, and Senacyt). Peru: (NAP Peru, NAP Lima). Europe: Bulgaria (BIX.BG and B-IX), Ukraine (Giganet, UA-IX and DTEL-IX), Germany (ECIX, DE-CIX, KleyRex). UK (Edge-IX, IXManchester and MCIX, Lynx, Lonap, RBIEX). Italy (MIX-IT, MiNAP). France: (France-IX, SFINX). Sweden: (SOLIX, Netnod, STHIX), Asia: Japan (BBIX, Equinix, MEX-CEC), Hong Kong (Equinix, HKIX), Singapore (SOX, SGIX. Africa: South Africa (JINX/CINX, NapAfrica)
IXP SIZE AND PHYSICAL CONNECTIVITY	
Number of Members	IXP size indicator
Number of ASNs Visible at IXP	IXP size indicator
Number of IP prefixes announced at IXP	Eyeball networks size indicator
Peak traffic (Gbps)	IXP Size indicator
Number of national fibre networks present at IXP	May be limited by deficiencies in local fibre links – see physically separate locations – below
Percent of national fibre networks present at IXP	Calculated from data above
Percent of international fibre links at IXP (interregional and intercontinental)	Calculated from data above
Number of physically separate locations	Some IXPs operate from more than 1 location, mainly because multiple locations makes reaching more members possible. Multiple locations may also increase reliability. In some cases, more than one location is needed because of deficiencies in the local physical fibre infrastructure, so multiple sites are necessary to ensure maximum connectivity. Other IXPs have adopted a multisite model in order to build trust between competing operators by housing the IXP in the premises of the different operators (e.g., Cote d'Ivoire where one site is MTN and the other is Orange).
Size of premises (sq. m)	
Number of rooms	
Average power consumption (kW)	

Table 5.1. Benchmark Table (continued)

Variable	Discussion Points, Comments, and Issues
IXP POLICIES AND NEUTRALITY – GOVERNANCE & BUSINESS MODEL, PEERING, FEES	
Operating Model (options: Commercial, Nonprofit, Volunteer, Public Sector, NREN-hosted)	Local and historical conditions often influence this. IXPs are usually formed by an initial group of network operators who decide on the model that best fits the local environment. The key questions that usually need to be addressed when deciding the most appropriate institutional and business model are: 1. Will the IXP have permanent staff or be operated by volunteers (at least in the short term)? 2. Will the IXP be a nonprofit or for-profit organisation? 3. Will the IXP be entirely cooperatively owned by its members or will it have external ownership? 4. Where will the IXP be located/hosted? 5. What cost-recovery method will be used?
Host Organisation Type (options: ISP, ISP/Telco Association, Independent nonprofit, government, regulator, neutral for-profit company, informal project)	Will depend on local environment, historical conditions. To include non-ISPs (i.e., content and applications provider networks), an independent nonprofit model is usually the most desirable.
Relationship with other IXPs (options: parent/subsidiary, partnership, twin)	IXPs in neighbouring countries may develop partnerships and links to allow their members to exchange routes between the two countries. For example, Balkan-IX in Bulgaria has this type of partnership with RONIX in Romania. Many smaller developing country IXPs have developed a special relationship with a larger, often developed-country IXP to obtain assistance in skills transfer and in general information sharing, often called "twinning." In other cases, there is a more formal business relationship between IXPs, such as AMS-IX's operations in Curacao (CAR-IX) and Hong Kong (AMS-IX Hong Kong) or DEC-IX's partnership with UAE-IX. Some commercial IXPs have global operations, notably Equinix, which has about 32 exchanges in 15 countries, and Terremark, which is present in 20 countries and 41 locations.
Neutrality of premises location (options: Independent site, ISP/Telco site, NREN, Government	Normally a site for an IXP is most attractive to all members if it is a neutral site not controlled by one of the local participants. In developing country situations, however, hosting by an ISP or incumbent operator may be the only option if there is no other suitable location. Due to the NREN's noncommercial interest in the market, and history of involvement of the emergence of the local Internet sector, hosting at an NREN NOC is relatively common. In a few countries the national regulator has offered facilities to help get the IXP started.
Membership categories	Commercial/noncommercial (maybe freely provided to NREN). In some cases, especially where the IXP is operated by an ISP-membership association, there may be different (higher) fees charged to non-members (such as JINX, CINX, and DINX in South Africa. In other cases, a membership in the association may be required in order to have access to the IXP.

Table 5.1. Benchmark Table (continued)

Variable	Discussion Points, Comments, and Issues
Member type exclusions (e.g., only licensed ISPs, etc.)	While most IXPs have no restrictions on member types because this maximises the potential participation, those in less mature markets may restrict membership to licensed Internet access providers.
Peering Policy (options: only multilateral, only bilateral, both)	Most IXPs allow their members to choose between multilateral or bilateral peering. However, a few exchanges oblige members to peer with all the members of the exchange. Perth IXP in Australia is an example of this, resulting in a membership-base that is largely composed of smaller and non-ISPs, The two largest providers, Telstra and Optus have not joined the exchange as they are not interested in peering with all members of the exchange.
Private Peering Policies	Normally, all traffic is exchanged on the Ethernet switch fabric via route server or via a VLAN. It may also be possible to establish private peering links directly between the routers of different members housed at the exchange. These arrangements can result in upsetting the business model for the exchange (e.g., the two networks pay the lowest port fees to connect to the IXP and exchange much higher volumes of traffic directly). To address this situation while allowing room for flexibility, this practice might be allowed as long as the highest port fee is purchased. For example, at JINX South Africa, this is permitted as long as both networks are renting 10Gbps ports. In addition, JINX permits direct traffic exchange when it is not technically possible through the switch; for example, for voice traffic which requires SS7 signalling. Generally, any restrictive policies the IXP may impose on traffic exchange of members may limit the attractiveness of the exchange, especially to larger operators who do not want to have their peering policies and practices dictated by an IXP.
Competition with member services	E.g., Transit, Colo facilities
Only certain member types allowed to peer	E.g., just licensed ISPs
Board of Directors	Often not appointed at IXP initiation – “get it going first” philosophy.
Constitution	If non-commercial, often not present at IXP initiation – “get it going first” philosophy.
Public accounts	If accounts are made public.
One time Joining/Setup Fees (US$)	IXPs usually charge a mix of setup, membership fees and port fees, ‘Free’ IXPs usually have large sponsors, e.g., Seattle IX. Some may waive fees initially to encourage membership, e.g., Calgary IX. Some do not charge membership fees, or setup fees but instead just port fees, e.g., AMS-IX.
Annual Membership Fee (US$)	
Annualised 10Mbps Port Fee (US$)	Port fees may be waived for ports that are used for hosted services (such as DNS servers). To improve cash flow, discounts for annual payments may be made; for example, CAR-IX gives a 3% discount for annual upfront payment. Some large IXPs do not provide services less than 1GE except via resellers (e.g., AMS-IX). Some IXPs may discount list price port fees to attract key customers, such as the dominant operator, others may provide ports on a ‘try-then-buy’ basis.

Table 5.1. Benchmark Table (continued)

Variable	Discussion Points, Comments, and Issues
Annualised 100Mbps Port Fee (US$)	
Annualised 1Gbps Port Fee (US$)	
Annualised backup 1Gbps Port Fee	Some IXPs provide a backup port service at a discounted rate (e.g., SFINX, France).
Annualised backup 10Gbps Port Fee	
Other fees (US$)	In some cases, if a particular ISP hosts the exchange, it is not required to pay connectivity charges to access the exchange and in return, may be expected to pay a 'hosting fee' (see, for example, JINX, South Africa. Other fees may be for use of remote hands, etc.).
IXP SERVICES AND FACILITIES: A HIERARCHICAL CATEGORISATION INTO BASIC, INTERMEDIARY, AND ADVANCED SERVICES. *(SERVICES LISTED AT LOWER LEVELS ARE ASSUMED PRESENT AT THE HIGHER LEVEL.)*	
Basic IXP	
Peering Policy Document	
Number 10Mbps ports	
Number 100Mbs ports	
Route Server(s)	
IPv4	
IPv6	With IPv4 address space scarcity, networks are increasingly switching to IPv6, which needs to be supported by the IXPs' switching and server equipment. In 2011, Packet Clearing House reported that of the 351 IXPs assessed, only 26% had IPv6 subnets.
Member traffic statistics	
Human Resources (number of volunteers, number of employees, etc.)	The human resources available to the IXP are an important determinant of the exchange's potential success. Staffing may be voluntary initially, but as the IXP grows, full-time employees will likely be required or at least part-time staff will be needed to augment full-time technical support to ensure reliability. Total staffing can be measured in terms of the number of "full-time equivalents" (FTE).
Staffing description	E.g., one half-time tech support, one part-time accounts administrator.
Email and telephonic point of contact	
Remote hands (part time)	Plug or unplug cables, power cycle equipment, replace equipment, etc., as instructed.
Equipment backups/duplication	I.e., The minimal equipment required is likely to be at least two route servers and two switches/routers.
Manual access security	Only authorised personnel or visitors should be allowed into the IXP facility. This will require a locked door or locked rack if inside another facility, with a manual access authorisation procedure. In the case of a small IXP this will probably be just during normal office hours.
Power backup	

Table 5.1. Benchmark Table (continued)

Variable	Discussion Points, Comments, and Issues
Cooling/Air conditioning	Equipment at an IXP generates significant amounts of heat. A normal rule of thumb is for every BTU of power output, a BTU of air conditioning will be required. The latter may vary according to the premises and the local climate. If the IXP is hosted in an existing server room or data centre with its own cooling facilities, the direct cost of cooling can usually be avoided.
Basic SLA available	
ccTLD host/mirror	At a minimum, this could be a copy of the local ccTLD. Many other DNS servers can also be hosted. See Intermediary IXP.
Administrative LAN	
Website	
Aggregated Traffic Statistics on website	
Individual member statistics available to members	
IPv6 Statistics	
Historical Data statistics (5-10 years)	
Route Server statistics	
Member application form on website	
Membership details on website (names of members, URLs)	
Entry in global peering databases (PeeringDB, etc.)	
Intermediary IXP ***(Assumes all of the Basic services are also provided)***	
1Gbps Ethernet ports	
Fractional 1Gbps Ethernet ports	200Mbps
Looking glass server	A looking-glass server hosted at an IXP provides routing information for ISPs that wish to establish peering sessions at the exchange.
NTP server	
DNS server mirror(s)	In the event of interruption in international connectivity, and also to help reduce international traffic and latencies on name-server lookups, IXPs are often a good location to host copies of the DNS root servers. In addition the IXP can provide a space for other international service providers who offer DNS services, including, Autonomica, Community DNS, Internet Systems Consortium, Packet Clearing House and UltraDNS. For example, JINX in South Africa hosts an anycast instance of the I-Root server together with about 20 ccTLDs and gTLDs as well as an instance of the F-Root, and instances of the .BIZ, .ORG, .INFO, .COOP and .AERO gTLDs. In addition instances of more than 40 ccTLDs are hosted.

Table 5.1. Benchmark Table (continued)

Variable	Discussion Points, Comments, and Issues
Route-views server	Managing complex routing requirements with multiple local and upstream networks is not a trivial task. A route-views server can help considerably to trouble shoot suboptimal traffic routing, both for members and for the IXP manager looking to improve the value of the IXP to its participants. The ability to check the routing tables in order to determine if more specifics are available than advertised is a particularly useful feature. See http://www.routeviews.org.
Link aggregation	Link aggregation allows IXP participants to smooth their upgrade path for capacity on the exchange, so that, for example, instead of having to upgrade from a 1Gbps port to a 10Gbps port, two or three 1Gbps ports may be aggregated together.
Remote peering	This allows IXP members to connect to an IXP without installing any equipment at the exchange by making use of an existing link provided by the IXP that connects to the remote network's location.
Multicast	
Real-time traffic, broadcast traffic, and multicast traffic statistics	SFlow is the real-time traffic statistics protocol that is normally used by IXPs and large networks. It needs to be supported by the switches used by the IXP. Some intermediary level IXPs can't yet provide real-time statistics (e.g., JINX) as its switches cannot support it.
24/7 telephonic technical support desk	
24/7 authorised member access control	
High-end SLA	Needs switches with probes on each port
Text message alert system for members	
Human resources — number of FTE staff	At least one; can be up to five for a large intermediary IXP
Staffing description	E.g., two half-time staff: one tech support, one member outreach
Cable distribution system/management, false floor, etc.	
Fire protection	
Additional cooling/air conditioning	As an IXP grows provision will need to be made for additional cooling to compensate for the extra equipment present. Unless the IXP is hosted inside a data centre and can make use of its cooling facilities, it is likely that a specialised Direct Expansion Computer Room Air Cooling unit (DX CRAC) will be required.
Quarantine VLAN	
Port security features	To minimise accidental (or even intentional) interference with other participants at the exchange, a port security feature can be used to automatically close down the port when a problem is detected, such as traffic that is not accepted on the network. Normally only IPv4, IPv6 and ARP packets are allowed to pass through the IXP switch.
Private peering via VLAN	Some IXPs provide VLAN service for private peering; for example, DTEL-IX in Kiev provides two such services: private peering between members in public VLAN or private peering between members in an isolated VLAN. Also called a "virtual IP connection."

Table 5.1. Benchmark Table (continued)

Variable	Discussion Points, Comments, and Issues
Configuration backups	
Governance document and agreement	
Site duplication at other locations	
Advanced IXP *(Assumes that all of the Basic and Intermediate services are also provided)*	
10Gbps Ports	
Fractional 10 Gbps Ethernet ports	2.5Gbps
100Gbps ports	
MPLS/VPLS	
Jumbo frames	
Out-of-band management network	System console access provided even in the event of primary network subsystem failure. This allows access to network equipment in times of failure, ensures management data integrity in case of failure, ensures quality of service to customers, minimises downtime, minimises repair time, and eases diagnostics and debugging.
Number of DNS root servers	
Spam filtering	
VoIP federation	
Automated site access security	This should comprise a smartcard-based automatic door opening procedure with CCTV to ensure only authorised personnel gain access.
Automated provisioning and billing	
Human resources — number of FTE staff	
Staffing description	E.g., three full-time staff: one tech support, one member outreach, one marketing.
Partner/reseller programme	Reseller is able to broker services of the IXP through their own or a separate port, e.g., DE-CIX. This arrangement can provide more efficient use of capacity, e.g., “one stop shop” for customers, etc.
IPX/GRX peering & statistics	These services are mainly for networks offering traditional voice services that require higher-level QOS. IPX service communities are described in GSMA’s IR.34 and are normally provided by offering separate Inter-IPX VLANs, such as GRX, IPX Packet Voice.
Blackholing	Some IXPs, such as DE-CIX, provide blackholing services to assist networks with Distributed Denial of Service (DDoS) attacks. Networks can announce their prefixes with a unique Blackhole Next-hop IP address (BN). When a DDoS attack is detected, the network issues a routing update with the IXP-provided BN address as a next-hop so that DDoS traffic is dropped at the IXP.
Other statistics	E.g., frame size, Ethernet packet type, etc.
Additional power backup and customer supply	To improve reliability, two redundant power feeds from the electrical substation, plus diesel generators in hot stand-by configuration may be required. For customers, both AC and DC current may be desired.

Table 5.1. Benchmark Table (continued)

Variable	Discussion Points, Comments, and Issues
BENCHMARKING ANALYSIS	
Participation Levels of Local Networks and CDNs	
Largest telecom operator exchanging all local traffic at IXP	In developing country environments, the dominant fixed or mobile operators often don't fully participate at the IXP. It may be present in name, but not exchanging traffic with all local peers. Even if they are required to interconnect with the exchange, they may participate but severely under-provision the link to the IXP. This constrains the IXP's effectiveness and ability to grow by attracting members. In these situations, some have suggested that the regulator should require the operator to interconnect fully at the exchange. The mechanism for this requirement could be as part of the dominant operator's license or as an ad hoc ruling. This is the case in Chile where all licensed Internet providers are required to connect to NAP Chile.
Percentage of fixed and mobile operators present at exchange	
National participation density (member ASNs visible/ASNs allocated to country) x 100 (percent)	
Nontraditional local member participation (number of local content providers, nonprovider or noneyeball networks/total members) *100 (percent)	A function of membership restrictions. Includes NRENs, Govt. networks, ccTLDs, Anycast network, Community DNS (brings many TLDs).
Number of external CDNs present (GGC, Akamai, Netflix, etc.)	Can be hosted off-site as long as traffic passes through IXP.
Geographic scope of IXP	
International scope (number of out-of-country ASNs present/total ASNs present) (percent)	All IXPs can be seen on a continuum from local (city) to regional. The degree of regionality or geographic scope of an IXP can be measured by the number of external (nonlocal) networks that are visible and/or reachable via the IXP. It is possible to develop a ranking of IXPs along a scale of geographic scope by counting the number of 'foreign' ASN's present since the visibility of these ASNs means they are either there through transit (via a regional carrier) or peering (if directly connected). For a value that more accurately reflects the geographic scope of the IXP, multiply that figure by the number of foreign countries the ASN's represent at the exchange. E.g., if there are 10 foreign networks/ ASNs at the IXP but from only two countries (=20), the exchange would be less regional than an IXP with eight networks from three countries (=24). This is clearly not a perfect measure and some assumptions could be made as follows: If 20% of the neighbouring countries ASN's are visible/reachable via the local IXP, the IXP is potentially a regional one. If, in addition to the 20%, another 10% are from regions outside of the Regional Economic Block and/or the continent, such a configuration that would make the IXP a defacto regional IXP. This would mean that if 30% of the prefixes and ASNs visible and reachable via the IXP are nonlocal, the IXP could be defined as a regional IXP.

Table 5.1. Benchmark Table (continued)

Variable	Discussion Points, Comments, and Issues
	The 30% is an arbitrary value at this point, but the assumption could be tested empirically by sampling a number of IXPs and looking at the normal distribution of foreign vs. local visibility of ASNs and prefixes. It may also be necessary to examine if the connections to the IXP are either through transit or direct peering.
Internationality (number of foreign ASNs x number of countries those ASNs are from)	
Continentality (number of ASNs from same continent * number of countries those ASNs are from)	
Subregionality – (neighbouring country ASNs x number of neighbouring countries)	
SCALABILITY & SUSTAINABILITY: GROWTH AND SUSTAINABILITY ARE KEY SUCCESS ELEMENTS	
Peak traffic/capacity of switch (percent)	
Total traffic on links/total capacity of links	
Number of ports in use/number of ports available	
Percent of rack space available	
Percent of floor space occupied	
Scarce resource policy	Ideally, an IXP will have sufficient ports and other resources to meet all of the needs of its users, but in practice, usually due to unexpected growth, there may be a limitation in providing sufficient resources over the short term. To make more efficient use of available resources and to smooth the growth path, the IXP should allocate scarce resources primarily on the basis of demonstrated use. IXP users may request an allocation above that required for demonstrated use; in such cases, the IXP should retain the right to reclaim under-utilised resources if they are needed for another user with demonstrated use. The policy will also likely need a dispute resolution procedure to resolve disputes in the allocation of a scarce resource,e.g., JINX in South Africa puts the matter to all active users of exchange who are ISPA members with one vote per user.
Rack space utilisation policy	To maximise the efficient use of physical space available at the exchange, some IXPs located in limited premises may wish to impose rack space usage policies. E.g., JINX in South Africa requires the following limits, over and above which, additional charges apply: 10Gbps – 8U max, 1Gbps – 6U, 100Mbps – 4U, 10Mbps – 2U. In addition, the IXP may impose a requirement that all equipment be rack mounted, and may reserve the right to disconnect equipment that is not rack mounted (exceptions may be made on a case-by-case basis). Even in IXPs with large premises, these rules can be imposed to ensure that the IXP retains its primary function as Internet exchange and not as an equipment hosting facility.
Cabling policy	To ensure consistency and reliability, some IXPs require that all cabling used to interconnect the customer routers with the switch be provided by the exchange. See JINX in South Africa.

Table 5.1. Benchmark Table (continued)

6. Case Studies and IXP Facts by Country

The selection of case studies presented here begins with the three largest exchanges in Africa — in Kenya, Nigeria and South Africa — before relating other developing country experiences as well as some developed country examples. These case studies provide an indication of how IXPs in emerging regions may develop. The country case studies have also been selected to show the range of national market and policy environments within which IXPs may be required to operate, the types of institutional models and interconnection policies adopted by IXPs, and how IXPs evolve over time.

As the case studies amply demonstrate, IP interconnection is still a relatively new arrangement and there are a wide variety of fee structures, institutional models, policy rules, and technical strategies adopted by IXPs across the world. Some of the choices made may have constrained growth in interconnection. In other cases, alternative IXPs have emerged to fulfil needs unmet by the existing IXPs.

A perusal of the case studies will show few geographic trends that can be deduced aside from the commercial/non-commercial divide between the US and the rest of the world; even this is now blurring with three European IXPs recently launching neutral membership-based services in the US.

More important, in the last two years, there has been a notable surge in the number of IXPs in secondary cities, particularly in Argentina, Brazil, and Indonesia, but also in cities such as Arusha, Adelaide, Buffalo, Cork, Durban, Edinburgh, Grenoble, Leeds, Lyon, Manchester, Manitoba, Mombasa, Port Harcourt, Saint Etienne, Toulouse, Turin, Winnipeg, and Zurich.

This trend reflects increasing local content consumption, decentralisation of content redistribution, and overall growth in bandwidth demand built on the steady extension of high bandwidth cable and wireless networks. While most of this growth has so far been in more developed economies, the same trends are becoming evident in emerging economies. In addition, aggregating outbound traffic and avoiding tromboning are likely to be more critical in smaller secondary city markets where local ISPs typically face higher transit costs and longer routes to desired content.

At the same time, the scale, reliability and geographic scope of existing IXPs is extending with many IXPs today offering multiple sites, remote peering, and partnership programmes, often called service provider or reseller plans. Such programmes leverage the benefits of the remote peering model and low-cost national or regional backhaul, minimising technical support needs for the IXP and taking advantage of link aggregation.

Regional extension of networks is also being encouraged in countries where the IXP may operate its own links to a neighbouring city or country. In France, members of France-IX may use up to 100Mbps from Paris to Lyon, Toulouse, Luxembourg and Italy, after which they need to purchase their own links.

Another feature of many IXPs is the presence of domain name server mirrors for a variety of gTLDs and ccTLDs. However, surprisingly few IXPs offer a wider variety of shared services such as time servers, CERT, software mirrors, etc. It is also noteworthy that policies that promote multilateral peering are present among a significant number of IXPs, either mandatory or incentivised in some other way (such as a discount on the port fee for the invited party). The majority of IXPs, however, also offer bilateral peering and VLAN services and of late, a few IXPs are beginning to offer VoIP or GRX-type services.

Many IXPs host regular social, technical or industry events to help build the local community of people involved in peering. Twinning programmes to support emerging IXPs have also been adopted by some of the larger exchanges such as those in London, Amsterdam, and Stockholm.

A significant number of IXPs are still operated without charge; however, the majority of IXPs have pricing arrangements for participation, ranging from a simple joining fee to fees that almost equal the cost of transit. The most important variable in IXP pricing is port speed, but this may need to be balanced against membership fees (if any) or setup fees (if any) and against the backhaul costs of getting to the IXP. as well as availability of link aggregation and discounts for second ports to allow smoothing the costs as network needs grow. (For example, a network needing 1.2Gbps could cost the same as 2X1Gbps ports or 1x10Gbps port without link aggregation).

In analysing the current costs for use of IXP services, 1Gbps and 10Gbps ports are the most commonly available. A minority of IXPs have 100Gbps services and below 1Gbps, ports may not be available or may even be free. The chart below shows the annualised port cost for 1 and 10Gbps ports at a variety of IXPs in different locations around the world. The chart's ranking according to 1Gbps port costs highlights the greater variability and inconsistency in charges for 10Gbps ports.

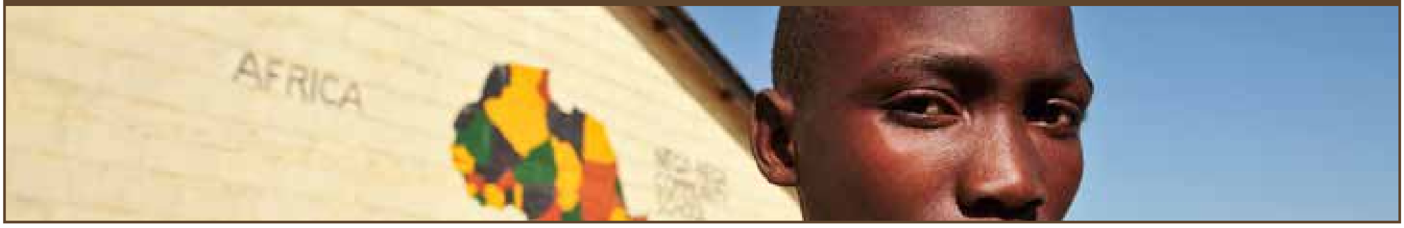
The case studies and data samples provided here draw on information from a variety of sources, including the IXP websites, national ICT market profiles, and personal interviews for this study with some IXP managers. Some case studies are presented in more detail than others due to variably available relevant data. In addition, some of the case studies presented later in the sequence contain redacted repetitive information that may already appear in the earlier case studies presented. Statistics, such as daily peak traffic rates and numbers of members, are drawn from the data as stated in November 2013 on a given IXP's website.

THIS TREND REFLECTS INCREASING LOCAL CONTENT CONSUMPTION, DECENTRALISATION OF CONTENT REDISTRIBUTION, AND OVERALL GROWTH IN BANDWIDTH DEMAND BUILT ON THE STEADY EXTENSION OF HIGH BANDWIDTH CABLE AND WIRELESS NETWORKS. WHILE MOST OF THIS GROWTH HAS SO FAR BEEN IN MORE DEVELOPED ECONOMIES, THE SAME TRENDS ARE BECOMING EVIDENT IN EMERGING ECONOMIES.

In the course of gathering this data, researchers found little consistency in the presentation of basic information on IXP websites. Few IXP websites in emerging markets provide the three primary categories of pricing, membership policies, and list of peers. Traffic statistics are also not provided many sites due to the fact that some IXPs are not yet keeping traffic statistics. Some IXP websites may show disaggregated data with the traffic history of each network connected to the exchange. In other cases, information may be buried in a hard-to-find link or may not be current. Overall, only a small minority of IXPs operate websites that fulfil the basic requirements of a prospective peer for up-to-date, easily accessible information.

Additional case study information and additional materials can be found on the IXP Toolkit portal: **http://www.IXPToolkit.org**

6.1. AFRICA



Kenya

As a result of attending the Networking Workshop for Developing Countries hosted by the Internet Society (ISOC) in California in 1999, one of Kenya's Internet engineers obtained knowledge about how to design, set up, and maintain an IXP. Upon returning to Kenya, he shared this information with other network operators who were keen to begin work on establishing a local IXP. After about a year of preparatory work, including the design and implementation of the technical operation, funding model, and legal framework, the first IXP was launched in Nairobi in November 2000 as KIXP.

The Telecommunication Service Providers Association of Kenya (TESPOK), a professional, nonprofit organisation representing the interests of ISPs and other telecommunication service providers in Kenya, operates KIXP. KIXP does not have a separate governance structure and policies are established through committees of TESPOK.

Licensing issues

Almost immediately following the launch of KIXP in 2000, the incumbent telecom operator, Telkom Kenya, filed a complaint with the national telecommunications regulator, the Communications Commission of Kenya (CCK). They argued, at that time, that KIXP violated Telkom Kenya's exclusive monopoly on the carriage of international traffic. Within two weeks, the CCK concluded that the KIXP required a telecommunications operators licence, found that KIXP was an illegal telecommunications facility, and ordered that it be shut down.

In response to the CCK's closure order, a case was presented to the Communications Appeals Tribunal with a strong technical argument showing that KIXP was merely a standard, off-the-shelf Ethernet hub. If KIXP were shut down on the basis of the Commission's finding, then the CCK would be required to shut down every computer network in the country since the technical architecture and components of those networks and KIXP were equivalent. The Kenyan Internet providers also argued that KIXP was a closed-user group and therefore legal under the Kenyan Telecommunications Act. It was also pointed out that the local exchange of domestic Internet traffic does not contravene Telkom Kenya's international monopoly, as all international traffic would continue to flow over its international links.

Telkom Kenya's opposition to KIXP was fierce, fed by the fear of losing a significant portion of its international leased line revenues. In the course of its arguments, Telkom Kenya misrepresented the situation. Because the matter was made public and had received a significant amount of attention and coverage in the local and international media, a face-saving solution was necessary.

The approach eventually adopted was the establishment of a company called KIXP Limited that applied for an IXP licence that CCK duly granted. This made Kenya the first, and only, country in the world to adopt an IXP licence requirement.

After nearly a year of intensive efforts, including public pressure, threats of litigation, and private diplomacy, TESPOK finally received the approval of CCK in the form of a license, granted in November 2001. KIXP became operational again in mid-February 2002, having interconnected five Kenyan ISPs.

Membership criteria

During 2004, TESPOK members adopted policies governing membership and use of KIXP that limited membership in and connection to the IXP to licensed ISPs. This condition prompted a policy review that lifted all restrictions on membership and lowered joining fees by 600%. Membership now costs KSH20000 (about US$330) per month. There are about 30 members peering at KIXP, including more than a dozen ISPs, one government network (Kenya Revenue Authority), one education network operator, one ccTLD operator, three Internet backbone gateway operators, one value-added telecommunication services provider, and two GSM operators.

NOTE TO OUR READERS: WE TRY TO STAY CURRENT WITH IXP DEVELOPMENTS AROUND THE WORLD. SOME OF OUR DATA, HOWEVER, MAY BE OUT OF DATE. HELP US IMPROVE THE CASE STUDIES FOUND HERE AND ON THE IXP TOOLKIT WEBSITE (**WWW.IXPTOOLKIT.ORG**) BY SENDING YOUR FEEDBACK TO **FEEDBACK@IXPTOOLKIT.ORG**

The IXP location

In order to ensure the acceptability of the IXP concept in Kenya, it was essential to emphasize the neutrality of the facility and obtain consent from prospective members on its location. One of the biggest issues in establishing KIXP related to deciding where it would be hosted. A number of options were evaluated, including the following:

1. Telkom Kenya was ostensibly the most suitable option since it was the incumbent public national telecoms operator. Some of the reasons cited in favour of Telkom Kenya included the fact that all Internet providers already had existing links to its data network. Additionally, due to Telekom Kenya's central location in Nairobi, it would be much easier for the members to gain physical access to the IXP regardless of their location. However, this option proved to be unworkable because, as described above, Telkom Kenya saw the IXP as a threat to its business and declined the ISPs' request to host KIXP.
2. The University of Nairobi was considered as an alternative host for KIXP mainly due to its dynamic computer studies faculty and its central location. The main concern about using the university as the location of the IXP was the frequency of student riots and related security concerns. Since KIXP was expected to serve a mission-critical purpose, this concern eliminated the university as a viable option.
3. Two ISPs with offices conveniently based in the Nairobi CBD offered to host the IXP. The challenges with this option were a) which of the two ISPs to choose and b) the fact that most of the other ISPs expressed a high level of dissatisfaction with the possibility that a competing ISP would manage the IXP without seeking to give themselves undue advantage.

After an evaluation all of the various existing options without finding one that satisfied all the potential members, the idea of leasing space in a provider-neutral, conveniently located building was posed. This option allayed most of the fears and concerns expressed and as a result, 1500 square feet of space was leased on the top floor of a strategically located office building in the Nairobi city centre.

Minimising costs

The main operational consideration related to KIXP was cost. As with any other type of data networking or communications infrastructure, costs fell into two broad categories: set-up and operating. Set-up costs included the cost of purchasing equipment for the core of the IXP as well as furnishing the room where the IXP was to be located with backup power, air-conditioning, equipment cabinets, and the relevant security fixtures. The initial equipment was funded both by a donation from Cisco Systems as well as a small grant from the United Kingdom's Department for International Development (DFID). Other set-up expenses were covered by funds from TESPOK. Since the space where KIXP was located was not free, it was necessary to find a way of covering the operating costs, such as rent, electricity and insurance costs. A monthly subscription fee for all members connecting to KIXP was introduced to cover such baseline operating expenses.

Technical model

A number of different technical models were evaluated for the Kenya IXP with agreement reached that KIXP would be based on the same model as the Hong Kong Internet Exchange — a Layer 2 Route Reflector IXP. As a result, the KIXP facility consists of two high-speed Ethernet switches and each KIXP member has the option of connecting their routing equipment to both switches. Under this arrangement, should one switch fail, the other would take over automatically. The core is supplemented by two 'route reflectors' that are specially configured routers that bounce routing logic to all members at the KIXP until all the routers have the same view of the network. This design aspect allows for quick and easy IXP agreed policy implementation at the exchange point, KIXP is capable of supporting up to 48 networks and capacity can be extended to support up to 200 networks. The current power consumption for KIXP is 15KVA.

Second location: Mombasa

In August 2010, KIXP launched the country's second IXP in Mombasa, located over 500kms from the country's first IXP in Nairobi. Mombasa is the landing point for all undersea fibre cables to Kenya and other landlocked countries in East Africa, making it an attractive location for international carriers to interconnect with the region. Operators perceived the choice to host the Mombasa IXP with Seacom as a neutral point. With KIXP in Nairobi and the IXP in Mombasa, Kenya is expected to increasingly become a hub for traffic in the region.

Outgrowing the original facility

With an annual growth rate of over 100%, the KIXP facility has outgrown its original location. As a result, a tender was published in 2013 to identify a new larger and more suitable location that would also have a more reliable power supply. The bid was won by the East Africa Data Centre, located at Sameer Park, and KIXP is expected to shift to the new location in early 2014.

The tender document required of the bidders:

1. Experience in operating data centres and offering data facility services.
2. Ability for the site to provide:
    - 24-hour, on-site access for all members using KIXP
    - Fully redundant air conditioning system
    - Fully redundant UPS and power reticulation systems

- Backup generators
- Fire protection systems
- Service availability levels and maximum time to repair each system unit in case of failure.
- Security and privacy of data
- Measures to address hardware and software failures
- Regulatory compliance
- Unrestricted access for licensed providers to install connectivity infrastructure to the facility
- Sufficient space for four racks, growing to eight over a two-year period with a negotiable payment option for a further two years.
- Adequate space allocation for infrastructure service provisioning not considered under the contracted footprint required for KIXP.
- Facility services to KIXP and its members at a subsidized cost that may cover either the cost of power or rack space or both.
- Logging procedures for persons accessing KIXP and access logs (ideally on line)
- Additional facilities such as remote online camera monitoring and remote console capabilities
- Procedures for installation and removal of equipment
- Availability of parking

3. Engineers and/or technicians who have qualifications and experience in network administration with two or more of them qualified with the license of telecommunications engineering certificate and or telecommunications installation certificate.

Routing policy, connectivity, and traffic

KIXP previously operated a Mandatory Multilateral Peering Agreement (MLPA) under the terms of which each member must allow peering with every other member. However, this requirement was changed in 2009; the agreement no longer imposes any restrictions on the peering relationships between participating networks.

Until KIXP became operational, all Internet traffic in Kenya was exchanged internationally. From 2000-2002 roughly 30% of upstream traffic was to a domestic destination. During the first two weeks of KIXP's operation, measurements indicated that latency was reduced from an average of 1200–2000 milliseconds (via satellite) to 60–80 milliseconds (via KIXP).

Local traffic has also improved due to the rise in local content that was due, in part, to digitisation of some government services and the arrival of international content companies, such as Google, that now host their services locally. All Google traffic (searches, mail, maps, applications and documents) goes through KIXP. Popular Google content, such as YouTube videos are served from a Google cache shared between members of KIXP.

Due to the limited capacity on the incumbent telecom operator's leased lines, most Internet service providers have moved to terrestrial fibre to connect to the KIXP which means that they have links of multiple megabits per second into the exchange.

Shared services

KIXP has implemented local instances of the Internet's F and J root servers in addition to local .com and .net resolution services. As a result, locally originated lookup requests for these services no longer need to transit international links for a response, improving the responsiveness of website lookups and reducing the load on international links.

In 2005, the Kenya Network Information Centre (KENIC), in line with its mandate to promote access to the Internet in Kenya, set up a GPS-enabled NTP Server at KIXP to provide date and time integrity for computers. Most service providers had implemented time synchronisation on their systems utilising network time servers located in foreign countries. However, these services were not extended to their clients due to the unreliable connectivity and prohibitive costs associated with international links. Some of the organisations now using the local NTP services include government bodies, ISP's, banks, companies and some educational institutions that are able to save on organisational expenses resulting from operational failures and data losses due to time inconsistencies.

KIXP also offers value-added services such as enabling members to exchange network security data and registering them in the global peering database.

KIXP publishes detailed information on Internet usage patterns. Overall, traffic now hits 1Gbps during peak time. The data reveals that traffic flows are highest during weekday business hours, highlighting the opportunity for ISPs in Kenya to maximize off-peak use by developing products and encouraging content attractive to home Internet users.

KIXP is a member of the European IXP association, EURO-IX.

KIXP summarises its benefits as follows:

- Access to the .KE Domain Name System and Servers
- Access to the Kenya Revenue Authority System
- Access to the three global Domain Name System Root Servers
- Access to an Authentic Network time Source Server

- Connectivity on Fibre Optic Connection
- Access to a Route Views Server
- Access to 34 Service provider networks in Kenya
- Access to 110 Networks (Autonomous System Numbers) from around the world

See also the Internet Society study: Assessment of the impact of Internet Exchange Points (IXPs) – empirical study of Kenya and Nigeria. ***http://www.internetsociety.org/ixpimpact***

http://www.kixp.or.ke

Nigeria

The idea of establishing an IXP was first discussed at a meeting of Internet Service Providers of Nigeria (ISPAN) in 2001, but the level of trust between ISPs was low. Consequently, the group attending the meeting decided that it would be imperative to hold a workshop aimed at raising awareness among the ISPs on issues of cooperation and specifically on the benefits of IXPs.

In March of that year, IXP activity first began outside the capital in the city of Ibadan when the first IXP (Ib-IX) in Nigeria went live with two members connected to a 10/100Mbit/s Ethernet switch and a route server. The maximum-recorded traffic between the two ISPs was about 100Kbit/s. In June, Maxwell Kadiri spearheaded an IXP workshop with the support of ISPAN and the French embassy in Lagos. However, no further developments took place for two years.

In early 2005, the ISP Association of Nigeria (ISPAN) began discussions on setting up an exchange in Lagos that was to be managed by an independent entity to be set up by ISPAN. However, in November that year, the President of Nigeria, Olusegun Obasanjo, directed the national regulator, the Nigerian Communications Commission (NCC), to ensure that a national IXP be established as soon as possible. With a budget of N35 million (about US$300,000.00), the Interim Board of the Nigerian IXP (IXPN) was inaugurated in March 2007, but the IXP did not actually become operational until 2010 when it began providing services from Marina, Lagos, with 15 initial members.

Since start up, the membership has grown to 38 and the IXP has established two other operating sites in Lagos in partnership with two different colocation operators, connected by fibre switch fabric across the locations. Four of the biggest mobile operators – South Africa's MTN, United Arab Emirates' (UAE) Etisalat, India's Airtel, and the second national operator, Globacom, have all connected to the exchange along with other major fibre carriers such as MainOne, Phase3 and Layer 3 (figure 6.1).

At the time of inauguration, the IXP planned for eight future sublocations: at Victoria Island, Ikeja, Ibadan, Port Harcourt, Abuja, Enugu, Kano, and Maiduguri. As indicated above, facilities in Lagos, Marina, Victoria Island and Ikeja were established initially, followed by Abuja in mid-2011 (with a grant from the National Information Technology Development Agency (NITDA)) and Port Harcourt in mid-2012. The remaining three locations are still in the planning phase.

The exchange operates at Layer 2 and each location has two Foundry switches connecting separate peering LANs to ensure reliability (figure 6.2). The primary peering LAN is interconnected on a 1Gbps circuit (fibre) while the secondary peering LAN is interconnected on a 450 megabit wireless backhaul. Two of the three operating locations have route servers in place. All the NIX switches provide 10/100BaseTX

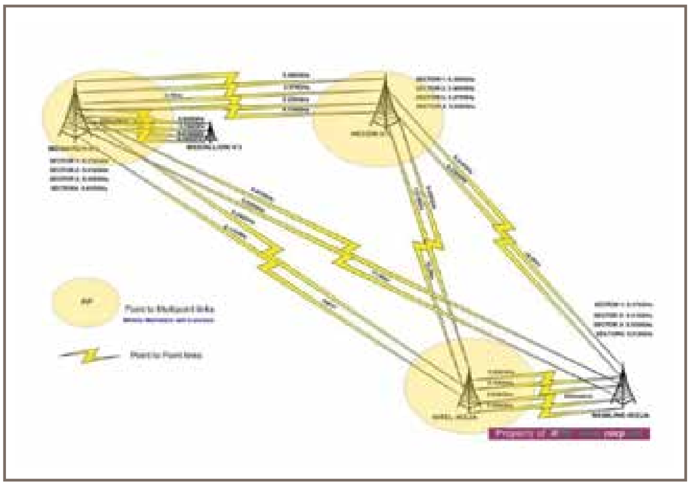


Figure 6.1. IXPN Network *(Source: http://www.ixp.net.ng)*

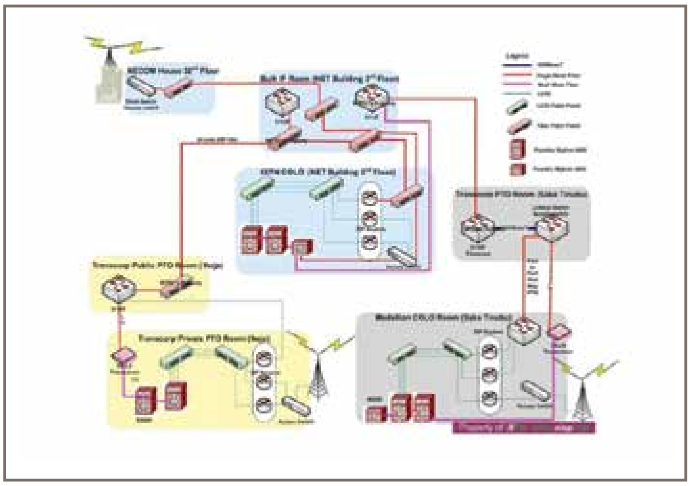


Figure 6.2. IXPN Network Details *(Source: http://www.ixp.net.ng)*

switched Ethernet and 1000BaseSX Gigabit Ethernet over multimode fibre connections.

Shared services include a CommunityDNS server and an F-root name server.

A board composed of the CEO and six directors oversees IXPN. A technical committee assists the staff and advises the Board on technical matters relating to IXPN operations.

IXPN joined Euro-IX, the European Internet Exchange Association in December 2011.

Routing Policies and Traffic

IXPN operates a Mandatory MLPA (Multilateral Peering Agreement) that requires every member to peer with the IXP's route servers. IXPN also offers a separate, private interconnect service for members wishing to have bilateral connections.

A BOARD COMPOSED OF THE CEO AND SIX DIRECTORS OVERSEES NIXP. A TECHNICAL COMMITTEE ASSISTS THE STAFF AND ADVISES THE BOARD ON TECHNICAL MATTERS RELATING TO NIXP OPERATIONS.

Traffic has increased by about 4,000% since the IXP's inception and live traffic statistics are available on the IXPN website. The statistics indicate that members are exchanging traffic at about 2 Gigabits per second during peak times. IXPN also publishes the disaggregated live traffic statistics of each of its members.

Multiple-location fee structure

Considering that there are two peering LANs for IXPN in Lagos, each additional port is charged at the same rate as the first unless a member intends to take a second port on the second peering LAN or if they have a single port on the primary peering LAN. A member's second 100M is free of port charge, but a member's second 1G port has a 25% discount on port charge. These discounts are offered to encourage members to take ports on both the IXPN peering LANs. In common with many other IXPs, IXPN has a port congestion strategy where, if the average measured traffic on a member's port exceeds 80% of its capacity, a Congestion Charge equal to the Basic Port Charge for that type of port is payable in addition to the other port fees.

For additional information on IXPN, see the ISOC study: Assessment of the impact of Internet Exchange Points (IXPs) – empirical study of Kenya and Nigeria.
http://www.internetsociety.org/ixpimpact

http://www.ixp.net.ng/

South Africa

South Africa's largest city hosts the Johannesburg Internet Exchange (JINX), operated by the Internet Service Providers' Association (ISPA), a nonprofit Internet industry body. In addition to operating IXPs, ISPA is actively involved in driving liberalisation and competition in the Internet access market and facilitating dialogue between the different independent ISPs, the South African Government's Department of Communications, the national regulator (ICASA), telecommunication operators, and other service providers.

In November 2013, ISPA had 167 members of which about 50 are members of JINX, comprising a wide range of large, medium, and small Internet service and access providers. ISPA membership is not a requirement for participating in JINX, but nonmembers pay higher port charges. There are currently about 12 participants at JINX that are not members of ISPA.

Currently, peak traffic at JINX is about 8Gbps. JINX has exceeded capacity in the Rosebank facility and its infrastructure has been extended to the neighbouring Parklands building, approximately 100m away. Both facilities are connected by fibre (up to 40GB capacity) for a single virtual JINX environment.

An exchange is also operated by ISPA in Cape Town (CINX). CINX has about 30 members and 3Gbps peak traffic.

Teraco Data Environments, a vendor-neutral data centre, recently won the bid to host the Durban Internet Exchange (DINX). It also runs NapAfrica (following page) with IXPs in Capetown, Durban, and Johannesburg.

Shared services

Aside from a Looking Glass server, a number of DNS services are hosted at JINX. ISPA also provides space to UniForumSA, the operator of the CO.ZA second-level domain, and several international service providers who offer DNS services, such as Autonomica, Community DNS, Internet Systems Consortium, Packet Clearing House, and UltraDNS. These include:

- An anycast instance of the I-Root server together with ~20 ccTLDs and gTLDs (operated by Netnod/ Autonomica)
- An anycast instance of the F-Root server (operated by ISC)
- Instances of the .BIZ and .CAT gTLDs (operated by PCH)
- Instances of the .ORG, .INFO, .COOP, and .AERO gTLDs (operated by UltraDNS)

- Instances of about 40 ccTLDs (operated by PCH and UltraDNS)

Graphs of the traffic across the JINX switch fabric are available at: http://stats.jinx.net.za. Information on the consolidated traffic at JINX is publicly available while detailed traffic graphs for each individual switch port is available to ISPA members.

Membership, fee structure and interconnection policies
There are five categories of ISPA membership: Large, Medium, Small, Affiliate, and Honorary. Large, Medium and Small are all voting membership categories, while affiliate and honorary are special non-voting categories. In order to qualify as a large, medium or small member, a South African Electronic Communications Service (ECS) or Electronic Communications Network Service (ECNS) licence must be held and/or the member must be in the business of providing Internet access services. These are defined as follows:

- Internet access providers, including Virtual Internet Access Providers (IAPs), are those where a member of the public contacts the company and obtains a price for Internet access, including Internet access bundled with VoIP.
- Server hosting companies where a member of the public can obtain a price for the hosting of a physical server (*not* a website)
- Internet infrastructure providers that provide equipment and on-going services critical to the operation of the Internet in South Africa

Applicants are free to determine their own membership category. The category of ISPA membership determines what level of access each member gains to ISPA's Internet exchanges.

There is a minimum membership requirement for access to some ports. For access to 10 Gbps and 1 Gbps ports, ISPs must be 'Large' ISPA members. For access to 100 Mbps ports, ISPs must be either Medium or Large ISPA members. Small, Medium, and Large ISPA members can all use 10 Mbps ports.

All interconnection at JINX must take place via the JINX switch fabric. This means that there may be no peer-to-peer interconnection within the JINX cage and that all traffic exchanged must be via the switch. The policy does not apply to an ISP paying the 10 Gbps port charge; this gives the ISP the right to interconnect privately. A JINX user can pay the 10 Gbps port charge to gain this benefit, but will use a lower-speed port on the switch.

ISPA does not require JINX users to interconnect with all other JINX users. Each organisation is free to establish its own policy for interconnection. Each user of JINX must negotiate interconnection agreements with the other JINX users. Each JINX user must provide ISPA with a clear policy for interconnection with other JINX users and must notify ISPA of any changes to this policy. Members not publishing a specific interconnection policy of their own agree to exchange traffic with all other participants on a no-charge basis. JINX members may also offer transit services to other members.

Content-server hosting is not available at the exchange. ISPA's policy is not to compete with its own members that provide hosting services. While it may seem appealing to host a server at a central location, ISPA points out that there is a negligible difference in performance if the server is hosted on the network of an ISPA member with a high-speed connection to JINX.

An example of a South African ISP's interconnection policy statement, provided by the Internet access provider Storm, states that the ISP will exchange traffic with all other participants on a no-charge basis, provided that they:

1. Are in the business of providing Internet access to more than one organisation or group of companies with common shareholding;
2. Act in good faith and in a cooperative manner on issues relating to the interconnection;
3. Respect Storm's acceptable-use policy and the generally accepted Internet etiquette;
4. Utilise the interconnection in such a manner so as to reduce the costs of exchanging traffic between the parties and improve connectivity between the parties;
5. Take all reasonable measures to ensure that they do not compromise the integrity or stability of Storm's network; and,
6. Comply with the technical requirements required to facilitate the interconnection, including ensuring that sufficient bandwidth is always available on interconnection links.

http://www.ispa.org.za/jinx

NAPAfrica
NAPAfrica is a more recent entrant into the South African IXP sector, hosted by the commercial Teraco data-centre facilities and operating since 2010 in the Johannesburg and Cape Town areas as neutral, Layer 2 facilities providing IPv4 and IPv6. The service is provided free with no membership or port fees. NAPAfrica promotes multilateral peering arrangements in which one agreement provides access to all peers without restriction and ability to provide up to 10 Mbps of fibre last-mile capacity to both JINX and CINX.

http://www.napafrica.com

Tanzania

The Tanzania Internet eXchange (TIX) is a project of the country's ISP association, the Tanzania Internet Service Provider Association (TISPA). TISPA was registered as a nonprofit organisation in 2002 with the primary purpose of establishing a formal entity to support the creation and management of a local IXP. By September 2003, the facilities were ready and the national regulator, the Tanzanian Communications Commission (TCC), issued a letter instructing all ISPs to connect to TIX. The first successful BGP session between two of the ISPs took place the following month.

THE HEART OF THE EXCHANGE IS A HP PROCURVE 8000M ETHERNET SWITCH WITH 64 10/100MBIT PORTS, DONATED BY THE NETWORK START-UP RESOURCE CENTER (NSRC).

TIX is situated in a small room on the top floor of an office block in Dar es Salaam. To cope with the unreliable power supply in the city, TIX has one 3kVA online UPS with 15 external batteries. To reduce the ambient temperature in the city's tropical climate, two window-unit air conditioners are deployed. All electronic equipment is housed in two full-height cabinets. The central IXP equipment is in one cabinet and the routers of participating ISPs and peers are in the second.

The heart of the exchange is a HP Procurve 8000m Ethernet switch with 64 10/100Mbit ports, donated by the Network Start-up Resource Center (NSRC) (www.nsrc.org). TIX has two route server routers: a Cisco 2514 and a Cisco 1760. An instance of the K-Root DNS server is also hosted at TIX.

http://tix.or.tz

Rwanda

Beginning in 2002, Internet providers in Rwanda discussed the need for an IXP. By mid-2003, the tipping point was reached with the presence of two independent ISPs in the country and technicians from the various Internet providers trained in the techniques of setting up and maintaining a peering point. After a year's preparation, the Rwanda Internet Exchange (RINEX) was launched in mid-2004 by the Government's Rwanda Information Technology Authority (RITA) with support from SIDA (the Swedish International Development and cooperation Agency) in collaboration with the Swedish Royal Technical Institute (KTH). Four technicians participated who were drawn from the two main educational institutions (which were also commercial ISPs) — the National University of Rwanda (NUR) and the Kigali Institute of Science and Technology (KIST).

Finding the appropriate facilities for the IXP was an initial issue in setting up RINEX. Obtaining independent premises supplied with electricity, a backup power generator, security, telephones, office space, and an air conditioner proved impossible. The academic entities in Rwanda lack appropriate physical facilities and the private ISPs had limited physical capacity. So it was decided to host the IXP at the premises of the incumbent telecom operator, Rwandatel, which already had existing connections to most of the Internet providers.

A Layer 2-based IXP model was agreed by the stakeholders. Each network operator provides a circuit from its backbone and a router that connects to the IXP switch. The equipment located in the IXP premises consists of the IXP core switch, member routers, and communications equipment. Currently, there are 5 members of the exchange and they are all required by government to exchange routes to their customers directly with each other over the exchange.

A major problem in maintaining RINEX was the absence of an industry association that could take responsibility for management of the IXP. As a result, the Rwanda Information Technology Authority (RITA) manages the exchange until its members are able to establish an appropriate management structure and nonprofit institution to host it. In the interim, a simple administrative model has been adopted where all members have equal decision-making power, independent of size. The management structure consists of two entities: the RINEX Council and the Executive Committee. The RINEX Council is a formal managerial unit that is responsible for making decisions regarding RINEX. The Council is composed of one representative from each connected organisation or member and a president. Presidency of the RINEX Council is continued on a rotational basis among all the members.

http://www.rinex.org.rw

Zambia

Based in Zambia's capital, Lusaka, the Zambia Internet Exchange (ZIXP) is a volunteer-driven, nonprofit membership exchange operating with donated equipment. The ISP Association of

Zambia (ISPAZ) hosts ZIXP. A national broadband provider, AfriConnect (owned by mobile operator Vodacom) provides space at its premises for the switching gear at no cost to the ZIXP community.

ZIXP currently has 13 members (all ISPs) with traffic mostly delivered over 100Mb Ethernet and with peak traffic running at about 280Mbps.

To support capacity building, ZIXP has twinned with UK exchange LINX (see below). Among ZIXP's objectives for 2013 were a redesign of its architecture, the opening up of membership to non-ISPs, and the hosting of .zm name servers. ZIXP intends to provide transit at the exchange for its infrastructure, and intends to join the African IXP association, Af-IX.

http://www.ispa.org.zm

See an in-depth interview with ZIXP on the IXP Toolkit Portal: ***www.ixptoolkit.org/casestudies***

Uganda

In 2001, the Uganda Internet Exchange Point (UIXP) was set up with three initial participants in Kampala in a small room in the parking garage of an office block provided by the national regulator, the Uganda Communications Commission. Since then, UIXP has grown to eight members with about 150Mbps of peak traffic.

Migration from a Layer 3 to a Layer 2 architecture took place in 2012 with support from an ISOC community grant. The project was started in January 2012 with the installation of a power backup system, and involved replacing the 800va inverter + 100ah battery, which had served for over 10 years, with a new 3kva inverter and two 100ah batteries. As a result of this upgrade, UIXP has been able to continue operations for months without any power outage despite frequent power cuts, thus paving the way for installation of more equipment.

WIth a donation from OSI, hardware for the route server was installed and commissioned in 2012 with both IPv4 and IPv6 peering enabled. Orange Uganda, which offered bandwidth and technical configuration to the UIXP, had launched IPv6 services during the week previous to the UIXP installation and was subsequently the first to peer with the new route server on IPv6.

http://www.uixp.co.ug

Reunion & Mayotte

The island of Reunion is a French Protectorate. The IXP, REUNIX, is hosted at the RENATER academic and research network facility at the Université de Saint Denis de La Réunion. With 10 members and free peering, REUNIX provides multicast and DNS services for .fr and .re. RENATER operates similar facilities in Mayotte (Mayotix) and in French Guyana (Guyanix).

Egypt

In 2002, Egypt became the first country in the Arab region to create an IXP, CAIX, on the back of a dynamic ISP market and Egypt's position as the hub location for a large number of international submarine cable landings. Egypt was also among the first countries in Africa to host root and top-level domain name servers at the IXP. Fostered by the Ministry of Communications and Information Technology (MCIT), 60 local ASNs with 232 international links were hosted at CAIX by 2010. CAIX continues to be operated by the National Telecommunication Regulatory Authority (NTRA) and hosted by Telecom Egypt in its Ramses central office. In addition, GPX Global Systems, a private-sector data centre operator with a presence in Mumbai, provides IXP services known as MEIX.

At CAIX, there are four ISPs (TEDATA, Vodafone, Linkdotnet, Etisalat) connected via a gigabit interface and three ISPs (Noor, MenaNet, YALLA) connected via Fast Ethernet. Peak traffic currently runs at about 1.1Gbps. In addition, CAIX hosts PCH's Anycast servers that have copies of about 30 ccTLDs.

There are no fees for connecting to CAIX; however, content providers and service providers wishing to host their servers where CAIX is located pay hosting fees to Telecom Egypt. Interconnection policy requires that all traffic exchanged must be via the CAIX switch fabric, that all members must peer with CAIX router, and that all members must advertise all local IP routes they have in their routing tables to the CAIX router. A scarce resource policy is also in place where the CAIX administration team has the right to reclaim under-utilized resources if they are needed for another CAIX member that can demonstrate a need for those resources.

http://www.caix.net.eg
http://www.gpxglobal.net

6.2. ASIA

Hong Kong

The first free IXP in Asia was the Hong Kong Internet Exchange (HKIX), started in 1995 and administered by the Chinese University of Hong Kong (CUHK). In 2004, the HKIX2 back-up mirror site was created. HKIX continues to be one of the primary locations for Asian peering with a peak traffic volume of about 265Gbps and 196 participants (112 licensed network providers and 84 service operators).

There are also a number of other IXPs in Hong Kong, including commercial data centre operators, iAdvantage and Equinix.

At HKIX, there is currently no plan to impose any charges for membership or connection. However, HKIX reserves the right to do so in the future should such charges become necessary. As with some other IXP's, HKIX's policy is that each participant must have its own global Internet connectivity through other Internet access provider(s) that are independent of HKIX facilities. In this respect, the connection to HKIX is not to be used as the primary connection to the global Internet. The only shared services provided by HKIX are instances of four root servers.

http://www.hkix.net

Indonesia

Biznet Indonesia eXchange (BIX) is one of about five IXPs in Jakarta. BIX is managed by Biznet Networks, one of the larger telecom operators in Indonesia that owns inner-city and intercity fibre optic networks in several major cities in Indonesia, providing voice and Internet services for both business and residential users (figure 6.3.)

BIX is directly connected with Biznet's Metro and FTTH fibre networks that provide connections between commercial offices, homes and data centres. It also provides NTP synchronisation and is available in two POPs in the city.

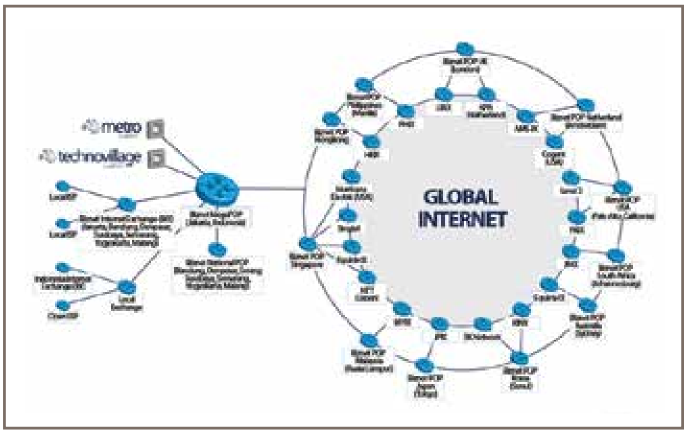


Figure 6.3. Biznet Networks *(Source: http://www.biznetnetworks.com/En/?menu=globalipnetwork)*

Once a port has reached 80% utilization, customers are required to upgrade or order a new connection to the peering switch. As would be expected from a telco-hosted exchange, multilateral peering agreements are expected. In addition, domestic networks must interconnect at a minimum of two physically diverse peering points. International networks may interconnect at a single peering point.

Other IXPs in Jakarta include the semicommercial NAP Info IIX, operated by a carrier, and OpenIX.

http://www.biznetnetworks.com
http://www.openixp.net
http://www.nap.net.id

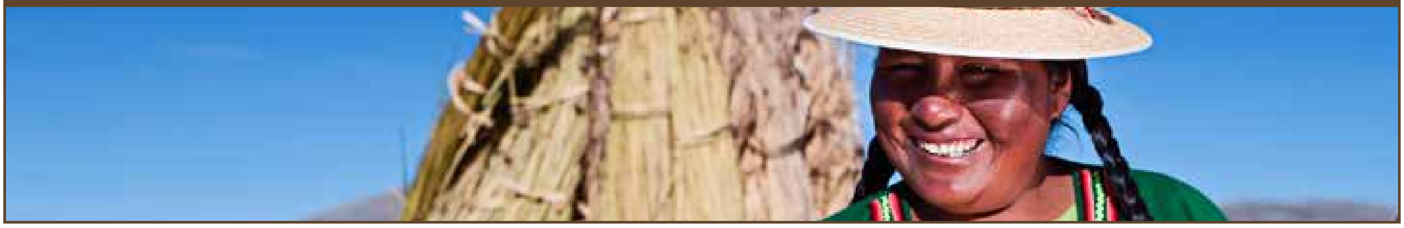
Mongolia

The case of Mongolia demonstrates that ISP cooperation with tacit support from governmental authorities can lead to the rapid and successful establishment of an IXP in a developing country. In January 2001, a group of leading Mongolian network operators met in Ulaanbaatar to explore the creation of a national IXP. At the time, all Mongolian ISPs were interconnected via providers in the United States or Hong Kong. As a consequence, satellite latencies amounted to a minimum of 650 milliseconds (over half a second) for each packet of data in each direction. Costs were needlessly high and not surprisingly, very few Mongolian Internet business services were hosted within Mongolia.

By 2001, this situation had created sufficient incentive for Mongolia's three leading Internet providers to agree to develop an independent exchange. Within 3 months of initiating the project, the three ISP members launched MIX in April 2001. By March 2002, the MIX had six ISP members with steadily increasing traffic between them. Local latency was initially reduced to less than 10 milliseconds per transaction (compared with a minimum of 1300 milliseconds in the pre-MIX days).

THE CASE OF MONGOLIA DEMONSTRATES THAT ISP COOPERATION WITH TACIT SUPPORT FROM GOVERNMENTAL AUTHORITIES CAN LEAD TO THE RAPID AND SUCCESSFUL ESTABLISHMENT OF AN IXP IN A DEVELOPING COUNTRY.

6.3. LATIN AMERICA



Brazil

Brazil has a large number of IXPs, the result of strong government policy support combined with an effective multi-stakeholder agency responsible for the stewardship of the Internet in Brazil, the Comitê Gestor da Internet no Brasil (CGI.br). CGI has access to funding from the registration of .br domains and has legal status as the agency responsible for promoting the development of the Internet in Brazil with representation from government, the private sector and civil society.

Until 2003, only three cities had an operational IXP. Almost 20 cities in Brazil have more than a million people, so there was much tromboning of local traffic, negatively affecting both costs and quality of service outside a few urban areas.

In 2004, CGI launched an initiative to create more IXPs, known as Ponto de Troca de Tráfego (PTTs), in cities across the country. These were established in partnership with a variety of network operators (from universities to large ISPs and telecom providers). CGI is responsible for network administration while NIC.br provides the equipment and management. This strategy has helped to reduce setup and transport costs for smaller players while still providing a neutral platform for traffic exchange with larger network operators.

The number of IXPs grew from four to 19 between 2006 and 2010 and the total today stands at 24 different locations,[1] covering 16 of Brazil's 26 states, with aggregate peak traffic of about 250Gbps. Charges are not normally levied on participants at these exchanges.

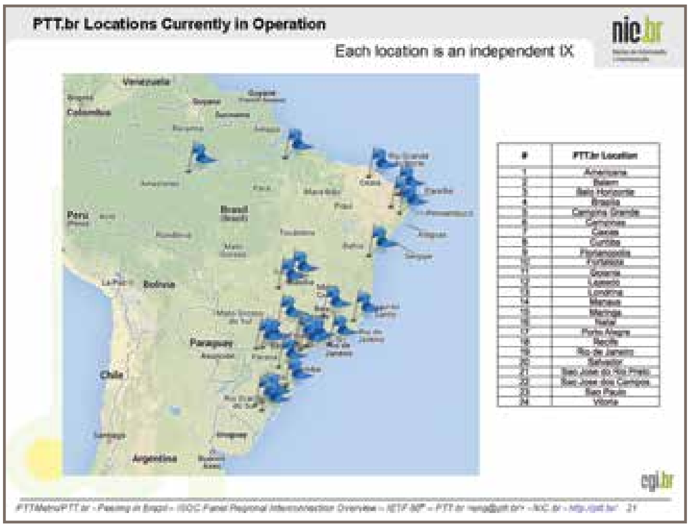
In the larger urban areas, most of the PTTs operate as geographically distributed IXPs within a particular metro area with multiple interconnection locations. The largest of these and the first IXP of the project was established in São Paulo; it is now the largest IXP in the region both in terms of peers and traffic exchanged. The exchange clocks about 175Gbps of peak traffic and with over 300 networks exchanging data, it is the seventh largest worldwide in terms of participants. Domain name root server instances are hosted at about 15 of the IXP locations around the country.

Brazil PTT IXP nodes throughout the country

There also are independent exchanges operating outside the PTT model, most notably Terremark (owned by Verizon) that operates NAP Brasil under agreement with Fapesp, a public research foundation. In addition, a variety of commercial data centres exist where networks peer bilaterally.

CGI lists 16 potential planned sites[2] for IXPs and 47 additional sites are under consideration. The ptt.br website

[1] http://ptt.br/localidades/atuais
[2] http://ptt.br/localidades/register



PTT.br Locations Currently in Operation

(www.ptt.br) actively solicits proposals for new IXP locations with a detailed online application form.[3] One of the criteria used to determine the need for establishing a new IXP is that at least three Autonomous Systems (AS) in the location are interested in participating in an Internet exchange. In determining the size of the area covered by an IXP, CGI normally uses a radius of approximately 80km for fibre optics and 200km for radio links.

http://www.cgi.br

Mexico

Despite its size and level of economic development, Mexico is the only OECD member country without any domestic Internet exchange capacity. Mexico has had a restrictive telecommunications and Internet service market until very recently and as a result, has not seen the emergence of an IXP. The lack of domestic traffic exchange has had a dramatically visible effect on Mexican transit pricing relative to other economies of similar size and development.

However, following substantial changes in legislation introduced in 2013 that open the telecom sector to new entrants, the market is now in a process of major change.[4] This change is underscored by recent public discussions regarding establishment of an IXP in the country — discussions that aptly demonstrate the entrenched positions typical of many incumbent or dominant fixed or mobile operators.

In November 2013, Telmex, the Mexican incumbent and dominant provider, claimed that it is not necessary to establish an IXP. To support its view, Telmex pointed out that local content only makes up 0.6 percent of the Internet traffic in Mexico, saying that so little traffic does not justify setting up a local Internet exchange. Aside from the benefits that an IXP can contribute to the creation of a better environment for local content generation, companies such as Kio Networks, which intends to install an IXP in its Santa Fe data centre in Mexico City, have responded by pointing out that the presence of such infrastructure would provide Mexico with greater sovereignty over data generated by local Internet users.

The six-membered Consortium for Internet Traffic Exchange is expected to develop and operate the IXP. Mexico's communications regulatory body, COFETEL, is supportive of the IXP.

Bolivia

Bolivian state-owned telecom operator, Empresa Nacional de Telecomunicaciones (Entel), and five privately owned operators are planning to set up the country's first two IXPs. Bolivia's telecoms regulator, La Autoridad de Telecomunicaciones y Transportes (ATT), is supporting the project. The five private firms are expected to jointly launch one IXP while Entel will build its own separate IXP. Both projects are expected to cost approximately US$30,000.

Argentina[5]

A group of small and medium-size network operators, called CABASE, founded the first IXP in Argentina (the first in South America) in 1998, NAP Buenos Aires, which now has 46 members. Drawing on this experience, CABASE began to establish IXPs in small and medium-size markets across Argentina in 2011 (table 6.1).

The model for these IXPs is unusual in that they both allow network operators to exchange local traffic and interconnect to NAP Buenos Aires, thus forming a virtual IXP with national reach. The first IXP was established in the city of Neuquén

[3] http://ptt.br/localidades/register

[4] COFETEL, the Mexican regulator, has opened access to competitive long-haul circuits and licensed a second national carrier.

[5] This section on Argentina is based on *Connectivity in Latin America and the Caribbean: The Role of Internet Exchange Points,* Hernán Galperin, Ph.D. Universidad de San Andrés/CONICET (Argentina). hgalperin@udesa.edu.ar

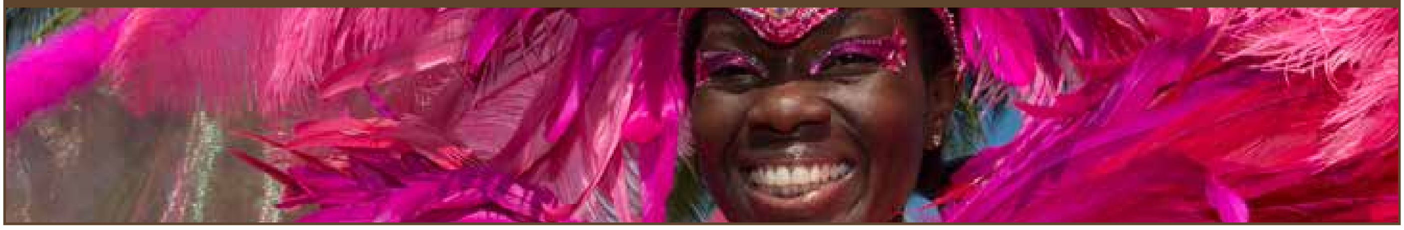
City	State	Pop. (in 000s)	# peers	Peak traffic (Mbps)
NAP Cordoba	Cordoba	1,390	9	100
NAP Bahia Blanca	Buenos Aires	301	12	180
NAP de la Costa	Buenos Aires	70	5	90
NAP La Plata	Buenos Aires	731	8	120
NAP Mar del Plata	Buenos Aires	765	4	270
NAP Mendoza	Mendoza	916	9	130
NAP Neuquén	Neuquén	233	13	750
NAP Rosario	Santa Fe	1,251	16	180
NAP Santa Fe	Santa Fe	500	8	55

Table 6.1. Snapshot of the CABASE Regional IXP Initiative April 2013 *(Source: CABASE and INDEC)*

with support from the local government. To date, nine IXPs operate in five provinces, connecting over 80 network operators through the central routing hub in NAP Buenos Aires. The total switched traffic across the networks is about 8.4Gbps, which currently represents over half of the ASNs allocated to Argentina.

The exponential rise in traffic from the establishment of new IXPs has enabled the Buenos Aires hub to attract peering from new operators and content providers such as Google, which joined NAP Buenos Aires as a special member in late 2011.

6.4. THE CARIBBEAN



THE ISLAND NATIONS OF THE CARIBBEAN HAVE suffered historically from high communication costs and market dominance by a small number of regional operators. The lack of competitive markets has resulted in relatively few ISPs and IXPs emerging in the region with IXPs existing, at present, only in the British Virgin Islands, Haiti, Grenada, St Maarten, Curacao and Dominica. Exchanges located on St Maarten (OCIX) and Curacao are the largest in the region with peak traffic of about 430Mbps and 3.8Gbps, respectively.

However, several other Caribbean countries, including Barbados, St. Lucia, Jamaica, and St Kitts and Nevis, are in the process of establishing local IXPs with technical assistance from Packet Clearing House (PCH),[6] a U.S.-based research nonprofit working to improve interconnection, and with support from the Caribbean Telecommunications Union, a regional ICT policy development agency.

THROUGH A REGIONAL OUTREACH INITIATIVE, BRANDED THE CARIBBEAN ICT ROADSHOW, THE CTU AND PCH HAVE BEEN RAISING AWARENESS OF THE PURPOSE OF IXPS AND THEIR POTENTIAL BENEFITS TO DEVELOPMENT IN THE REGION. AS A RESULT, TWO IXPS EMERGED IN 2011, BVI-IX IN THE BRITISH VIRGIN ISLANDS AND THE GRENADA INTERNET EXCHANGE POINT (GREX).

[6] Much of this section is based on PCH's Bevil Wooding article at http://www.circleid.com/posts/20110524_building_caribbean_internet_infrastructureone_ixp_at_a_time/

Through a regional outreach initiative, branded the Caribbean ICT Roadshow, the CTU and PCH have been raising awareness of the purpose of IXPs and their potential benefits to development in the region. As a result, two IXPs emerged in 2011, BVI-IX in the British Virgin Islands and the Grenada Internet Exchange Point (GREX). These IXPs were "turned-up" following a watershed agreement to exchange local traffic from the region's largest ISPs, which had traditionally been reticent about exchanging local traffic. The governments and national regulatory agencies played roles in supporting the IXP implementations, while CTU and PCH aided the process with technical and policy recommendations and interventions to help bring the service providers into agreement.

The Dominica National Internet Exchange Point (DANIX) was launched in early 2013. Working groups to help set up IXPs have been established in St. Kitts and Nevis, Trinidad & Tobago, St Lucia, Suriname, and Barbados. Root domain name server copies have also been set up in St Maarten, Grenada, and Haiti.

Puerto Rico

In 2011, Google partnered with the Puerto Rico Bridge Initiative (PRBI) to improve broadband speeds and costs in Puerto Rico. One of the significant challenges facing Puerto Rico is that most Internet traffic is routed to the US mainland. By deploying Google Global Cache at the PR-NAP in Puerto Rico and peering with PRBI in Miami, it was possible to reduce the amount of Internet traffic traversing the key links.

https://cw.ams-ix.net
www.bvi-ix.net
www.ocix.net
http://ixgd.wordpress.com
http://www.prbridgeinitiative.org

6.5. THE PACIFIC

New Zealand

In New Zealand, CityLink Limited, a telecommunications company that was formed as an initiative of the Wellington City Council in 1995, operates five neutral Internet-exchanges nationwide. CityLink started with a fibre-optic network in the city's central business district (CBD) in 1996 that runs along the overhead network used for the city trolley buses. Now part of the TeamTalk group, CityLink operates a network of fibre optic cabling around the CBDs of Wellington and Auckland and has a network of Wi-Fi hotspots around Wellington. The exchanges are operated under the ExchangeNET brand and are present in Auckland, Hamilton, Palmerston North, Wellington and Christchurch. Auckland is the largest exchange with 83 members.

CityLink announced this year that it would adopt a software-defined networking solution in the five peering points. It has been testing equipment from SDN-enabled switch vendors over the past year and claims that the SDN architecture approach for the exchanges is the first of its type in the world. According to the company, the main benefits of SDN IXPs are that they are more secure, stable and predictable. North American SDN switch vendor, NoviFlow, will supply the OpenFlow 1.3 compliant switches for CityLink. The cost of the SDN rollout is said to be similar to current 10Gbps networking equipment.

Small Islands

The Pacific Islands face even more severe problems than the Caribbean Islands, with very high communication costs and small markets scattered over vast distances. In some respects, this increases the value of an exchange where there is more than one upstream network provider. This is the case in Fiji where Telecom Fiji and FINTEL networks are now directly connected locally following the successful establishment of an IXP earlier this year.

In Vanuatu, after four years of negotiation with the stakeholders, the technical infrastructure to start the country's first IXP was set up in two weeks.

6.6. WESTERN EUROPE

United Kingdom

The UK has increased the spread of neutral exchange points in the country with the two IXPs in London now being joined by ones located in Manchester, Leeds, and Edinburgh. In the 2000s, there were at least four well-known IXPs in London along with several smaller ones. However, it appears that the city cannot sustain so many neutral IXPs as LINX and LONAP are the only two that remain. There are a number of commercial interconnection services available in London and other major centres from network providers such as Edge-IX.

The London Internet Exchange (LINX)

LINX is one of the world's largest and longest-established Internet exchanges. LINX currently has about 400 members in over 50 countries. While most of the members are from Europe, many are based outside this region, particularly from North America but also from Africa, the Middle East, Asia, and Oceania. LINX facilities have over 890 connected member ports with about 450 member-facing 10GigE ports and over 1.2Tb/sec of peak traffic.

LINX is a mutually-owned membership association for Internet operators that also represents the interests of its members on related public policy matters. Initially, LINX membership was restricted to operators of Internet access networks (traditional ISPs). In 2000, this restriction was relaxed and now a wide variety of networks peer at LINX exchanges, including large content providers such as the Google, Yahoo, and the BBC. The diversity of service providers peering at LINX is increasing and includes gaming and gambling specialists, media streaming providers, DDoS mitigation specialists, software-as-a-service providers, and advertising networks.

Infrastructure

LINX operates a number of separate switching infrastructures, including two in London and one in Manchester, and provides technical support for one in Scotland. The LINX London network consists of two separate high-performance Ethernet switching platforms installed across ten locations:

1. Telehouse North
2. Telehouse East
3. Telehouse West
4. TelecityGroup, 6&7 Harbour Exchange Square
5. TelecityGroup, 8&9 Harbour Exchange Square
6. TelecityGroup, Bonnington House, Millharbour
7. TelecityGroup, Sovereign House, Marsh Wall
8. TelecityGroup, Powergate
9. Equinix, London-4
10. Interxion, London City

LINX does not own any of these sites, but is a tenant in an existing co-location facility or carrier hotel. At least two switches (one from each vendor) are installed in each LINX London location. The locations are interconnected by multiple 10-gigabit Ethernet circuits (across dark fibre) to form two physically separate backbone rings (one with Juniper equipment, the other with Extreme).

Most LINX members connect to both switching platforms that reduce the impact of any downtime on a single network element. For extra redundancy, some members choose to connect at multiple locations. LINX also provides a 'Linx from Anywhere' remote peering service that is provided by Layer 2 carriers to enable peering at LINX from around the globe. About 50 LINX members currently use this method to connect, hosting no equipment in London but instead, taking an Ethernet port from one of its partners. Normally, the member pays the carrier for the transport service and LINX for its standard fees although some carriers may bundle LINX fees as well. This is part of LINX's ConneXions service that allows third parties to resell LINX 10GE or 100GE ports.

Physical protection of the dark fibre network is achieved by using diverse paths where available. Management of the redundancy of the network uses rapid-failover protection mechanisms (EAPS or MRP) so that in the event of a network interruption, the redundant links are activated within tenths of a second.

Geographic expansion

The Manchester site, known as IXManchester, was launched in June 2012 and is run on Brocade switches located in Telecity Williams House. Members can also connect to IX Manchester from Telecity Kilburn. Members of IX Manchester are full members of LINX, paying the same membership fee and having the same voting rights. The LAN in Manchester is completely separate to the two London LANs and is open to all LINX members. This location was the first in an on-going regional peering programme that includes plans for other major UK locations.

TO ADDRESS THE SCARCITY OF PUBLIC PEERING OPTIONS IN THE US AS COMPARED TO EUROPE, LINX HAS ALSO BEEN INVOLVED IN SETTING UP EUROPEAN-STYLE, NONPROFIT INTERCONNECTION FACILITIES IN THE US KNOWN AS OPEN IX.

The most recent of these is IX Scotland, hosted at the Pulsant SouthGyle data centre in Edinburgh and launched in October 2013. There have been at least two efforts to set up an IXP in Edinburgh in the past 15 years, both of which failed. In 2004, LINX supported one of these — UIXP — with a loan of hardware and general assistance, but UIXP was unable to continue operations because the data centre hosting the IXP, Scolocate, withdrew support. IX Scotland has a steering group that is responsible for managing the community; LINX provides the technical support. To access IX Scotland, it is necessary to be a LINX Member.

To address the scarcity of public peering options in the US as compared to Europe, LINX has also been involved in setting up European-style, nonprofit interconnection facilities in the US known as Open IX. Traditionally, private peering has been the dominant model in North America, but there is a demand from network operators for mutually-owned public peering in the United States. The biggest IXPs in the world are all based in Europe with only one North American exchange being in the world's top 10 (Terremark's NAP of the Americas located in Miami), a situation that contrasts with the fact that there is more traffic in the US than anywhere else. The aim of the Open IX project is to work with major data centres to allow third-party interconnect platforms in their premises.

The first Open-IX exchange was launched in October 2013 in the Northern Virginia area with a choice of three different physical data centre locations. Called LINX NoVA, the exchange is built with Juniper MX series routers and will be available in Ashburn, Reston, and Manassas. The sites will be connected by diverse dark fibre lit by LINX.

The Open-IX proposal states that in order to participate, each data centre must agree to open up their Meet-Me-Rooms (MMR) to the operator of the interconnect service and agree to an initial term of five years. Services will include the provision of a public Internet exchange, private VLAN and private wavelengths plus point-to-point dark fibre.

LINX also has a twinning programme to support IXPs in emerging markets and has twinned with the Zambian exchange, ZIXP.

LONAP

LONAP is a neutral, not-for-profit IXP that has been based in London since 1997. LONAP currently has 134 members, making it the second largest IXP in the United Kingdom with traffic currently peaking at about 44Gbps. LONAP membership is usually the first step in peering for smaller ISP's and hosting companies prior to joining LINX.

As a membership organisation, the exchange is owned by the networks that participate in it. As a condition of membership, the rules of the exchange require a member to connect and peer at the exchange, but membership is open to any organisation worldwide that wishes to peer. Membership of the organisation is UK GBP2000 per year; this fee provides for two 1Gbit/s connections to the exchange at no further charge. 10Gbit/s Ethernet ports are charged at UK GBP2500 per year.

LONAP uses a network of interconnected Extreme X series switches linked to each other through diverse 10 Gbps fibre rings that connect five sites in the London Docklands and City areas; Telehouse Docklands North & East, Telecity Sovereign House, Telecity Harbour Exchange, and InterXion London City.

In addition to these sites, remote peering is possible via LONAP, using a third-party, Layer 2 network with dark fibre or wavelengths. Members based in multiple points of presence (PoPs) can connect to LONAP in more than one location in order to increase their service resiliency. Members are permitted to pass traffic between their own ports and can request private VLANs between their own ports or to other members for purposes such as for DSL aggregation. LONAP has on-site spares of the critical equipment that powers the network; these spares assist in responding quickly to any problems that may arise. An off-network, 'out-of-band' connection is present at LONAP sites so that problems can be addressed remotely without waiting for staff to be on site.

IX Leeds

After two years of preparatory work to establish an exchange in the Yorkshire area, IXLeeds was set up in 2010. It is an independent, not-for-profit IXP based in Leeds with 18 members and about 2Gbps of peak traffic.

http://www.linx.net
http://www.lonap.net
http://www.edge-ix.net
http://www.ixleeds.net

Netherlands

AMS-IX

To meet the needs of its many and diverse members, AMS-IX has one of the most sophisticated networks found in an IXP as well as a particularly detailed set of policies, procedures and traffic metrics.

To fill the gap between 1, 10, and 100Gbit/sec port offerings, AMS-IX offers link aggregation for 1Gigabit and 10Gigabit Ethernet ports. This technique allows for the bundling of two or more Gigabit Ethernet links into one virtual channel, negating the need for additional routers.

Service-level quality is regularly measured by a trusted third-party and AMS-IX provides a carrier-grade SLA with service credits up to 100% of the monthly fees upon under-performance. AMS-IX provides members with statistics on key performance indicators: delay, delay variation (jitter) and frame loss. To measure these indicators, AMS-IX uses Delay Measurement Messages provided by the ITU-T Y.1731 Ethernet OAM standard. Every switch in the network has a measurement probe attached to it that exchanges these measurement messages over the platform in a separate VLAN.

AMS-IX technical policies include:

- 100base and 10base Ethernet interfaces attached to AMS-IX ports must be explicitly configured with speed, duplex or other configuration settings; i.e., they should not be auto-sensing.
- Because the AMS-IX infrastructure is based on the Ethernet II (or “DIX Ethernet”), standard LLC/SNAP encapsulation (802.2) is not permitted.
- Frames forwarded to an individual AMS-IX port shall all have the same source MAC address.
- Use of proxy ARP on the router’s interface to the exchange is not allowed.
- Frames forwarded to AMS-IX ports cannot be addressed to a multicast or broadcast MAC destination address except as broadcast ARP packets and multicast ICMPv6 Neighbour Discovery packets.
- No traffic for link-local protocols on AMS-IX ports except for ARP and IPv6 ND
- All new ports activated are first placed in their own separate Quarantine VLAN, together with a monitor port, in order to first ensure proper functioning and configuration of the link.

Statistics provided include:

- Colocation traffic
- Real Time Stats
- sFlow Stats
    - Frame size distribution
    - IPv6 Traffic
    - Ether Type
    - Multicast
    - Broadcast
- Historical Traffic Data
- Route Server Stats
- GRX Statistics

https://www.ams-ix.net

France

SFINX

SFINX, the first IXP in France, was established in 1995 and hosted by the French academic and research network, RENATER (Réseau National de Télécommunications pour la Technologie, l’Enseignement et la Recherche). The exchange has two POPs in Paris interconnected by two 10 gigabit Ethernet links. With 90 members, peak traffic runs at about 28Gbps.

SFINX provides VLAN services and also hosts an NTP server as well as domain name mirrors for three root servers and four AFNIC DNS servers. RENATER’s CERT service is supported by SFINX.

FRANCE-IX

France-IX is the largest IXP in France with 223 members and about 220Gbps of peak traffic. France-IX’s infrastructure consists of seven PoPs in Paris and one PoP in Marseille, using Brocade and Force 10 equipment.

France-IX also operates its own links to a number of neighbouring IXPs (SFINX, LyonIX, LU-CIX (Luxembourg), Top-IX (Italy), TouIX (Toulouse), etc.). France-IX members may use these links for connections of up to 100Mbps after which they need to purchase their own links.

LyonIX, GrenoblIX, SaintetIX and ADN-IX

These four exchanges, in Lyon, Grenoble, Saint Etienne, and Valence are managed by the nonprofit group Rezopole. LyonIX was the first and is the largest of the four, established in 2001 by a group of Internet pioneers who subsequently formed the Rezopole group to promote connectivity in the Rhone-Alps region.

LyonIX has two POPs providing service to 80 members. Aside from peering services, it also provides to its members dark fibre and wavelengths between its POPs as well as hosting services, DNS resources for a number of TLDs, NTP synchronisation, RPKI facilities, ftp servers, and open-source software mirrors. LyonIX also provides a link to the Italian IXP network, Top-IX.

Services are also provided to the general public, including video conferencing, data storage (up to 1Gb), FTP for up to 10 files, a Google Maps API, an RDV meeting scheduler, and group document editing. The LyonIX website is notable in displaying a map showing the location of each of its members and POPs.

SaintetIX was set up in 2009, while GrenoblIX and ADN-IX were established in 2012. GrenoblIX has two POPs and currently has three members while the other two exchanges each have two members.

In Strasbourg, the IXP is called EuroGix. It is intended to be a cross-border IXP for the upper Rhine basin and currently has five members.

Fr-IX is operated as a cooperative called Opdop and has 18 members. Its mission is to support the development of local Internet providers. Fr-IX has a presence in Paris (six sites), Rennes, Le Mans, and Marseille. Fr-IX provides route-server access but does not offer private peering or VLAN services.

https://www.sfinx.fr
https://www.franceix.net
http://www.rezopole.net
http://www.lyonix.net
http://www.grenoblix.net
http://www.saintetix.net
http://www.eurogix.eu
http://www.fr-ix.fr

Ireland

Dublin's IXP is called the Internet Neutral Exchange (INEX). A similar IXP operates as the Cork Neutral Internet eXchange (CNIX) in the city of Cork. Both are industry-owned associations.

INEX currently has 77 members with 53Gbps of peak traffic spread across three POPs. Its members use a variety of different equipment vendors, including Cisco, Brocade, and FastIron. There is a notable, and possibly unique, peering matrix published on INEX's website that shows the peering links of each member. ***https://www.inex.ie/ixp/peering-matrix***

Established by four ISPs in 1996, INEX was volunteer-run until 2004 when it employed a general manager. That year the Irish Government's Industrial Development Agency (IDA) provided a loan facility to the exchange for capital expansion and marketing. The investment also provided the means to expand the exchange to a second site and employ a second staff person to do marketing and membership development. The second site went live in March 2005 with two resiliently-configured Cisco 6500s connected with a dark fibre ring.

An Associate Membership category was announced in 2005 to address the needs of organisations that do not have IP traffic to peer at the exchange but want to join the community that INEX represents – Internet-related services, including fibre wholesalers, colocation and hosting facilities, related technology suppliers, and public service organisations. Associate members benefit from being part of this community by receiving free access to INEX member meetings, invitations to key industry events arranged by the association, and access to various INEX mailing lists.

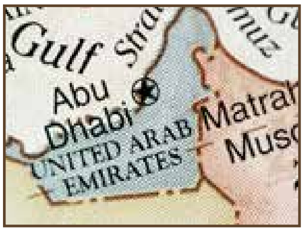
Further technical developments in late 2005 led to the implementation of multicast at the exchange in order to provide an opportunity for the broadcast community to use the Internet as a delivery platform.

Currently in testing phase, INEX is hosting a trial VoIP exchange-LAN to enable VoIP operators to exchange IP traffic over a network protected from the rest of the Internet.

INEX has also developed an IXP management software suite called IXP Manager; it is a web application with associated scripts and utilities that allow IXPs to manage customers, provision new connections and services, and monitor traffic usage. It also has a customer portal that allows IXP members to view their IXP traffic statistics, and peer-to-peer traffic. The portal also contains many other tools such as My Peering Manager and the Route Server Prefix Analysis Tool. Auto-provisioning features include configurations for route collectors, route servers, AS112 services, and reverse DNS. INEX is keen to encourage other IXPs to use its open-source software and is willing to assist with installations in order to build better documentation.

INEX's routing policy includes provisions that require each member to register in advance in the RIPE routing registry or another public routing registry with all routes to be announced through any peerings at INEX. In addition, if a member advertises any routes to another member, it must also advertise these routes to the INEX route collector and each member must maintain a peering relationship with at least four other members or 10% of other members, depending on which is the greater number.

6.7. MIDDLE EAST



United Arab Emirates

A joint project between the UAE's Telecommunication Regulatory Authority (TRA) and the Frankfurt IXP, DE-CIX has resulted in the establishment of the country's first neutral exchange, UAE-IX, in Dubai in October 2012. A year later, UEA-IX had gained 20 participating members that collectively service about 55% of the users in the Middle East.

One reason for this growth is the so-called UAE-IX Transit Zone, created with the support of the TRA. The Transit Zone is considered an "off-shore" location where customers can land their own international capacity via one of the local operators. Customers can set up interconnection and peering activities within the Transit Zone to non-UAE based entities without the need for a UAE Telecom Licence. Content hosted in or passing through the Transit Zone is not subject to any content filtering requirements.

The exchange is run as an independent company that is wholly owned by DE-CIX, one of the largest exchanges in the world. UAE-IX operates on a redundant switching platform located in two data centres in the International Media Production Zone (IMPZ) in Dubai: Datamena and Equinix.

6.8. EASTERN EUROPE

Albania

The Balkans Internet eXchange (BIX) in Tirana is being developed by US-based UNIFI to serve as Albania's first fibre-connected data centre. UNIFI is implementing a regional fibre network, for now from Tirana to Bari in Italy, to provide connectivity from Albania to the major telecoms hubs in Western Europe. Subsequent phases will connect to Greece, Kosovo, Macedonia, and Montenegro.

Bulgaria

Bulgaria has one of the highest levels of broadband connectivity in the world. Surprisingly, the Bulgarian IX (BIX.BG) was only established in mid-2009. It now has eight sites and 56 members exchanging 97Gbps of peak traffic, using Juniper and Cisco equipment. BIX.BG is notable for its simple service-pricing model: no nonrecurring costs or setup costs, only monthly port costs for 1G and 10G ports and discounted prices for additional ports.

http://www.bix.bg

Czech Republic

Prague's NIX.CZ was amongst the first neutral exchanges in the world. Established in 1996 and initially operated by volunteers, it now has eight staff, 111 users and 260Gbps of peak traffic. A membership association, NIX.CZ operates five PoPs across Prague and hosts regular social and technical events for members.

http://nix.cz

Hungary

Like NIX.CZ the Budapest Internet Exchange (BIX) was also founded in 1996 by 12 domestic ISPs, including the largest Hungarian telecom operators. Managed by the the Council of Hungarian Internet Providers (IsZT), BIX now has 51 members and 172Gbps of peak traffic with five PoPs in the city. At the main PoP, Force10 Terascale E1200i switches are used with capacity between sites managed by CWDM multiplexers (80Gbps LAGs).

BIX'S GOVERNING CHARTER ONLY ALLOWS LICENSED INTERNET ACCESS PROVIDERS TO CONNECT TO BIX. OF PARTICULAR NOTE IS THAT FREE PEERING WITH ALL OTHER MEMBERS IS ENCOURAGED WITH A 50% REDUCED MONTHLY FEE.

BIX's governing charter only allows licensed Internet access providers to connect to BIX. Of particular note is that free peering with all other members is encouraged with a 50% reduced monthly fee. If a BIX member is invited by another BIX member to exchange domestic bilateral traffic mutually free of charge, then the invited BIX member must accept this invitation and is only required to pay the 50% discounted fee.

http://bix.hu

Kosovo

KOSIX started operating in mid-2011 as a functional unit within the Telecommunications Regulatory Authority (TRA) and is housed at the University of Pristina's Electrical and Computer Engineering Faculty. The project to develop the exchange was supported by the United States Agency for International Development (USAID), the Norwegian Government's Ministry of Foreign Affairs and Norwegian embassy, and Cisco Systems.

KOSIX currently has four members exchanging about 60Mbps of peak traffic. Of note is that the KOSIX website is keen to promote the data sovereignty benefits of the exchange: "[T]he advantages offered by KOSIX are many, one of the most important being the advancement of security and privacy of communication on the Internet, keeping the local traffic 'local' within national borders, without leaving the national boundaries as it has previously been prior to the function of KOSIX. This reduces the risk component when sending sensitive data across national borders and through many exchange points."

http://www.kosix.net

Serbia

The Serbian Open Exchange (SOX) was established in 2010 with four networks. It now has 23 members from Serbia and five other countries of the SEE region, and can access the six POPs in the capital city of Belgrade. SOX was provided with the necessary communications facilities authorisation by the national regulator.

Other features of SOX include:

- Recent introduction of SDH DXC equipment that provides SDH cross-connect services for telephone company ("telco") operators.
- Fully automated performance monitoring system.
- An Anycast copy of the L-Root server.

http://sox.rs

Ukraine

DTEL-IX in Kiev was founded in 2009 as an independent commercial IXP and is located at Data Center with POPs in two other locations. Starting with a few local connections, it now connects more than 70 networks, not only from Ukraine but also from Russia and Europe, which exchange about 275Gbps of traffic at peak times.

In common with most other IXPs, DTEL-IX offers both public peering with route-server and private peering between members in a public VLAN. Private peering between members on an isolated VLAN and colocation services are also available. So far only 1Gpbs and 10Gpbs ports are available, but 100Gpbs ports are expected to become available soon.

http://dtel-ix.net

6.9. NORTH AMERICA

Canada

Surprisingly for such a large and industrially advanced economy, Canada only had two IXPs as of 2012, a large one in Toronto (TorIX), and a smaller one in Ottawa. This situation is attributed to the restrictive telecom and ISP market in Canada that is dominated by three large companies and to the long border with the US which has a more competitive market. As a result, most traffic between Canadian cities transits through the US.

During 2013, however, the major cities in the states of Alberta, Quebec, Saskatchewan, and British Columbia either had IXPs operational or in planning. In a manner similar to the model of Brazil, where the ccTLD registry is able to use its considerable financial base to provide support for IXPs, the Canadian Internet Registration Authority (CIRA) has also been helping these new Canadian IXPs emerge. However, CIRA does not manage them, but primarily provides non-material support to help local ISPs begin planning to set up IXPs in their cities.

THE RECENT ATTENTION BEING PAID TO FOREIGN SURVEILLANCE HAS ENCOURAGED, IN SOME WAYS, THE EFFORTS OF ISPS TO KEEP CANADIAN TRAFFIC LOCAL.

The recent attention being paid to foreign surveillance has encouraged, in some ways, the efforts of ISPs to keep Canadian traffic local. Currently, up to 40% of the country's domestic Internet traffic travels via the US. On the other hand, suspicions have been voiced over the potential to abuse IXPs as handy one-stop-shops for surveillance.

Annex 1. References and Resources

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Woodcock, Bill, and Benjamin Edelman. Toward Efficiencies in Canadian Internet Traffic Exchange, September 12, 2012. http://www.cira.ca/assets/Uploads/Toward-Efficiencies-in-Canadian-Internet-Traffic-Exchange2.pdf.

Additional Resources

ISOC IXP Information Page with resources in English, French, and Spanish
http://www.isoc.org/educpillar/resources/ixp.shtml

Software

IXP Manager: https://www.inex.ie/ixp/index/about

UnganaIxbase: http://ungana.sourceforge.net/

Regional IXP Associations

Regional associations of IXPs have now been established in all the major regions except North America. These associations generally aim to share information about technical, operational, and business issues and to promote peering. Euro-IX is the most robust association and it welcomes members from other regions. Euro-IX is also supporting the formation of a global federation of IXPs.

Asia-Pacific Internet Exchange (APIX)
http://apix.asia

The African Internet Exchange Point Association (AF-IX)
http://www.af-ix.net

European Internet Exchange Association (Euro-IX)
https://www.euro-ix.net

Latin American IXP Association (LAC-IX)
http://lac-ix.org

IXP Directory Providers

Packet Clearing House IXP Directory. Lists 614 IXPs, with 405 active.
https://prefix.pch.net/applications/ixpdir

Euro-IX IXP: Lists 331 known IXPs
https://www.euro-ix.net/resources-list-of-ixps

BGP4.AS Lists 169 Global Internet Exchange Points and BGP Peering Points
http://www.bgp4.as/internet-exchanges

Wikipedia List of Internet exchange points: Lists 300+
http://en.wikipedia.org/wiki/List_of_Internet_exchange_points

List of Latin American IXPs
http://www.lacnic.net/en/web/lacnic/ixps

OAfrica: African IXPs
http://www.oafrica.com/business/updated-list-of-african-ixps/

Online Resources, Network Operator and Organisations Supporting IXPs

The Asia Pacific Operators Forum (APOPS)
http://www.apops.net

APRICOT (Asia Pacific Regional Internet Conference on Operational Technology)
http://www.apricot.net

The European Internet Services Providers Association (EuroISPA)
http://www.euroispa.org

The Latin American and Caribbean Region Network Operators Group (LACNOG) mailing list
https://mail.lacnic.net/mailman/listinfo/lacnog

The Middle East Network Operators Group (MENOG)
http://www.menog.net

The Network Startup Resource Centre (NSRC)
http://www.nsrc.org

The North American Network Operators' Group (NANOG)
http://www.nanog.net/

The South Asian Network Operators Group (SANOG)
http://www.sanog.org/

PeeringDB: A database established by the peering community for networks to provide peering-related data: peering policies, traffic levels, contact information, etc.
https://www.peeringdb.com

Key Research Papers

Anatomy of a large European IXP (ACM 2012): http://www.eecs.qmul.ac.uk/~steve/papers/ixp-sgcm.pdf

Internet Traffic Exchange: Market Developments and Policy Challenges (OECD 2012) http://www.oecd-ilibrary.org/science-and-technology/internet-traffic-exchange_5k918gpt130q-en

The relationship between local content, Internet development, and access prices. (ISOC/OECD/UNESCO 2012) http://www.internetsociety.org/localcontent

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McLaughlin, A & Zuckerman, E, Introduction to Internet Architecture and Institutions,

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Walubengo, J, Msiska, K, & Kasonde Kasolo, T, Internet eXchange Points (IXPs) and Continental Backbone for Africa: Means to an End?

Internet Governance Research Project, Diplo Foundation, http://www.diplomacy.edu/

Annex 2. Sample IXP Policy Document: Kenya

Operations

1. Board members shall attempt to govern the IX in accordance with technical and policy best practices generally accepted within the global community of IX operators as represented by AfIX-TF, APOPS, Euro-IX, and similar associations.

2. From time to time, the Management of KIXP may recommend certain charges to the Technical and Operational policies of the IX to the Members. Such recommendations may only be implemented with the approval of a majority vote by the Members.

3. General KIXP technical and operational policies shall be made publicly available on the KIXP website. (MOU)

4. The KIXP shall impose no restriction upon the types of organization or individual who may become members and connect to the exchange.

5. The KIXP shall impose no restrictions upon the internal technical, business, or operational policies of its members.

6. The KIXP shall make no policy and establish no restrictions upon the bilateral or multilateral relationships or transactions that the members may form between each other, so long as the KIXP cooperation is not involved.

7. Members must provide 24x7 operational contact details for the use of KIXP staff and other Members. The personnel available by this means must understand the requirements of this Memorandum of Understanding.

8. Members shall be required to sign a copy of the KIXP policies document, indicating that they understand and agree to abide by its policies, before any resources shall be allocated to them.

9. The primary means of communication with other Members will be via email.
10. Members shall subscribe to a KIXP email list, operated by the KIXP board.
11. Members must provide an email address in which requests for peering should be sent.
12. Members have a duty of confidentiality to the other KIXP Members in KIXP affairs.
13. Members must not refer their customers, or any agent of their customers, directly to KIXP members' support staff. All queries must be directed through the KIXP technical staff.
14. Members must ensure that all contact information held by KIXP in connection with their membership is correct and up to date.
15. Members shall be required to provide and maintain current technical contact information, which shall be publicly posted on the KIXP website. This information shall include at a minimum an internationally dialable voice phone number, a NOC email role account, the IP address assigned to the member at the exchange, and the member's Autonomous System Number if they have one.
16. Members may only connect equipment that is owned and operated by that Member to KIXP. Members may not connect equipment to KIXP on behalf of third parties.
17. Members must only use IP addresses on the interface(s) of their router(s) connected to the KIXP allocated to them by the KIXP.
18. Members may only present a single MAC address to any individual KIXP port that is allocated to them.
19. It is preferred that each member have their own Autonomous System Number, members without which an ASN allocation will be assigned from a private ASN space by the KIXP Staff.
20. Any member who has previously been connected to the KIXP using private ASN and then later acquires their own full ASN must notify the KIXP Staff as soon as possible in order to incorporate this development into the BGP peering at KIXP.
21. Peering between Members' routers across KIXP will be via BGP.
22. Members shall not generate unnecessary route flap, or advertise unnecessarily specific routes in peering sessions with other Members across KIXP.
23. Members may not advertise routes with a next-hop other than that of their own routers without the prior written permission of the advertised party, the advertise.
24. Members may not forward traffic across KIXP unless either the traffic follows a route advertised in a peering session at KIXP or where prior written permission of the Member to whom the traffic is forwarded has been given.
25. Members must, on all interfaces connected to the KIXP, disable; Proxy ARP, ICMP redirects, CDP, IRDP, Directed broadcasts, IEEE802 Spanning Tree, Interior routing protocol broadcasts, and all other MAC Layer broadcasts except ARP.
26. Members must, on all interfaces connected to KIXP, disable any duplex, speed, or other link parameter auto-sensing. Full Duplex or Half Duplex Only Fixed.
27. Members shall not announce ("leak") prefixes including some or all of the KIXP peering LAN to other networks without explicit permission of KIXP.
28. Members must set net masks on all interfaces connected to KIXP to include the entire KIXP peering LAN.
29. Any equipment and/or cabling installed by a Member at KIXP must be clearly labelled as belonging to the Member.
30. Members will not touch equipment and/or cabling owned by other Members and installed at KIXP or in the room containing the KIXP without the explicit permission of the Member who owns the equipment.
31. Any members who for purposes of enhancing the services of the KIXP will wish to bring their equipment into the KIXP will be required to seek permission from the management.
32. Members who bring their equipment to the KIXP will be responsible for their equipment and will be expected to show proof of insurance of the equipment.
33. Members will not install 'sniffers' to monitor traffic passing through KIXP, except through their own ports. KIXP may monitor any port but will keep any information gathered confidential, except where required by law or where a violation of this Memorandum of Understanding has been determined by the KIXP Management.
34. Members will not circulate correspondence on confidential KIXP mailing lists to non-members.
35. Members must ensure that their usage of KIXP is not detrimental to the usage of the KIXP by other Members.
36. Members may not directly connect customers who are not KIXP members via circuits to their router housed in any KIXP rack.

37. Members should not routinely use the KIXP for carrying traffic between their own routers.
38. Members will be required to install routers that support the full BGP-4 standard.
39. The technical committee will set up certain monitoring features on the server at the KIXP.
40. Members must not carry out any illegal activities through KIXP.
41. Members connecting to the KIXP will be registered as TESPOK members of a special category with a joining fee of Ksh 30,000/- and monthly subscription as per level of traffic as agreed upon by members.

Disconnection and Reconnection

1. Members who fail to abide by the terms of the KIXP policy will be brought before the technical committee who will effect the disconnected following review of their actions.
2. Members who fail to pay up their monthly subscription for a period of 3 months or more will be given a fifteen day notice within which they clear any outstanding dues, after which they will be disconnected immediately without any further notice.
3. Any notice on disconnection with regard to outstanding monthly subscription will be communicated by the Administrator and copied to the Management.
4. Members who will have been disconnected will be locked out of peering for a period not exceeding 1 month and will be require to get approval from the management before they can re-connect to the KIXP.

Annex 3. Technical and Equipment Recommendations

Rack Space

We recommend at least four 42U cabinet racks fitted with trays, door locks, and mesh doors for cooling, and measuring 800 x 900. Recommended rack allocations are as follows:

- One 42U for carrier(s) transmission equipment
- One 42U for the peering fabric switch and servers
- One 42U for value-added services
- One 42U for Peering member routers

Structured Cabling

The structured cabling is necessary to ensure quality of service and presentation of the facility.

Power Backup and Distribution

We recommend the supply and installation of a three phase inline 10KVA UPS with extended battery pack. A 10KVA power inverter with batteries to last at least 12–24 hours would be needed in location with prolonged power problems and without a generator. In addition a power distribution board installed for the facility and rack distribution units installed for each rack for proper power management.

Server Room Cooling

The formula for calculating cooling is: Total Heat Load = Room Area BTU + Windows BTU + Equipment BTU + Lighting BTU

Room Area BTU = length (m) x width (m) x 337 = 15m2 x 337 = 5,055BTU

Windows BTU = length (m) x width (m) x 870 = 9m2 x 870 = 7,830 BTU

Equipment BTU = total wattage x 3.5 = 10,000w x 3.5 = 35,000 BTU

Lighting BTU = total wattage x 4.25 = 100w x 4.25 = 425 BTU

Based on the above formulae, the estimated total heat load for the room operating at full capacity is: 5055 + 7830 + 35000 + 425 = 48,310 BTU.

We therefore recommend at least two 36,000 BTU split system air conditioning units for the MOZIX. During the initial period one air conditioning unit will support the facility and one will serve as backup.

Switch and Route Server

We recommend the acquisition of 2 x 48 10/100/1000Gbps with at least 2– 4 Gigabit (SFP) interfaces to cater for current requirements, future growth and redundancy. The switch should support Sflow features.

A server-based route-server that supports BGP with IPv4 and IPV6 is recommended. Therefore two servers for the route-servers as per the server specifications below will be useful for the lab.

Server Hardware Recommendations

The IXP best practices require that an IXP operator provide additional information such as a member's mailing list, a website with contact information for the IXP and the members available, an email address, and at least some statistical information on the traffic exchanged at the IXP. Some IXPs also keep an archive of their historical traffic growth to track growth. Others provide a ticketing system for lodging queries and have gone further with advanced network monitoring tools. All the efforts are aimed at ensuring that an IXP is able to provide efficient and reliable services for their members. Computing resources are required in order to host and offer these additional services. Therefore at least five 2U rack mount servers with the following specifications;

- Intel Quad Core Processor
- At least 8GB of RAM
- At least 4 x 450GB 3.5 SAS with 10,000 rpm Hard Disk
- Built-in Raid controller (minimum Raid 1)
- DVD ROM/Writer
- Dual (2) 1Gb Ethernet controllers
- Redundant power supply
- Rack mount kit

The usage is as follows:

- Two servers for route-servers (redundancy)
- One server for IXP email, helpdesk and website
- One server for network monitoring services
- One server for backup, flow analysis, R&D, etc

Security and Access Control

The security and access control is important in order to safeguard the equipment hosted at the facility.

Network Monitoring

To enhance service delivery there will be a need for monitoring of the network devices. In addition to the computing resources, it's also necessary to acquire a SMS notification unit that can alert technical staff of outages via SMS messages.

THE IXP BEST PRACTICES REQUIRE THAT AN IXP OPERATOR PROVIDE ADDITIONAL INFORMATION SUCH AS A MEMBER'S MAILING LIST, A WEBSITE WITH CONTACT INFORMATION FOR THE IXP AND THE MEMBERS AVAILABLE, AN EMAIL ADDRESS, AND AT LEAST SOME STATISTICAL INFORMATION ON THE TRAFFIC EXCHANGED AT THE IXP. SOME IXPS ALSO KEEP AN ARCHIVE OF THEIR HISTORICAL TRAFFIC GROWTH TO TRACK GROWTH. OTHERS PROVIDE A TICKETING SYSTEM FOR LODGING QUERIES AND HAVE GONE FURTHER WITH ADVANCED NETWORK MONITORING TOOLS.

Annex 4. Glossary

THIS SECTION PROVIDES DETAILS ON THE MAIN terms and concepts that relate to the deployment of IXPs.

24x7
A service that has permanent availability – 'always on' (i.e., 24 hours a day, every day of the week); such as for a technical support service at an IXP or network operator.

Acceptable Use Policy (AUP)
A policy adopted up by a network operator describing the rules for using the service – most often limiting the volume of data that may be transferred over certain time period or defining types of network abuse, such as accessing undesirable types of websites, downloading pirated media, or using the network for sending unsolicited bulk email (spam). Some IXPs provide services, such as anti-spam measures, to support the enforcement of their member's AUPs.

African Internet Exchange Point Operators' Association (AF-IX)
A community of practice set up in 2013 to "provide a collaborative environment for Internet Exchange Point Operators in the African region to be able to share knowledge, experiences, and to provide support for each other." http://af-ix.net

Africa Network Information Centre (AFRINIC)
One of the five regional Internet registries (RIRs) that provides IPv4 and IPv6 address allocation services for the African. AFRINIC, like most of the other RIRs, it has an active IXP support programme.

American Registry for Internet Numbers (ARIN)
One of the five regional Internet registries (RIRs) that provides IPv4 and IPv6 address allocation services. The ARIN service region includes Canada, many Caribbean and North Atlantic islands, and the United States.

Anycast
Anycast is a networking strategy where the same IP address prefix is advertised from multiple locations. Users of an anycast service (such as DNS) will always connect to the closest server available.

Asia-Pacific Internet Exchange Point Association (AP-IX)
Serves as a forum for Internet Exchange Points to exchange experiences. APIX members meet twice a year at the APNIC Conference and Members meeting. http://apix.asia

Asia Pacific Network Information Centre (APNIC)
One of the five regional Internet registries (RIRs) that provides IPv4 and IPv6 address allocation services; APNIC serves the Asia-Pacific region except for China, India, Japan, Korea, and Taiwan, Vietnam, which each have their own National Internet Registry (NIR) to handle address allocation and assignment.

Autonomous System Number (ASN)
An identifying number allocated to an Autonomous System on the Internet. ASNs are a basic requirement to run a network with more than one link to the Internet and are almost always required when joining an IXP. ASNs are used in conjunction with the Border Gateway Protocol (BGP) to determine the path along which to route traffic. RIRs assign ASNs.

Backbone
The main route of a network used as the path for transporting traffic. Also used to refer to long-distance fibre optic links, such as in 'national backbone.'

Bandwidth
A measure of the capacity of a communications channel to transfer a certain amount of data in a specific time, usually defined in bits per second (bps), as in Kbps, Mbps, Gbps.

Bilateral Peering
This is peering negotiated between any two providers, through an IXP switch or privately. See Peer/peering.

Bit
Binary digit, i.e., 0 or 1; it is the basic unit used in computing and data transmission. Eight bits usually define a single character that is called a Byte. See Byte.

Bits per Second (Bps)
The number of bits passing a given point every second. This is the transmission rate for digital information, i.e., a measure of how fast data can be sent or received. Often expressed as Mbps, for Megabits per second for broadband links. See Bandwidth.

Blackholing
A configuration technique used to deal with DDoS attacks or routing configuration errors on other networks in which packets to or from selected destinations are 'blackholed' or dropped.

Border Gateway Protocol (BGP)
An IETF routing protocol defining the way in which Autonomous Systems exchange information to determine the path to use in order to send data. Participants at an IXP normally must be able to configure and maintain routers that run BGP. See IETF.

Broadband
A high-speed (multimegabit) data connection, normally provided to the end-user. The International Telecommunication Union (ITU) currently defines broadband as greater than 256Kbps. In practice, however, a broadband connection is usually expected to be at least 1Mbps. In many countries, 10Mbps is now a commonly seen domestic broadband connection (on the download link), 50+Mbps is also becoming increasingly available, and some residential service providers are even providing 1Gbps broadband connections, where fibre to the premises is available.

Byte
Eight bits of data, sometimes called a "word" or an "octet." While data streams are usually measured in bits, file sizes and units of data storage are normally measured in Bytes; e.g., a one terabyte hard drive.

Cache
A copy of a set of data that is stored closer to the end user than the original source of the data in order to improve performance, reduce bandwidth requirements, or limit real-time access to the original content. Caches are filled when a piece of content is downloaded the first time, and usually refreshed at regular intervals or when a later version of the content becomes available. Web browsers often include a cache and so do IXPs. See Content Distribution Networks.

Category 5 Cable (Cat5)
A specification of twisted-pair copper cable able to provide a performance of up to 100Mhz that is suitable for up to 1000Mbps (1Gbps). It has been superseded by the CAT5e (enhanced) specification.

Cloud Service
A service provided via the Internet that gives its users access to applications and data-storage facilities that are hosted remotely on a 'cloud' service provider's network consisting of distributed storage and application servers, which may be spread around the world. Cloud services provide a business model that allows entrepreneurs the ability to more easily scale up and offer service(s) without provisioning their own infrastructure. Typical examples of cloud-based applications are DropBox, Gmail, and Hotmail. Increasing use of cloud services means end-users are ever more dependent on fast and reliable Internet connectivity, adding to the incentive for networks to peer at an IXP.

Co-location (colo)
The renting of space for housing computer equipment, usually in buildings specially designed to support a high density of computers and network connections, often called data centres but also called telehouses or carrier hotels. Co-location is not normally an IXP service as it usually competes with exchange participants, however many IXPs are hosted at colo/data centres.

Connection Redundancy
Two or more connections, ideally via physically different paths to different networks, linked to the Internet. Redundancy ensures continued availability of the Internet in the event of a service interruption on one of the connections. IXPs can help to improve a network's reliability by making it easy to access more than one connection to the rest of the Internet. This may also require two physically independent connections to the IXP unless the network is also using a direct connection to a peer or transit provider.

Content
The data that travels over a network, which can also be termed "traffic," but from the user's perspective, it is the material that the user is accessing and interacting with over the network. Because IXPs help to reduce local bandwidth costs and improve network performance, they help to encourage hosting of content, including local content. See Content Distribution Network.

Content Distribution Network (CDN)
A network whose primary aim is to deliver content to end users and that is often hosted at an IXP to improve performance by bringing the content closer to the end user. These can be content redistribution networks that act as intermediaries, such as Akamai, or content generators themselves, such as Google and Netflix.

Country Code (cc)
A two-letter code uniquely identifying a country; used in top-level national domains, such as .ca (Canada) and .fr (France). Standardised by ISO3166-1. See ccTLD.

Country code Top Level Domain (ccTLD)
The last part of a domain name using a country code allocated to a specific nation. This normally signifies the country in which the domain is registered and usually, but not always, indicates where the holder of the domain name is based. Some ccTLDs have also been used for denoting certain types of content services or websites, such as .tv (Tuvalu). The database of sub-domains registered under a specific ccTLD are termed name servers and are often hosted at IXPs to improve performance and reliability for end users.

Data Centre
Data centres primarily focus on hosting content although they often host IXPs, especially carrier-neutral ones (i.e., not those built by a specific telecom operator, but those that have multiple carriers terminating links into the data centre). Some commercial data centres operate as IXPs and may provide good value for purchasing transit capacity, but are often less cost-effective for peering. See Co-location.

Dense Wave Division Multiplexing (DWDM)
A technology that enables multiple data streams to be transmitted simultaneously on a single optical fibre by using different optical wavelengths (colour) for each data stream. Up to 160 (and theoretically more) wavelengths can now be transmitted on a single optical fibre. Availability of DWDM fibre is helping to meet exploding bandwidth requirements.

Domain Name
A sequence of characters (a name) for use by Internet applications; e.g., someone wishing to access *Le Monde* newspaper via a web browser would type www.lemonde.fr. The registered domain name is *lemonde.fr.*

Domain Name System (DNS)
A distributed database that allows names to be associated with IP addresses. A query of a DNS server will match a domain name to the IP address required by the computer in order to route the traffic to its destination; e.g.,www.lemonde.fr will match to the IP number 62.116.143.15 — the IP address of the web server hosting Le Monde's online service.

Downstream
A network's paid traffic, in contrast to upstream traffic for which a network must usually pay transit fees, and peered traffic which is usually settlement free. See Peers/Peering.

Ethernet
The communications protocol used within a switch to route data packets inside the local network. It is normally only used within a local network because the packets are broadcast to every device attached to the switch. This is computationally inexpensive, but makes this protocol less suitable for long-distance, usually more expensive, lower-capacity links. Ethernet switches are normally used to interconnect the routers of participants at an IXP. Maximum Ethernet speeds have steadily increased and some IXPs are now able to support 100Gbps Ethernet connections. GE is a common notation for one-gigabit Ethernet links, 10GE for 10Gbps links.

Eyeball Networks
Networks that focus on provision of Internet access to the end user. These networks provide the demand for content networks that operate applications or services desired by end users.

European Internet Exchange Association (Euro-IX)
An Association of European exchange points and other members formed to exchange ideas and information on IXP and related issues. Most IXPs in Europe have joined Euro-IX

to share information about best practices. The association is not restricted to European members and welcomes members from other regions. It is also assisting the formation of a global federation of IXP associations.

Fibre Optic Cable; also Optical Fibre Cable
The use of specially manufactured glass fibre for the transmission of data. The signal is transmitted along the fibre using pulses of light from a laser or a light-emitting diode (LED). Current modulation technology allows fibre cables thousands of kilometres long to carry many terabits of data per second (see DWDM above). Optical fibre patch cables are used in IXPs to connect with high speed ports, such as 10 or 100Gbps.

Gbps
Gigabits per second.

generic Top Level Domain (gTLD)
A top-level domain of the Internet that does not carry a ccTLD identifier. In contrast to ccTLDs (see above), gTLDs are normally used to register names that are not associated with a particular country. However, due to the history of the emergence of the Internet, most US-based organisations have, in practice, also used gTLDs in place of the .us ccTLD. Currently, seven gTLDs are commonly used: .com, .org, .net, .edu, .gov, .mil, .int. Another six have more recently come into use: .aero, .biz, .coop, .info, .museum, and .name. The management of TLDs is the responsibility of ICANN. ICANN is now in the process of greatly expanding the number of gTLDs in use. IXPs often host copies of gTLD and ccTLD databases to improve local performance in name lookups.

Gigabit (Gb)
One billion bits.

Gigabit Ethernet (GE)
Ethernet that supports data transfer rates of 1 Gbps. See Ethernet. Most IXPs now support 1Gbps and 10Gbps ports.

Global Routing Table; also Global BGP Table
A database of the different paths in the public Internet over which traffic can be routed. In mid-2013, there were about 480,000 IPv4 and 14,000 IPv6 routes visible on the Internet. This information is used by routers that run the BGP protocol to decide on the most efficient path over which to direct traffic. In practice, with the common use of route filters and rapid changes in Internet routing, no router has the complete view of all routes available. Large IXPs, which usually have routes seen by multiple large networks are among the best places to assess global Internet routing.

Information and Communication Technologies (ICT)
The most common means of referring collectively to both computing and communications technologies, which include the Internet.

Interface
The hardware and software that connects a computer or communications devices to each other or to the end user.

International Gateway
A telecommunications link that crosses a national bounder. It is usually a service that aggregates international traffic from many networks and end users. It is also a construct used by some developing country governments to restrict access to international capacity to particular license holders, often the incumbent state operator, and to mobile network operators. In some cases this is a single entry point through which Internet traffic must pass, creating a de facto IXP, but without the benefits of building a community. This arrangement often constrains local growth of the Internet through inefficient routing or by imposing non-cost-based pricing for local traffic exchange. The resulting construct can also often be a significant barrier to creating an IXP for the other ISPs in the country.

International Telecommunication Union (ITU)
The UN agency responsible for the development of infrastructure, orbital slot and coordinated spectrum allocation, and development of technical standards used in telecommunication networks, particularly traditional voice networks. The ITU has also recently become more involved in Internet public policy and other related matters.

Internet
Interconnected networks that use the TCP/IP protocol (see TCP/IP) to communicate with each other. Emerging from military and academic research in the 1960s, the Internet is continuing to double in size every year. Currently, the Internet is made up of about 44,000 independent networks that connect about 2.5bn end-users to each other and to millions of content and application providers. The Internet is also now emerging as the platform for machine-to-machine communications, known as the 'Internet of things,' which will result in the Internet growing even faster and becoming even larger.

Internet Corporation for Assigned Names and Numbers (ICANN)
The highest level coordinating body for the technical resources of the Internet, responsible for global policy and management of Internet domain names and IP numbers.

Internet Engineering Task Force (IETF)
The body responsible for developing standards for the technical operation of the Internet. The IETF is an open community of network designers, operators, vendors, and researchers concerned with the technical aspects of the operation and evolution of the Internet. It is open to any interested individual.

Internet Exchange Point (IXP)
A physical location that allows many Internet-based networks to exchange traffic with each other at a common meeting point, thus eliminating the need to build separate bilateral links with each local network. Most IXPs are non-commercial organisations funded by membership and other fees paid by the participating networks. Commercial exchanges are also common, particularly in North America where IXPs are often called Network Access Points (NAPs). INX and IX are also common abbreviations. In Latin America, additional abbreviations are NAP, PIC, PIT, and PTT.

Internet Protocol (IP)
The basic packet communications protocol used on Internet networks. See IP Packet.

Internet Service Provider (ISP)
A company or organisation that provides individuals, organisations, and enterprises with access to the Internet. Aside from connecting users, ISPs often provide other services such as email and hosting of websites for their customers. ISPs are also known as 'eyeball networks' that essentially aggregate bandwidth in bulk and resell it to consumers and businesses in smaller chunks. This is in contrast to content networks that focus on providing content and applications for end-users. These two types of networks most often meet at IXPs.

Internet Service Providers Association (ISPA)
An association of ISPs often run on a membership basis in a defined geographic region, usually in a country or a capitol city of a country. Many IXPs are operated by national ISP associations.

Internet Society (ISOC)
A cause-based organization that works with governments, industries, businesses, policymakers, regulators and others to ensure the technologies and policies that helped develop and evolve today's Internet will continue into the future. Its programmes support and advocate for an Internet that is open and accessible to everyone, everywhere, and ensures that it will continue to be a tool for creativity, innovation, and economic growth. Working with its members and Chapters around the world, the Internet Society enables the continued evolution and growth of the Internet for everyone.
http://www.internetsociety.org

IP Address
A unique numeric identifier for a device connected the Internet. Until recently, this was usually expressed as four sets of numbers in the range 0–255 separated by dots (e.g., 196.6.208.1), which is known as an IPv4 IP address. Due to the unexpected growth of the Internet from the time it was first developed, this addressing model cannot provide enough addresses to uniquely identify every device that needs to be connected to the Internet because it is inherently limited to 4,294,967,296 addresses. Consequently, a new, larger standard of IP Address was developed – IPv6, which can provide 3.4 X 1038 addresses in the form of eight groups of four hexadecimal digits separated by colons (e.g., 2001:0cb 7:64g2:0342:1000:8a2e:0370:7334). However, methods of abbreviation of this full notation can be used. IPv6 has enough addresses to connect every device for the foreseeable future.

IP Packet
A discreet unit of data that contains the source and destination of a transmission for routing purposes, along with other management information, as well as the user's data. Because each packet contains the source and destination, each packet can be treated independently by the networks it travels through to reach its destination. Different packets may take different routes before being reassembled as the data stream on the recipient device.

Kilobits per Second (Kbps)
A data transfer rate of one thousand bits per second.

Latency
Typically measured in milliseconds (ms), latency is a measure of the delay in the round trip time (RTT) required for a packet of data to reach and return from its destination.

Latin America and Caribbean Internet Exchange Point Association (LAC-IX)
The association's objectives are to increase Internet traffic in the region, represent the member IXPs worldwide, support governments on policies, provide statistics and advice related to Internet Exchange Traffic, simplify cooperation between the IXPs, and promote and support the establishment of new IXPs. http://lac-ix.org

Latin America and Caribbean Network Information Centre (LACNIC)
One of the five regional Internet registries (RIRs) around the globe that provide IPv4 and IPv6 address allocation services (for the Latin American and Caribbean region except for Brazil, Chile and Mexico, which each have a National Internet Registry (NIR) to handle address allocation). LACNIC has recently helped to launch an association of IXPs in the region called LAC-IX.

Leased Line
A telecommunications circuit leased between two or more locations from a telecom provider. Networks will normally need to lease a line or deploy their own infrastructure to connect with the IXP.

Link Aggregation Control Protocol (LACP)
Link aggregation is used by some IXPs to provide higher-capacity links to members.

Local Area Network (LAN)
A local network of devices interconnected physically through one or more Ethernet switches or wireless links. An IXP is essentially a set of participant routers connected to a LAN. An IXP may have additional LANs for administrative purposes or for providing other shared services.

Looking Glass Server
A server hosted on a network or IXP that makes it easy to identify the routes available at that location.

Megabits per Second (Mbps)
A data transfer rate of Mega (million) bits per second.

Metropolitan Area Network (MAN)
A network spread over a metropolitan area. This may refer to a physical fibre or microwave network, such as may be operated by a telecom provider to carry voice and data traffic within a large city, or it may refer to an IP network linking different locations in one city, including an IXP with several locations in the same city.

Multihoming
An IP network with two or more physical links to other networks in order to provide resilience and/or diversity. An AS number and appropriate routers are required to operate multihoming networks connected to the Internet. Knowledge of multi-homing router configuration is a basic prerequisite for joining an IXP.

Multilateral Peering
A type of peering policy available at many IXPs where members agree to exchange traffic with every other member present at the exchange, usually through a route-server. This contrasts with bilateral peering or 'private peering' where two networks agree to exchange traffic with each other in a private arrangement. A choice of multilateral and bilateral peering is usually available at most IXPs.

Network Access Point (NAP)
Another name for an IXP. NAP was the name given to the first exchange points established in the United States when parts of NSFNet, the first TCP/IP-based network, were spun off from its academic roots into commercial operations. NAP is also more commonly used in Latin America.

National Regulator Authority (NRA)
See Regulator.

Network
Two or more interconnected computers or data communications devices. "IP network" or just "network" is now the commonly used term for a distinct group of interconnected devices linked to the Internet and operated by a specific entity.

Nongovernmental Organisation (NGO)
A nonprofit organisation whose shareholders or other governing body do not financially benefit from the organisation's primary activity. Noncommercial IXPs may be registered as NGOs or as nonprofit companies.

Optical Fibre Cable (OFC)
See Fibre Optic Cable.

Packet
A discreet unit of data traffic. Packet switched networks are the basis of Internet in contrast to the older circuit switched networks that were developed in the previous century for voice networks.

Peer/Peering
Peers are networks that agree to exchange routes (and therefore traffic) with each other, normally on a settlement free basis. The distinction between settlement-free peering and 'transit,' where one network pays another to exchange traffic (usually to reach most of the other remote networks on the Internet), is blurred by options where some routes may be settlement free while other routes carry a fee ('paid peering') or where there is some other form of compensation between the two networks. In all these cases, specific business arrangements between two networks are called 'bilateral peering' or 'private peering.' Bilateral peering can either take place at an IXP or through direct physical interconnection between the two networks. The latter is normally called 'private peering.' The other common form of peering at an IXP is called 'multilateral peering.' See Multilateral Peering.

Petabit
One thousand Terabits.

Plain Old Telephone Service (POTS)
A traditional fixed-line copper cable phone service. See PSTN and PTO.

Point of Presence (PoP)
A physical infrastructure location where a network or end user can access the services of a provider.

Private Peering
See Peer/Peering.

Protocol
At a technical level in the ICT world, a protocol is usually a set of rules that determine the way in which two networked devices communicate with each other; e.g., routers exchange routing information using the border gateway protocol (BGP) just as all devices connected to the Internet must exchange traffic using the Internet Protocol (IP).

Public Switched Telephone Network (PSTN)
The traditional circuit switched voice telephone system; however, may also refer to mobile networks.

Public Telecom Operator (PTO)
Usually the circuit switched fixed line telecom operator although technically, as communication technologies converge toward the Internet, the distinction between fixed-line operators, cellular operators and ISPs is becoming increasingly blurred. PTOs usually have a different business culture to the new Internet network operators and are often the dominant network operator, a status that may limit their interest in peering locally as opposed to selling transit.

Public-Private Partnership (PPP)
A partnership between the private sector and government in a common project. In some cases, IXPs are established as a partnership between privately operated commercial networks and government bodies. Not to be confused with the Point-to-Point Protocol as used in computer networking or with Purchasing Power Parity (a mechanism to compare the relative values of currencies).

Quality of Service (QOS)
A measure of the level of service provided by a network. There are many different QOS measures. Common examples include up-time (e.g., five 9's – operational for 99.999% of the time), packet loss, round-trip time, etc. QOS may be defined in a business relationship called a Service Level Agreement (SLA). QOS rules can also be applied to different types of traffic passing through a router; for example, voice traffic might be given a higher priority than email. IXPs may provide certain QOS and SLA commitments to their members.

Regional Internet Registry (RIR)
One of the regional organisations that are allocated blocks of IP addresses and ASNs by ICANN/IANA for onward allocation to individual local networks (except for 10 countries in Asia and Latin America which operate their own national registries). Currently, there are five RIRs – one for each major geographic region: ARIN, APNIC, AFRINIC, LACNIC and RIPE NCC.

Regulator
A government entity with legally mandated responsibility for executing national ICT policy by establishing a set of regulations that govern the sector. Ideally the regulator is semiautonomous with an income derived from license fees that provides substantial independence, although the state usually appoints the executive body. Ideally the regulator helps ensure that there is a level playing field in telecom and Internet markets. In this respect, it often has a major responsibility to curb the impact of market dominance of the incumbent operator, especially in developing countries. (In some economic regions with a high level of integration, such as the EU and ECOWAS (West Africa), a significant level of policy and regulatory development takes place at the regional level that the member states are obliged to adopt.)
The regulator does not normally have a direct role in IXP development although in some countries the IXP may be hosted by the regulator or facilitated by regulatory proceedings allowing the IXP to exist. The regulator can play an important role in helping to ensure that dominant operators participate fully in the IXP and in ensuring that there is a competitive market for national and international Internet capacity.

Remote Hands
A facility provided by IXPs and data centres where participants can make use of a local on-site engineer to perform physical activity at the exchange, such as rebooting a router, installing patch cables, etc.

Réseaux IP Européens Network Coordination Centre (RIPE NCC)
One of the five regional Internet registries (RIRs) around the globe that provide IPv4 and IPv6 address allocation services (for Europe and the Middle East).

Request For Comment (RFC)
The IETF procedure used for the development of Internet standards. For example, RFC 5963 describes how IPv6 may be deployed at IXPs.

Root Name Server
Root name servers are used to determine the location of other DNS servers. DNS servers are the authoritative source of information about top-level domains (e.g., .com, .org, .int, and, .arpa). There are currently 13 root servers around the world with the domain names 'a.root-servers.net,' 'b.root-servers.net,' up to 'm.root-servers.net.' Copies of these root server databases are often hosted at IXPs or other well-connected locations in order to increase the resiliency of the Internet locally in the event of international connectivity interruptions. Copies of these root servers are often called 'instances' or 'mirrors.' For a map of these entities, see http://root-servers.org/map/.

Route
The path through one or more networks that is taken by IP packets. Due to the dynamic nature of routing on the Internet, packets from the same data stream may travel to their destination by different routes.

Router
A device that receives IP packets and decides where to send them based on which device is 'closest' or 'least expensive' on the way to the packets' final destination. Routers usually make these decisions based on a set of preconfigured rules combined with dynamic routing information exchanged with other routers on the Internet, usually based on the BGP routing protocol. Routers with only one physical connection to another network are usually configured with a 'default route' that is the upstream connection to the rest of the Internet. Normally, a network participating in an IXP will have a router at the IXP premises that will be connected to the other participants' routers via an Ethernet switch.

Routing Policy
The routing rules that a network applies when carrying traffic from other networks.

Spam
Unsolicited email, usually used in questionable marketing practices. Some IXPs provide an anti-spam service.

TCP/IP
Transmission Control Protocol/Internet Protocol – the key protocols for transmitting packet-based data on which the Internet is built.

Terrabit
One thousand gigabits.

Tiered ISP Model
Internet Service Providers have traditionally been classified by size into 3 tiers: Tier 1 ISPs are the largest (usually global ISPs that peer directly with each other), Tier 3 ISPs are the smallest local ISPs, and Tier 2 ISPs fall somewhere in the middle. These distinctions are blurring as the ISP sector evolves, but normally it is assumed that ISPs from lower tiers usually have to purchase transit from higher tier ISPs.

Top Level Domain (TLD)
See gTLD and ccTLD. http://en.wikipedia.org/wiki/Top-level_domain; http://archive.icann.org/en/tlds/; http://www.icann.org/en/resources/cctlds.

Transit
The capacity or routes purchased from a larger network, usually to reach remote networks on the Internet. See Peer/peering.

u
A unit of measurement mainly used to describe the height of rack-mounted computer equipment (especially servers and routers) and the racks into which they are fitted. One "u" is 1.75 inches or 4.445 centimetres. IXPs may have policies on the amount of rack space that can be occupied by each participant at the exchange.

Unshielded Twisted Pair (UTP)
A type of data cable containing four pairs of conductors, each pair being twisted together. UTP is used extensively in connecting local Ethernet network devices together.

Upstream Traffic
Traffic that a network must usually purchase as transit in order to make connections with other networks. This is in contrast to downstream traffic, which is usually the revenue generator for a commercial access provider ('eyeball') network, or for a lower-level wholesale capacity provider. See Peer/Peering.

VoIP
Voice over Internet Protocol. There are many Internet-based VoIP services, such as Skype and Google Talk. Traditional circuit switched voice networks are also increasingly migrating to the Internet. The 'best effort' model of Internet service provision requires that specialised traffic management techniques may need to be applied to deliver the same level of QOS that is expected by customers of traditional voice networks. In addition, gateways between IP and circuit switched voice networks may require specialised signalling to support features such as caller ID. Some IXPs are now implementing these techniques so that voice networks can continue to migrate smoothly to an all-IP environment.

Wide Area Network (WAN)
A network normally spanning a larger physical area than a LAN, in particular denoting the use of different physical transmission media. The most common use of WAN terminology is in the WAN port(s) on a router which collects traffic from the LAN and passes upstream traffic to the WAN links, usually to the rest of the Internet, and vice versa.

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