IGF 2016

Best Practice Forum on IXPs

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Contributing to the success and continued development of Internet exchange points

Editor: Wim Degezelle

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Executive Summary

The Best Practice Forum (BPF) *Contributing to the Success and Continued Development of Internet exchange points (IXPs)* collected best current practices that have proven to contribute to building strong and successful IXPs.

The BPF on IXPs was part of the community intersessional work program of the Internet Governance Forum (IGF). This report is the outcome of an open an iterative process over the months preceding the 11th IGF meeting in Guadalajara, Mexico, 6-9 December 2016.

The BPF on IXPs and this best practice outcome document want to serve as a flexible and useful resource intended to inform policy debates on IXP-related issues in a neutral way. This is not a normative document but a sharing of community experiences.

The Internet is a network of networks, which collectively constitute a global communication system. *Internet exchange points (IXPs) are physical locations where three or more networks can connect at a common point to exchange data traffic.* Exchanging traffic at an IXP has a number of benefits that can contribute to a more affordable, stable, faster and more reliable Internet of a higher quality in a region, and as such can help to enable inclusive and sustainable growth of the local Internet ecosystem.

The 2016 BPF on IXPs has built on the work of the 2015 BPF *Enabling environments to establish successful IXPs* that collected best practices to create a supportive environment that facilitates the establishment and development of an IXP. The success of an IXP will largely depend on its capacity to create an environment of trust and cooperation among its members and stakeholders.

The success of an IXP should be measured by its ability to sustainably contribute to the development of the Internet ecosystem within its community. Traffic volume alone is not an accurate indicator of success. The 2016 BPF focused on the management and operation of an IXP and identified factors that can contribute to the success. IXPs and their stakeholders often look for experiences of other IXPs in order to identify what made them flourish.

After their establishment IXPs must continue the efforts to build trust and gain the support from their local community. Outreach will remain important, to explain to stakeholders and decision makers what the function of an IXP is and how it can contribute to the development of the local Internet.

Once the IXP is set up and the technology is installed and running, the attention needs to shift to the long-term growth and sustainability of the IXP. The IXP, whether it is for-profit or not-for-profit, needs a business plan. A good business plan will allow the IXP to foster growth, foresee challenges and better cope with changes. The BPF discussed why a business plan is

important, also for e.g. not-for-profit, small, or subsidized IXPs. IXP leaders have to run their project with a business mindset, but also understand that putting together a business plan does not necessarily means commercializing the IXP.

An IXP's business plan can be simple or more elaborate, but it is advisable that it contains at least a basic budget, with revenues and expenditures, and a marketing plan to gain visibility and approach potential new members. The business plan can help to prepare for changes and to early address challenges. The BPF identified a number of challenges IXPs can meet on their path: coping with growth in a timely way so that the IXP is not slowed down due to capacity issues, dealing with volunteer and donor fatigue, raising the IXP's visibility, foreseeing and reacting on changes in the market, assuring the financial sustainability of the IXP, attracting content providers and CDNs, securing the technical sustainability of the IXP and foresee in local technical capacity building, etc.

Unfortunately there is no golden or one-size-fits-all solution. Each IXP is embedded in its local environment, with different particularities, challenges and opportunities. This does not mean that IXPs cannot learn from each other's experiences, on the contrary. Therefore the BPF collected case studies from different parts of the world, selected because their story is in one way or another unique, and can inspired their peers. The BPF document presents the case studies from IXPs in Canada, Vanuatu, Thailand, Rwanda, Bangladesh, Ecuador and Argentina.

The BPF on IXPs held a workshop at the IGF meeting in Guadalajara where the question why an IXP needs a business plan, and other IXP best practices were addressed and discussed with IXP operators. A video recoding of the workshop can be found on the link below:

> *BPF on IXPs workshop at the 11th IGF meeting,*
> 8 December 2016, Guadalajara, Mexico
> https://youtu.be/S6fFinDt5U0 (YouTube video)

Exchanging experiences and mutual learning is key for new and developing IXPs as well as for those already exist for some time. There is a huge amount of knowledge available within the IXP community and many more places other than this BPF document where IXPs and their stakeholders can exchange information, ask peers for advice and learn from each other's failures and successes. The last section of the document and the annexes contain a non-exhaustive overview of existing initiatives, meetings, organizations, and resources.

Glossary of Terms

- **Autonomous System (AS):**
  An IP network, or set of IP networks, with a single (i.e. autonomous) routing policy.
- **AS Number (ASN):**
  An identifying number allocated to an Autonomous System on the Internet.
- **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'.
- **Bit / Binary Digit:**
  A digit to base 2, i.e. 0 or 1, which is the fundamental mathematical unit used in computing.
  - **Bps:** bits per second, the number of bits passing at a given point every second.
  - **Mbps:** a data transfer rate of Mega (million) bits per second.
  - **Gbps:** a data transfer rate of Giga (thousand million) bits per second.
- **Border Gateway Protocol (BGP):**
  An Internet Standard protocol defining the way in which Autonomous Systems exchange routing information.
- **BPF:**
  Best Practice Forum, one of the activities of the community intersessional work program of the IGF.
- **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.
- **Content Distribution Network or Content Delivery Network (CDN):**
  A network of distributed servers whose primary aim is to deliver content to end-users and is often hosted at an IXP to improve performance by bringing the content closer to the user.
- **Hosting:**
  A loose term for the function of holding and sometimes managing servers.
- **IGF:**
  The Internet Governance Forum.
- **Internet Protocol (IP):**
  The communications protocol used on Internet networks.
- **IP network:**
  A network using the Internet Protocol.
- **Internet Service Provider (ISP):**
  A company or organization that connects end-users and businesses to the public, global Internet.

- **IX, IXP:**
  An Internet Exchange or Internet Exchange Point is a physical location where three or more networks can connect at a common point to exchange data traffic.
- **Latency:**
  Typically measured in milliseconds (ms), latency is a measure of the delay in the round trip time (RTT) it takes for a packet of data to reach and return to its destination.
- **Network:**
  Two or more interconnected computers or data communications devices.
- **Peering/Peers:**
  Peers are networks that agree to exchange routes (and therefore traffic) with each other, normally on a settlement free basis.
  - **Multilateral Peering (MLP):** a type of peering policy available at many IXPs where members agree to exchange traffic with every other member present at the exchange.
  - **Bilateral Peering (BLP):** Peering negotiated between any two providers, through and IXP switch or privately.
- **Protocol:**
  A set of rules governing the way in which two networked devices will communicate with each other. For example, routers exchange routing information using the BGP protocol, Internet devices exchange traffic using the Internet protocol (IP).
- **Point of Presence (PoP):**
  A physical infrastructure location where a network or end-user can access the services of a provider.
- **Regulator:**
  A government entity with legally mandated responsibility for executing national ICT policy by establishing a set of regulations that govern the sector.
- **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.
- **Root name server:**
  Root name-servers are used to determine the location of other DNS servers. DNS server are the authoritative source of information about top-level domains (e.g., .com, .org, .de etc.).
- **Transit:**
  A term used generally, but not exclusively, to describe the routing of Internet traffic between and IP network and the public Internet.

The explanations and definitions were taken from the IXP toolkit and the Euro-IX Glossary of Internet Exchange Definitions, Acronyms and Abbreviations:

https://www.euro-ix.net/tools/glossary/
http://ixptoolkit.org/content/glossary

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1. Introduction

The Best Practice Forum (BPF) *Contributing to the Success and Continued Development of Internet exchange points (IXPs)* collected best current practices that have proven to contribute to building strong and successful IXPs. This is not a normative document but a sharing of community experiences.

The 2016 BPF on IXPs builds on the knowledge collected by the BPF on *Enabling Environments to Establish Successful IXPs,*[1] which was part of the IGF Community Intersessional work program in 2015. While the 2015 BPF mainly focused on creating and establishing new IXPs, the 2016 BPF is about growing and further developing an IXP.

IXPs can play a critical role in improving the affordability, performance, and reliability of the Internet; thus, they can play an important role in enabling inclusive and sustainable growth in their communities.

This BPF output will document and acknowledge the benefits of an IXP, and identify factors that can contribute to the development and success of IXPs as well as the broader Internet ecosystem. The information and examples in this document come from case studies and input from individuals belonging to multiple stakeholder groups. The outcome of the BPF is considered to be a "living" and flexible resource intending to inform all kinds of policy debates on IXP-related issues in a neutral way.

1.1. The Internet Governance Forum and Best Practice Forums

One of the key outcomes of the World Summit for the Information Society (WSIS) was the Internet Governance Forum (IGF). The IGF is a global forum where governments, the technical community, civil society, academia, the private sector, and independent experts discuss Internet governance and policy issues.[2] The annual IGF meeting is organized by a Multistakeholder Advisory Group (MAG) under the auspices of the United Nations Department of Economic and Social Affairs (UN DESA). The 11th annual IGF meeting took place in Guadalajara, Mexico, on 6-9 December 2016.

The IGF Best Practices Forums (BPFs) bring experts and stakeholders together to develop a tangible and useful best practice output through a collaborative, bottom-up process. The BPFs are an answer to the call for intersessional work and more tangible outputs of the IGF.

1 Available at: http://www.intgovforum.org/cms/documents/best-practice-forums/creating-an-enabling-environment-for-the-development-of-local-content/582-igf-2015-bpf-ixps/file .

2 IGF website: http://www.intgovforum.org .

The BPF on IXPs finds inspiration in paragraph 50 of the Tunis Agenda for the Information Society[3] on international Internet connectivity, for the development of strategies to increase affordable global connectivity, and from chapters 4 and 6 of the World Summit on the Information Society (WSIS) Action lines[4] that address capacity building and an enabling environment and the U.N.'s Sustainable Development Goals (SDGs)[5].

2. Scope and Goal of the 2016 BPF on IXPs

2.1. The 2015 BPF Enabling environments to establish successful IXPs

The 2015 BPF on *Enabling environments to establish successful IXPs* produced a best practices outcome document that was discussed at the 2015 IGF meeting in João Pessoa, Brazil. The 2015 document explains why IXPs matter, and it focuses on ways to create enabling environments that facilitate the establishment and development of IXPs.

IXPs will only succeed if they are embedded in a supportive community. IXPs have to find peers that agree to set up and run the IXP, get the necessary support to obtain equipment, training, and capacity building, and invest in community building. More than 80% of the success of the IXP will depend on its capability to create an environment of trust and cooperation among its stakeholders.

Governments and regulators can play a facilitating role by resolving potential legal and regulatory issues that prevent IXPs from deploying and developing, by providing support when the IXP is starting up, by bringing stakeholders together, and by stimulating the development of the country's infrastructure, including a healthy competitive market for national and international connection.

The 2015 best practices document provides case studies, references, and links to background material that will inspire and help stakeholders create an environment that enables the establishment of successful IXPs.

The outcome document of the 2015 BPF on IXPs is available on the IGF website:
http://www.intgovforum.org/cms/documents/best-practice-forums/creating-an-enabling-environment-for-the-development-of-local-content/582-igf-2015-bpf-ixps/file

2.2. The 2016 BPF on IXPs: Scope and Goals

The 2016 BPF on IXPs discussed factors that can contribute to the development and success of IXPs, and in particular to their successful management and operation.

The 2016 BPF on IXPs defined its scope and goals in an open discussion held on a dedicated mailing list and during virtual meetings in July and August 2016.[6] The IGF Secretariat provided the support to host the mailing list and set up the virtual meetings. The discussions

3 Tunis Agenda for the Information Society: https://www.itu.int/wsis/docs2/tunis/off/6rev1.pdf .

4 WSIS Plan of Action: http://www.itu.int/wsis/docs/geneva/official/poa.html .

5 U.N. Sustainable Development Goals (SDGs): https://sustainabledevelopment.un.org/sdgs .

6 The Scope and Goals document can be found at http://www.intgovforum.org/multilingual/filedepot_download/3408/83 .

identified and acknowledged linkages between the presence and benefits of active IXPs and the general theme of the IGF - "Enabling Inclusive and Sustainable Growth" - as well as the IGF's work on Policy Options for Connecting and Enabling the Next Billion[7] and the achievement of the U.N.'s Sustainable Development Goals (SDGs)[8].

The outcome document of the 2016 BFP on IXPs intends to serve as a resource for policymakers, regulators, governments, and decision-makers in the private sector. IXPs and their stakeholders often look to the experiences of other IXPs in order to identify what made them flourish and ultimately be successful.

The BPF acknowledges work that is done by other fora in order to minimize duplication, and incorporated knowledge and expertise from organizations, such as the IXP associations, the IXP Toolkit, the Internet Society (ISOC), Packet Clearing House (PCH), network operator groups, and individual IXPs. The outcome of the BPF is intended to be a "living" and flexible resource, not a one-time initiative.

2.2. The purpose of the BPF outcome document

The aim of this BPF is to make existing community knowledge more widely available and easily accessible. The best practices outlined in this document have been provided by a wide range of experts and stakeholders through an iterative and open process. These best practices, together with the 2015 BPF on IXPs output document, are meant to serve as the foundation of a flexible framework for creating successful IXPs. This framework is not meant to be static, but intended to serve as a starting point, and can be improved as more IXPs are deployed around the world and share their experiences.

What this document is not:
The information and examples in this document are useful regardless of the country or continent; however, this does not mean that they are applicable in every context.

The BPF on IXPs does not intend to formulate prescriptive policy recommendations, as there is no one solution or panacea that will work in all circumstances and in every country, region, or context. In this context, the BPF will, among other, explain how, in specific cases, certain regulatory approaches affect(ed) the development of the IXP because such information could help inform the relevant stakeholders about making policy choices.

The IGF is not an appropriate forum to discuss or teach the technical knowhow that is needed to create and/or run an IXP, nor is this document a technical manual for routers and switches. There are specialist meetings and forums that dive into the technical details of how to establish, operate, and sustain an IXP. In addition, technical guidelines and reference documents are available from IXP operators and managers. Section 6 and the appendixes of this document provide a non-exhaustive overview of IXP-related fora and reference documents for those seeking detailed information, including technical guidance and technical best practices.

7 http://www.intgovforum.org/multilingual/content/policy-options-for-connecting-the-next-billion

8 http://sustainabledevelopment.un.org/sdgs

2.3. Methodological note

This document is the outcome of an open and iterative process that occurred over the months preceding the 2016 IGF meeting in Guadalajara, Mexico, (6-9 December 2016). The structure and content of the document was developed through online discussions on an open mailing list and through regular virtual meetings in which all community members could participate and contribute. Their real-life experiences and testimonials helped to shape this best practices document. The IGF Secretariat provided practical support to the BPF on IXPs, hosting of the mailing list, organization of the virtual meetings, editing services, maintenance of a dedicated section on the IGF website, and other.

Drafts of this document were made available on the IGF website for public input prior to and during the 2016 IGF meeting. Additional input was received during the face-to-face session of the BPF on IXPs during the 2016 IGF meeting in Guadalajara, Mexico, on Thursday, 8 December 2016. A video recoding of the BPF on IXPs workshop is available online: https://youtu.be/S6fFinDt5U0.

For additional information regarding the 2016 IXP BPF process, please refer to the IGF website: http://intgovforum.org/multilingual/content/bpf-ixps .

3. Internet exchange points (IXPs): definition and role

3.1. What is the function and role of an Internet exchange point (IXP)?

The Internet is a network of networks which collectively constitute a global communication system. Internet exchange points (IXPs) are physical locations where three or more Internet networks can connect at a common point to exchange data traffic. All Internet networks can interoperate because they speak a language known as the Internet Protocol (IP). Within the Internet the term Autonomous System (AS) is used for an IP network or set of networks, managed and supervised by a single entity.

> *Definition of an Internet exchange point*
>
> An Internet exchange point (IXP) is a network facility that enables the interconnection of more than two independent[9] Autonomous Systems[10], primarily for the purpose of facilitating the exchange of Internet traffic.
>
> An IXP provides interconnection only for Autonomous Systems.
>
> An IXP does not require the internet traffic passing between any pair of participating Autonomous Systems to pass through any third Autonomous System, nor does it alter or otherwise interfere with such traffic.
>
> IX-F, the Internet eXchange Federation, http://www.ix-f.net/ixp-definition.html

9 “Independent” means Autonomous Systems that are operated by organizational entities with a separate legal personality.

10 “Autonomous Systems” has the meaning given in BCP6/RFC4271 , “A Border Gateway Protocol BGP4”.

The practice of exchanging data between networks at an IXP is called peering. Peering at IXPs is typically based on settlement-free agreements made between networks for mutual benefit. By interconnecting and exchanging traffic at a common point, Internet service providers (ISPs) save costs and enable a more competitive market environment while also improving their network performance.

IXPs typically support multilateral and/or bilateral peering. The former enables interconnection between multiple networks while the latter enables interconnection between two specific networks. IXPs can, as a matter of policy, either require all networks to exchange traffic with each other, or allow each network to establish bilateral peering with others as they choose.

The IXP model of network interconnection and traffic exchange is a widely adopted industry practice with around 500 known active IXPs in more than 100 countries. The location and distribution of IXPs in the world can be explained by looking at factors such as country demographics, market conditions, and global economics.

Table 1: The number of active IXPs by region 2016

Region	Number of IXPs	Number of countries	Number of cities
Africa	34	28	31
Asia	98	19	53
Europe and the Middle East	204	49	150
Latin America and the Caribbean	56	16	53
North America	104	2	58

Source: IX-F Database, October 2016

3.2. What are the benefits of having an IXP?

- **Reduction of a network's operational costs:** Using cost-neutral transactions for the exchange of traffic between networks at an IXP reduces the network's operational cost. This means that it becomes cheaper for the network to be part of the Internet and to provide services to its clients.

- **Keeping local traffic local and decreasing latency:** The direct interconnection of networks at an IXP allows the networks to keep local traffic local and to deliver the traffic destined for each other with the lowest possible latency.[11]

- **Better control and more autonomy of the network:** Using IXPs gives networks more autonomy and control over the network's own resources, including routing and traffic management, because it decreases a network's dependency on third-party networks.

- **Increased stability, resilience, and robustness for the local Internet:** Increasing the number of direct paths and routes between networks increases the stability, resilience, and robustness of the Internet in the case of network outages, distributed denial of service (DDoS) attacks, and other related circumstances.[12]

- **Enabling competition by facilitating new market entries:** Evidence suggests that IXPs can enable competition by facilitating the entry of new service providers and content delivery networks (CDNs) in a cost-effective way. For instance, new entrants do not have to build out their networks to all the other networks that are exchanging traffic at the IXP. Additionally, an IXP generally provides a neutral traffic exchange point whereas bilateral interconnection can be expensive and include other barriers to entry.

3.3. The IXP participants and stakeholders

The participants or members[13] of an IXP are operating an independent Autonomous System (a network). They can operate any kind of network such as an ISP network, a government network (e.g., for e-government services), a university or national research and education network (NREN), a private enterprise network (e.g., a bank or financial institution), a content provider or CDN, hosting providers, and providers of other services.

IXPs are embedded in their local ecosystems. Apart from the IXP members, several other stakeholders can directly or indirectly be involved in the exchange. Among them are the IXP operator, a country's regulator, government and government bodies and agencies, the operator of the facility that hosts the IXP's infrastructure (e.g., a webhotel, a university data center, etc.), or local and community facilitators (e.g., the local technical community, network operator groups (NOGs[14]), university project teams, Internet associations, business associations, civil society organizations, etc.).

The 2015 BPF on IXPs further elaborated on the different participants and stakeholders of an IXP and their respective roles. See section 3 of the 2015 BPF outcome document.[15]

11 Latency is the time elapsed between the transmission of IP packets from the originator and reception of those IP packets at the receiver. It is one of the four parameters that define the quality of service (QoS) of an Internet connection, the others three being packet loss, jitter, and out-of-order delivery.

12 As for examples described in: https://blog.cloudflare.com/think-global-peer-local-peer-with-cloudflare-at-100-internet-exchange-points/

13 Note that "members" could refer to a particular legal structure – e.g. a membership organization – while IXPs exist in different institutional and juridical forms.

14 A list of active NOGs is available here: http://www.senki.org/network-operations-groups-meeting/ .

15 Available at: http://www.intgovforum.org/cms/documents/best-practice-forums/creating-an-enabling-environment-for-the-development-of-local-content/582-igf-2015-bpf-ixps/file .

4. How can IXPs contribute to enabling inclusive and sustainable growth?

The Internet plays an increasingly important role in today's societies and economies, and the expectations for the future are high. A further developing Internet will continue to create opportunities for the developing and developed world. Given the United Nation's emphasis on the 17 Sustainable Development Goals (SDGs),[16] the call for the sustainability of the Internet in the Tunis Agenda for the Information Society,[17] and IGF 2016's focus on inclusive and sustainable growth[18] in particular, it is important to consider how IXPs can contribute to such development. As noted in the 2015 BPF on IXPs outcome document, "IXPs are an opportunity to strengthen, amplify, and accelerate connecting the next billion and final billions."[19]

While IXPs indirectly contribute in multiple ways to realizing inclusive and sustainable growth, they directly help to achieve U.N. *SDG 9.c.* to "Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020".

Sustainable Development Goal 9:[20]

"Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation."

IXPs contribute to a more affordable, stable, faster, and more robust Internet of a higher quality in their region. They also promote local network infrastructure, which is an important component for creating local digital content. Empirical research has shown that "there is a strong correlation between the development of network infrastructure and the growth of local content, even after controlling for economic and demographic factors.[21] IXPs are also ideal points to host probes and anchors that provide various Internet measurements and statistics, which includes "valuable information about local and regional connectivity." Since many of these statistics are public, such metrics can be used by regional Internet registries (RIRs), academics, researchers, the private sector, members of the technical community, and others for a host of useful purposes that can ultimately help strengthen and expand local and regional infrastructure and services.[22]

16 http://www.un.org/sustainabledevelopment/sustainable-development-goals/ .

17 https://www.itu.int/net/wsis/docs2/tunis/off/6rev1.html .

18 http://www.intgovforum.org/multilingual/content/igf-2016 .

19 http://www.intgovforum.org/cms/documents/best-practice-forums/creating-an-enabling-environment-for-the-development-of-local-content/582-igf-2015-bpf-ixps/file .

20 https://sustainabledevelopment.un.org/sdg9 .

21 "The Relationship Between Local Content, Internet Development, and Access Prices." Internet Society (ISOC), the Organisation for Economic Co-operation and Development (OECD) and the United Nations Educational, Scientific and Cultural Organization (UNESCO). 2011. https://www.internetsociety.org/sites/default/files/The%20Relationship%20Between%20Local%20Content%2C%20Internet%20Development%2C%20and%20Access%20Prices_0.pdf .

22 See: https://atlas.ripe.net/about/anchors/ .

IXPs have proven to be crucial for delivering content in Africa in particular, which is significant since it is the region with the lowest Internet penetration[23] and one that often struggles with cross-border interconnectivity.[24] In general, countries with a well-functioning IXP are well placed to attract local data centers, root server mirrors, and hosting providers, content providers and/or CDNs. The presence of the IXP fosters the development of the local Internet ecosystem.

When Google installed a cache in Kenya and Akamai installed a server in Rwanda, to bring their content closer to the user via the local IXP, usage increased significantly. "The main reason for the increase in usage is that latency decreases, which makes it easier for users to access the content and results in more usage. At the same time, ISPs no longer have to effectively 'import' that content from abroad over expensive international links, and thus save significant resources."[25] More specifically, a study examining local content hosting in Rwanda found that "the reliance on hosting locally relevant content abroad has cascading impacts on stakeholders and the local Internet economy, including, notably, its end users," in particular as it relates to cost, usage, and latency.[26] It is important to note here that a major result of lower latency is the enabling of time-sensitive services such as voice or video calling[27].

It should be noted that the case for local hosting is not a case for forced "data localization", the free-flow of information into and out of a country helps to develop a thriving Internet ecosystem, and forced "data localization" can paradoxically lead to lower internet and infrastructure development in a country.

A 2013 report examining the the IXP environment in Argentina, Brazil, Colombia, and Ecuador, for example, determined that, among other roles, IXPs in Latin America and the Caribbean "play an important role in promoting Internet development in areas serviced by small and medium-size ISPs, which tend to be poorer and more isolated than those serviced by larger ISPs."[28] Specifically, the report stressed:
"By peering at an IXP, these operators can not only exchange local traffic but, even more critically, aggregate outbound traffic. This allows small and medium-size ISPs to collectively negotiate better transit prices, and to attract peering from content providers. When sufficient traffic is aggregated, international backbone providers have incentives to establish PoPs closer to the IXP, thus balancing international transit costs more evenly between parties. As mentioned, IXPs also create incentives for small network operators to invest in their own infrastructure in order to reach a neutral point where traffic can be negotiated with other participants."[29]

23 See: http://www.internetworldstats.com/stats.html .

24 https://www.itu.int/en/ITU-D/Regional-Presence/ArabStates/Documents/events/2016/IXP/Pres/S1ISOC_Arab%20States%20-%20IXP%20Workshop%20-%20ITU-ATI%20(5-6%20April%202016)1.pdf

25 'Promoting Content in Africa', Internet Society, Aug 2016, http://www.internetsociety.org/sites/default/files/Promoting%20Content%20in%20Africa.pdf .

26 Promoting Local Content Hosting to Develop the Internet Ecosystem. Internet Society. January 2015. https://www.internetsociety.org/sites/default/files/Promoting%20Local%20Content%20Hosting%20to%20Develop%20the%20Internet%20Ecosystem.pdf.

27 "A policy framework for enabling Internet access." Internet Society. September 2016. https://www.internetsociety.org/sites/default/files/Policy_Framework_for_an_Enabling_Environment_-_Stable.pdf .

28 "Connectivity in Latin America and the Caribbean: The Role of Internet Exchange Points." Hernán Galperin (Universidad de San Andrés / CONICET). November 2013. https://www.internetsociety.org/sites/default/files/LAC_IXP_Report_2013%20English%20(updated%202014).pdf .

29 Ibid.

Evidence from Bolivia also supports the importance of IXPs on Internet development, specifically that the Bolivian Internet exchange (PIT Bolivia, http://www.pit.bo) has made a positive impact on network performance in the country.[30]

In addition to the development of the infrastructure, it is important that services provided over the Internet are affordable[31] for the intended local end-users. The cost of connectivity is one of the factors that will influence the price of the service. Providers may significantly reduce costs by connecting to an IXP and avoiding the costs of international transit, which in the case of developing countries can be extremely high.[32] Lower traffic costs also facilitate "high bandwidth services such as video streaming." The Development Bank of Latin America, for instance, found that "The development of [IXP] technology in [Latin America] can reduce up to 38 percent of the costs associated with Internet international traffic.[33]

Relevant cases also exist in Asia. For instance, a 2015 report from the International Telecommunications Union (ITU) noted that local stakeholders in Pakistan expected cost savings (especially from content hosted outside of Pakistan that travels via international bandwidth), more local content hosting, and an improved cloud infrastructure, as the potential benefits of an IXP.[34]

The reliability and resilience of the network is another important element, especially if governments and businesses intend to use the Internet to deliver services. Participation in the digital economy, including cloud computing, requires uninterrupted access to broadband networks. According to a 2015 Internet Society report, "Where [uninterrupted access to broadband] is unavailable, developing countries will miss out on economic opportunities available to their competitors. Reliable power supply, spectrum availability, redundancy in network capacity, secure networking, low levels of transmission latency, and IXPs are all important to Internet affordability, reliability, and local access."[35]

Conclusion; IXPs have the potential to indirectly contribute to inclusive and sustainable growth in their communities via the positive impact that IXPs can have on the development and reliability of a local internet, the affordability of services, and the availability of local content.
As mentioned in Section 3 and in the 2015 BPF document, governments, regulators, and other policy- and decision makers can play an important role by supporting IXP development by for example:

- Ensuring legal and policy clarity for local content developers, hosting providers, CDNs, and data centers;

30 "Do Internet Exchange Points Really Matter? Evidence from Bolivia." Hernán Galperin et al. September 2014. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2418576 .

31 "The 2015-16 Affordability Report." Alliance for Affordable Internet. 2016. http://a4ai.org/affordability-report/report/2015/ .

32 "The Relationship Between Local Content, Internet Development, and Access Prices." Internet Society (ISOC), the Organisation for Economic Co-operation and Development (OECD) and the United Nations Educational, Scientific and Cultural Organization (UNESCO). 2011. https://www.internetsociety.org/sites/default/files/The%20Relationship%20Between%20Local%20Content%2C%20Internet%20Development%2C%20and%20Access%20Prices_0.pdf .

33 "IXP in Latin America: Low cost internet at higher speed." Development Bank of Latin America. August 2014. https://www.caf.com/en/currently/news/2014/08/ixp-in-latin-america-low-cost-internet-at-higher-speed/?parent=16139 .

34 "IXP Challenges in Pakistan." International Telecommunications Union. 2015. http://www.itu.int/en/Lists/consultation2015/Attachments/30/Pakistan%20Response%20on%20IXP.pdf .

35 "The Internet and Sustainable Development." Internet Society. June 2015. https://www.internetsociety.org/sites/default/files/ISOC-ICTs-SDGs-201506-1.pdf .

- Assuring a reliable power supply;
- Reducing high duties and taxes on IXP equipment imports as well as long and unpredictable customs checks;
- Connecting e-government services to local IXPs;
- Not placing constraints through licensing or regulation on operators' ability to connect and peer at an IXP; and
- Removing barriers to entry for IXP operation and peering, and promote bottom-up community development and support for IXPs.[36]

5. Explaining success: IXP Best Practices and Experiences

Generally speaking, the success of an IXP should be measured by its ability to sustainably contribute to the development of the Internet ecosystem within its community. Too often, the performance of an IXP is only assessed by looking at the volume of traffic passing through the exchange, which is not an accurate indicator of success.

Unfortunately, there is no one size fits all model that guarantees success. Up to a certain extent each IXP is unique, and characterized by its organization model, its policy and the way the IXP is managed and run, the geographic environment, the local policy, the economic situation, the development of the Internet in the country, etc.. Some of the differences are given and outside the control of the IXP, other differences results from choices and decision made by the IXP within its local context.

5.1. Building a well-functioning IXP - Institutional and policy questions

Availability of local IP transport capacity
There are regions and countries where the IP transport infrastructure is well developed and IP transport is available at a reasonable price, and countries where IP transport is expensive and the infrastructure is poorly developed. Most countries are situated somewhere in between, and closer to one of both extremes.

In areas with an adequate IP transport capacity at a reasonable price, network operators, CDNs and other content providers (banks, NRENs, financial institutions, public administrations, etc.) can easily connect to the IXP and the IXP can serve as the exchange for IP traffic at the local level.

A poor infrastructure and/or expensive IP transport makes it more difficult or costly for providers to realize and finance the connection to the IXP's physical location to exchange traffic. In some cases the higher cost can be explained by the geographic characteristics of a country, the lack of a competitive environment for metro and long-haul transport, or a limited and expensive international transit and access to submarine cables. Countries with a national fiber monopoly for their backbone infrastructure might also see a slower development of the infrastructure and higher prices.

36 "A policy framework for enabling Internet access." Internet Society. September 2016.
https://www.internetsociety.org/sites/default/files/Policy_Framework_for_an_Enabling_Environment_-_Stable.pdf .

Availability of locally hosted content
Locally hosted content can boost the development of the IXP. If a substantial amount of content is hosted on networks that connect and peer via the IXP, more traffic can be exchanged via the IXP. The amount of traffic is one of the factors that can contribute to the better functioning, growth and sustainability of an IXP.

There is locally hosted local content and the content from large content providers and CDNs that is stored or cached locally. Both are important and can contribute to the development of the local Internet and increase the traffic passing through the IXP. It takes a different approach and strategy to stimulate the development and hosting of local content locally or to attract content providers to host or cache their content in the country.

- Local hosting of locally created content. The involvement of local partners like software developers, the NREN, financial institutions, the public administration and the owners of data centers is indispensable for the creation of local content. Another factor is the availability of local hosting for small and medium-sized projects at a reasonable price. For many African countries the reality is that buying hosting from an overseas provider in Europe or the USA is still cheaper due to the limited capacity inside the country. Also the trust - for technical and other reasons - in hosting offers outside the country is often higher than in local hosting.

- Hosting of content from content providers and CDNs. Approaching content providers to deliver their consumer products and services from local cache servers connected to either the IXP directly, or to operators that peer such content at the IXP, has in some locations significantly contributed to the growth of traffic volume at the IXP. In addition, the access to CDNs can make the IXP more attractive for new members to join. There are many examples of how the delivery of Google and Akamai cache traffic via certain IXPs in Africa stimulated the development of IXPs.

Peering policies and technical requirements
The peering policy of an IXP is typically defined as one of three types: bilateral, multilateral, or mandatory multilateral.

A bilateral peering policy allows each network operator to choose which other network operators it wants to exchange traffic with. Peering connections must be manually established through coordinated technical action taken by both parties in the peering relationship. Given the manual work required to establish each peering relationship, bilateral peering can be an increased technical and administrative burden for an IXP when dealing with a large number of networks, but it leaves the choice and control with the peering networks.

A multilateral peering policy allows all of the operators connected to the IXP to automatically exchange traffic with each other by making a single connection to a central route server. This makes it easy for network operators to establish and manage large numbers of peering relationships at the exchange. IXPs that allow multilateral peering can also allow bilateral peeing if two members prefer so.

Mandatory multilateral peering is the forced requirement that all network operators peer with each other at the exchange, typically via one or more route servers. This takes away control from the network operators, which can discourage some from joining the exchange if they

believe they will be forced to interconnect with networks they would otherwise not choose to peer with. This can hamper the growth of an exchange.

Institutional and operational models

❑ ***Institutional models and juridical form***

The institutional and governance model of an IXP can greatly influence its development trajectory. The choice for a specific form and model must be seen within its local context. The different choices have their pros and cons, but most important is that an IXP chooses the model that works well given the local circumstances. There are six common legal entity types:

INSTITUTIONAL MODELS	TYPICAL JURIDICAL FORM
Industry associations (e.g. ISPA)	Not-for-profit company
Private not-for-profit	Not-for-profit company
Private for-profit	For-profit company
Academic institution	Not-for-profit company
Government	Not-for-profit company
Informal	None

For the purpose of comparison, these six categories can be grouped into two categories: not-for-profit and for-profit organizations.

A majority of IXPs in the United States are for-profit organizations, while the majority of IXPs in Europe, Africa, and South America are not-for-profit organizations.

In some countries the IXP's institutional model and the choice between a for-profit or not-for-profit organization may depend on local legislation.

❑ ***Business models***

IXP business models vary depending on whether an IXP is for-profit or not-for-profit. In general, a for-profit IXP aims to be profitable and distributes this profit as a dividend, or equivalent payment, while not-for-profit IXPs exchange traffic without the intention of distributing profit, but with the intent to invest any surplus in the future development of the IXP.

Some not-for-profit IXPs will charge for their services based on a cost-recovery model; some will seek external support such as subsidies, sponsorships, or donations. Typically, not-for-profit IXPs will operate under one of the following models: free, subsidized, or independent.

The free business model relies on contributions from IXP network members and volunteers. Contributions can be in the form of labour, equipment, transit, or other as per the IXP's needs. The IXP in Seattle and Washington in the USA and the IXP in Uganda (UIXP) are examples of the application of this model. IXPs that operate under a free business model

often transition to a different business model in the longer term, when growth leads to an increase in operating costs and other resource requirements.

The subsidized business model is based on subsidies from the government or another external entity that sponsors the IXP, mostly for a limited period of time. In some cases contributions from IXP members gradually allow to cover operational costs and members to take ownership of the IXP and eventually to a transitions to a fully independent model. The IXP in Nigeria (IXPN) and the IXP in Malaysia can serve as an example of this.

The independent business model is based on income generated by fees paid by members on a recurring basis. Most of European IXPs, the Kenya IXP (KIXP) and the IXP in Johannesburg (JINX) are a good illustration. Typically this model is introduced when the IXP matures and has proven its value to operators and the ecosystem.

For the non-commercial IXPs, the choice of business model is an important factor that impacts the management and sustainability of its operations. IXPs should aim to choose a model that most effectively and sustainably can promote the growth of the IXP, provide value to its members, and contribute to the development of the Internet ecosystem within its area of operations.

Each IXP however works and develops within its own context and environment, with different challenges and opportunities. There is no one size fits all model and different variations on the here-described common types exist. The IXP Ecuador, for example, is a for-profit company and is pursuing a not-for-profit goal. Its for-profit business model foresees in Consultative Council with representatives from all members to assure the IXP's neutral course in the benefit of the local Internet ecosystem.

5.2. Taking action to achieve success - management and operational factors

Before discussing best practices for a successful IXP management and operation, it is important to repeat again that (1) no one size fits all, each IXP exist within its own environment with specific challenges and opportunities and (2) the success of an IXP largely – some say up to 80% – depends on community support.

5.2.1. Business Mindset[37]

Why does an IXP need a business plan?
Whether the IXP is for-profit, not-for-profit or subsidized and regardless of the chosen organization form, business planning can contribute to the stability, growth, sustainability and long-term development of the IXP. Some of the large European exchanges have shown that with the right business plan and strategy, a not-for-profit membership-based IXP can become a business employing 50+ people with a turnover of $15m per annum or more[38].

After the preparation and set-up phase of the IXP project (bringing participants together, get support and initial funding, installing the technology and successfully launching the IXP) the

37 The content of the section is amongst other, based on the panel discussion on 'IXP business models' at the 2016 AfPIF
Recording at https://www.internetsociety.org/afpif-2016/day3-presentations-and-livestream .

38 For example see LINX Annual Report 2015, at https://www.linx.net/documents/www.linx.net/uploads/files/LINX-2015-Annual-Report.pdf .

attention needs to shift to the long-term growth and sustainability of the IXP. It is import to understand however that developing a business plan and mindset is not a synonym for commercializing the IXP.

> Important: *A business mindset does not mean commercialising the IXP!*

5.2.2. Growth, volunteers and donors

For-profit as well as not-for-profit IXPs need a business plan and strategy. Apart from some basics, like a simple budget with all income and expenditures, IXPs need to be aware of a number of challenges and risks. The below challenges are in particular important to not-for-profit IXPs:

- Coping with growth.

Increased traffic and membership can increase demands on the infrastructure and management of the IXP. To cope, an IXP might need new or additional equipment, more space, and/or more people to run it. If the IXP fails to adapt to the increasing demands, the development of the IXP can slow down and eventually loose members.

"From the start there was the challenge to technically cope with doubling and tripling amounts of traffic, very challenging, as soon as new equipment is in place you need to start planning the next phase."

Bastiaan Gosling, AMS-IX at the BPF IXP workshop

- Volunteer fatigue.

Many IXPs are started and/or operated by a small number of highly motivated volunteers. They invest time, knowledge, and sometimes money in the project. Over time, they may detach from the project, sometimes unexpectedly, due to a change of jobs, health issues, loss of interest, etc. This can present a risk to the continuity and stability of an IXP.

- Donor fatigue

Many IXPs rely on donations, in cash and kind, and lack the funds to invest in own equipment. Donated equipment typically does not come with a commitment to repair, replace, or upgrade. This creates insecurity and is a risk factor in case equipment breaks down or becomes obsolete. Soliciting donations is an ongoing concern for IXPs that rely on them.

5.2.3. Business Development

Developing an IXP is a long-term project. It is important to have active members and see the number of active members grow over time. In general terms, if more members connect and share traffic at the IXP, membership will be more interesting for those connected and the IXP will become more attractive for new members to join.

- Visibility & branding

An IXP must be visible. If no one knows that the IXP exists and why it exists, it will be difficult to get community support and attract members. A lack of visibility might stagnate the development of an exchange. Visibility is important and the IXP should take initiatives to

raise awareness ('telling people what you're doing'), to develop a strong brand and promote the benefits of peering at the exchange. In its communication and outreach an IXP could among other emphasize the security, and stability of the IXP and highlight the value and benefits of the IXP for its members and the community.

"*A simple marketing plan for a starting IXPs could be to make a list all the organizations with a own network (with an AS number) in their region and contact them to present the IXP."*

Allan MacGillivray, CIRA, at the BPF IXP workshop

- Know your market

IXPs work in a dynamic environment. It is important to be conscious of the commercial environment and market, observe trends and understand how the market is developing. Are there direct competitors for the IXP? Can other factors dramatically change the current situation? A stable and quiet commercial environment can quickly transform in a more competitive market. For example new players offering international transfer or the commissioning of new undersea cables can increase the competition and lower the prices for international transfer. Such a change would have a direct effect on the price networks pay to exchange traffic abroad and as a result have an impact on the cost saving networks could realize by peering at the local IXP.

- A growing and diverse membership

A growing and more diverse membership might bring along different needs and expectations form members, and over time needs might change. The IXP has to be ready to cope with a growing number of members and avoid loosing the interest from individual members. Some IXPs will organize regular meetings or have specific channels to consult with their members.

- Attracting content providers and CDNs

Having access, via the IXP, to the content of important global and local content providers and CDNs can increase the value of the IXP membership for individual networks. Their presence can lead to a reduction of the total IP transit cost for IXP members and the community. Accessing content on a cache server that is hosted much closer to the end user can improve the user experience. The IXP should have a strategy to convince content providers to connect and attract CDNs to install cache servers at the IXP. Typical requirements that are important for content providers and CDNs are the availability of good and reliable IP transit, space and power.[39]

5.2.4. Financial Sustainability – fee structure and budget transparency

Many starting and developing IXPs depend on the support from donors and volunteers. It was already explained why this is not a stable ground for a long-term strategy and how their unpredictability can be a risk factor for the technical stability of the IXP. There are several examples from IXPs that evolved from a free model to a fee-based model, to allow them to invest in their own infrastructure, conclude maintenance contracts with vendors, and in some cases to employ staff.

Setting up a fee structure and choosing the right fees are not easy decisions. It is advisable to benchmark with other IXPs, particularly with IXPs of similar size or working in similar

39 Quoted from: 'The 1000$ Internet Exchange', Remco van Mook, UKNOF, September 2015, https://indico.uknof.org.uk/event/34/other-view?view=standard

environments. There must be a good balance between the value members get from connecting to the IXP and the price they pay for their membership.

Budget transparency is essential. It is important to show to donors and members what their money is used for. A lack of budget transparency can lead to discussions, questions from cost conscious members, a reduction of trust and support, refusal to pay, etc.

Also later on in the life of an IXP, fee structure and budget transparency will remain a central issue. Fund allocation and transparency is key to ensuring success. Having a well thought out budget and budget-roadmap goes a long way.

5.2.5 Technical Sustainability – infrastructure and capacity building

An IXP that for its technical infrastructure depends on donations and donated equipment might run into problems when equipment needs to be updated, repaired or replaced. This issue was already addressed in the previous points. IXPs in this situation should be aware that this is a risk factor.

Starting IXPs usually heavily count on external technical expertise and support. Operating an IXP is not considered to be rocket science, but this doesn't mean that there is no need for training and local capacity building for those that will have responsibility for the daily operation of the IXP.

Growth – more traffic, more traffic from more members – comes with a series of technical challenges that need to be addressed. IXPs should not be afraid to reach out to the community for assistance, consult with peers or look at other technical leaders for guidance on solutions.

5.3. Lessons learned from IXP success: Case Studies

5.3.1. The Canadian experience: 5 new IXPs in 4 years

Prior to 2012, Canada had only two IXPs, TORIX, in Toronto, Canada's largest city, and OTTIX, in its capital Ottawa. Since then 5 new ones have been established, often with the involvement and support of the ccTLD manager for Canada, CIRA, the Canadian Internet Registration Authority. These new IX's are in Vancouver British Columbia, (VANIX), Calgary Alberta (YYCIX), Winnipeg Manitoba (MBIX), Montreal, Quebec (Échange Internet de Montréal QIX) and Halifax, Nova Scotia (HFXIX).[40] Each of these has its own story - for some the establishment took a number of years to achieve, with varying degrees of success. These stories will not be told individually, but rather an attempt is being made to distill the factors, which are seen to have contributed to these successes.

Canada is by international standards a rich country, but it is also a country of enormous size, which has presented challenges; while it is second only to Russia in area, it is ranked about 230th in population density. A number of these recently established IXPs are in relatively small centers, Winnipeg, population less than 700,000 people and Halifax, with less than

[40] TORIX https://www.torix.ca/ ; OTTIX http://www.ottix.net/ ; CIRA https://www.cira.ca/ ; VANIX http://www.vanix.ca ; YYCIX https://www.yycix.ca ; MBIX http://www.mbix.ca ; QIX http://www.qix.ca ; HFXIX https://www.hfxix.ca .

300,000 people. What follows is based on the experience of establishing new IXPs in Canada.

Getting Organized – the Pre-Planning

The establishment of an IXP is not an end in itself, but rather a means to an end. Its real *raison d'être* is to facilitate the local exchange of Internet traffic, in order to improve network performance, reduce transit costs to more distant points of exchange and improve network resiliency, by ensuring that local routing of traffic may continue even when an upstream provider experiences outages. It follows that the drivers of any new IXP need to be its potential clients and customers – the entities that may peer.

All of these new Canadian IXPs have been established as 'not-for-profit' corporations, and are small by international standards – the largest of these new ones is QIX which currently has traffic of about 30G per day, while the smallest has less than 1 gig. To put this in perspective, the long established TORIX has about 300G while LINX has 2.6T. Establishing a new IXP, at least in Canada, means a reliance on an 'all volunteer' model, which in all of these recent examples, involves not-for-profit entities. So the first step was to get the local community together because they would serve as the IXPs 'labour force' as well as its 'customer base'.

Getting the Community Together

In Canada, the manager of .ca, the ccTLD, the Canadian Internet Registration Authority (CIRA) decided to do what it could to stimulate the creation of new IXPs. It announced to the national Internet community its general intention to get involved to support the creation of new IXPs. It received responses from many individuals across the country. Sometimes people responding had already identified like-minded individuals in their area; at other times, CIRA was able to connect them. As a next step, CIRA offered to call a meeting to discuss the establishment of an IXP and publicized it within the local Internet community. It was found that the initial champions were typically from the Internet technical community because they best understand the network performance and potential benefits of an IX.

Making a Plan

Once a core group of individuals comes together, they need to make a plan. It was not always written but it always considered how to address the essential elements of setting up an IXP:

- A switch
- A place to put it
- A critical mass of potential peers
- Access to technical resources
- A simple business plan

The Switch

Of these the switch is likely the easiest to obtain – it can be a simple $100 piece of gear or a more sophisticated piece of equipment worth tens of thousands of dollars. Some of the Canadian IXPs were established using donations of used equipment while others were able to have new equipment donated.

Location of the Switch

This is critical. Since the IX's main customers, at least initially, will be ISPs, the choice of location should be where the ISPs already have, or could easy acquire, infrastructure. The IXP is typically put in an existing co-location facility but the cost of the co-lo (see

below) must be reasonable enough to make it affordable. Occasionally, someone, a government perhaps, may offer a free location, but this can be a false economy if the ISPs do not have infrastructure close to it. If it is too costly to get to, many potential peers will not join the IX

Critical Mass of Peers

Initially, a core group of peers will need to be found in the local community - word of mouth is the best initial way to seek out potential peers and volunteers. Another way is to go to the Regional Internet Registry (RIR) e.g. ARIN, RIPE for a list of entities (companies, governments) in the area who have AS numbers. APNIC has developed a tool[41] that estimates the number of users of each ASN so it can serve as a good source of such information. Many potential customers may already be exchanging traffic at a more distant IXP so their peering lists can be reviewed for possible customers. PCH has a very good IXP directory[42].

A Business Plan

In establishing the IXP, a business plan will be needed. This need not initially be too complicated. The IXP will have expenses, so it will need offsetting revenues. These will need to at least balance. So the business plan could initially be just a forecast of expenses and revenues. Later, matters such as expanding the number of peers, acquiring additional equipment, undertaking marketing could be added.

With the need for revenues will come the need to charge peers port fees - or find other sources of funding. Some IXPs have provided an initial discount on these, as an incentive to join the IXP. Prospective peers will also want to know other things, such as the cost in the co-lo (power, cross connects etc.)

Access to Technical Resources

It is likely that many in the nascent IXP group will not have had direct experience in the technical aspects of choosing, installing and configuring a switch. The IXP community is fortunately made up of a number of individuals and organizations who are prepared to help with this. Worldwide, ISOC, RIPE, EuroIX have been very active. In Canada, members of its oldest IX, TORIX in Toronto, as well as representatives of CIRA, the manager of Canada ccTLD, .ca, have been quite active.

Regulatory Approvals

Unlike many jurisdictions, in Canada a license from the telecommunications regulator or the ministry is not required to enter the telecommunications marketplace, and this includes establishing an IXP – no license is required.

Moving Forward

Once all of the above steps have been taken, a decision will need to be taken on whether to proceed with the IXP. Likely this will mean that a switch has been found, or at least a source for one has been identified, a location chosen, some assessment of costs finished and an initial group of peers established. The next step will be to decide on the governance model.

41 http://stats.labs.apnic.net/cgi-bin/aspop

42 https://www.pch.net/ixp/dir

Incorporation

At some point, the group, organizing the IX will need to decide whether or not to incorporate. Most IXPs in Canada are incorporated, as 'not-for-profit' corporations. Most jurisdictions will provide for equivalent legal arrangements. There are pro's and con's to incorporation which will need to be assessed. The main benefits are protection from civil liability – for example, if the switch catches fire in the co-location facility and damages other people's equipment, it is the corporation and not the people running the IX who would be liable for damages. Incorporation also indicates a certain measure of stability that can be useful in attracting potential peers, content delivery networks (CDNs) in particular. It also simplifies financial management, as any funds will be kept in the name of the corporation and not individuals. This may also be important is soliciting donations, for a switch in particular. Donor organizations may be reluctant to donate money, or transfer ownership of an expensive switch, to an individual.

There are however downsides to incorporation, in particular, increased overhead costs. Depending on the jurisdiction of operation, actual incorporation may require a lawyer, the drafting of bylaws, payment for auditing of books and records, insurance for directors etc. Some IXPs delayed actual incorporation until many other start-up issues have been addressed, but all have ended up doing this.

Board of Directors

Typically, the initial organizing group will become the board of directors of the incorporated IXP. In choosing an initial board, care must be taken in choosing the terms for board members – these should not all be the same to avoid having them all expire at the same time. Also, expiry of terms will serve as a catalyst to seek out new directors who will often serve as volunteers for the organization. A diversity of skill sets among directors is desirable – see below.

The organization will need to establish how frequently to meet and what represents a quorum in terms of decision-making. Regardless of whether the IX is incorporated or not, individuals will need to be chosen to take on key tasks, in particular that of chair and treasurer. Incorporated entities will also need a secretary who will take minutes etc. In fulfilling these rolls, individuals with previous experience are extremely useful, such as experience:

- in leading – to be the chair;
- in financial management – to help with business planning;
- in legal matters, to help with incorporation;
- in other volunteer board work – to help with the actual management of board meetings.

Many successful IXPs have adopted 'term limits' for board members to ensure that there is a continual influx of fresh people, with new ideas and to avoid burnout from overreliance on a small number of individuals.

Importance of Regular Board Meetings

It will important to establish a set of books and records, so as to take the financial position of the IXP as it is, in effect, a small business. This is ordinarily the responsibility of the treasurer. If the business plan that was formulated to establish the IXP was not written, or even if it was, it will need to be continually updated, to

include longer term forecasts of revenues and expenses to aid the overall management.

Marketing

Once an IX is established, it will likely only have a very few number of peers – it will want to seek out more peers in order to improve the benefits for existing peers, as well as for the local economy and provide more revenue to sustain operations. This involves doing some marketing. A formal marketing plan need not be complicated; it can be as simple as taking the list of potential peers, developed from the list of local and regional AS number holders, and asking different members of the IX and/or board to contact them.

The Canadian Success

TORIX, Toronto Internet Exchange, https://www.torix.ca/
OTTIX, Ottawa Internet Exchange, http://ottix.net
VANIX, Vancouver Internet Exchange, http://www.vanix.ca
YYCIX, Calgary Internet Exchange, http://yycix.ca
MBIX, Manitoba Internet Exchange, http://www.mbix.ca
QIX, Echange INternet de Montréal, http://www.qix.ca
HFXIX, Halifax Internet Exchange, https://hfxix.ca

Case Study by Allan MacGillivray, CIRA.

5.3.2. Establishing an IXP on a remote Pacific Island: Vanuatu Internet Exchange

The Republic of Vanuatu is an island nation in the South Pacific Ocean. Vanuatu is located some 1,750 km east of Australia and 500 km north-east of New Caledonia. The 83 Islands in the archipelago together form an area of 12,189 km² or 4,706 sq miles inhabited by approximately 285,000 people. Most of the population is rural but over 20% lives in the two largest cities Port Vila and Luganville. The capital city, Port Vila, counts more than 30,000 inhabitants.

Since January 2014 Vanuatu is connected to the international submarine cable system via a cable linking Port Vila via Fiji into the high capacity Southern Cross cable between Australia and the USA.[43] Before, Vanuatu was only connected to the Internet via satellite connections.

The Vanuatu Internet Exchange Point (VIX) started its activities in 2013. It is an example of the successful cooperation between the Government, the Regulator and the country's network operators.

Regulator picking up the idea from network engineers and facilitating the process

In informal discussions on the development of the Internet in Vanuatu, the Telecommunications and Radiocommunications Regulator (TRR)[44] learned from local network engineers that Vanuatu was missing a common point to connect and exchange traffic

43 The ICN1 cable connects Port Vila to Suva on Fiji. A second cable, 'ICN2', to connect Port Vila with Luganville and Port Moresby on Papua New Guinea is under construction http://interchange.vu

44 Telecommunications and Radiocommunications Regulator (TRR) http://www.trr.vu

between networks. In 2012, the Regulator called a meeting with representative from all network operators and launched the plan to establish the national Vanuatu Internet Exchange Point (VIX).

The plan received unanimous support from the operators, and TRR was able to move fast to the next step. After the initial meeting a VIX Committee with representatives from the regulator, the government and the operators started to investigate the technical requirements for the IXP. The Committee also prepared a policy document and drafted a MoU for IXP members to sign upon joining.

Already in December 2012 MoUs were signed between the government and four network operators. The incumbent telco - although actively involved in the preparatory talks – would only join later, in 2014. Today, all Vanuatu's ISPs and the government institutions are connected to the IXP.

Government Datacenter as neutral location

VIX is operating from the government datacenter. The datacenter is centrally located in Port Vila and has a good connection for ISPs over fiber and wireless. The government is offering the collocation space for free and covers the operational costs of the IXP (electricity, acclimatization, etc.).

Training and setting up VIX

VIX received foreign support from different organisations to set up the IXP and to provide training for the network operators and their technical staff. Amongst other APNIC, NSRC, PCH, Google, Netnod and PITA helped to create and develop VIX. In March 2013 for example, APNIC conducted a two-day workshop in Port Vila for the participants of the IXP. The network operators were taught the basics on the OSPF[45] and BGP[46] protocols and learned how to connect their networks to VIX.

A few months after the launch of VIX, a Google cache server and an instance of the I-root and E-root server were installed at VIX. The effects on the traffic were immediately visible. The amount of traffic started to grow and even outperformed the expectations. VIX would soon be confronted with a traffic volume that flirted with the limits of the IP transit capacity. The time and negotiations needed to solve the issue slowed down the growth of the IXP.

Predicting traffic and making a right assessment of the transit capacity that will be needed is essential for a starting IXP. Insufficient capacity can cause problems and slow down the development of the IXP, as occurred for VIX in 2015. For the people at VIX it had been extremely difficult to predict the transit capacity because there were not many cases of starting IXPs in countries with similar characteristics to Vanuatu to learn from.

In 2016 Akamai servers were installed on Vanuatu and VIX continues to look at other global CDNs (Cloudflare, Netflix), but there are no concrete plans at the time of writing.

Creating local content and generating local traffic

Now that Google and Akamai are present at the IXP, the focus has shifted from getting CDNs connected to VIX to generating local traffic by creating more local and locally stored content.

45 Open Shortest Path First (OSPF)

46 Border Gateway Protocol (BGP)

A lot of websites from local media (newspapers, tv, radio) and local companies are still hosted overseas. It proofs to be very difficult to convince these companies to move their content to local servers. Many of them don't see the benefits, they do not find a competitive local hosting package or they have doubts about the security and service quality of local hosting providers.

The Vanuatu Government is leading by example. It has all its content hosted locally and its network is connected to VIX. Accessing and browsing government websites is stable and fast.

Case study by Jethro Webston (VIX) and the Internet Society.

5.3.3. Creating a national neutral exchange: Bangkok Neutral Internet Exchange, Thailand

BKNIX, the Bangkok Neutral Internet Exchange is the first neutral Internet exchange in Thailand and a pioneer in Southeast Asia. BKNIX launched in 2015. Ten members joined BKNIX in the first year. BKNIX is managed by the Thai Network Information Center Foundation (THNIC)[47]. THNIC is a not-for-profit organisation that supports the development of the Internet in Thailand. THNIC is also the manager of the .th domain name.

An Expanding Internet without a neutral exchange

The Internet in Thailand showed a steady growth in the past 25 years. Network operators and Internet service providers in different parts of the country established businesses and built networks. They invested in infrastructure to connect their clients to the Internet and developed a business model for their organisation. Providers concluded commercial agreements with other providers in the same region to exchange traffic amongst each other; they bought transport capacity from commercial carriers and made individual arrangements with providers and Content Delivery Networks (CDNs) outside of Thailand. Thailand had nine exchange points before BKNIX was launched, but they were all transit exchanges where no peering is done between the connected networks.

In absence of a central point for networks to connect and exchange traffic, the communication from one network to another often passes through several hubs and networks before reaching its destination. Data from a domestic sender to a domestic receiver is frequently routed outside of Thailand and sent back. The complex route data travels has a negative impact on latency and cost.

The Internet providers that invested in bilateral deals with content provider networks and caches outside of Thailand, have no incentive to share this direct connection with their competitors and their competitor's clients in Thailand. Providers have the choice to either invest time and money in their own direct link with the CDNs or look for indirect (expensive) solutions.

Without a neutral IXP, the internet in Thailand is more expensive, of poorer quality and knows a delay in data transmission.

47 http://www.thnic.or.th

Advocating and seeking support for a neutral IXP

Thailand's Internet pioneer professor Kanchana Kanchanasut[48] played an important role in raising awareness and advocating the benefits of a neutral Internet Exchange. She noticed that in Thailand *"The ISPs were interested in working together but were unable to move on to a better setup because it wasn't financially or technically easy for any of them to run an IXP. What was needed was a "neutral party" that wouldn't favor one ISP over any other, and that could help create trust in the community."*[49]

Professor Kanchanasut reached out to a number of international partners and organisations that had been supporting IXP projects in other countries[50]. Organisations and companies such as the Internet Society, Alcatel-Lucent and Cisco showed interest in the plans for a neutral IXP in Thailand.

Securing practical support from international partners was fairly easy. But the main work needed to be done inside the country: raise awareness, make people understand the benefits of an IXP and gain the support of the local stakeholders. An IXP needs to be carried by a supportive local community. Building this community costs time and energy, and is a never ending task that continues even after the launch of the IXP.

In 2013 THNIC organised a workshop[51] to educate ISPs, the government, and the regulator on the function and the benefits of a neutral IXP. The idea to create BKNIX was well received and THNIC proceeded with appointing a project manager and putting together a project team. The members of the project team came from ISPs, THNIC and NECTEC[52], which is the government agency tasked to promote and support IT development. The project team, lead by Mr. Chaya Limchitti, and was tasked to identify potential peers and search for a suitable neutral location to store the IXP's equipment.

The project team reported on its activities at a follow up workshop in 2014 and proposed a location to host BKNIX. The preparations to establish BKNIX started immediately after this workshop and Thailand's neutral IXP launched on 9 February 2015.

Selection of a neutral location

The project team had looked at several colocation providers and made site visits to check the suitability of datacenters to host BKNIX's equipment. The ideal location had to be operated by a neutral operator, was reachable by a neutral carrier[53] and met the technical and security requirements to host an IXP.

The BKNIX required the collocation space to:

1) Have optical cable access from all carrier providers;
2) Be neutral in the sense that no existing ISP could have a competitive advantage form the IXP's location;
3) Be ready and immediately operational;

48 http://internethalloffame.org/inductees/kanchana-kanchanasut

49 'Internet Hall of Famer Realizes Dream in Southeast Asian IXP', Kanchana Kanchanasut, IXPtoolkit Blog, March 2015, http://www.ixptoolkit.org/blog/2015/03/30/internet-hall-famer-realizes-dream-southeast-asian-ixp

50 Very important were the informal talks at the 2013 Internet Hall of Fame induction ceremony where Prof. Kanchanasut was honored for her work as Internet pioneer in Thailand.

51 TH-Neutral IX workshop, 20-21 May 2013, http://25th.in.th/index.php?page=thneutralworkshop&new_language=1

52 The National Electronics and Computer Technology Center, http://www.nectec.or.th/en

53 a carrier that is not owned by or linked to one of the IXP's future members.

4) Be a world-class facility (room, electricity, air conditioning, security, etc.);
5) Be in a low risk area (low risk on natural disasters, riots, etc);
6) Be able to make a long term commitment to host BKNIX;
7) Have enough room/space for potential future growth.

Finding the right location was more complex and delicate than expected. There were no neutral data centers or web hotels in Thailand. Almost all existing data centers that were offering colocation space to external clients were owned by network operators, ISPs or their parent companies. Hosting BKNIX in a data center controlled by a potential member or competitor to future members can easily compromise the perception of neutrality of the IXP. This neutrality is a key element to establish trust in the exchange. A lack of trust, or the suspicion that one member benefits more than the others could be a reason for peers not to join BKNIX.

In addition and to assure carrier neutrality, the project team sought for a location that is served by multiple carriers so that members can select the carrier of their choice to reach BKNIX.

There were a few data centers that met the criteria. Of them, the one with the highest score was chosen to host BKNIX. The location[54] is served by all carrier providers that are active in Thailand.

Plans are being made to launch at second location in Bangkok. A single location is a single point of failure. At the moment, most of the members only have one link to the IXP. The second location will serve as backup link.

Training and equipment
With the help of the Internet Society the BKNIX project team got in touch with a number of external partners that were instrumental for the launch of the IXP. Alcatel-Lucent, for example, sponsored a router and provided training. Cisco-Systems donated a switch.

BKNIX – management and organisation
BKNIX is a project of the THNIC Foundation. The THNIC foundation's Board of Directors is the decision taking body of the IXP. The five members of the THNIC Board have an academic background.

Members organize and finance their connection (fiber) to the BKNIX location. They pay a one-time setup fee (10,000 THB) to get connected to BKNIX and are charged yearly port fees. There are different port fees depending on the port size (10,000/month 1Gbps, 50,000/month 10Gbps, 400,000/month 100Gbps).

The port fees were waived for those joining BKNIX during the first year. Members that now join get a three-month free trial period after which they have to confirm their membership. So far, only one ISP canceled its membership after the initial trial period. The reason for cancelling was a merger into a larger IXP.

54 https://www.tcc-technology.com/en/page/50/Data%CEnter%20Services

From no till 10 peers in the first year
Within the first year 10 members joined BKNIX and traffic peaked at 70 Gbps. More local ISPs have expressed interest in joining.

Since its launch in February 2015 BKNIX is reaching out to as many ISPs as possible. Small and large ISPs are equally welcome. However, experience from IXPs in other countries has learned that it takes time to convince the larger and incumbent providers while smaller ISPs are keener to connect early on. It is very attractive for smaller providers to only have to pay for one connection and be able to exchange traffic directly with several networks in the country.

The older and more established Internet providers have their structure and business plan in place. They invested in contracts with carriers, CDNs and other providers. Their current business model is based on an environment without an IXP and it takes time to adapt. It is a challenge to convince the larger players to connect to BKNIX. The large ISPs follow how BKNIX is developing, which is a positive sign, but they are cautious. All Thailand's large ISPs attended the first BKNIX Peering Forum[55] in May 2016.

One of Thailand's large streaming providers and one of the larger last mile providers already peer at BKNIX. Traffic peaks are visible during big events (e.g. football games). At the time of writing talks are ongoing to connect one of Thailand's mobile operators to join BKNIX. (expected to be effective later in 2016). More local ISPs have expressed interest in joining. Soon a first CDN will connect to BKNIX: Akamai confirmed that it'll will ship and install equipment starting from June 2016. Contacts with other global CDNs are ongoing.

The Thailand Digital Economy and Society Development Plan
In 2016 the Thai Government announced a Thailand Digital Economy and Society Development Plan, which amongst other, wants to build a country-wide high-capacity digital infrastructure (strategy 1) and turn Thailand into a ASEAN connectivity hub. The presence of BKNIX makes Bangkok and Thailand attractive for foreign and international companies and BKNIX can play a key role in obtaining the government's goals.

Website: http://www.bknix.co.th
BKNIX presentation movie: https://youtu.be/WJYvOXrv-OU

Case study by Chaya Limchitti and Pernsi Arun (BKNIX) and the Internet Society.

5.3.4. From a voluntary IXP to professional organisation: Rwanda Internet Exchange

By the end of the 1990ies Internet providers and community members in Rwanda discussed the potential benefits that an IXP could bring to the country. The Rwandan Government, through its Information and Technology Agency (RITA), and with the support of the Swedish international Development and cooperation Agency (SIDA)[56], started an initiative that would lead to the creation of RINEX, the national peering point. As part of this project, technical staff of local ISPs were trained on how to connect their networks to an IXP and how to configure the traffic flows over the exchange.

55 http://peeringforum.bknix.co.th/2016/

56 http://www.sida.se/English/

2004-2014: from a voluntary IXP to a professional organization

In 2004 RINEX was a fact. RITA, the government agency, kept the responsibility over the RINEX project when two peers, Rwandatel (the then state owned incumbent) and MTN Rwandacell agreed to exchange traffic via RINEX. Finding a suitable and neutral location to host the equipment was a major issue.

At the beginning, RINEX equipment was placed at the Rwandatel data center because there was no suitable neutral location available in the country. Later, RINEX was moved to a neutral hosting facility at the Telecom House building in Kigali, where it was hosted first free of charge, and later against a fee.

Members of RINEX must hold a valid license or business certificate to operate an Internet or Data service provider in Rwanda or any other country.

The early RINEX had no organizational structure of its own. It existed because network operators agreed to connect and exchange traffic. In absence of a sector organization there was a lightweight structure under the government agency (RITA). The technical operation was in the hands of a group of volunteers, most of them employees with one of the IXP's peers.

2014 - 2016: RINEX managed by RICTA, a non-for-profit

In 2014, a memorandum of understanding (MoU) officially handed over the management of RINEX to an independent not-for-profit organization. The MoU was signed between RURA, the Rwanda Utilities Regulatory Authority[57] and RICTA, the Rwanda Information & Communication Technology Association[58]. RICTA is a not-for-profit organization representing the interests of the Rwandan Internet Community. The local Internet community members founded RICTA in 2005 to request the re-delegation of the .rw country code domain name (ccTLD) and bring its management back to Rwanda. In 2011, RICTA was officially established as a not-for-profit limited organization and is since 2012 the official manager of the .rw ccTLD.

In the MoU signed with the Regulator, RICTA commits to managing RINEX and transforming the volunteer model into a professional organization. The current MoU is up for renewal in 2017.

The community supported the decision to place RINEX' management in the hands of RICTA. It was a logical next step: RICTA was the first and only not-for-profit in Rwanda; RICTA was a working organization, with own staff and budget; and RICTA had already proven to be capable of managing the .rw ccTLD. Both the .rw registry and the exchange are considered as national critical infrastructure in Rwanda.

Fee Structure

RINEX charges no setup fee to connect to the IXP. Members have to pay a yearly port fee, which depends on the port speed. Members can chose between 10 Mbps, 100 Mbps, 1 Gbps, and 10 Gbps ports. The detailed fee structure is published on the RINEX website: http://www.rinex.org.rw/?-Pricing- .

57 http://www.rura.rw

58 http://ricta.org.rw

Location and operation

Finding a neutral facility to host RINEX was a challenge at the beginning. RINEX had to obtain its own independent premises with electricity supply, backup power, security, and air conditioning, suitable to host an IXP. The academic entities in Rwanda were lacking appropriate physical facilities and none of the private ISPs had the capacity to host it. Therefore it was decided to host the IXP at the premises of the incumbent telecom operator, Rwandatel. Many of the Internet providers in Rwanda were already connected to the Rwandatel datacenter, which made it easier for them to connect to RINEX at the start.

However, few years later, RINEX was relocated to a neutral facility at the Telecom House building in Kigali, in a small datacenter room owned by the then called RITA (Rwanda Information Technology Authority).

Since 2014, RINEX is renting collocation space for its infrastructure. The infrastructure is now hosted at the Virtual Landing Point-VLP room, a neutral facility, managed by Broadband Systems Corporation-BSC, still at the Telecom House in Kigali.

The RICTA/RINEX staff occupies two offices in the same building. The Rwanda Development Board-RDB offers the office space free of charge. The rent for the colocation space and all other operational expenditures (including staff wages) are paid from revenues generated by RICTA.

Recently, in April 2016 and with the support of an African Union grant, RINEX scaled up its infrastructure from 1 Gbps to 10Gbps port size. At the moment, RINEX hasn't yet met its full capacity.

Accessing Content via RINEX

All government content can be accessed via RINEX. Members have access to a local instance of the DNS I, E and J Root name servers, which connect to RINEX. VeriSign also provides DNS services for the .com and .net domain names at RINEX.

Since mid 2013 RINEX members can connect to a Global Google Cache (GGC). In October 2014, a local AKAMAI cluster was turned on in Rwanda, which is accessible via RINEX. Both content caches can be accessed under a paid peering model.

Effect of RINEX for the Internet in Rwanda

RINEX has lowered the costs for its members and increased the quality of the Internet in Rwanda. The networks that are connected to RINEX exchange traffic directly with their peers. They no longer have to pay for expensive transit to exchange data at a hub outside Rwanda. Moreover, the direct exchange via RINEX shortens the distance over which data has to travel and avoids "traffic tromboning". This decreases latency and end users will experience a faster working Internet. The access to the DNS root server instances will speed up DNS look-ups, which also improves the end-user experience.

The traffic volume through RINEX increased up to fourfold after the GGC connected to the Exchange. Before, (YouTube) videos, which consume a lot of bandwidth, took a long time to load and as a result people were not interested. The videos now load much faster from the

GGC in Rwanda. The lower latency led to a better user experience and created more (new) traffic.[59]

Based on results provided by Akamai, a study by the Internet Society described the effect of the Akamai cluster as follows: 'By hosting content in a local cache, latency decreased, making it faster for users to access the content. (...) (L)atency also impacts the resulting throughput of data - and the Akamai data show just how significantly throughput is impacted. Prior to locating the cache in Rwanda, the vast majority of users - around 90% - experienced throughput below 500 kbps when accessing relevant content abroad. The day the cache was turned on, 50% of these users saw throughput exceed 500 kbps, in some cases by quite a bit - 5% of the users experienced throughput in excess of 20 Mbps, accessing the same content, using the same mode of access."[60] Throughput is a measurement for the amount of information that is processed in a given time frame.

Reaching the IXP - the peers' main challenge

RINEX is a simple Layer2 based IXP. Each network operator is responsible to connect its backbone to the IXP and has to provide the router that connects to the IXP switch. The equipment located at the RINEX premises consists of the IXP core switch, member routers, and/or communications equipment.

Physically reaching RINEX is complex and expensive. Peers can use fiber, microwave or copper to connect to the infrastructure at the Rwanda Telecom House. But either way, it is a burden for the network operators, in particular if they are not based or present in the capital Kigali. Some Internet providers are interested in peering at RINEX, but are not capable to connect to the IXP because they need to invest in several kilometers of fiber or pay high fees to a third party carrier for the data transport between the own network and RINEX. This situation slows down the development of RINEX.

A second location, which could also serve as backup location, would make RINEX better reachable for some of the ISP that are not yet connected. There is a plan to launch a second location. However, even with a second location in a different city, the problem will remain for peers that are located further away.

The price for IP transit within Rwanda is high compared to other countries that are not landlocked (e.g. near submarine cable landing points in Mombasa or Dar-es-salaam), but IP transit wholesale prices are decreasing year-on-year.

In addition, RICTA/RINEX is actively advocating at any possible forum to introduce a price differentiation between the cost for international transit and local loops. As a result of this price differentiation, sending traffic over a local loop to exchange it at RINEX should become cheaper than sending it abroad and back. The current high price of local loop circuits is not stimulating providers to store local content locally. It was one of the topics discussed at the 2015 Rwanda Internet Governance Forum (RwIGF), where it was concluded that: '*In terms of local loop there is no current differentiation which is something operators will be considering to be put in place and will be taken as a recommendation to be worked on.*'[61]

59 Promoting Local Content Hosting to Develop the Internet Ecosystem, Michael Kende and Karen Rose, Internet Society, January 2015, p. 24

60 Promoting Local Content Hosting to Develop the Internet Ecosystem, Michael Kende and Karen Rose, Internet Society, January 2015, p. 24-25

61 'Rwanda IGF 2015, Meeting minutes', C. Sugira, 28 October 2015, http://ricta.org.rw/IMG/pdf/igf_2015_minutes.pdf

Affordable local hosting and the Rwanda We Hosting project

"RINEX has had a beneficial impact on local Internet services in Rwanda, but its ultimate potential as a catalyst for growing the broader Rwandan Internet ecosystem has been limited by the lack of locally hosted content."[62]

The availability of affordable local hosting is another challenge that slows down the growth of RINEX and the expansion of the Internet in Rwanda. The possibilities to host content locally are expensive and are still a niche market for those capable of paying the high hosting fees. There are no packages for small content providers that can compete with the offers from providers outside the country that offer (almost) unlimited space and substantial computing capacity at a very low price.

RICTA launched the *Rwanda We Hosting project* to support the creation of local content. The project was originally called "10k project" referring to 10,000 websites hosted within Rwanda, but in the meantime the project set its aim higher. The project wants to enable a local hosting business environment in Rwanda. *Rwanda We Hosting* works with local partners to bring existing local content back to Rwanda from wherever it is hosted, and to create new content. *Rwanda We Hosting* is expected to achieve between 2,000 and 3,000 locally hosted websites/domain names in the next 3 years. RICTA works closely with RURA (i.e. The Rwanda Utilities and Regulatory Authority) and the Internet Society (ISOC) on this project.

Website: http://www.rinex.org.rw

Case Study by Ghislain Nkeramugaba (RINEX) and the Internet Society.

5.3.5. From a sustainable development project to a successful IXP: Bangladesh Internet Exchange (BDIX)

The Bangladesh Internet Exchange (BDIX) was created in 2004 when some pioneering ISPs in Bangladesh linked their networks together to exchange traffic locally with the intention to increase speed and quality of service and reduce costs by avoiding international transit for local traffic. BDIX was the first Internet exchange in Bangladesh.

The ISPs were convinced of the benefits of an IXP but needed to find the technical know-how and financial support to set up and manage an IXP. BDIX could count on the support of several national and international technical specialists and received its initial technical equipment (switches, routers, etc) from the United Nations Development Programme (UNDP). In June 2014 BDIX received a license from the Bangladesh Telecommunication Regulatory Commission (BTRC) to operate as national Internet exchange. Since 2004 BDIX is running as a not-for-profit IXP[63].

BDIX grew from 10 ISPs-members in 2004 to a diverse membership of more than 75 organisations in 2016. ISPs but also mobile operators and content providers are now peering

62 Promoting Local Content Hosting to Develop the Internet Ecosystem, Michael Kende and Karen Rose, Internet Society, January 2015, p. 14

63 BDIX is a not-for-profit venture of the Sustainable Development Networking Foundation of Bangladesh (SDNF http://www.sdnf.org.bd), and works since 2014 under the license of the Bangladesh Telecommunication Regulatory Commission.

at the IXP and BDIX is also hosting mirrors of the D, E, F and J Root Servers, VeriSign TLD servers, PCH looking glass and .org mirror an NTP servers, etc.

BDIX is a Layer 2 Internet Exchange point – each network provides its own router and traffic is exchanged via an Ethernet switch – and supports both IPv4 and IPv6. Network operators have the choice between 100 Mbps, 1 Gbps and 10 Gbps ports to connect to the IXP. Members pay a one-time contribution per port and a monthly fee, which depends on the port size.

The traffic at BDIX increased year over year. The average traffic in 2009 was 50 Mbps. By 2015 average traffic had increased to 5200 Mbps and will reach 8200 Mbps for 2016.

BDIX is expecting to grow as more ISPs and telcos are planning to join. Work is underway to open a second PoP outside of the capital city Dhaka.

Challenges
The Regulatory Commission, after issuing a license for the operation of the IXP, has plans to regulate the tariff IXPs have to charge to their members. The license also suggests that BDIX needs to peer with other IXPs in the country, which would be challenging and may damage the IXP eco system. BDIX is reaching out to the government to educate on the function of the function of an Internet exchange and the IXP eco system.

Website: http://www.bdix.net

Case study contributed by Sumon A. Sabir,

5.3.6. From a natural disaster to a new IXP business model: IXP Ecuador

On 16 April 2016 Ecuador was struck by a severe earthquake, which caused destruction and casualties around the country and mainly in the coastal provinces Manabi and Esmeraldas. The earthquake indirectly led to the creation of a new IXP in Ecuador.

Ecuador has a large number - around 300 - small ISPs that often work as resellers of Internet plans for one of the big providers in the country. Many of these small ISPs do not have their own IPs or ASN. Efforts in the past, to organize the small ISPs and create an IXP were unsuccessful due to a lack of funds.

Already before the earthquake, many of the small ISPs suffered under the poor condition of the national economy. Dozens of ISPs were obliged to reduce or close their business because of the economic situation. The earthquake made their position worse. On top of this, there is an aggressive competition with the big Internet players in the country and for these small local ISPs, connecting to the existing IXP in Ecuador is very expensive.

A number of small IXPs finally decided to create a new IXP, IXP Ecuador. IXP Ecuador is a for profit IXP that functions under the umbrella of a business partner that is financing the infrastructure, the connection, the operational and administrative costs, and provides the ISPs with access to the IXP, and with their own IPs and ASNs. The IXP Ecuador developed a competitive and sustainable business model for everybody.

IXP Ecuador could count on the support of ISOC Ecuador, the Ecuadorian chapter of Internet Society, and of Google.

The project plans 15+ IXP nodes all around the country, of which the first 3 nodes have already been installed and are operational.

While the IXP Ecuador is run as a for profit IXP, all of its members are represented in the Consultative Council of the Company, to assure that the IXPs decisions are in the benefit of the IXP members and the Internet Users.

Website: *http://www.ixp.ec*

Case study contributed by Carlos Vera, Ecuador

5.3.7. CABASE - Developing a network of regional IXPs in Argentina

Introduction
CABASE - la Cámara Argentina de Internet (the Argentine Chamber of Internet) launched its first IXP in 1998. The IXP was located in a neutral site in the Buenos Aires area, had 18 members connected, and was the first IXP in Argentina and probably also in the LAC region, to exchange traffic locally among its members.

Before the IXP existed, the traffic between ISPs based in Argentina was exchanged in Miami. The main driver to create an IXP was the wish to keep Argentine traffic within the country. Soon the members discovered other benefits, e.g. that an IXP also allows them to have a better quality and is a more efficient method of traffic exchange. The peering agreement was based on a multilateral model and the IXP's expenses were distributed among the members.
CABASE always promoted that IXPs are best run as a collaborative effort of the members and should support the development of a strong technical community for having a better and larger Internet in Argentina.

Since 2010 and under the umbrella of the Broadband Access Federalization initiative, CABASE created more new IXPs. They were originally called Regional IXPs as they were located outside of the capital city of Buenos Aires.

To date, CABASE has 21 IXPs around the country with more than 350 members connected to them. CABASE is a non-profit organization as well as are its IXPs. From the beginning, the CABASE IXPs have been open to hosts community initiatives like Root Servers, Anycast DNS nodes, etc.

Members
Members of CABASE are not just ISPs, but also Universities, Government Agencies, CDNs and other organizations belonging to the Internet Community, that want to exchange traffic with the IXP´s members. To become a member it is required to have an ASN. CABASE does not limit membership to Argentine organizations; so International companies can also become members of the IXPs.

Peering Agreements
Multilateral peering is mandatory for everyone at the CABASE IXPs but members can also conclude additional bilateral peering agreements. The reason for this policy is to protect small ISPs of potential discrimination from the larger members.

Regional IXPs

In 2005, the incumbent operators left the initiative and some people feared for the survival of the IXP. In 2010 CABASE reinforced its believe in the future of the IXP and created a second IXP in the country. It was set up in Neuquén, an important city in the south west of Argentina. In Neuquén, as in other regions out of Buenos Aires, the option to get an Internet connection was either limited to the incumbent operator or to the choice between the incumbent operator and a big carrier. As a result of this situation, prices for Internet connectivity in that region were very high. The creation of the IXP in Neuquén, not only resulted in an immediate and important drop in cost for connectivity, it also increased the availability of bandwidth for the region.

Currently CABASE has 21 IXPs around the country, a number that keeps growing every year. Initially, the traffic IXP members exchanged via the IXP represented around 10% of their total traffic. Today, and depending of the size of the ISP, the traffic exchanged through an IXP can reach up to 70%.

Central Routing Strategy

Argentina is a country with a high concentration of population in the Buenos Aires region. Therefore CABASE choose to link all of its IXPs in a central routing site.

Each IXP works autonomously for the exchange of all the local traffic. The central routing facility is there to:

- Provide via the regional IXP access to CDNs that are mostly located in Buenos Aires;
- Enable access to the very competitive offer of IP transit services in Buenos Aires, which is the place where most of the International providers are located;
- Promote the exchange of traffic among IXPs (except for CDNs, this type of traffic is usually small compared to the others described).

Governance

All the members of the different IXPs adhere to rules and regulations that are common for all IXPs in the CABASE network. There are common documents for the Interconnection agreement as well as a Manual of policy and procedures. A commission that exists out of one representative from each IXP and representatives from CABASE updates these policy documents. This group holds monthly meetings to discuss and decide aspects common to all the IXPs. On the other hand, each IXP has the autonomy to take local decisions. Therefore, each IXP has a local commission with representatives of its members, to discuss and take decisions.

Cost

As mentioned previously, the IXPs are not-for-profit and the expenses and investments are shared by members, based on the infrastructure assigned to each of them.

There exist two type of cost:

a- Costs that belong only to the individual IXP. These costs are shared among the members of that IXP. They include the operational cost to run the IXP and investments to let it grow, and the connection between the IXP and the central routing facility.

b- Cost that are common to all the IXPs. These costs are shared among all the members of the different IXPs. These cost include the operational costs and

investments for the central routing facility, and other expenses such as videoconferencing systems, etc.

Periodically, IXPs receive donations in the form of hardware from International organizations.

LAC-IX
CABASE is one of the founding members of LAC-IX, the Latin America and Caribbean Internet Exchange Association. CABASE believes that IXPs are important for the development of a better and larger Internet in the countries the LAC region. Since 2011 LAC-IX actively promotes the establishment new IXPs and the collaboration among the IXPs in the LAC region.

Final Notes.
The figures alone, 21 IXPs with 350 Members and the tremendous cost savings , are enough proof of the success of the project. However, as important is the fact that one succeeded in enabling small ISPs to have access to the Internet with the same quality and at the same cost as the biggest ISPs. This was one of the objectives of Broadband Access Federalization embraced by CABASE in 2006.

Website: http://www.cabase.org.ar

Case study contributed by Hernán Arcidiácono, IPlan Argentina

5.4. Lessons learned from IXP failures

When finally, after a long process of talks and preparations, the goal is achieved and IXP is launched there's no guarantee for success. The kickoff is the start of a long journey. Previous sections discussed best practices to help IXPs to grow and develop during this journey. In addition, it is always useful look for lessons that can be learned from less successful examples. A number of often cited causes of IXP failure[64] are listed in this section. Some are directly related to the management of the IXP, other to member and community support or environmental factors.

- Inability to provide reliable service or cope with traffic/member growth
- Exclusive arrangements with co-lo providers which subsequently go out of business
- Failure to build critical member/traffic mass before seed funding/goodwill runs out
- Incomplete set of resources
- Nonprofits can't easily borrow or raise funds so are vulnerable to cash-flow crunches
- Acquisition or capture by non-neutral operator
- Market consolidation to outside of region
- Lack of well-defined need - there is no point in creating an IXP for the sake of it

64 'Internet Exchange Evolution, 1994-2011 & beyond', Keith Mitchell, TorIX AGM, April 2011, https://www.isc.org/wp-content/uploads/2011/05/TorIX-11_Apr.pdf

Based on more than 20 years of IXP experience in the UK, Keith Mitchell[65] recently explored why IXP initiatives failed, while others in the same country became world-leading success stories.

- Building IXPs is all about community building - this takes years, not weeks
  No amount of investor capital or public sector support will help if you don't get that right.
- Do not alienate or split your stakeholder base!
- IXPs do not magically create the base level of infrastructure needed to support them
- The technology component is the easy part
- Even in the non-profit world of IXPs, there's a balance between competition, cooperation and innovation
- There is an overhead that goes with building a pure non-profit, neutral membership association
  - This may set the sustainability bar too high for smaller IXP capture areas
  - But where they succeed, they seem to be more stable in the long term
  - Data center neutrality is hard when the local market base is small
- Euro-IX has been a great community based answer to many issues of IXP viability and coordination

6. IXP best practice exchange and multistakeholder cooperation

This section provides an overview of existing initiatives, meetings, organizations and associations where IXP knowledge and best practices is shared. The intention is to give with examples a high-level impression of what is going on. This section should not me read as an exhaustive list.

6.1. Best Practices Exchange and Multi-stakeholder Cooperation

6.1.1. Meetings and Events

At the local level
IXPs require many actors - some of whom may be competitors - to come together and exchange traffic. The success of the IXP depends on its facilitative environment and support by stakeholders. Many IXPs take initiatives to actively support the exchange between local stakeholders. They host open mailing and discussions lists and organize events where their members and other stakeholders meet. Many of the topics discussed on the lists and at the meetings are of interest to the local community. They are not limited to IXP related issues.

At the regional, International and global level
The work of IXP associations and their Fora: Regional IXP associations form a crucial link in the networking of IXPs and can act as venues for meaningful multi-stakeholder exchange within the community. As IXP Associations are managed by stakeholders in the IXP, they are responsive to the needs of IXPs. IXP Associations foster inclusivity and provide a structure for ensuring that IXPs play a leading role in organizational governance.

65 'Great British IXP Failures', Keith Mitchell, UKNOF32, 16 Sept 2016 https://indico.uknof.org.uk/event/34/contribution/30/material/slides/0.pdf

Regional Peering Forums: Peering forums usually meet periodically to share best practices and serve as fora to find peering partners. Many of them are organised or co-organised by IXPs (for example the European Peering Forum is jointly hosted by AMS-IX, DE-CIX, LINX and Netnod; www.peering-forum.eu) or organized alongside Internet community technical organization meetings (for example LAC Peering meets in tandem with LACNIC/LACNOG meetings). Others are organized by organizations that participate in IXP development (for example The African Peering and Interconnection Forum is organized by ISOC and other partners).

Peering forums serve several goals. They bring IXPs together, members of IXPs and potential new IXP peers together and provides a platform to meet, exchange information, learn about regional and global best practices and discuss issues of mutual interest. The forums are also an opportunity to reach out to potential new members and interested parties.

Events for collaboration within the IXP community: Meaningful multistakeholder exchange can happen at global and regional fora where dedicated sessions are held to unpack various stakeholder groups' positions. For example:

- The IGF and the workshop of the Best Practice Forum on IXPs at the IGF.
  The IGF is an annual gathering of the multistakeholder Internet community. Many representatives of IXPs, IXP organizations and other IXP stakeholders participate to the IGF.
- ITU-D Study Group Meetings
  These are held every year and can be a forum for collaboration.
- Peering and Interconnection fora (PIF)
  Meet periodically to share best practices and serve as fora to find peering partners.
- Network Operator Group (NOG) meetings
  Organized by RIRs, ISOC, NSRC network operators and other stakeholders

6.1.2. Projects

This section wants to showcase some examples of projects and initiatives that effectively help to spread community knowledge among IXPs and among IXPs and their stakeholders.

Euro-IX Mentor-IX Program: https://www.euro-ix.net/ixps/support-ixps/mentor-ix/
The *Euro-IX Mentor-IX Program* is aimed at helping exchange points with tools, a framework for management and provides assistance in adhering to the best practices for IXP operation as elucidated by the IX-F (Internet Exchange Point Federation). This program also includes a staff exchange, giving IXPs a chance to work in different environments and take improvements home.

Peering DB: www.peeringdb.com
PeeringDB is an initiative where all networks register themselves and provide relevant information including peering policies. It serves as a tool to help find information about networks and IXPs.

PCH Looking Glass: https://www.pch.net/tools/looking_glass
All major IXPs around the world use the PCH Looking Glass Service for troubleshooting and network visibility in IXP environment. A looking glass service allows its users to look at a network's routing information.

Best Practices and Technical Training workshops
Organizations such as ISOC, the African Union, ITU, PCH, RIPE, Euro-IX, and other partners hold best practices and technical training workshops that help build sustainable communities and train local technical experts.

Euro-IX Fellowship Program: https://www.euro-ix.net/ixps/support-ixps/fellowship-program/
The *Euro-IX Fellowship Program* is aimed at bringing IXPs to the Euro-IX fora to meet with other IXPs who can share their ideas, learn from experience first hand and have the opportunity to make contacts for future support.

6.1.3. Resources

The following initiatives provide guidance on Best Practices for IXPs

1. Best Common Operational Practices (BCOPs) by Euro-IX: https://www.euro-ix.net/ixps/set-up-ixp/ixp-bcops/
2. Euro-IX Technical Recommendations https://www.euro-ix.net/ixps/set-up-ixp/ixp-bcops/technical-recommendations/
3. Packet Clearing House best practices in Internet Exchange Operation https://www.pch.net/resources/Papers/Best-Practices%20in%20Internet%20Exchange%20Point%20Operation.md
4. ISOC's IXP Toolkit Guide http://ixptoolkit.org
5. IXP Wishlist https://www.euro-ix.net/m/cms_page_media/49/ixp-wishlist.pdf
6. ITU Consultations on IXPs: http://www.itu.int/en/council/cwg-internet/Pages/consultation-june2015.aspx

More references and links to IXP forums, resources and background documents can be found in the appendixes.

7. List of contributors

With the risk of not being fully comprehensive the list below represents a record of active contributors to Best Practice Forum (BPF) *Contributing to the Success and Continued Development of Internet exchange points (IXPs)* by their contributions on the mailing list, their participation to the virtual meetings or direct involvement in the drafting this document.

Hernán Arcidiácono, Pernsi Arun, Abdeldjalil Bachar Bong, Mike Blanche, Jane Coffin, Bastiaan Goslings, Gary Hunt, Malcolm Hutty, Chaya Limchitti, Allan MacGillivary, Keith Mitchell, Antonio Moreiras, Mike Nelson (MAG member), Jon Nistor, Ghislain Nkeramugaba, Christian O'Flaherty, Michael Oghia, Douglas Onyango (MAG member), Sumon A. Sabir (MAG member), Bijal Sanghani, Ismail Settenda, Kyle Spencer, Sharada Srinivasan, Salanieta Tamanikaiwaimaro (MAG member), Nico Tshintu Bakajika, Carlos Vera, Jethro Webston, Wim Degezelle (IGF consultant, editor)

The BPF on IXPs wants to thank the MAG and IGF secretariat for their support.

8. Appendices

Appendix 1: Definition of an Internet Exchange point

Definition of an Internet Exchange Point

An Internet Exchange Point (IXP) is a network facility that enables the interconnection of more than two independent Autonomous Systems, primarily for the purpose of facilitating the exchange of Internet traffic.

An IXP provides interconnection only for Autonomous Systems.

An IXP does not require the Internet traffic passing between any pair of participating Autonomous Systems to pass through any third Autonomous System, nor does it alter or otherwise interfere with such traffic.

"Autonomous Systems" has the meaning given in BCP6/RFC4271 , "A Border Gateway Protocol BGP4".

"Independent" means Autonomous Systems that are operated by organisational entities with separate legal personality.

Explanatory Notes

1. An Internet Exchange Point is a technical facility. This is distinct from the organisation that provides that facility, which might be termed an *IXP operator*.
2. An IXP is distinct from an Internet access network or a transit network/carrier.
3. The function of an IXP is to interconnect networks. An IXP does not provide network access or act as a transit provider/carrier. An IXP also does not provide other services unrelated to interconnection (although this does not preclude an IXP operator from also providing unrelated services).
4. An IXP exists to interconnect networks that are technically and organisationally separate.

   a. Without qualification the term "network" is too flexible and fails to identify the degree or kind of separation required. Once interconnected, separate

networks are arguably part of the same network: the entire Internet is often considered a network, a network of networks.

b. To resolve this terminological problem we employ the term "Autonomous System", which is the standard technical definition of a technically stand-alone network.

5. The network operators whose networks are interconnected in an IXP are sometimes collectively termed "*IXP participants*", which generalises the relationship between those entities and the IXP operator; IXP participants may be members of the IXP operator, customers of the IXP operator, or some other relationship.
6. An IXP is a facility where numerous participants interconnect (at least three); this distinguishes Internet Exchanges from bilateral network interconnection, in which one network connects to one other.

Source: http://www.ix-f.net/ixp-definition.html
IXP definition by the Internet eXchange Federation (IX-F), which is the global cooperation platform for Internet Exchange Point Association (IXPAs).

Movie explaining the role of an IXP

The European Internet Exchange Association (EuroIX) produced a movie explaining the function of an IXP in the Internet. It is available in different languages:

English: https://youtu.be/QuBde4Sn3f0
French: https://youtu.be/laF6U29Cx7g
Arabic: https://youtu.be/YF2Jr46lifQ
Chinese: https://youtu.be/dIjZ7F3tJ_A
Spanish: https://youtu.be/3dumPYhmYZM
Russian: https://youtu.be/3wlOeDInRQE

More languages: https://www.youtube.com/channel/UCFyucVRAAMzxyJIsxnGwsjw

Appendix 2: Non-exhaustive list of technical forums and reference documents

IXP Construction Checklists

https://wiki.pch.net/pch:public:ixp-construction-checklist
https://wiki.pch.net/pch:public:ixp-construction-checklist
https://wiki.pch.net/pch:public:basic-ixp-guide
https://www.euro-ix.net/ixps/set-up-ixp/ixp-models/
https://www.euro-ix.net/ixps/set-up-ixp/ixp-infrastructure/

IXP Toolkit (ISOC)

http://www.ixptoolkit.org

http://www.internetsociety.org/internet-exchange-points-ixps-0

IXP Best Current Operational Practices (Euro-IX)

https://www.euro-ix.net/ixps/set-up-ixp/ixp-bcops/

Open-IX: OIX1 IXP Standards & Certification

http://www.open-ix.org/standards/ixp-technical-requirements/

http://www.open-ix.org/standards/ixp-technical-requirements/

Other IXP Best Practices Efforts:

ITU Council Working Group on Internet-related Policy Issues: Open Physical Consultation

http://www.itu.int/en/council/cwg-internet/Pages/consultation-june2015.aspx

Appendix 3: Non-exhaustive list of Community-organized IXP training

Source: Internet exchange point (IXP) training, "For the community, with the community, by the community," IXP Toolkit.
(http://www.ixptoolkit.org/content/internet-exchange-point-ixp-training)

Network operator groups (NOGs):

NOG meetings are key places to obtain technical training, connect with experts, and build a community and human networks of trust.

- African Network Operator Group: AFNOG - http://www.afnog.org/
- Asia-Pacific Regional Internet Conference on Operational Technologies: APRICOT https://www.apricot.net/
- Caribbean Network Operator Group: CaribNOG - http://www.caribnog.org/
- Eurasia Network Operator Group: ENOG - http://www.enog.org/
- Latin-American Network Operator Group: LACNOG - http://www.lacnog.net/

- Middle East Network Operator Group: MENOG - http://www.menog.net/
- North American Network Operator Group: NANOG - http://www.nanog.org/
- South Asian Network Operator Group: SANOG - http://www.sanog.org/

Regional Internet registries (RIRs)

RIRs offer key training sessions at their meetings, and work with ISOC and others to conduct trainings around the world.

- AfriNIC and AfriNIC Mailing Lists
  http://www.afrinic.net/
  http://www.afrinic.net/en/community/email-a-mailing-lists
- ARIN and ARIN Mailing Lists
  https://www.arin.net/
  https://www.arin.net/participate/mailing_lists/
- APNIC and APNIC Mailing Lists
  https://www.apnic.net/
  http://www.apnic.net/community/participate/join-discussions
- LACNIC and LACNIC Mailing Lists
  http://www.lacnic.net
  https://lacnic.net/en/lists/
- RIPE and RIPE Mailing Lists
  http://www.ripe.net/
  http://www.ripe.net/ripe/mail

IXP Associations (IXPAs):

IXPAs provide training, networking, and business opportunities. For newly established IXPs, they also provide an excellent venue to obtain mentoring or "twinning" assistance. Basically, an established IXP can help a newly established one by working closely together. You also can meet people from organizations like ISOC, PCH, NSRC, and RIPE NCC who can offer equipment, hands-on training, and more.

- Asia-Pacific Internet Exchange Association: APIX
- African Internet Exchange Association: AFIX
- European Internet Exchange Association: Euro-IX
- Latin American and Caribbean Internet Exchange Association: LAC-IX

IXP Resources:

IXPs have created resources like INEX's IXP Manager to better manage, troubleshoot, collect data, and improve operations and processes: https://www.inex.ie/index.php.

The Internet Engineering Task Force (IETF) http://www.ietf.org/

IETF meetings are where technical experts converge to build and develop Internet standards (known as protocols), examine Internet architecture issues, exchange information, and build technical capacity. You can find more out about the IETF here.

The Network Startup Resource Center (NSRC) http://www.nsrc.net/

NSRC experts conduct training all over the world at NOG meetings. They also conduct hands-on training. Contact them here.

African Union Internet Exchange System (AXIS) http://pages.au.int/axis:

Best practices and technical assistance workshops

Appendix 4: The global IXP landscape: Background data (references)

Public and reusable data can be taken from:

https://prefix.pch.net/applications/ixpdir/summary/

https://www.euro-ix.net/ixps/list-ixps/