The Importance of IXPs in Australia

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1 Introduction

The Internet is a critical infrastructure of the modern world. The increase in working-from-home resulting from Covid-19 has made the Internet more vital than ever to both our ordinary lives and to industry and government. Cisco reports that Australia can expect 21.5 million Internet users (82% of the population) by 2023 [1] and this growth is forecast to continue.

By its very nature the Internet is a network of networks. The component networks (which are run by a multitude of organisations around the world) must connect to each other to provide end-to-end data transmission. Those connections take a number of forms:

- (bilateral) customer-provider linkages where one network operator pays the other to "transit" their traffic;
- (bilateral) private peering agreements; and
- public peering through Internet eXchange Points (IXPs).

It is not practical for bilateral connections to connect all of the Internet. There are around 70,000 component networks in the Internet, and connecting each pair would result in a picture somewhat reminiscent of Pratt, Kansas around 1900 (Figure 1) where every house attempted to connect its telephone to every other by a direct connection. The alternative is to introduce an exchange (similar to the switchboards that reduce the problem in the telephone network). These are IXPs.

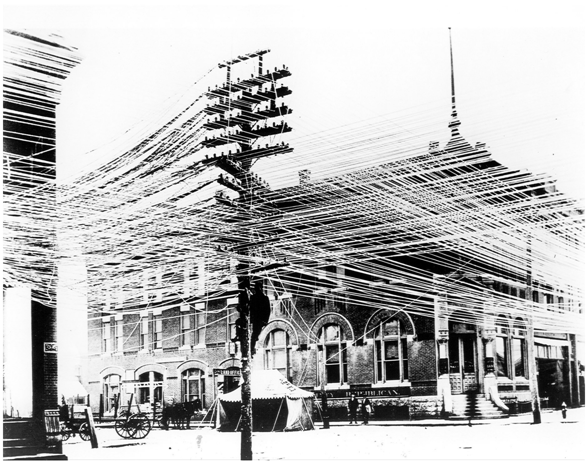

Figure 1: A telephone pole in Pratt Kansas, circa 1900.

Without the inter-connectivity provided by IXPs the Internet becomes vastly less efficient, and in extreme cases even fails to work. Indeed, one of the key challenges identified by the ITU (the International Telecommunication Union, the major standardisation body for world-wide telecommunications) for extending the Internet into the developing world is the creation of IXPs to support efficient and reliable local networks [2].

Thus IXPs bring a wealth of advantages, not just for their members but for all participants in the Internet. This report details those advantages based on the most recent scientific studies of IXPs and the role they play in the Internet.

2 Technical Background

The Internet is composed of a large collection of interconnected Autonomous Systems (ASes). The term AS is used to designate a grouping that is sometimes synonymous with a single network organisation, but the term AS derives from the routing and addressing concepts used to construct the overall network, and so does not always mesh perfectly with the intuitive notion of a single network provider. However, for the purposes of this and many other reports the terms AS and network are treated as synonymous. Readers are referred to [3] for a more detailed discussion.

All participants of the Internet connect through an AS and there are approximately 73,000 ASes as of the writing of this report[1]. They vary in size tremendously from organisations as small as a single University up to globe-spanning corporate giants. ASes are diverse in other ways: some cater to consumers, others to content providers and there are many other variations.

The vast majority of traffic in the Internet is not internal to a single AS. Even the largest carriers in the world transit more than 90% of their traffic through or onto other networks. In Australia, that percentage is much larger because we are a comparatively small player in the global internet, and we have a highly diverse population who access content from around the world. Hence most traffic must travel over at least two networks to get from source to destination.

In fact, most traffic in the internet traverses *more than* two ASes from source to destination. Huston [4] reports that the average path length in 2020 is between 5 and 6 hops (for IPv4). Sometimes traffic can traverse as many as 12 ASes but this is undesirable because each hop takes time and uses resources, so a shorter path (a path with fewer hops) is more desirable both from the point of view of the customer, and the Internet Service Providers (ISPs) that must manage the resources involved and deal with the complaints of unsatisfied customers when the Internet performs poorly. There are also security considerations for longer paths.

A schematic of connectivity in the Internet is shown in Figure 2. In order for this system to work, the individual ASes must connect to each other. Those connections take a number of forms with the most common being

- (bilateral) customer-provider relationships where one AS pays another to "transit" their traffic;
- (bilateral) private peering agreements; and
- public peering through Internet eXchange Points (IXPs).

Peering is a term used in this domain to refer to the logical connection between ASes with the implication of a cost neutral arrangement. It is sometimes called settlement-free, *i.e.,* neither party pays the other for the exchanged traffic. However, there is still a cost to build the interconnect, and this is shared, often through a third party such as an IXP.

An IXP is defined by the Internet Governance Forum (IGF) [5] to be "a physical location where three or more networks can connect at a common point to exchange data traffic." Euro-IX use a slightly refined definition [6] of an IXP as being: "A

[1] https://www.cidr-report.org/as2.0/

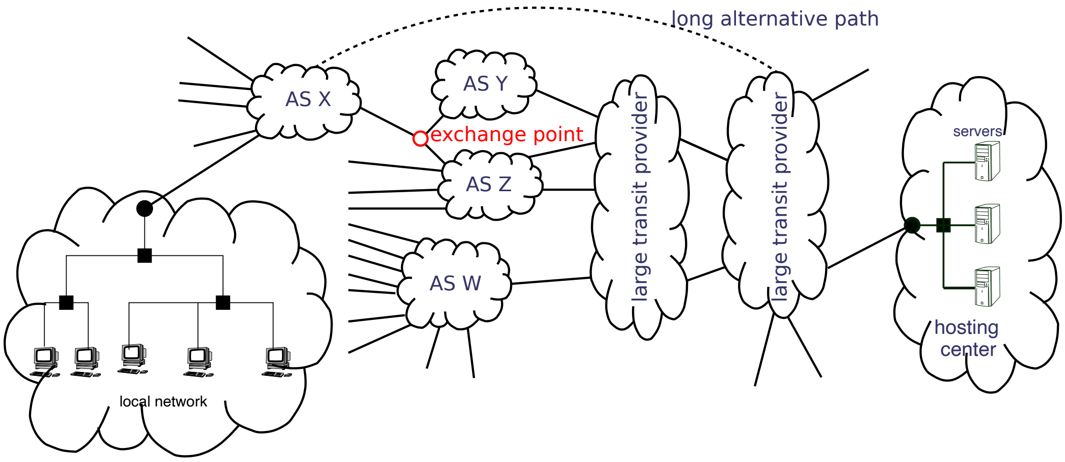

Figure 2: An illustration of a network of networks showing the two main styles of interconnect: private, bilateral connections and one multilateral IXP connecting ASes X, Y and Z. The dashed line shows a longer path that goes through multiple ASes (not shown).

network facility that enables the interconnection and exchange of Internet traffic between more than two independent Autonomous Systems. 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."

The last phrase is important: IXPs fill a kind of "neutral broker" role in the Internet. Their neutrality is an important part of their stable and continued functioning because the networks that come together at an IXP are often competitors. The network operators must have a high degree of trust in the IXP to treat all members equitably. Maintaining status as a non-profit helps build trust because members can see that the IXP will not put profits or other commercial agendas above the need for fairness.

2.1 Core Benefits

A healthy set of IXPs leads to several advantages. Without IXPs traffic often ends up on costly and slow "hair pin" or "trombone" routes. For instance, consider the example of Figure 2. If traffic needs to go from AS W to AS X, it must traverse one of the large transit providers, and then AS Y, a trip of 4 hops. A direct link between AS W and AS X would result in the path length halving, but such direct links are impractical between all pairs of networks. The IXP connecting ASes X, Y and Z, however, provides just such a link, avoiding the longer path for these ISPs.

Note also that although AS W **does not** participate in the IXP shown in Figure 2, AS W benefits from shorter paths between themselves and others such as AS X. The alternative would be the long dashed pathway. It is common for two ISPs – neither of them members – to benefit from shorter path lengths provided by IXPs; a fact validated in the scientific literature, as we shall see in the following section.

The problem is easily exacerbated by the fact that the largest transit providers are global, and thus frequently transit traffic flows off-shore. This is particularly a problem for Australia because off-shore almost always means the traffic must traverse the Pacific, incurring additional delays, and using up a scarce resource (submarine cable capacity) and causing congestion. For instance see Figure 3.

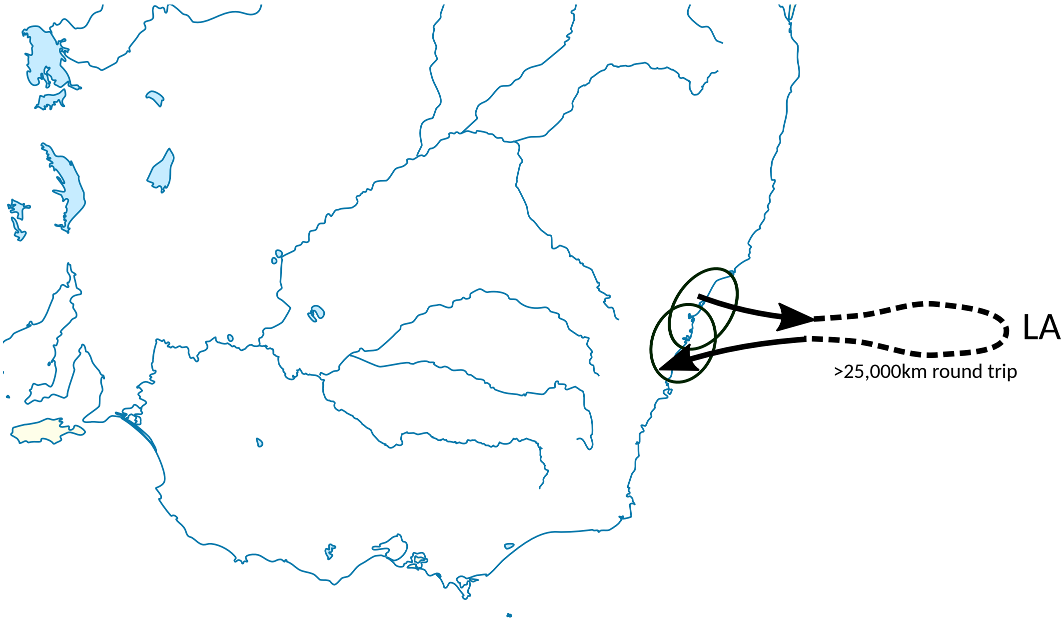

Figure 3: An illustration of a path that "trombones" through the US in order to transit traffic from ISP 1 to ISP 2, both in the Sydney region. The regions covered by the two ISPs overlap, but they do not interconnect at an IXP. The path consequently traverses the interconnect to the US in LA, a round trip of some 25,000 km.

Historically, nearly 80% of Australian (non-US bound) Internet traffic was routed through the US. The vast majority of paths from or to Australia that were not intended for the US, used the US as a transit path [7]. Around the date of this report (2000) it was common to obtain round-trip measurements of around 2-3 seconds[2]. The rise of IXPs in Australia reduced this problem dramatically (along with a richer set of international interconnects) resulting in measured round-trip-times 10 to 100 times faster. Measurements (discussed in the following section) validate the claims of massive performance improvements by looking at the changes in countries that have more recently introduced IXPs.

Another key advantage of ISPs is the provision of alternative routes. Alternative routes can alleviate congestion and enhance users' experiences. But note that this applies not just to the users of the alternative pathways: an analogy might be building a new circle-route around a busy city to offload traffic onto a more efficient pathway, and thus alleviate congestion for drivers who must venture into the city.

The richer system of alternative pathways through the Internet provided by IXPs also benefits overall Internet reliability. The individual components of the Internet are subject to failures (cables broken by earthquakes and accidents; and hardware

[2] Personal measurements.

and software failures). The Internet achieves a high level of reliability despite these failures through the use of redundant pathways. Think of them as detours around roadworks. IXPs are a major source of such detours for everyone, not just their members.

2.2 Security Benefits

There are security benefits that arise from IXPs; most obviously from the shorter paths provided by IXPs. A shorter path is less susceptible to man-in-the-middle attacks, route hijacking and various other malfeasances.

Additionally, IXPs have a naturally broader view of the Internet than single ISPs, so they can help mitigate or prevent security problems by providing information to expose hackers and debug problems that do occur; and education about how to prevent such attacks.

IXPs are also a natural point at which to deploy security mechanisms such as RPKI (Resource Public Key Infrastructure), a security service for Internet routing, and other mechanisms such as registries for DNS names. The registries themselves are a potential point of attack for some hackers, so placing such services in highly reliable and trusted points like IXPs makes them a more robust security mechanism.

A higher level of security benefits all Australian Internet participants by raising the barriers for hackers and other bad actors in the Internet, and protecting what is now a vital infrastructure.

2.3 Extended Benefits

IXPs are a natural place in the Internet ecosystem at which to place additional services. Examples deployed at IXPs include:

- DNS (Domain Name System) servers, which are crucial to resolving Internet URLs into Internet addresses, and which could become a major bottleneck if they are not deployed widely in trusted locations like IXPs.

- Open-source software repositories (such as the Ubuntu operating system software archive). These are huge collections of software, and providing them close to their users reduces the overall load on the larger Internet.

IXPs often provide such services freely in order to maximise their benefit not just to their members but also the wider Internet community.

2.4 The Landscape

IXPs use a variety of technologies and business models but at their heart is a the simple idea that there is a common gain in sharing the connectivity resource. As a result it is common worldwide for IXPs to be either not-for-profit or government-run organisations.

The smallest IXPs in the world might connect less than a dozen ASes, and the largest connect over 1000. The largest IXPs can carry 10 terabits per second of traffic, a similar amount to the largest ISPs.

The number of IXPs has grown tremendously since the start of the modern Internet. Figure 4 shows the growth in IXPs in PeeringDB [8]. For instance, in Europe they grew from 136 in 2010 to 255 in 2020 [6]. The growth has fostered stability in the Internet. Castro [8] shows that as IXPs have grown they have provided redundant paths through the Internet that have increased its reliability and reduced the number of hops that traffic must traverse (with concomitant improvements in performance).

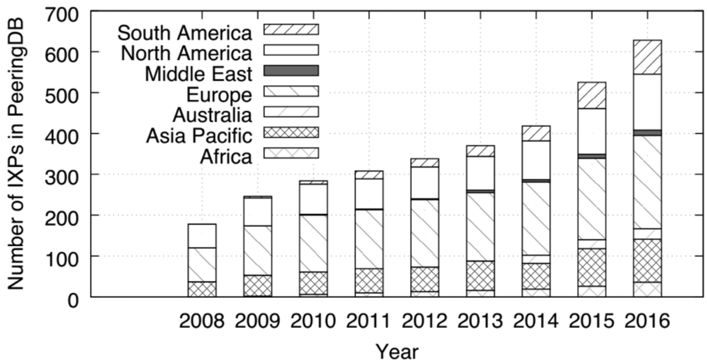

Figure 4: The growth of IXPs in PeeringDB (reprinted from [8]).

The presence of a strong IXP system in a country also provides a natural location for Content Distribution Networks (CDNs) and other hosting and tech companies to interconnect, and this has been linked to economic and social advantages for those countries.

These results are well known. A short list of quotes from relevant organisations illustrating the across-the-board understanding of those facts follows:

- RIPE NCC [9] "By facilitating a neutral interconnection point between the independent networks (Autonomous Systems or ASes) that form the Internet, IXPs play a vital role in ensuring a resilient and open infrastructure that can support the continued growth of the Internet in traffic volume, as well as in number of participating networks."

- ITU-T [2] "Internet exchange points (IXPs) have been established successfully in some countries. These allow exchanges of local Internet traffic between two Internet service providers within the same country, thereby saving on the use of international bandwidth."

- The Tunis Agenda of the World Summit on the Information Society (2005) "We therefore call for the development of strategies for increasing affordable global connectivity, thereby facilitating improved and equitable access for all, by ... (b) Setting up regional high-speed Internet backbone networks and the creation of national, sub-regional and regional Internet Exchange Points (IXPs)."

- Internet Governance Forum [5] "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," and "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."

- Internet Society (ISOC) [10] "IXPs are important to building national, regional, and international Internet ecosystems. ... They are a key part of a country's Internet ecosystem, representing a vital way to increase affordability and quality of connectivity," and "The presence of an IXP can attract out-of-country service operators by providing lower collective access costs to multiple potential local customers. This positions IXPs as a means to develop a region's communications infrastructure, including national and international fibre cables, and local datacentre development," and "IXPs can also improve the level of stability and continuity of access—their switching capabilities provide additional flexibility in redirecting Internet traffic when there are connectivity problems."

2.5 Case Study: Canada

In writing this report I sought detailed information about the Australian IXP landscape[3]. However, there is little detailed literature on the IXP landscape in Australia. Of countries that have been studied, the closest analogy is Canada [5].

Canada is a wealthy, developed country, rich in natural resources and with a high standard of education and technology use, much like Australia. Canada also has the problem that is geographically large with an comparatively low population density, and with the population focussed heavily into a much smaller geographic area, so it faces much the same telecommunications challenges as Australia.

Canada had seven IXPs: TORIX[4], OTTIX[5], VANIX[6], YYCIX[7], MBIX[8], QIX[9] and AIXP[10] (as of the writing of [5] in 2016).

Canada's IXPs are **all not-for-profit organisations** that charge fees to members.

For instance TORIX charges up to CA$ 18,000 yearly for access through a single port[11].

Despite their many benefits, IXPs are not invulnerable. OTTIX (The Ottawa eXchange Point) failed when its facilities were acquired by an ISP, breaking its neutrality [12]. Fortunately for Canada it has been replaced by OGIX [12]. OGIX is another not-for-profit organisation, but charges up to CA$ 20,000 yearly per port.

The case illustrates that although IXPs often (or even usually) operate as not-for-profit organisations they have substantial costs and must operate with a strong business plan to maintain their viability over the long term.

[3]One study [11] focusses on the Asia-Pacific region but it aims at hosting trends, which is only peripherally relevant to this document.

[4]https://www.torix.ca/who-we-are/

[5]No longer operational.

[6]https://vanix.ca/

[7]http://yycix.ca/about.html

[8]http://www.mbix.ca/about/

[9]https://www.qix.ca/

[10]https://aixp.ca/

[11]https://www.torix.ca/pricing/

[12]https://ogix.ca/

2.6 Summary

The value and importance of IXPs around the world is so broadly accepted, and so fundamental to the efficient and reliable functioning of the Internet, that it is easy to take them for granted. The example of Canadian IXPs shows:

1. IXPs that charge members (substantial) fees are usually treated as not-for-profit organisations because of the universal public good that they create; and

2. IXPs are not invulnerable, and like any sustainable organisation must have a strong business plan and favourable regulatory environment.

The remainder of this report uses the technical, scientific literature to substantiate the benefits that IXPs provide to the vast majority of the public of a country, some 82% in Australia, as predicted in [1].

3 Review of the Scientific Literature on IXPs

There has been a small volume of technical research on the nature and the role of IXPs. In this section we report on that research.

Xu *et al.* [13] might be credited as the first scientific study of IXPs. The concept of an IXP evolved from that of Network Access Points (NAP) in reference to the National Science Foundation Network (NSFNET) structure. However, the scientific community (as opposed to the network engineering community) was relatively unaware of the importance of IXPs until the early 2000s.

The paper provides a statistical summary of the size and distribution of IXPs in the Internet of that time. Given the data is drawn from nearly 20 years ago it is not directly relevant today, but it is noteworthy that of the 82 IXPs studied only 3 were located in the whole of Oceania. There has been substantial growth since 2004.

Deeper scientific study of IXPs would wait until 2009, in particular, Augustin *et al.* [14] a paper that is primarily concerned with the routing fabric of the Internet; a description of how the pathways through the Internet are formed. It shows that IXPs played (even in 2009) a critical role in establishing a reliable set of pathways through the global Internet. For example, they state "This IXP substrate is a critical component of the economic fabric of the Internet."

In parallel IXPs were also a topic of [15]. As in the previous publication, the main topic of this paper was the routing fabric of the Internet, however it was not specifically focussed on IXPs – it merely included them in a larger study. The paper states that "Our results show that nearly 95% of the peer-to-peer links missed from the BGP tables are incident at IXPs." They are saying that the IXPs they measured facilitated some 95% of pathways through the Internet. Once again, this shows the crucial nature of IXPs in supporting the whole Internet. This finding is reinforced in [16] (though specific numbers vary).

Ager *et al.* [17] is the first detailed study of an IXP from an inside view (past studies applied external measurements to derive properties). It examines a large European IXP with measurements based in 2011. The study is based on detailed measurements of the traffic carried at the exchange point and routing information visible at this point, and is published in one of the most prestigious data communications forums (ACM SIGCOMM).

The (unnamed) IXP had close to 400 members, and this enabled some 50,000 new routes through the Internet. This routing diversity is one of the key benefits of an IXP, which is enabled through multi-lateral peering. The IXP carried 10 petabytes of traffic daily[13]. At the time, the largest ISPs and backbone transit providers in the world carried around 30 petabytes of traffic daily, so this IXP was a crucial junction point in Europe. The work published in [17] shows that without this IXP, the European Internet would be crippled. And this is a single IXP in a large ecosystem.

The other important detail shown in the study is that the traffic matrix (the matrix of traffic between peers) is highly skewed. Around 30% of the members contributed 90% of the traffic. Viewed the other way around, the IXP is enabling a large number of smaller players to operate on a level playing field with larger ISPs. The study confirms this by showing the diversity of types of businesses that

[13]For reference, 1 petabyte = 1 million gigabytes.

participate as members.

Restrepo *et al.* [18] support these analyses of IXPs. They stated (in 2012) that based on their measurements "Today's public Internet eXchange Points (IXP) are a crucial element in the Internet ecosystem, carrying around 20-24 terabits per second, *i.e.,* 15-20% of Internet's inter-domain traffic."

This series of papers had a seminal effect on the research communities understanding of the Internet's underlying structure. For instance, [17] is cited (according to Google Scholar) more than 370 times, so it enabled a wave of research using an improved understanding of the Internet.

Chatzis *et al.* [19] have a different focus. They describe measurements obtained from an IXP and how they can be used to understand the wider Internet. The crucial point of relevance to this report is that in their study they saw traffic from the whole Internet traverse the IXP. They saw traffic from the vast majority of ASes, including ASes that are not members of the IXP, and also from a quarter of a billion IP addresses (corresponding to end users, servers or other participants of the Internet). This means a **quarter of a billion** Internet participants[14] – the vast majority of which were not members of the IXP – benefited from the IXP. In fact a geographic study of the traffic showed a considerable proportion from North America and Asia (The USA, China and Japan are all listed in the top-10 country participants, for instance). An Australian IXP is unlikely to have the reach and impact of a European IXP, but nevertheless the point remains that IXPs benefit the overall Internet ecosystem, not just their members.

The same authors extend their work in [20], with additional discussion but no new results.

The papers above provide an excellent summary and justification for the primary importance of IXPs. However, there are additional works that focus on technical benefits.

For instance [21] considers how the technical expertise embedded in IXPs has led to provision of services (namely route servers) that help network operators "debug" problems in the Internet. IXPs have enhanced visibility of the Internet because they interact with many players and so they often take a role in providing both help in debugging and education to prevent problems. Such services primarily acrue to members, but nevertheless benefit the larger Internet because Internet problems can propagate through what is sometimes called a Cascading Network Failure (CNF). Thus IXPs play a key role in stabilising the entire system. In contrast consider the power grid where, for instance, in 2016 a CNF resulted in a power outage for much of South Australia, affecting 850,000 people. The power grid has no equivalent concept to an IXP, which can help avoid or mitigate such collapses, and so it was vulnerable in a way that IXPs prevent in the Internet.

Very recent work [22] considers the economic benefit to a country in having IXPs. They show that an IXP reduces the Internet costs of a country by 2.5 times and that **all** ISPs benefit from this, not just members. That paper supplements earlier findings [23,24] regarding the role of IXPs in Africa. An additional insight from these reports comes from an analysis of the network performance improvements created.

[14] One estimate of the total number of hosts at the time based on allocated address was 3.5 billion. This estimate is known to have flaws, but provides at least a reference scale suggesting that the number seen at this single ISP was around 7% of the entire Internet.

In particular [23] states "Kenya Internet Exchange Point (KIXP) currently localizes more than 1 Gbit/s of peak traffic, dramatically reducing latency (from 200-600 ms to 2-10 ms on average), while allowing ISPs to save almost $1.5 million per year on international connectivity." A similar reduction in noted in IXPN in Nigeria. It is also noted that

- the presence of IXPs localises revenues in regional ISPs instead of such revenue being shipped off-shore to international providers; and
- e-government benefits from the presence, resulting in further social benefits to the population of Africa.

The theme of performance enhancement is continued in [25] focussing on Italy. The authors used advanced routing techniques to create artificial paths through the network to test the delays of probe packets through paths that include or exclude the local IXPs. It is important to note that in this study the ISPs measured may participate as members of the IXPs in question, but the probes were used to explore web pages that largely were not. They show, for instance, that "about 70% of probes that choose IXPs have an average RTT of 30ms or less, while only 20% of those that do not traverse IXPs have the same performance." This is very marked improvement.

In preparing this summary, a larger literature was considered. Not all papers are discussed in detail above because most are not germaine to this report as they deal with technical, architecture or software design of the Internet. A very short summary of these is included below in order to demonstrate that this report is a comprehensive study of the literature on IXPs:

- Klöti *et al.* [26] examine three IXP databases of the worldwide set of IXPs but their main finding is that these sources of information are flawed, and they say little novel about IXPs themselves.
- Hoeschele *et al.* [27] consider the importance of IXPs for the 5G mobile network system. The primary goal of this work is to estimate how the increasing deployment of 5G will impact traffic demands on the public Internet, and hence on IXPs. Thus the paper is more concerned with how IXPs should plan to accommodate the increasing load induced by 5G.
- Several papers [28, 29] consider how to perform advanced measurements in IXPs. One paper [30] shows how such measurements can be used in the context of understanding cyber-security threats.
- Böttger *et al.* [31] considers IXPs and their relationship to Netflix. The papers conclusions are somewhat confused, however, by the single viewpoint through Netflix.
- Several papers [32, 33] consider problems faced by IXPs, and how to mitigate these problems.

These papers do not add (or subtract) from the commentary made above.

Confusingly the keyword IXP also appears in other network contexts, *e.g.,* [34] considers the development of The Intel IXP processor. Such references have been excluded from this report.

4 Conclusion

This report considers the benefits that IXPs provide not just to their members but also to the wider public. Those benefits are substantial and validated through scientific studies that have shown improvements in performance, reliability and security of the Internet as a whole.

IXPs also stand as key locations for Internet intelligence, to improve debugging, and education to prevent problems, through their uniquely broad perspective.

There are other hypothesized benefits of ISPs that lie in the technical domain. For instance, in combining traffic from multiple sources it is likely there is a "multiplexing gain." Such gains are commonly observed in transit networks, but are not publically documented for IXPs, but as they are essentially carrying the same traffic these benefits are likely. More study, however, is warranted on this issue.

Biography

Matthew Roughan has held the position of Professor in the School of Mathematical Sciences at the University of Adelaide since 2012 and now holds the position of interim Director of the Teletraffic Research Centre (TRC). His research, broadly within the area of data science, involves mathematical and statistical modelling of complex systems, in particular networks, including aspects of stochastic and formal models, cybersecurity, machine learning and optimisation.

A major area of work – Internet measurement and modelling – won him recognition in 2018 in the form of being elected a Fellow of the Association for Computing Machinery (ACM), the international learned society for computer science. The ACM has more than 100,000 members worldwide, and only around 50 fellows are elected each year. In 2019 he was also elected a Fellow of the Institute of Electrical and Electronics Engineers (IEEE). The IEEE has over 400,000 members, and produces 30% of the world's literature in the electrical and electronics engineering and computer science fields, and elects a similarly small proportion of fellows. The work that won this recognition was based in part on the measurement and modelling of what at the time was one of the largest data-sets in the world (the Internet traffic at the telecommunications giant AT&T), which represented around a petabyte of traffic.

Prof Roughan has over 150 refereed publications, over 9000 citations, and h-index of 39, and his work has won several awards including the prestigious ACM Sigmetrics, "Test of Time" Award (2013) awarded for a paper that still has impact a decade after its publication. He has also worked frequently with industry, for instance with AT&T and Ericsson, and as a result holds six patents. He has been asked to present keynotes and plenary presentations around the word, has served on many editorial and technical program committees, and since returning to Australia has been Chief Investigator on over $20 million of competitive grants, including an ARC Centre of Excellence (ACEMS) in the broad area of data science.

Declaration

The creation of this report was funded by the Internet Association of Australia (IAA). However, I am not a member of the IAA, nor have I any conflicts of interest of which I am aware with IAA or any other members or directors, and all analysis and conclusions of this work are my own.

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