



**IGF 2016
Best Practice Forum on IPv6**

***'Understanding the commercial and economic incentives
behind a successful IPv6 deployment'***

Editor Wim Degezelle

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Executive Summary

The Best Practice Forum (BPF) *Understanding the commercial and economic incentives behind a successful IPv6 deployment* was part of the community intersessional work program of the Internet Governance Forum (IGF). This document is the outcome of an open and iterative process over the months preceding the 11th meeting of the IGF in Guadalajara, Mexico, 6-9 December 2016. A BPF collects best practices from around the world and provide an opportunity to learn from each other by sharing experiences.

IPv6 adoption was selected as a topic for a BPF in 2015 and 2016. While in the first year the BPF focused on best practices to create an environment favorable to IPv6 adoption, in 2016 the BPF explored the commercial and economic incentives behind IPv6 deployment.

Generally speaking, devices connect to the Internet via numerical Internet Protocol addresses (IP addresses). The first pool of IP addresses was created in the 1970s and contained approximately 4 billion unique numbers. This is the Internet's legacy addressing system – Internet Protocol version 4 (IPv4). The growth of the Internet has virtually exhausted the IPv4 address pool.

A new addressing system, Internet Protocol version 6 (IPv6), was developed in 1995 to deal with IPv4 exhaustion. The IPv6 address pool is huge by comparison. The practical size of the IPv6 space can be equated to 32 Billion times the size of the IPv4-based Internet.

Anyone running the old protocol needs to adopt the new one. For the Internet user, IPv6 secures the quality of service of his/her Internet connection and assures that he/she continues to be able to use new services and applications and to connect to all content on the Internet. Technologies – for example “NAT” and “CGN” – have been developed to extend the life of IPv4. They should be considered only as temporary solutions.

The number of networks that already support IPv6 today proofs that IPv6 adoption is a technically feasible option for businesses. IPv6 adoption is on the rise – not only in the global North, but also in a number of countries in the southern hemisphere. The BPF invited people to share their commercial experiences with IPv6, with the aim of establishing a better understanding of the commercial and economic incentives that sit behind a successful deployment of IPv6.

Based on the case studies, the BPF formulated the following observations:

- The imminent shortage of IPv4 is the obvious and most cited motivation behind the decision to deploy IPv6. IPv6 is regarded as the long-term solution to prepare the company's or organization's network for the future.

- Deploying IPv6 now to avoid the expected and increasing cost of the alternative solutions to extend the life of IPv4 is an important incentive.
- The higher quality of service with IPv6 and related benefits is a third reason for the decision to deploy IPv6. This includes, for some, providing new services (e.g. VoLTE, IoT, M2M communication) that would be very hard to deploy in full scale without IPv6.
- Deploying early, and creating a momentum for others to follow has been the motivation for early adopters, among which are several universities and national research and education networks (NRENs).
- Being known as an early adopter of new technologies fits well in the branding strategy of Internet companies and service providers.
- In some areas the government or regulator acted as an external motivator for IPv6 deployment, e.g. by defining guidelines and timelines, or via its own procurement policy. Elsewhere, sector organizations have been promoting IPv6 deployment and provided information or support.

Based on the collected examples of successful IPv6 deployment, the BPF document describes per sector the main observations, incentives and challenges (see section 4 and 5). Short descriptions of the different case studies, per geographical region and country, can be found in section 6. Based on the received input and discussion the BPF formulated takeaways for policy and decisions makers. They can be found in section 7.

The reader will notice from the case studies that no situation is alike. As a consequence, there exists no one size fits all solution that works in all circumstances and for every company, network, country or region. This is an important takeaway for governments that wish to support the IPv6 uptake in their country. They should reach out to decision makers in the industry and stimulate them to deploy IPv6 (not regulate!) and lead by example.

The BPF on IPv6 held a workshop at the IGF meeting Guadalajara. A video recording can be found on the link below:

*BPF on IPv6 workshop at the 11th IGF meeting
7 December 2016, Guadalajara, Mexico
<https://youtu.be/g9EmjZXpscA> (YouTube link)*

Glossary of Terms

- **AFRINIC:**
African Network Information Centre is the RIR for the African region.
- **APNIC:**
Asia Pacific Network Information Centre is the RIR for the Asia Pacific region.
- **ARIN:**
American Registry for Internet Numbers is the RIR for the North American region.
- **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.
- **Bit / Binary Digit:**
A digit to base 2, i.e. 0 or 1, which is the fundamental mathematical unit used in computing.
- **BPF:**
Best Practice Forum, one of the activities of the community intersessional work program of the IGF.
- **IAB:** Internet Architecture Board.
- **IETF:** Internet Engineering Task Force.
- **IGF:** The Internet Governance Forum.
- **Internet Protocol (IP):** The communications protocol used on Internet networks.
- **IP network:** A network using the Internet Protocol.
- **IP address:**
A unique numerical address that identifies a device on the Internet or a local network.
- **IPv4:**
IP version 4. An IPv4 address is a binary number consisting of 32 bits that are organized into four bytes. The four bytes are usually portrayed using a dotted decimal notation such as 1.2.3.4. Each decimal number is equivalent of a byte; the dots used between the decimals are used to separate the bytes. For example, 205.150.58.7.
- **IPv6:**
IP version 6. An IPv6 address is 128-bit address long, it is conventionally expressed using hexadecimal strings, for example, 2001:0db8:582:ae33::29 .
- **Internet Registry / Regional Internet Registry (RIR) / National Internet Registries (NIRs) / Local Internet Registries:**
An Internet Registry (IR) is an organization that is responsible for distributing IP address space to its members or customers and for registering those distributions.
- **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.

- **LACNIC:**
Latin American & Caribbean Network Information Centre is the RIR for Latin America and some Caribbean Islands.
- **LAN:** Local Area Network.
- **LIR:**
A Local Internet Registry primarily assigns address space to the users of the network services that it provides. LIRs are generally ISPs, whose customers are primarily end users and possible other ISPs.
- **NAT / Network Address Translation - CGN / Carrier Grade NAT**
Network Address Translation (NAT) is the process of modifying a network address while in transit for the purpose of remapping a given address space into another.
- **NIR:**
A National Internet Registry primarily allocates address space to its members or constituents which are generally LIRs organized at a national level. NIRs mostly exist in the Asia Pacific region.
- **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).
- **RFC:**
Request For Comments - the name for an Internet standards-related specification.
- **RIPE NCC:**
Réseaux IP Européens Network Co-ordination Centre (RIPE NCC) is the Regional Internet Registry for Europe, the Middle East and parts of Central Asia.
- **RIR:**
Regional Internet Registries (RIRs) are established and authorized by respective regional communities and recognized by the IANA to serve and represent large geographical regions. The primary role of RIRs is to manage and distribute public Internet address space within their respective regions.

Source: most definitions are taken from <https://www.apnic.net/apnic-info/a-z-glossary> .

IGF 2016

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1. Introduction & Background

1.1. About the IGF & BPFs

The Internet Governance Forum¹ (IGF) at the United Nations is an open, global forum where different participants from various stakeholder groups – governments, the technical community, civil society, academia, and the private sector – discuss Internet Governance and policy issues, on equal footing. The Best Practice Forums (BPFs) at the IGF seek to collect, discuss, and disseminate the different “best practices” used by people and organizations around the world for different Internet Governance and policy issues. BPFs provide opportunities to learn from each other by sharing experiences – successes, as well as miscalculations.

IPv6 adoption was selected as a topic for a BPF in 2015 and 2016. While in the first year the BPF focused on best practices to create an environment favorable to IPv6 adoption, in 2016 the BPF explored the commercial and economic incentives behind IPv6 deployment.

1.2. Scope and Goal of the 2016 BPF ²

1.2.1. Scope

The 2016 BPF on IPv6 brought together representatives from different stakeholder communities and offer a great opportunity to look at the topic of IPv6 adoption with focus on economic elements and business cases. The BPF did not want to replicate or duplicate work already undertaken by other groups (e.g. the substantive work or technical training done by the Internet technical community). Rather, the BPF took any such work as a starting point

¹ <http://www.intgovforum.org>

² The 2016 BPF on IPv6 discussed and agreed the Scope and Goals for its activities during its first (23 June 2016) and second (6 June 2016) open Virtual meeting.

and input for the discussion. The purpose of the BPF is to contribute to the best practice exchange and mutual support between stakeholders.

1.2.2. Goals for 2016

The 2015 BPF on IPv6 focused on creating capacity building platforms and awareness raising, in the form of national and regional IPv6 taskforces and other initiatives. Building upon the outcome of the 2015 BPF on IPv6, the activities of the 2016 BPF focused on the *economic decisions* and *commercial drivers* behind the decision to adopt IPv6.

1.2.3. Problem statement

Feedback received from the participants to the 2015 BPF on IPv6, especially those with a technical community background, suggested that the decision to adopt IPv6 is not only a technical one, but also that other economic factors play an important role.

Most of the networks that make up today's Internet are built and operated on a commercial basis, and must include IPv6 adoption into their business plan, accordingly. The same goes for not-for-profit and public sector network operators, who must take into account the cost versus benefit when deciding to upgrade their networks to the new version of the Internet Protocol. The number of networks that already support IPv6 today proves that IPv6 adoption is a technically feasible option for businesses. IPv6 adoption is on the rise - not only in the global North, but also in a number of states in the southern hemisphere and there appears to be little correlation to GDP and IPv6. There remain some questions such as:

- Why is there such a difference in IPv6 adoption in comparable markets?
- Why is cost often cited as a reason not to adopt, while at the same moment commercial ISPs of all sizes are deploying IPv6?

Some studies explore the “why and when” of IPv6 adoption or model the economic effects of IPv6 versus the prolonged use of IPv4, but in general there is not that much documentation around the commercial aspects of IPv6 deployment, especially not based on specific positive cases of adoption. This is the focus of the 2016 BPF IPv6.

The 2016 BPF invited people to share their commercial experiences with IPv6, with the aim of establishing a better understanding of the commercial and economic incentives that sit behind a successful deployment of IPv6 in commercial as well as public sector networks and Internet services.

1.2.4. Methodology

The BPF on IPv6 was part of the community intersessional work program over the months preceding the 2016 IGF meeting in Guadalajara, Mexico, (6-9 December 2016). Participation in the BPF was open to all. 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. The BPF's discussions were coordinated by MAG members Ms. Izumi Okutani and Mr. Sumon A. Sabir and supported by Mr. Wim Degezelle, consultant with the IGF secretariat. The IGF Secretariat further provided practical support for the BPF on IPv6, among other things by hosting the mailing list, organizing the virtual meetings, providing editing services, and maintaining a dedicated section for BPF on IPv6 on the IGF website.

The BPF on IPv6 worked in an open and iterative way. The best practice examples were collected via a public survey that was targeted at commercial network operators, service providers and businesses that have deployed IPv6 on their networks, for their services or products. The BPF also consulted online available sources, e.g. business cases that were presented at other meetings and forums and could draw from the comments on the NTIA's request for comments 'Incentives, Benefits, Costs, and Challenges to IPv6 Implementation'.³

Drafts of this document have been 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 IPv6 during the 2016 IGF meeting in Guadalajara, Mexico, on Wednesday, 7 December 2016. A video recording of the BPF on IPv6 workshop is available online: <https://youtu.be/g9EmjZXpscA> .

For additional information regarding the 2016 IXP BPF process, please refer to the IGF website: <http://www.intgovforum.org/multilingual/content/bpf-ipv6> .

³ <https://www.ntia.doc.gov/federal-register-notice/2016/incentives-benefits-costs-and-challenges-ipv6-implementation-0>

2. Why deploy IPv6?

Note: IPv6 and its deployment are in detail discussed in the BPF 2015 outcome document⁴; this section is a summary.

2.1. The Internet Protocol version 6 (IPv6)

Generally speaking, devices connect to the Internet via numerical Internet Protocol (IP) addresses. An IP address is a numerical address (e.g., 69.65.11.25) used to identify devices on the Internet.⁵ The Internet's legacy addressing system - Internet Protocol version 4 (IPv4) was created in the 1970s. The pool of IPv4 address numbers contains approximately four billion unique numbers. The growth and expansion of the Internet has virtually exhausted the IPv4 address pool.

A new Internet protocol, IPv6, was developed in 1995. One of the goals of IPv6 was to solve the IPv4 address exhaustion. IPv6 addresses are longer in length: An IPv6 address is represented by eight (8) groups of hexadecimal values, separated by colons (:). The IPv6 address size is 128 bits, opposed to 32 bits in an IPv4 address. A bit is a digit in the binary numeral system and the basic unit for storing information. The preferred IPv6 address representation is: xxxx:xxxx:xxxx:xxxx:xxxx:xxxx:xxxx:xxxx, where each x is a hexadecimal digit representing four (4) bits. "X" ranges from "0-9" or from "a-f."

The IPv6 space is significantly larger in comparison to the IPv4 pool. IPv6 theoretically increases the number of unique IP addresses to 2^{128} unique combinations. The practical size of the IPv6 space can be equated roughly to 32 Billion times the size of the current IPv4-based Internet.⁶

The adoption of IPv6 went very slow during the past decade. Today the global user adoption has reached 15%. If growth continues at the same rate like in the past 4 years, we will reach 50% in 2018.

2.2. Why Adopt IPv6?

The Internet's sustainable growth depends on IPv6 adoption. The booming mobile market and the Internet of Things (IoT), alone, will require much more IP address space than is available with IPv4.

⁴ <http://www.intgovforum.org/cms/documents/best-practice-forums/creating-an-enabling-environment-for-the-development-of-local-content/581-igf2015-bpfipv6-finalpdf/file>

⁵ Technically speaking an IP address identifies an interface on a device, not the device itself.

⁶ The following video visualizes the massive amount of IPv6 addresses: <https://youtu.be/7LZfbqYSWdY>

Anyone running the old protocol needs to adopt the new one in order to support the increasing demand on the global network as more people – and more machines and “things” – come online. IPv4 and IPv6 are two different protocols. IPv6 is not backwards compatible with IPv4. Devices that communicate using only IPv6 cannot communicate with devices that communicate using only IPv4.

Technologies have been developed to extend the life of IPv4, for example Network Address Translation (NAT) and Carrier Grade Network Address Translation (CGN) that allow different devices to share one IPv4 address. Unused IPv4 address blocks are being traded on so-called secondary or aftermarkets. These efforts should be considered only as temporary solutions and come with their own costs and downsides. They are sometimes relied upon to forestall what is ultimately inevitable for a business, a government, or end users: IPv6 adoption.

Until recently, there has been little immediate benefit in deploying IPv6 and, in competitive terms, there was no “early adopter” advantage. However, now that more Internet users are connecting via IPv6, the immediate benefits of deploying the new protocol are gaining visibility, for example:

- Content providers and publishers can see a direct performance benefit if traffic is delivered directly to the end user over IPv6 and no longer has to flow through NAT or CGN devices.
- Network operators will save on the operating and maintenance cost of NAT and CGN infrastructure.
- End users with IPv6-enabled devices can access content from IPv6-ready content providers with improved performance (provided that their ISP offers IPv6 services).

On 7 November 2016, the Internet Architecture Board (IAB) published the advise that network standards need to fully support IPv6. ‘The IAB expects that the IETF will stop requiring IPv4 compatibility in new or extended protocols’, and that ‘future IETF protocol work will then optimize for and depend on IPv6’. The IAB recommends ‘that all networking standards assume the use of IPv6, and be written so they do not require IPv4’ and ‘that existing standards be reviewed to ensure they will work with IPv6, and use IPv6 examples.’⁷

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IAB Statement in IPv6, 7 November 2016

⁷ IAB Statement on IPv6, 7 November 2016, <https://www.iab.org/2016/11/07/iab-statement-on-ipv6/>

2.3. ‘Creating an Enabling Environment for IPv6 Adoption’

The 2015 BPF on ‘Creating an Enabling Environment for IPv6 Adoption’ looked at initiatives that promote and support the deployment of IPv6. The growth of IPv6 use in a certain region or environment will almost always be the result of a combination of initiatives, practices and other factors. What follows is a high level overview of the different practices that can help to create an enabling environment for IPv6 adoption that were discussed by the 2015 BPF on IPv6.

2.3.1. IPv6 task forces, a platform for best practices

IPv6 task forces can be organized ad hoc, by the community, or supported by government. They conduct various activities and serve various purposes: raising awareness about IPv6, providing advice on how to deploy IPv6, conducting outreach, or developing fully-informed policy recommendations to the government that should result in their country seeing higher IPv6 use.

National IPv6 task forces often collaborate on a regional basis. Regional meetings enable participants to exchange information with members of other task forces who, while from different countries, may operate in similar cultural, economic, and regulatory environments.

2.3.2. Capacity-building

Capacity-building on IPv6, both in terms of technical training for engineers and operators, and raising awareness for non-technical policymakers, law enforcement, and business decision-makers, is fundamental to creating an enabling environment for IPv6 adoption. Many different organizations, for profit and not-for-profit, provide IPv6 training, including the Regional Internet Registries (AFRINIC, APNIC, ARIN, LACNIC and RIPE NCC)⁸ and national research and education networks (NRENs).

The 2015 BPF noted that many people who are new to IPv6 wrongly think that they have to do everything at once and that too much new knowledge is needed, while on the contrary it is advised to break a deployment into smaller tasks and evaluate them step- by-step.

A good planning can reduce the cost of IPv6 deployment to almost zero. IPv6 awareness at all relevant decision making levels and a good planning are key for a smooth IPv6 deployment. Many of the often mentioned ‘hurdles’ and costs, such as upgrading existing equipment and applications, will be minimal if they happen alongside the existing cycles to maintain or renew equipment. IPv6 should be a requirement for any new IT project or purchase.

⁸ AFRINIC <http://www.afrinic.net> ; APNIC <https://www.apnic.net> ; ARIN <https://www.arin.net> ; LACNIC <http://www.lacnic.net> ; RIPE NCC <https://www.ripe.net>)

While most of the capacity-building focuses on network operators, IPv6 training for law enforcement officials, policymakers, and corporate-level (C-level) business decision-makers (e.g., CEOs, COOs, CFOs, etc.) is also important for creating an enabling environment for IPv6 adoption. It is important to:

- Build confidence at the decision-making level that IPv6 is “proven technology” and (perceived) risks are manageable;
- Work with decision-makers directly to help them understand the importance of IPv6 deployment, at a level where they can make a meaningful risk assessment for their business;
- Ensure that non-technical staff understand the long-term, positive effect of IPv6 deployment on their business goals (for example, enabling growth and the potential for reducing costs).

2.3.3. Lessons from the private sector

Discussions relating to best practices in the private sector – for ISPs and content providers in particular – resulted in a set of high-level suggestions. Planning for IPv6 deployment might begin with a review of existing infrastructure and an assessment of vendor IPv6 readiness.

Employee training is necessary; particularly in the case of technical employees but, depending on the business, for some non-technical personnel as well (e.g. customer service representatives).

As for IPv6 deployment, businesses should consider working from the outside in: deploying IPv6 via dual stack technology for public-facing services first, and then migrating to IPv6 on internal networks, second. To make the transition easier, they should set internal deadlines and engage with customers, keeping them notified, if not engaged, during the deployment process. Other approaches are also possible.

One policy option for encouraging IPv6 adoption that was suggested was for ISPs to use cost incentives, for example raising the price for IPv4, a scarce resource that is becoming costly to maintain, and providing IPv6 to the customer without extra charge. Finally, collaboration with others in deploying IPv6, as happened during the 2012 *IPv6 World Launch*⁹, has shown to be effective.

2.3.4. Research and education networks and tertiary institutions

Many national research and education networks (NRENs) and tertiary institutions (like universities) have been running IPv6 in production on their networks for more than 10 years. They are important sources of knowledge and expertise on the subject. NRENs conduct

⁹ <http://www.worldipv6launch.org>

valuable research on IPv6 and participate in the work at the IETF to develop RFCs. Universities can help promote IPv6 by supporting student research projects.

2.3.5. Government initiatives

Governments are in a powerful position to create an enabling environment for IPv6 adoption. They can lead by example by requiring the public administration to adopt IPv6. They can require IPv6 in ICT procurement policies, which, in turn, obligates businesses tendering for government contracts to provide IPv6-capable products and services. The development of IPv6 profiles can assist public administration in its own procurement processes and evaluation of tenders, and requiring vendors to themselves use IPv6 results in businesses needing to be able to “walk the walk” – not only providing IPv6 services to their clients but running IPv6 themselves.

Submissions to the 2015 BPF on national deployment strategies featured different approaches, from working with the private sector on pilot projects that showcase best practices for the benefit of all, to organizing a national IPv6 launch with IPv6-ready groups, to creating a national IPv6 mandate across the public and private sectors. Governments can help industry by publishing an IPv6 adoption guide that tailors relevant information to different stakeholder groups. Collaboration with industry through government-supported national working groups, study groups, or outsourcing experiments to the private sector has yielded successful results.

2.3.6. IPv6 measurements – tracking success

IPv6 measurements are useful, illustrative tools that IPv6 advocates can use when engaging with policymakers. Measurements can also be used, of course, to gauge the effectiveness of a best practice. Measuring IPv6 usage before and after the implementation of a policy can help reveal that policy’s impact.

3. Facts and Figures - IPv6 deployment

3.1. Introduction

The global Internet keeps on growing and changing. It becomes increasingly important for the Internet to accommodate scale. IPv6 will enable the Internet to cope with the huge demand for IP addresses in the future. Estimates predict that by 2020 52% of the world population or 4.1 billion people will be using the Internet. The IP traffic is expected to triple between 2016 and 2020. It is predicted that by 2020 there will be 26.3 billion networked

devices and connections globally, 5.5 billion global mobile users and 11.6 billion mobile-ready devices and connections.¹⁰

This chapter makes a status update of the IPv6 deployment. It looks at the IPv6 readiness of the Internet infrastructure and will assess the uptake in IPv6 usage. There are different ways to measure and track IPv6 deployment. Appendix I provides a non-exhaustive overview of indicators, measurements and tools that are being used to monitor progress in IPv6 deployment.

3.2. IPv6 deployment status 2016

3.3.1. Global uptake: historic evolution

The past ten years saw a yearly increase of the number of IPv6 allocations by the Regional Internet Registries (RIRs). In each year the number of IPv6 allocations was smaller than the number of IPv4 allocations, but because the allocated IPv6 blocks were much larger, the total volume of allocated IPv6 addresses per year was much higher.¹¹

Table – Number of individual Address Allocations by the RIRs per year for the period 2005 - 2015

Allocations	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
IPv6	217	473	841	1,243	2,477	3,700	3,403	3,840	4,407	4,733
IPv4	5,646	6,312	6,969	6,701	7,758	10,061	8,619	7,110	10,853	11,732

Source: Addressing 2015, Geoff Huston, <https://labs.apnic.net/?p=758>

Table – Volume of Address Allocations by the RIRs per year for the period 2005 - 2015

Addresses	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
IPv6 (/32s)	9,854	6,916	15,634	1,555	4,754	20,009	18,136	23,935	17,513	20,225
IPv4 (/32s)(M)	168.1	203.9	203.3	189.4	248.8	201.0	114.9	65.1	63.9	64.7

Source: Addressing 2015, Geoff Huston, <https://labs.apnic.net/?p=758>

3.3.2. Global uptake: IPv6 slowly entering mainstream in 2016?

The global IPv6 deployment is on the rise and IPv6 is slowly entering mainstream usage. In many ways 2016 has been a remarkable year. Since mid 2016, for example, one could observe a rapid growth in IPv6 supported content.¹² Some observations:

¹⁰ Cisco VNI, <http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html>

¹¹ There's a double effect; IPv6 is allocated in larger blocks of which the size is a matter of choice for the requesting party and special policies came into force to allocate the last /8 IPv4 blocks by APNIC, APNIC and RIPE NCC.

¹² <https://mobile.twitter.com/bajpaivaibhav/status/798558510086836224>

Google

Five years ago, in January 2011 only 0.2% of the users reached Google over IPv6. This number increased but was still less than 3% by the end of 2014.

At the beginning of 2016 the percentage of users that accessed Google using IPv6 flirted for the first time in history with the 10% threshold. By June 2016 Google already measured more than 12% users accessing the search engine over IPv6, by October 2016 it reached 15% and the positive trend continues.

Source: <https://www.google.com/intl/en/ipv6/statistics.html>

Akamai

Akamai, one of the world's leading content delivery network service providers, saw IPv6 increasingly entering the mainstream in 2016 and reported on major movements in deploying IPv6 by many of the top networks and content providers in the world. Of Akamai's top five network providers by traffic volume, all but one have IPv6 adoption over 20%. Of the top 25 networks by volume, 14 have IPv6 adoption over 10%, and around a third of the top 100 networks by volume have started rolling out IPv6.

Source: <https://blogs.akamai.com/2016/06/four-years-since-world-ipv6-launch-entering-the-mainstream.html>

Cloudflare

In November 2016 almost every site using Cloudflare (more than 4 million in total) was using IPv6. Globally, Cloudflare reported a significant increase of IPv6 traffic where networks had enabled IPv6 for the end-users.

Source: <https://blog.cloudflare.com/98-percent-ipv6/>

RIPE NCC

During the first half of 2016 RIPE NCC counted for the first time ever more than 25% of networks (Autonomous Systems AS) within its service region that announced one or more IPv6 prefixes. This was only 5% in 2009 and 15% at the beginning of 2012.

Source: <https://labs.ripe.net/statistics/?tags=ipv6>

Facebook

On 17 August 2016, for the first time ever, IPv6 was used more than IPv4 to access Facebook from the 4 major USA mobile networks.

Source: <https://www.facebook.com/ps/posts/10157221242360858>

ARIN

By September 2016, one year after full IPv4 depletion for the North American region, more than half of the networks in the ARIN membership had registered IPv6 addresses. ARIN continues issuing IPv6 address blocks to 60-100 additional organisations per month.

Source: <http://teamarin.net/2016/09/26/life-after-ipv4-depletion/>

AT&T

AT&T began planning for the transition to IPv6 in 2006. As of 30 September 2016, approximately 60% of the wireline traffic and nearly 15% of the wireless traffic originating from AT&T Autonomous System Numbers (ASNs) was using IPv6.

Source: https://www.ntia.doc.gov/files/ntia/publications/att_10_3.pdf

IPv6 in DNS

In October 2016, an APNIC blogpost described the significant progress in IPv6 deployment in the domain name system (DNS). Slightly more than one third of all users were capable of resolving names using IPv6.

Source: <https://blog.apnic.net/2016/10/20/ipv6-and-the-dns/>

3.3.3. Regional trends

This section gives an overview of the current state of IPv6 deployment in the world per geographical region and lists the top 50 countries by IPv6 deployment. It is good practice to only compare data over time and between regions that is based on the same methodology. The BPF therefore agreed to only use the APNIC Labs statistics for this section.

According to the APNIC Labs measurements for mid November 2016, the global IPv6 capability was close to 8%. The Americas (18% IPv6 capable) and Europe (12% IPv6 capable) scored above the global average. IPv6 capability in the other regions is situated below the global average. The country-by-country comparison in this section will show that there are huge differences within the regions and that in each region a few champions boost the regional average. The USA for example, has an IPv6 capability that is almost twice as high as the regional score for the Americas. In the same region, only Ecuador and Peru have an IPv6 capability that is (slightly) higher than the average.

IPv6 deployment per region.

	IPv6 Capable	IPv6 Preferred
World	7.50%	6.75%
Americas	18.16%	16.82%
Europe	11.52%	11.04%
Oceania	6.83%	6.35%
Asia	3.83%	3.05%
Africa	0.13%	0.12%

Source: APNIC Labs, data for 21 November 2016, <http://stats.labs.apnic.net/ipv6/>

Of the top-50 countries ranked by IPv6 capability 17 showed a double digit deployment rate in October 2016. Of these 17 countries, 10 are European, 3 Latin American, 2 from the Asia Pacific region and 2 from North America.

Only one country, Belgium (56% IPv6 capable), scored higher than 50% on IPv6 capability in October 2016 and with 46% Belgium also leads the ranking in terms of IPv6 use ratio. Belgium is followed by the US (34% IPv6 capable - 31% IPv6 use ratio) and Switzerland (31% IPv6 capable - 27% IPv6 use ratio).

Ecuador, Peru and Brazil are leading in Latin America with IPv6 capability and use ratio between 10% and 20% IPv6. From the Caribbean, Trinidad and Tobago is flirting with the 10%.

Japan (16% IPv6 capable - 14% use ratio) and Malaysia (15% capable - 15% use ratio) show the highest IPv6 deployment in the Asia Pacific region. India showed rapid growth in 2016, it started the year with less than 5% but would end 2016 with a deployment rate of over 13%. All other countries from the region have deployment rates lower than 10%.

Saudi Arabia (5% IPv6 capable - 4% use ratio) is leading in the Middle East.

Early October 2016, no African country scored higher than 1% on IPv6 capability. On 28 September, however, an important provider in Zimbabwe¹³ turned on IPv6 and one month later Zimbabwe was leading on the continent with 2.75% IPv6 capability, and 5.28 % IPv6 use ratio.

Top 50 countries IPv6 deployment per region.

Global ranking IPv6 Capable	CC	Country	IPv6 Capable	IPv6 Preferred	IPv6 Use ratio
Europe					
1	BE	Belgium, Western Europe, Europe	55.64%	50.17%	45.89%
3	CH	Switzerland, Western Europe, Europe	30.78%	29.27%	26.61%
4	GR	Greece, Southern Europe, Europe	27.51%	26.90%	23.00%
5	DE	Germany, Western Europe, Europe	27.05%	25.30%	25.20%
6	LU	Luxembourg, Western Europe, Europe	23.23%	21.82%	19.41%
7	PT	Portugal, Southern Europe, Europe	23.19%	22,39%	19.28%
8	GB	United Kingdom, Northern Europe, Europe	20.68%	19.70%	22.16%
11	EE	Estonia, Northern Europe, Europe	17.17%	16.74%	15.29%
15	FR	France, Western Europe, Europe	13.87%	13.22%	11.51%
16	FI	Finland, Northern Europe, Europe	12.63%	11.08%	10.68%
19	CZ	Czech Republic, Eastern Europe, Europe	9.41%	8.41%	8.37%

¹³ <https://afnog.org/pipermail/afnog/2016-September/002869.html>

Africa					
**	ZW	Zimbabwe, Western Africa, Africa	2.75 %	2.68 %	5,28%
45	LR	Liberia, Western Africa, Africa	0.95%	0.82%	2.26%
(-58-)	SD	Sudan, Northern Africa, Africa	0.19%	0.18%	0.14%
(-62-)	BW	Botswana, Southern Africa, Africa	0.12%	0.07%	0.01%

** ZW, Zimbabwe, data for 7 November 2016,

Source: APNIC Labs, data for 7 October 2016, <http://stats.labs.apnic.net/ipv6/> , <http://labs.apnic.net/dists/v6dcc.html>

3.3.4. IPv6 deployment and Economic performance

The previous section shows that in general the higher adoption rates can be found in more developed regions and an overall low IPv6 deployment in developing nations of the Global South. However there are also huge differences within the regions and between countries with a similar development level.

There are outliers, for example Peru and Ecuador in South America, and large differences between the national deployment rates within the European Union. These differences in IPv6 deployment don't line up with differences in the size or strength of the economy between IPv6 leaders and the other countries.

If you compare the IPv6 deployment rate per country with GDP, there is a general trend observed that you are much more likely to have IPv6 if you are in the top-50 countries in GDP per capita.¹⁴

At the same time, high IPv6 deployment rate is not limited to countries with high GDPs, as you can see from cases such as Bolivia, Ecuador, Peru, where relatively high IPv6 deployment is observed, while not being in the top 50 countries with GDP. It is also not guaranteed that countries within the top 50 GDPs have a high IPv6 deployment rate.

Comparable markets behave differently and even in the same region and markets, comparable operators that use similar technology and equipment will make different choices to IPv6 deployment.¹⁵

Another interesting observation was made by Geoff Huston: In the Spring of 2015, 94% of IPv6 users in the world, confined to just 5 of the world's 30 largest ISPs¹⁶.

¹⁴ 'Are We There Yet? IPv6 as Related to GDP per Capita', Alain Durand, RIPE 73, October 2016, <https://ripe73.ripe.net/presentations/101-IPv6-GDP-ripe73.pdf>

¹⁵ 'Can You Make IPv6 Work Commercially?', Marco Hogewoning, 07 July 2016, https://labs.ripe.net/Members/marco_hogewoning/can-you-make-ipv6-work-commercially

¹⁶ Geoff Huston 'May 2015 Update on measuring IPv6', <http://www.potaroo.net/presentations/2015-05-14-ipv6-stats.pdf>. The same article noted that 'These 30 ISPs together serviced 42% of the entire internet population, and if 'these 30 providers were to achieve an average 50% IPv6 uptake in their customer base, then the total IPv6 capability level across the entire Internet would be 20% today, rather than 3.6%'

Geoff Huston 'May 2015 Update on measuring IPv6', <http://www.potaroo.net/presentations/2015-05-14-ipv6-stats.pdf>

These observations together suggest that economic performance cannot always clarify the successful IPv6 deployment in a country. It seems that IPv6 deployment often depends on individual decisions to deploy IPv6 by one or more large ISPs or operators. This is often the case in Europe and the United States. In some Asia Pacific countries IPv6 deployment results from the collaboration between industry players, encouraged by the government (for example in Japan).

4. Understanding the commercial and economic incentives

The BPF collected case studies from companies and organizations that finished the transition or are implementing IPv6 for their networks and services. The case studies have been collected via an online survey, online research and direct contributions to the BPF. This section will reflect general observations and summarize main experiences and lessons learned per sector or type of industry.

4.1. General Observations

4.1.1. Motivation to deploy IPv6

The imminent shortage of IPv4 addresses is the obvious and most cited motivation behind the decision to deploy IPv6. IPv6 is regarded as the long-term solution to prepare the company's or organization's network ready for the future.

Deploying IPv6 now to avoid the higher cost of the alternative solutions to get around IPv4 exhaustion and extend the life of IPv4 is the second most frequently cited motivation.¹⁷

The higher quality of service and related benefits is a third argument behind decisions to deploy IPv6. Sometimes the request to deploy IPv6 or to provide new services over IPv6 comes from one or more important clients.¹⁸

¹⁷ One of the case studies submitted to the NTIA RFC describes the issue of IPv4 exhaustion and address sharing through Network Address Translators (whether NAT44 or NAT64 types of carrier-grade NAT) as it bring a host of concerns.

- Some applications, such as peer-to-peer, work poorly or not at all.
- Companies may appear to be blocking P2P, in violation of Net Neutrality principles, but actually have no recourse for managing their networks.
- Address sharing means fate sharing: if an IPv4 address is blocked by a web site, either because one user did something malicious, or because the web site thought that one user was maliciously generating the traffic of multiple users, then all users sharing that address will be affected.
- Similarly, if a translator runs out of ports assigned to a user, some applications may fail or degrade.
- The architecture of address translators may not provide the same performance as native IP traffic, with either higher latency or lower throughput experienced by consumers.

Deploying early, and creating a momentum for others to follow and start deploying IPv6 has been the motivation for early adopters, among which are several universities and NRENs. Being known as an early adopter of new technology fits well in the branding strategy of Internet companies and service providers.

In some areas the government or the regulator acted as an external motivator for IPv6 deployment by defining guidelines, requirements and timelines, or via its own procurement policy. Elsewhere, sector organizations have been promoting IPv6 deployment and provided information or support to their members. An example of this is the campaign and project by the Brazilian Federation of Banks.

4.1.2. Economic and Business Incentives

The transition to IPv6 is inevitable. IPv6 guarantees the long term sustainability of the business or service. At the BPF workshop during the IGF meeting in Guadalajara, LACNIC's Carlos Martinez added that IPv6 not necessarily brings along new things, but 'assures that you are not going to lose what you have right now.' A respondent to the BPF survey warned "if you don't do IPv6 now, you will run into a brick wall at some point".

In a competitive market service providers like to position and brand themselves as a company that has a high technical know-how and is ready and capable of adapting to new technical evolutions. By deploying IPv6 and offering IPv6 services to the customers a provider can show that he knows what he is doing. Such a perception is important for large service providers but can also help smaller companies to build a distinct image of a leading edge company.

Deploying IPv6 to save costs is an important incentive. To estimate the possible cost savings, an organization or a company could calculate what it would cost to continue to buy IPv4 addresses and/or develop and maintain more complex solutions to support future customer growth without IPv6 (e.g. the maintenance cost of a NAT or CGN). Such a comparison would easily show that sticking to IPv4 is not a good decision in the long term. In several case studies it was noted that avoiding costs in the future was an important incentive to decide to deploy IPv6. (See section 4.1.5. for more on the cost factor.)

There are examples of service providers that were obliged to deploy IPv6 because one or more of their customers asked them explicitly to do so.

¹⁸ For example, with IPv6 managing a real e2e-network will be easier as no middleware is needed. The quality of service for the users is affected by CGNAT and other techniques to deal with the lack of available IPv4 addresses. New services like VoLTE, IoT and M2M communication would be extremely hard to deploy in full scale without IPv6.

Providing a high quality of service is another reason mentioned in the case studies. The service provider wants to assure that all users can access content from any kind of device and network.

IPv6 adoption is observed to have technical/operational advantage in certain cases. For example, Facebook uses IPv6 with Identifier-Locator Addressing (ILA) feature, which splits the function of addresses as identifier and locator of devices in virtual networking. NTT in Japan provides infrastructure for large scale image streaming for IPv6 Multicast feature.

4.1.3 Decision Making

Based on the received case studies it can be concluded that in general, the decision to deploy IPv6 is made at an executive level.

Typically, IPv6 deployment is first promoted by one, or a few employees, usually at the technical level, before the initiative is pushed up to the decision making level. At the executive level, the engineers or the technical department then has to convince their company to adopt IPv6. Such a scenario seems to be common case in Europe.

In other cases the decision to deploy IPv6 is triggered by an external factor. The external reason can be an executive who learned about the need to deploy IPv6 at an industry event, a competitors that deployed IPv6, or a government initiative to promote or require IPv6 deployment. In such cases it is the executive level that requests the technical department to adopt IPv6. This scenario is common in Asian countries where governments took on a leading role in the promotion of IPv6

4.1.4 External Factors

In Asia governments play a leading role and encourage organizations to deploy IPv6. Examples can be found in Japan or Korea. Elsewhere, as is the case in Malaysia, the government defined requirements (for ISPs) to deploy IPv6 by certain deadlines. Case studies from Brazil mentioned the stimulating role from NIC.BR and initiatives in the banking sector. As mentioned in last year's BPF document, several governments in Europe and North America¹⁹ lead by example, for example by defining internal deadlines for IPv6 deployment for government networks and e-gov services and by requiring IPv6 readiness in public procurement.

One of the replies to the NTIA's RFC on IPv6 deployment described how governments can play a leading role by bringing industry leaders, government agencies, and civil society

¹⁹ For example: https://www.whitehouse.gov/sites/default/files/omb/assets/egov_docs/transition-to-ipv6.pdf

together to discuss the transition and accelerate deployment.²⁰ An example of soft leadership by the Japanese government was shared in a presentation at AprIGF 2016:

https://aprigf2016.files.wordpress.com/2016/08/tatsuya_akagawa160728_mic_ipv6_aprigf_r04.pdf.

4.1.5. Long term cost savings

Several case studies mentioned that adopting IPv6 at an early stage and doing it step by step reduces the cost of the transition. Planning early allows aligning the deployment of IPv6 with regular refresh cycles and other IT initiatives. For an ISP or large network, the planning and preparation can take up several months and the implementation process can then be spread over several years, fitted in other planned or necessary work. The longer well-prepared process has the advantage that the IPv6 enabled machines or programs can replace the existing hard- or software when it comes at the end of its lifecycle. This is much more cost efficient than buying the equipment or develop/buy the software and afterwards, when IPv6 has become inevitable, spend resources on upgrades.

Other case studies mentioned a policy that requires all new services and applications to support IPv6, even if the network does not yet allow IPv6 communication. This avoids that time and money needs to be invested replacement, adaptation or redevelopment of equipment and software in the future.

Solutions such as Carrier-Grade NAT (CGN) and the need to continue to buy IPv4 addresses on an IPv4 transit market as long as the transition to IPv6 hasn't been completed, can be an important financial burden, in particular for ISPs. There exist different models to assess these costs. Lee Howard calculated that for an ISP in the USA 'CGN costs \$1.5 million over five years for every 10,000 users, or \$30 per user per year'²¹. The Swisscom case study mentions that throughput of 1Gb/S of data costs CHF 8,000 over IPv4-CGN (without cost for logging) and CHF 1,650 over IPv6, a simple calculation concludes that the IPv4-CGN solution is four times more expensive.²²

LACNIC developed an economic model to compare the costs of various transition alternatives. The model allows ISPs to assess the cost of three alternative interim solutions for their company: deploying dual-stack with CGNAT, deploying CGNAT44 and purchasing IPv4 addresses to support the growth of their customers without address sharing. The model is available as an easy to use module on the LACNIC website: <http://stats.labs.lacnic.net/PROYECTOCAF/modelo/>.²³

²⁰ 'The Cost of Carrier-Grade NAT', Lee Howard, https://conference.apnic.net/data/36/cost-of-cgn_1377486548.pdf

²¹ 'The Cost of Carrier-Grade NAT', Lee Howard, https://conference.apnic.net/data/36/cost-of-cgn_1377486548.pdf

²² See section 6

²³ The methodology behind the model is described in chapter 6 of the LACNIC/CAF study 'IPv6 Deployment for Social and Economic Development in Latin America and the Caribbean', December 2015, <http://portalipv6.lacnic.net/wp-content/caf-lacnic/CAF-LACNIC-IPv6-Deployment-Social-Economic-Development-in-LAC.pdf>

4.2. Sectorial Observations

There are several commercial IPv6 deployments by ISPs across different regions and there is substantial experience within this sector. For ISPs, nearly all current routers and access equipment that is available today supports IPv6. At the same time, although it is technically feasible and several commercial IPv6 deployments are observed, there is still room for improvement in this sector.

According to a calculation in May 2015 by Geoff Huston, APNIC's Chief Scientist, the 30 largest ISPs serviced 42% of the entire Internet user population. The effect of an IPv6 deployment by one or more of these large providers on the global IPv6 deployment rate is immediately visible.

Major cloud services and Contents Delivery Networks (CDNs) provide IPv6 by default. Up to date OS for both windows and mac are IPv6 supported. Major global contents providers have their contents available in IPv6. In other words, the environment for end-users is getting ready, without users being aware of IPv6. Therefore if an ISP turns on IPv6 by default, an immediate substantial volume of IPv6 traffic can be expected.

Some mobile operators observed rapid growth in IPv6 traffic. On the other hand, there is room for improvement in sectors such as exchange points in some geographical areas, datacenters, and the ability to connect to local content over IPv6. Further, more vendor support is needed in specific areas. IPv6 adoption cases for corporate networks are not large in number but global corporations such as BMW and Sony, as well as several financial companies have deployed IPv6.

4.2.1. ISPs

ISPs play an important role in the deployment of IPv6. There is a wide variety among ISPs. They exist in different sizes, are active in regions where the Internet is well developed or is in a developing stage, they operate large scale or smaller networks, etc..

One general observation for ISPs that provide Internet access to home users is that their mainstream customers don't care whether they have IPv4 or IPv6, as long as they are provided with stable good internet access. The choice for IPv6 is not made by the individual customer, but is a decision that is up to the ISPs. There are examples, e.g. in Japan, of ISPs that deployed IPv6 without informing or requiring action from their clients who did not notice the change from IPv4 to IPv6. Of course, such a project requires thorough planning and preparation.

The legacy equipment at the customers' premises – the CPE or customer-premises equipment – has to be IPv6 ready. These are in the first place the modems and routers owned or provided by the ISP to their customers. Replacing or upgrading the CPE is a challenge, in

particular for large networks. Case studies show that this can be addressed by planning ahead and deploying IPv6 at the time of large scale network upgrades that require legacy CPE to be replaced, by installing IPv6 capable CPE when an old devices are broken or at the end of their life cycle, and by providing all new clients with IPv6 capable equipment.

A recent survey (November 2016) on IPv6 deployment showed that 69% of the ISP employees that replied to the survey responded using IPv4, while almost every response came from a network that has both IPv4 and IPv6 allocations. The researchers concluded from this observation ‘that corporate LANs, even in ISP networks have not yet deployed IPv6 in all their subnets.’²⁴

A 2015 LACNIC study²⁵ surveyed ISPs that already finished or had started IPv6 deployment. ISPs gave as reasons for the deployment:

1. Declining availability and raising cost of IPv4 addresses;
2. Corporate image;
3. Migrating to IPv6 without further IPv4 growth is the most cost-effective solution;
4. Significant customer base growth;
5. Business opportunity.

The study further observed that ‘in many cases deployment began as a result of corporate clients requirements, particularly universities’, and that 58% of the ISPs that already started deploying IPv6 replied that deployment had improved their business results.

The ISPs that didn’t yet deploy IPv6 and indicated that they didn’t have plans to do so in the near future gave as reasons: ‘Current infrastructure presents problems for transitioning to IPv6’, and ‘Deployment and operational difficulties are expected’.

The fact that globally a relative small number of ISPs service a large part of the Internet users means that the effect of an IPv6 deployment by one or more of these large providers on the global IPv6 deployment rate is immediately visible.²⁶ A number of these largest ISPs, however, operate in the developing world, and tend to be late adopters so as to reduce capital risk for their enterprise.²⁷

4.2.2. IXPs²⁸

The IPv6 uptake by Internet Exchange Points (IXPs) is uneven across the different continents. Already in 2011 the European IXP Association (Euro-IX) announced that all of its

²⁴ <https://labs.ripe.net/Members/jordipaletm/results-of-the-ipv6-deployment-survey>

²⁵ <http://portalipv6.lacnic.net/wp-content/caf-lacnic/CAF-LACNIC-IPv6-Deployment-Social-Economic-Development-in-LAC.pdf>

²⁶ G.Huston calculated that an average 50% IPv6 uptake in the customer's base of the 30 largest ISPs would have increased the global IPv6 capability rate in May 2015 from 3.6% to 20%.

²⁷ Geoff Huston ‘May 2015 Update on measuring IPv6’, <http://www.potaroo.net/presentations/2015-05-14-ipv6-stats.pdf>

²⁸ Information received from the IGF BPF on IXPs, [bp_ixps@intgovforum.org](mailto:ixps@intgovforum.org) mailing list, 20 October 2016.

members were IPv6 ready and enabled²⁹ and today networks can peer IPv6 traffic at all Euro-IX members.

In developing regions the situation is different. In particular in regions where none of the local networks that peer at the IXP are IPv6 enabled or dual-stack there is not much incentive for starting IXPs to deploy IPv6. Organizations that support the creation of IXPs and the RIRs in developing regions are promoting IPv6 deployment. However, it is not because an IXP is capable of handling IPv6, that it will see IPv6 traffic passing through its infrastructure. On the contrary, there is often little or no IPv6 peering activity as member networks often do not yet use IPv6 themselves. UIXP³⁰, the Uganda Internet eXchange Point, for example has been IPv6 enabled for years (i.e. the IXP infrastructure was ready and every member had been assigned an IPv6 address) but saw only recently the first IPv6 peering after some member networks activated IPv6³¹.

4.2.3. Data centers

The general deployment of IPv6 in data centers is still limited. There are some commercial deployments but, in the short term, data centers still need globally unique IPv4 to be accessible for their customers. There are some successful examples such as UOL Diveo in Brazil, or data centers that provide connectivity in IPv6 but through IPv4 based translation technology such as 6rd.

4.2.4. Cloud Service and Content Delivery Network (CDN) providers

There have been some recent developments with cloud service providers deploying IPv6 for (parts of) their services. Akamai has made an announcement that IPv6 is on by default for new customers. CloudFlare has enabled IPv6 for their existing customers. AWS and Microsoft Azure gain native IPv6 connectivity.³²

Lee Howard describes the situation for cloud providers in the United States as follows “Content is moving slowly. Only 16 of the top 50 U.S. web sites are capable of IPv6, essentially unchanged for nearly two years, and 15% of the top 25000 worldwide. Recent announcements from Amazon Web Services (AWS) and Microsoft Azure are almost as encouraging as Akamai’s announcement that IPv6 is on by default for new customers, and that CloudFlare has enabled it for their existing customer. A lot more companies need to follow CloudFlare’s lead and enable IPv6 for existing web sites.”³³

²⁹ ‘Euro-IX IXPs are IPv6 ready!’, Euro-IX, 7 June 2011

http://www.netnod.se/sites/default/files/Euro-IX_IPv6_press.pdf

³⁰ <https://www.uixp.co.ug/>

³¹ Kyle Spencer, UIXP

³² <https://redmondmag.com/blogs/the-schwartz-report/2016/10/azure-gains-ipv6-connectivity.aspx>

<https://azure.microsoft.com/en-us/updates/ipv6-for-azure-vms/>

³³ https://www.ntia.doc.gov/files/ntia/publications/1_howard_10_3.pdf

4.2.5. Content Providers

Several content providers at the global level support IPv6, among them are Google, Yahoo, Facebook, and LinkedIn. The number of users accessing content over IPv6 is increasing. For example, the number of users accessing Google websites over IPv6 is increases by 1% every three months and was more than 14% in total in September 2016.

On the other hand, in October 2016, only 5.8% of the Alexa top one million websites was IPv6 ready, and 22% of the Top Alexa 1000 websites.³⁴

Further, it is also important that local content providers make their content available over IPv6. UOL DIVEO in Brazil or Kakao talk in Korea are good examples.

4.2.6. Vendors

Vendors of ICT equipment play an important role as their implementation and feature roadmap decisions have an impact on the IPv6 readiness of other actors in the chain. Important progress has been made, but there are still areas that need improvement. This is only possible with more and wider adoption since primarily the improvements are related to issues typically found with practical experience.

For ISPs and network operators, nearly all current routers and access equipment support IPv6. The most recent mobile devices fully support IPv6 as well as all current computer operating systems (OS). Therefore, once IPv6 is turned on by default, users should be able to connect to IPv6 without having to do any re-configuration.

There are already devices for consumers, such as cameras, televisions and other on the market that support IPv6. However, most consumer devices that are being used do not support IPv6. The consumer market is still evolving in the direction of IPv6 adoption. There are still issues due to overall lack of understanding and Internet protocol knowledge, but many efforts are being undertaken to help resolve this.

The security features and functionalities for both IPv4 and IPv6 capable devices need consistent enhancements as the Internet keeps evolving. For IPv6 there are some varying protocol nuances that vendors need to understand to create effective mitigation features. Also the interaction between IPv4 and IPv6 co-existing networks need to be taken into account. As much as operational training is needed for engineers deploying IPv6 networks, vendors also need training to effectively create and implement security solutions for IPv6 capable devices. Some areas that need attention are logging, auditing and filtering capabilities that directly influence devices such as intrusion detection and firewall devices. Also, more needs to be

³⁴ https://aprigf2016.files.wordpress.com/2016/08/ipv6_measurement20160726-shian-shyong-tseng.pdf
<http://www.worldipv6launch.org/measurements/>

done for specific functionalities such as ND inspection OSPFv3 neighbor authentication, VXLAN overlay IPv6 transport, and there is a limited or missing IPv6 support in many operational and security tools and services (including DDOS mitigation services).

“IPv6 requirements for ICT equipment - RIPE-554”

To address the needs of the ICT vendor community and the people responsible for procuring IPv6 capable equipment, the RIPE community developed the procurement document, RIPE-554 – *“IPv6 requirements for ICT equipment”*. The document is used by many global organizations as a guideline during equipment evaluation and in the RFP creation process to require IPv6 support in equipment and software. RIPE-554 is a list of IPv6 requirements that vendors must meet in order to qualify for consideration for IPv6 capable equipment purchases. RIPE-554 has been translated in numerous languages and widely used around the world. As a result, many vendors have included this set of specifications in their IPv6 implementation roadmaps.

RIPE-554 advises that every tender includes the following text:

“All ICT hardware as subject of this tender must support both the IPv4 and IPv6 protocols. Similar performance must be provided for both protocols in input, output and/or throughput data-flow performance, transmission and processing of packets.

IPv6 support can be verified and certified by the IPv6 Ready Logo certificate.

Any software that communicates via the IP protocol must support both protocol versions (IPv4 and IPv6). The difference must not be noticeable to users.”

After this general requirement the tender should list detailed specifications and requirements for the equipment or software needed. RIPE-554 provides guidelines to specify requirements and lists for different types of hardware and software what standards the tender initiator requires.

RIPE-554 is intended to be used as a template to include detailed requirements into the RFP. Adding the words “equipment must be compliant with RIPE-554” is not sufficient! To support the authors of the tender, there’s a must-read first section, called “how to use this document”.

The IPv6 requirements for ICT equipment - RIPE-554 can be found at:

<https://www.ripe.net/publications/docs/ripe-554> .

4.2.7. Mobile networks

Mobile networks have been growing fast and the mobile Internet is expected to continue this growth in the future and accommodate new large numbers of subscribers in the coming years. In the US, several mobile operators, among others T-Mobile and Verizon Wireless have started deployment of IPv6 in their networks. Reliance Jo in India recently observed over 70% of traffic in IPv6. In Japan, the government raised IPv6 as a topic on the national level as a way forward for the mobile phone providers and defined a milestone for mobile providers to adopt IPv6 by default by 2017. SKTelecom in Korea has completed commercial deployment in its mobile network in September 2014.

As from the iOS9 Apple made it a requirement for all applications in the Apple Store to support IPv6. Today’s sold handsets, both Android and iPhone support IPv6.

At the BPF IPv6 workshop at the IGF in Guadalajara, Lise Fuhr from ETNO³⁵, the European network operator’s association, voiced the opinion from ETNO members that IPv6 is the

³⁵ <https://www.etno.eu>

early and long lasting solution for the problem of IPv4 exhaustion. The deployment is a complex and costly matter that is not done in just one day. On top of this comes that every company is different and works in a different environment. As a result there is no strategy or technical solution that fits all. Some European providers took the decision to implement IPv6 because it is inevitable for the future. Others preferred to first test the deployment before it becomes acute and need to be rolled out in the network. Another group have started to embed IPv6 in all new projects, in order to make them future proof.

Lise Fuhr further noted that, at the moment, IPv6 projects are still driven by technical reasons and not business reasons. Telecom operators, especially those in Europe where competition is fierce, also need to have a business argument.

4.2.8. Adoption for non-Internet infrastructure and large scale business networks

IPv6 adoption is observed in some new applications outside the conventional global Internet connections. For example, smart meters in the electricity grid in Japan use IPv6 addresses and Japan's largest telecom company with over 19 million subscribers is using IPv6 multicast services for a nation wide infrastructure platform for image streaming. BMW³⁶ is IPv6 ready for their website, and they have presented about their plans for IPv6 transition in network infrastructure, devices and services, and IPv6 for innovative applications. There are several banks and financial services firms that have adopted IPv6, such as Banrisul, Banco do Estado do Rio Grande do Sul, Rabobank and Wells Fargo. Sony has its corporate network deployed in IPv6 and also provides commercial TV, which can be connected with IPv6.

5. Remaining challenges

The case studies and discussions among BPF participants identified some remaining challenges. There are two main types of 'remaining' challenges: There are the challenges faced by networks, operators, etc. when implementing and after the deployment of IPv6. On the other hand there are the challenges typical for the regions where IPv6 is not taking off, and in particular for developing countries. The remaining challenges are compiled below.

5.1. Remaining challenges after implementing IPv6

Bugs and technical issues

Bugs and technical issues after deployment are a common challenge, which was most mentioned in the case studies. Especially those that are early adopters in their sector can come across unexpected technical issues. The type of issues may vary per sector. In areas

³⁶ <http://d2zmdbbm9feqrf.cloudfront.net/2016/eur/pdf/CCSIP6-2006.pdf>

where there are more deployment cases, later adopters can learn from their experiences and there are fewer issues.

Several companies in the US have explicitly stated that there is a need for more vendor support for IPv6³⁷. Some case studies expressed that debugging an IPv6 supported product was the most challenging part of IPv6 deployment.

Case studies in particular mentioned:

- Specific functionalities, such as ND inspection OSPFv3 neighbor authentication, VXLAN overlay v6 transport, etc.;
- A lack of support in some critical product sets;
- Limited or missing IPv6 support in many operational and security tools and services, including DDOS mitigation services.

Some suggested as a possible way forward that governments would stimulate vendors to support IPv6.³⁸

Cost of staff training and human resources for commercial deployment

For small and medium ISPs and Data centers in a competitive market, the cost to train staff to have sufficient knowledge to deploy and run the IPv6 network can be an additional burden. Governments, industry bodies, the (technical) community, etc. can play an important role by organizing or continuing to organize training, seminars, and workshops. Also here is the same mantra applicable; each situation or region is different, and different initiatives might work differently in different situations.

ISP infrastructure is IPv6 ready but CPEs in customer premises do not support IPv6.

As related issue, it was noted that consumers are in many cases buying their own modems, gateways, and other equipment they use to connect to the Internet. Most consumers don't know anything about IP. This means that IPv6 has limited value as a sales argument in retail.

³⁷ For example Microsoft shares the following experience.

Hardware with larger addressing tables to accommodate IPv6 in the Microsoft datacenter environment was significantly more expensive than the IPv4 solutions already in use. In addition, we encountered IPv6 breaking bugs during vendor firmware updates which strongly indicated that IPv6 test processes were not at parity within the vendor engineering departments.

When rolling out IPv6 to users of the Office 365 Exchange Online email service, Microsoft encountered multiple customer-impacting bugs in service providers, from mobile operators to edge network providers. One such bug remained open for several months as the mobile operator worked with their hardware supplier; in retrospect, the difficulties they shared with us could have been a good predictor of troubles we would have with our own supplier months later.

³⁸ For example, Microsoft makes the following request to the NTIA.

NTIA should encourage public sector entities to mandate that all hardware, software and online services providers have a published IPv6 roadmap with a clear service level agreement in place for mitigating IPv6 issues which arise. These mandates should be more than checkbox requirements in contracts or blog posts on government sites. They should be backed by resources who can participate with suppliers to ensure roadmaps and support processes are sufficiently developed. Governments may be loath to make such mandates because their own efforts may be nascent, late or even nonexistent. This choice merely postpones the essential engagement with suppliers of hardware, software and online services by IT, procurement and standards agencies within the public sector.

Some ISPs require customers to apply for IPv6

It was mentioned in one of the case studies that some ISPs only provide IPv6 connection if the customers requests so. As reason was given that some ISPs fear that there will be too many issues and complaints from customers if IPv6 is made the default. They fear that customers will experience a deterioration of the quality of service, because the user's own tools or equipment is not IPv6 capable.

Often technical issues that are linked to IPv6 are in fact the result of misconfigurations. This type of issues could best be addressed and prevented by a better training for the ISP's technical staff. Further, it can also be addressed by preparing the same environment in both IPv6 and IPv4 in areas such as CDN cache and routing.

Cost for IPv6 is relatively higher for small businesses

The absence of economies of scale and scope typically results in relative higher investment costs for small businesses. For example, while rural carriers often include IPv6 capability in their specifications when seeking to procure new products, rural carriers' purchase patterns and needs are often different from larger carriers. Smaller companies' lack of market power limits their ability to enhance the demand for, or drive specific development of, IPv6-capable hardware and software.

5.2. Challenges for regions where deployment is not taking off

In the recent years IPv6 deployment has been paced up in different parts of the world and especially in Europe and USA. There is significant progress in Latin America and in parts of Asia.

As discussed before, differences in economic situation, development or Internet penetration do not always coincide with differences in IPv6 uptake. KISA, the Korea Internet & Security Agency wanted to know more about the differences between European countries and Korea. They held an informal survey among ISPs and companies at the RIPE meeting in May 2016 and shared their findings with the BPF³⁹:

Observations comparing European countries and Korea in IPv6 deployment
KISA attended the May 2016 RIPE in Copenhagen and interviewed ISPs and companies on differences between countries in the RIPE region and Korea.

1. Why is Europe relatively ahead of other regions in terms of IPv6 deployment?
 - There are many multi-national ISPs and there is a competitive market environment.

³⁹ shared by Billy MH Cheon, KISA, Internet Governance Division

- CGN may cause legal problems in some countries.
 - Companies where the CEO has a technical background might more easily adopt IPv6.
2. Was there any direct government support for IPv6 deployment?
 - Almost none. If there was, it was not effective.
 - An indirect approach would be more effective, e.g. smart cities with IPv6.
 - Respondents from countries with a high IPv6 adoption rate mentioned the voluntary activities by network operator groups (NOGs).
 3. Any benefit from IPv6 deployment?
 - None in the short-term;
 - After complete IPv6 adoption, ISPs may be able to make a profit from selling their IPv4 at good price.
 4. Any other specific difficulties in operating IPv6 network?
 - Same, not much different from operating an IPv4 network.
 5. Additional fee for IPv6?
 - No additional fee should be charged.
 6. Any highlighted challenges?
 - Changing the legacy equipment.
 - Too many CPE equipment on leased lines.

In most developing countries the IPv6 deployment rate is far behind on the global average. As part of the 2016 IPv6 BPF initiative we have also tried to find the deployment challenges in the developing nations. It has been observed in the survey that in several countries there is still a lack of motivation, combined with technical challenges, and in most of the countries no real initiatives from the governments to promote or encourage IPv6 deployment.

Most of the service providers (ISPs, Mobile Operators) are aware of the fact that sooner or later they will need to deploy IPv6. Some deployed IPv6 in the transit paths and in their core networks but at the access layer, there is no visible IPv6 deployment and they largely keep on depending on Carrier Grade NAT (CGN).

Some ISPs mentioned that they can offer IPv6 to their corporate customers without any challenge, but that there is not much interest from these customers. In some cases they add that there is a lack of knowledge among the customers about IPv6 deployment and IPv6 security.

Regarding IPv6 deployment for the last mile broadband users, some ISPs mentioned that they have technical difficulties in shaping the bandwidth in IPv4 and IPv6 dual stack environment and are looking for technical solutions that comply with the commercial packages they are offering.

Some acknowledged that not all their engineers are capable enough to manage IPv6, especially IPv6 security.

Another major issue for the ISPs is the CPE. For example in many countries in South Asia more than 90% of the Wifi access points presently in use are not IPv6 capable. Which is one of the main demotivation factors in deploying IPv6 for the last mile broadband users. Still a large number of cheap CPEs that is being sold on the market are not IPv6 capable.

Mobile operators in some countries have been waiting for more smart phone users before deploying IPv6. But in recent years, the use of smart phones grew rapidly. One of the mobile operators in Bangladesh mentioned that their smart phone users are now more than 20% and continues to grow fast. Now they are considering deploying IPv6 seriously. But any fixed strategy and timeline is yet to be fixed.

Regarding content, only a handful of content providers are offering content that can be reached over IPv6. Lack of awareness seems to be the major factor in this area. No major technical or other challenges were mentioned in the case studies.

In developing areas it is therefore even more important to convince decision makers about the need of IPv6. In rural areas in some developing countries second hand equipment is very popular. These are usually only IPv4, hence it will take another cycle before IPv6 enabled second hand equipment will be available in these regions.

Based on his own experiences in Cameroon, and his endeavor to get an IPv6 connection for his organization, Willy Manga put together a roadmap that may inspire administrators in in Africa and elsewhere that want to deploy IPv6⁴⁰:

- 1) Get interested in IPv6, and convince yourself of its use.
- 2) Explain the importance of IPv6 to the decision makers in your organization.
- 3) Engage with your ISP to obtain a (written) commitment for an IPv6 connection.
- 4) Install a tunnel and start to experiment with IPv6 on a part of your network.
- 5) Ask your ISP to integrate IPv6 in its services. (Regular clients can put some pressure.)
- 6) Don't follow courses (e.g. AFRINIC trainings) to then forget what you have learned!
- 7) REMOVE NAT FROM YOUR MINDS AND NETWORKS !!

⁴⁰ <http://ongola.blogspot.com/2016/05/utiliser-ipv6-au-cameroun-en-tant.html>

6. Case Studies - Regional Observations

In section 3 and 4 we discussed the general trends in IPv6 deployment on a global, regional and national level. This section on regional observations is a showcase of concrete case studies of companies and organizations that deployed IPv6. The BPF collected case studies via an online survey that was promoted via the IGF website and BPF-IPv6 mailing list. In addition the BPF drew information from the NTIA's RFC on IPv6 adoption⁴¹, blog posts and presentations at other meetings and forums. The case studies are summarized with a special attention for the motivational factors and incentives.

Disclaimer:

The BPF wants to share a variety of experiences and examples.

This section does not intent to be exhaustive or representative for a specific country or region!

The following cases are discussed in this section⁴²:

Europe

Swisscom (Switzerland)

Forthnet (Greece)

Continental (Germany)

BMW (Germany)

Estonia Telekom (Estonia)

Proximus (Belgium)

Latin America

Telefónica del Perú (Peru)

UOL DIVEO (Brazil)

Globo (Brazil)

America Movil Brasil (Brazil)

Banrisul (Brazil)

NIC.br and CGI.br (Brazil)

Universidad de Guadalajara
(Mexico)

North America

AT&T (USA)

6connect (USA)

Microsoft (USA)

Wells Fargo (USA)

Comcast (USA)

Asia Pacific

Telekom Malaysia (Malaysia)

NTT East (Japan)

Sony (Japan)

FPT Telekom (Vietnam)

SKTelecom (Korea)

Kakao Talk (Korea)

Middle East

Africa

Global players

6.1. Europe

From Europe, we received cases of ISPs in Switzerland and Greece, two countries that have an IPv6 deployment rate of over 27% (Sept 2016), the case of Continental that has deployed

⁴¹ <https://www.ntia.doc.gov/blog/2016/ntia-seeks-input-it-develops-initiatives-increase-ipv6-adoption>

⁴² The submissions to the BPF survey are published as a separate document on the IGF website.

IPv6 for its websites, and case studies from Proximus (Belgium), Tele2 (Sweden), PC Extreme B.V. (Netherlands) received via the survey.

Switzerland

Swisscom (Telecom operator, Switzerland)

Swisscom is a full-service telecom operator providing wireless and wireline services (voice, TV, Internet, networking) for residential, business and wholesale customers in Switzerland. Their IPv6 capable rate is 58%, as of Sep 2016, according to APNIC Labs' IPv6 measurement.

For Swisscom the main motivation to deploy IPv6 was that IPv6 is the only long term solution to the shortage of IPv4 addresses. By deploying early, they wanted to create momentum for others to deploy and use IPv6. IPv6 deployment is a strategic technical decision to keep the services that are offered today running in the future. The introduction of IPv6 - and in particular of IPv6 only networks - helped to relieve the impending shortage of IPv4 addresses. Deploying IPv6-only networks is possible for wireless networks. Swisscom deployed VoLTE on an IPv6-only APN, and they are planning to migrate the APN for Internet-access to IPv6-only.

Taking an incremental approach in the IPv6 deployment was a factor that contributed to the success of the project. Swisscom started early and progressed with small steps, so that no big “program” was necessary. The two elements that helped the IPv6 deployment to succeed were:

1. Convince the right people that IPv6 must be deployed and that deployment better start early than late;
2. Develop and deploy in small increments that fit normal project budgets.

Using 6rd (RFC 5969) helped immensely to start an IPv6 service early that scales to carry all traffic.

IPv6 is a factor that sets Swisscom apart from competitors. Leadership on IPv6 deployment contributes to the image of being a technical leader, which in commercial terms translates into a willingness of customers to pay for quality. So far, Swisscom doesn't consider IPv6 (yet) to be an enabler for new business, and customers that prefer to stick to IPv4 can still do so. IPv6 is not yet an enabler for new business for Swisscom. Customers can still do with just IPv4.

The Swisscom case study also mentioned that throughput of 1Gb/S of data costs CHF 8,000 over IPv4-CGN (without cost for logging) and CHF 1,650 over IPv6, a simple calculation concludes that the IPv4-CGN solution is four times more expensive.

Greece

Forthnet (ISP, Greece)

Forthnet S.A. is a Greek Internet Service Provider. Forthnet enabled IPv6 on its corporate network in 2011 and its retail Internet service is fully IPv6 enabled since 2013. At the time of writing Forthnet was running a pilot project for business services and expected to have its business Internet service fully IPv6 enabled in Q4 of 2016.

As of September 2016 Forthnet had an IPv6 capable rate of 43%. Their motivation to deploy IPv6 was the imminent lack of IPv4 addresses and the high cost of other solutions.

From a comparison of the cost of "buying" IPv4 addresses vs enabling IPv6 and DS-Lite, Forthnet concluded that continuing on the IPv4 path would not support the customer growth envisaged by their business plan. Forthnet started migrating existing customers to DS-Lite, freeing IPv4 addresses for new customer. In addition, there was an internal requirement for every new network-related project at Forthnet to take IPv6 into account.

Germany

Continental (Automobile Industry, Germany)

Continental, the globally active German Automotive Group, has enabled IPv6 for its websites in Germany, the Asia Pacific, Europe, North America and Latin America. Overall target is to enable the IPv6 protocol and dual-stack on the network infrastructure of Continental to the public Internet. Continental set the requirement that connectivity to external partners via the Internet must run over IPv6, and the own network of Continental is being prepared for this.

Below are the most important steps:

- Public DMZs of Continental is IPv6 enabled incl. lines. (ext. IPv6 clients can connect to IPv6 web service in DMZ);
- Continental public websites are accessible for IPv6-only consumers;
- Public-website-content provided over IPv6 is accessible via Continental Internet-proxies (dual-stack enabled including lines);
- Employees using IPv6 can connect via Conti-Remote Access; Remote Access Gateways are IPv6 enabled incl. Lines;
- Ext. Continental DNS-root is IPv6;
- IP-Address-Management tool of Continental is functional to register IPv6;
- IPv6-addresses used for public internet access are registered in the Continental IP-Address-Management tool;
- IPv6 address/subnet routing concept for Corporate Services is documented.

The deployment of IPv6 on the Continental network was driven by the company's decision that connectivity to external partners via Internet must run over IPv6. Therefore, the network of Continental needed to be prepared for this situation.

There was no defined business case with a financial benefit. The major driver was to avoid any risks in connectivity for B2B and B2C, for example in case a business partner or consumer can only access via IPv6 or IPv4 CGN.

Evaluation for IPv6 in Continental products/services or IoT/smart factory is ongoing. The main lesson learnt was that it requires a lot of effort in training, planning and testing for IT-staff. There was no major invest in hardware, licenses or services for IPv6.

BMW

German car manufacturer BMW presented at the Cisco Live 2016 event in Berlin in February 2016, on it's approach to deploy IPv6:

“BMW Group - An Enterprise Introducing IPv6”, Christian Huber, at Cisco Live 2016, Berlin, February 2016

Presentation: <http://d2zmdbbm9feqrf.cloudfront.net/2016/eur/pdf/CCSIP6-2006.pdf>

Video: <https://www.ciscolive.com/online/connect/flowPlayerRedirect.wv>

(free registration needed for video)

Estonia

Estonia Telekom (ISP, telecom operator, Estonia)

In 2015 IPv6 in Estonia went from almost not existing to 6% in little than four weeks time. The main reason for this sudden uptake was that Estonian Telekom, the largest Internet provider in the country enabled IPv6 for its networks. One of the leading engineers documented the IPv6 project in a blog post.⁴³

Several years of planning preceded the actual IPv6 deployment. It was difficult to build a business case that justified the cost of the IPv6 deployment. Therefore it was decided to wait and combine the transition to IPv6 with a major infrastructure update: the replacement of the broadband network gateway (BNG) platform. To avoid future additional costs it was decided to provide native IPv6 from day zero. In order to minimise the disruption to the services that transition might cause, it was chosen to make the transition in one time and roll out IPv6 connectivity to all end users with last generation CPE.

⁴³ 'IPv6 deployment in Estonia', Tarko Tikan, June 2015, https://labs.ripe.net/Members/tarko_tikan/ipv6-deployment-in-estonia
(accessed 15 Nov 2016)

The transition had to happen without the end users noticing it. While the ISP can decide to deploy IPv6 on its network, it has no control on the customer's home network on the other side of the CPE. To avoid causing problems for the user at home it was decided to rely on Happy Eyeballs to have an IPv4 fallback mechanism in case the IPv6 connection malfunctions.

More technical details can be found here:

https://labs.ripe.net/Members/tarko_tikan/ipv6-deployment-in-estonia .

The transition went smoothly as planned and also in the months after the transition there were no problems affecting the customers. Six months after the deployment almost 15% of the customer base were active IPv6 subscribers, and 81% of them had at least one IPv6-enabled device in their LAN.

Next Estonia Telekom intends to deploy IPv6 in its mobile network.

Belgium

Proximus (Telecom operator, ISP, Belgium)

Proximus, the incumbent telecom operator and one of the main ISPs in Belgium started the implementation of IPv6 more than 10 years ago. The main motivation was to be ready by the time IPv4 exhaustion impacts. The deployment was seen as a 'must do', while the business case was negative. The replacement of CPE is an important cost factor that needs to be taken into consideration. The program board that oversees the IPv6 deployment consists of representatives from different departments.

Even though Proximus started deploying IPv6 more than 10 years ago, it will take another 5 to 10 years to have all services IPv6 ready.

A recent article⁴⁴ on IPv6 in Belgium mentioned that in 2012 the Belgian Regulator, the Federal Computer Crime Unit (police) and the ISPs agreed in a code of conduct on the use of CGN and to limit the sharing of 1 IPv4 address to a maximum of 16 subscribers. One can assume that this agreement and the fact that it made using CGN/NAT solution more costly, was an motivational factor for the operators to start deploying IPv6, and might be one of the factors behind the high IPv6 deployment rates in Belgium.

The Belgian regulator is currently (end 2016) working on a report on the IPv6 deployment in the country, which amongst other will evaluate the code of conduct and its effectiveness⁴⁵.

⁴⁴ <http://www.networkworld.com/article/3100968/internet/why-belgium-leads-the-world-in-ipv6-adoption.html>

⁴⁵ [http://economie.fgov.be/nl/binaries/Studie naar de invoering van IPv6 in Belgie tcm325-264455.pdf](http://economie.fgov.be/nl/binaries/Studie%20naar%20de%20invoering%20van%20IPv6%20in%20Belgie%20tcm325-264455.pdf)

6.2. Americas (and the Caribbean)

6.2.1. Latin America

Ecuador, Peru and Brazil have the highest IPv6 deployment rate in Latin America. Ecuador and Peru had an IPv6 deployment rate of 18% as of Sep 2016. The IPv6 deployment rate in Brazil was at the same time approximately 10%.

Peru

Telefónica del Perú (ISP, telecom operator, Peru)

Within Peru, Telefonica Peru has the highest IPv6 deployment rate of 24%. Telefónica del Perú has deployed IPv6 native connectivity to more than 2.5 million broadband residential customers (mainly ADSL lines). Thanks to this, Peru has been the leading country in the región until Apr 2016 (later on surpassed only by Ecuador). According to Google stats around 16% of users in Peru accessed Google over IPv6.⁴⁶

Telefónica is a leading provider within the Hispam region. Telefónica del Perú has modern infrastructures and experienced engineers. Therefore Perú was well placed to roll out the new IPv6 technology.

IPv6 is seen a matter of business continuation and is simplifying comms for new business paradigms such as IoT, Smartcities, Smart Industry, etc. Only those playing with the technology at first hand will be able to identify the business and differentiation opportunities:

- New businesses such as IoT, Smartcities, etc. are all developed with IPv6 in mind.
- IPv6 means costs today that might be lowered by correctly phasing network deployments/updates.

The government of Peru has been pretty active by promoting IPv6 to local corporations and the local administration, for example by organizing events.

One of the most important lessons that was shared in the case study was to plan ahead and correctly phase the deployment; this will reduce complexity and save on extraordinary costs.

Brazil

UOL DIVEO (Content and service provider, Brazil)

Universo Online (known by the acronym UOL) is a Brazilian company that provides web content, products and internet services. UOL is subsidiary of Grupo Folha. As of January 2015, UOL's website was ranked 73rd on SimilarWeb and 108th on the Alexa Internet globally.

⁴⁶ <https://www.vyncke.org/ipv6status/compare.php?metric=p&countries=pe,ec,br,bo>

In 2012, UOL was ranked by Alexa as the fifth most visited website in Brazil, after the Google portals (Google Brasil, Google EUA, YouTube) and Facebook. According to Ibope Nielsen Online, UOL is Brazil's largest Internet portal with more than 50 million unique visitors and 6.7 billion page views every month.

UOL started providing IPv6 for its service infrastructure to be able to handle IPv6 end user traffic to UOL websites, which increased when the telecommunication companies started to roll out IPv6 to their customers. There was no external factor involved.

The short term motivation was to continue to receive the traffic from users that had migrated from IPv4 to IPv6. UOL had many end users using IPv6. They needed to be able to access the products and to be reached by advertisement traffic.

The mid term motivation was the end of availability of IPv4.

Long term: Customers started to ask for IPv6 as a new requirement. UOL provides both hosting services and content. Customers of hosting services started to request IPv6 service so that they can set up IPv6 supported websites. UOL also received requests to have their website, as content provider IPv6 ready.

The main takeaway from UOL is : the market demanded IPv6, so it was necessary to deploy IPv6. Without the IPv6 deployment UOL would had lost clients and revenue in the last 4 years.

Globo (Content provider, Brazil)

Globo is a content provider for the largest media group in Brazil. Their motivation for IPv6 deployment is to ensure that the quality of service for their users is not affected by CGNAT and other techniques that will be used to deal with the IPv4 exhaustion. The stimulus to deploy came from NIC.BR.

By deploying IPv6 Globo wanted to assure that all its users can access their content from any kind of device and network. IPv6 will assure that Globo can reach all of its users without the limitations that they have in IPv4.

One of the main takeaways from the Globo case study is that they needed the commitment from the board to implement IPv6 and to get that commitment, the board needed to understand the importance the IPv6 deployment.

America Movil Brasil (Mobile operator, Brazil)

The exhaustion of free IPv4 addresses was the main motivation for the IPv6 project. The exhaustion could force the company to suspend new sales, because of a lack of public IPv4 addresses available in the network.

The government set a deadline for CPE manufacturers to avoid that new products would still be “IPv4 only”. That decision helped companies like America Movil that wanted to deploy IPv6 on their network, because IPv6 ready equipment became available on the market.

The biggest challenge was the lack of content and Dual Stack and unavailability of CPE compatible with IPv6, which forced:

- to use CGNAT in many locations;
- to develop an automated process to provide fallback for customers who have applications only capable of IPv4 that do not work with CGNAT (IP cameras for example);
- to set up an audit process to identify unjustified public address requests to prevent any IPv4 public address waste.

Other devices like IP Cameras, Residencial WiFi Routers, Connected Home devices and SmartTVs without IPv6 generated an important financial impact in CGNAT and Legal ID Platform.

After defining the strategy and solution, a program was created inside the Corporate Project Managing Office (PMO) involving several projects on 4 fronts:

- IT Front: New legal identification system / big data; adequation of provisioning systems, CRM, BSS and Field Services; new BI reports.
- Engineering Front: IPv6 implementation along the whole network; CGNAT implementation on the main cities; log collector systems; team training; adequation of Management, Provisioning and OSS platforms.
- Customers Front: internal and external communication, training of the call center and field technicians; revision of the customer service processes; monitoring of customer experience KPIs (churn, visits, contact rate, etc).
- Regulatory and legal Front: coworking with NIC.br, government areas, customer defense entities; revision of contracts and services delivered to the clients.

The project implementation was managed inside the company as a survival strategy and technological evolution. There were no business gains up to now.

Conclusions: There was no financial gain in the IPv6 deployment. The costs of CGNAT increased, but delivering only IPv6 was not an option for our customers, because of the resistance coming from the industry (IoT, IP Cameras, WiFi routers, SmartTV, etc) about

IPv6 compatibility of their products. Several cloud systems, APPs, eCommerce and eGov still don't support IPv6, what forces ISPs to use CGNAT solutions and pay the bill.

The key factor contributing to the success was that a enough time was spent on tests, homologation and planning. In addition, the simulation of the client's environment, the small pilots and the accompaniment of the project's engineers / IP architects in the field visits were very important.

The support from the executive level to maintain the project's original guidelines also contributed to the success.

Banrisul - Banco do Estado do Rio Grande do Sul (Financial institution, Brazil)

The Brazilian bank Banrisul deployed IPv6 for the following two main reasons:

1. Allow new clients who already use IPv6 connectivity to have access to the Internet Banking of the Banrisul.
2. Guideline of FEBRABAN - The Brazilian Federation of Banks – (The main entity representing the Brazilian banking industry) to have all financial institutions implement IPv6 before July 2016 for access to Internet Banking services.

The pressure of FEBRABAN made that the company management took a favourable position so that it was possible to mobilize the main areas of the bank (development, security, infrastructure, etc.) and overcome the initial challenges of mobilization and commitment to the project. The main challenge is to maintain the mobilization and commitment to the project. IPv6 training needs to be emphasized and maybe repeated in some areas.

Takeaways from the Banrisul case study:

The main lesson learned is that training is essential. The commercial and economic incentives were attracting new customers that were using new technologies and required alternatives to access services available on the Internet.

Banrisul didn't measure the financial impact of the IPv6 deployment in the Internet Banking services, yet. However, one was surprised of the amount of IPv6 connections, which exceeded all expectations.

The project cost was low and limited to the internal costs of the teams involved, and the cost of hiring a consultant expert in IPv6.

Including IPv6 training for all teams involved at the beginning of the project would have made it easier to overcome some challenges, especially in the Development Unit.

As a financial institution, Banrisul must capture the source IPv6 address and store logs for legal purposes. This was a challenge to the Development Unit.

NIC.br and CGI.br stimulating IPv6 deployment (Brazil)

Since 2009, the Brazilian Network Information Center (NIC.br) along with the Brazilian Internet Steering Committee (CGI.br) led the deployment of IPv6 in Brazil. Together, they created a project, IPv6.br, to help all Brazilian companies that have services related to Internet to work with IPv6. This project to improve the IPv6 deployment has three pillars:

First of all, free IPv6 training courses. As ISOC has stated in their website, one of the major IPv6 transition costs is staff training. In order to minimize cost and help companies, NIC.br already gave more than 150 courses teaching over 6000 network administrators around the country.

Second, collaborating with working groups that seek what is the biggest problem to deploy IPv6 in different areas. For the cases stated in this document two groups are relevant. One group was formed by the Brazilian Government in order to coordinate the work required to adoption of IPv6 in large telecommunications companies (like AMERICA MOVIL BRAZIL), and other was created by FEBRABAN in order to assist banks to migrate to IPv6 (like Banrisul).

Lastly, promoting events related to IPv6, like “World IPv6 day”, “Semana IPv6” (local event), “World IPv6 Launch” and “Fórum IPv6” (local event). All these events were important to increase the recognition of the companies which have deployed IPv6, primarily to content providers like Globo and UOL that have participated in all events.

6.2.2. North America

United States

AT&T:⁴⁷

AT&T envisions a future in which literally billions of IP-enabled devices are connected to the network, and IPv6 is a critical enabler of this vision. Accordingly, AT&T began planning for the transition to IPv6 in 2006. As ever more devices connect to the Internet such as computers, smart phones, netbooks, tablets, connected vehicles, smart cities and the Internet of Things (IoT), each of which requires its own unique IP address the legacy system supplying those addresses is rapidly nearing the point of exhaustion. In short, we are running out of IP addresses. Transitioning to IPv6 is a critical step for supporting the continued, sustainable growth of the Internet. Ultimately, IPv6 gives the industry greater room to grow, innovate and support new devices. According to WorldIPv6Launch.org, as of September 30,

⁴⁷ Submission to the NTIA: https://www.ntia.doc.gov/files/ntia/publications/att_10_3.pdf

2016, approximately 60% of the wireline traffic and nearly 15% of the wireless traffic originating from AT&T Autonomous System Numbers (ASNs) is using IPv6 today.⁴⁸

The single largest factor that contributed to AT&T's decision to migrate towards IPv6 remains overcoming the impending unavailability of IPv4 addresses. Also, the greatest incentive for dual stack of native IPv6 is the cost of implementing other technologies (such as Carrier Grade Network Address Translation (CGN), tunneling (6rd) or other work-arounds).

They describe that the primary benefit of IPv6 is that :

- It addresses the address exhaust concerns around IPv4.
- Direct connection
 - IPv6 is critical for the deployment of Voice over LTE (VoLTE) services because VoLTE is dependent upon a direct connection to the end user and will not function behind Network Address Translation (NAT) or other technologies that would otherwise be used to extend the life cycle of IPv4 addresses.
 - Because IPv6 enables that direct connection, IPv6 can offer lower latency, which improves call quality.
 - More advanced users also may find it easier to run servers; e.g., host games, support their own email server etc., again because of the absence of NAT.

The fundamental motivation behind an organization's decision to implement IPv6 ultimately boils down to necessity. ISPs or service providers such as AT&T know that, despite current workarounds, eventually IPv4 addresses will exhaust, and that supporting the ever-escalating demand for Internet access makes migration to IPv6 inevitable.

6connect (Network Resource Provisioning , US)

6connect provides network resource provisioning and automation⁴⁹. IPv6 is not planning for 6connect, it's a required part of all deployments. Most internal resources in the company are v6 only.

The decision was made a few years ago to treat v4 as legacy and not to turn back. This means in many cases, not only are they single stacked over v6, but even dual stacked hosts have heavy dependency on v6 only services.

As the motivation behind the decision to deploy IPv6, first, IPv6 has an attractive factor for 6 connect. It gave the the ability to deploy more infrastructure at a lower cost and a repeatable architecture done once, without ever having to look back and size of pop or resource utilization. The costs are now easily calculated for new deployments and have no unknown

48 <http://www.worldipv6launch.org/measurements>

49 <https://www.6connect.com/> , <https://www.6connect.com/blog/>

cost factors. The vendor selection and partner selection has become far easier with v6 intelligence at the top of the requirements list. Second, they could completely eliminate NAT. They are now able to have a single security policy which applies globally simplifying security policy. Lastly, compared to other current technology, IPv6 turns out to be low hanging fruit. There are far greater challenges in the orchestration automation technology space, so v6 is one of many easy things to tick off the list and keep the company on its toes. The biggest issue is having to educate partners, vendors and customers. The technology itself will always have some issues just like every other protocol or network service out there.

As business case, as a cost factor, they updated their architecture in hardware, software, services, etc, while this technology had an economic impact, the was relatively small, compared to technologies such a virtualization. IPv6 is just another required update to the architecture. 6 connect sees that , while there are some performance and policy benefits, the true benefit is staying in business. They consider v6 is a _requirement_ to continue to conduct business on the Internet.

As lessons learnt, 6connect believes IPv6 will be only as hard as you make it. Many inefficiencies were removed related to Out Of Band networks and NAT. They are now able to operate with lower network cost and no longer need to check on IP resource utilization per pop. All pop sizes are now the same IP architecture despite serving small, medium or large service areas. To have done better planning, removing dual stack earlier would have saved time and money. IPv4 support turned out to be the larger cost than just moving to single stack IPv6 where possible.

Microsoft⁵⁰

Microsoft has a long history of supporting IPv6, starting with Windows Vista, Windows Server 2008, and Windows XP Service Pack 3. Aside from the obvious benefit of a much-larger address space, IPv6 benefits to Microsoft include improved peer-to-peer networking for communications and multiplayer gaming and improved delivery of personalized user experience using IP-based location services.

As a provider of online services, Microsoft's motivations are described above. As a networked organization, Microsoft is looking for internal efficiencies in its "Intranet of Things", including servers, workstations, BYOD, and infrastructure embedded devices such as cameras, sensors, clocks and displays. The demand for low-latency peer-to-peer networking in communications and gaming has greatly increased, mobile operators are attempting to build IPv6-only LTE networks to deal with IPv4 address depletion, and governments are considering support mandates for IPv6 from their vendors and suppliers. IPv4 addresses are increasingly difficult and costly to obtain, and location services which

⁵⁰ https://www.ntia.doc.gov/files/ntia/publications/microsoft_10_4.pdf

deliver targeted experiences to end users based on IP addresses are hobbled by network address translations. Each of these changes accelerates the need for native IPv6 support at the customer-facing network edge and further vindicates Microsoft's early and ongoing investments of IPv6 in our online services and in Windows clients and servers.

Microsoft expect to see minor performance benefits as address translators are removed and implementations are improved. Since some equipment implements IPv4 in hardware, but IPv6 in software, hardware parity over time should improve performance. To date, IPv6 performance in Microsoft has been the same as IPv4 for practical purposes.

As return on investment, for Microsoft as a service provider, the anticipated return is a mixture of reduced risk and increased market opportunity. The internal use of globally non-routable addresses creates risk because the addresses can leak into the Internet due to human error and misconfiguration. Moreover, the need to purchase IPv4 addresses on the open market introduces risk due to fluctuating commodity prices. Market opportunities increase when customers mandate IPv6 support and when IPv6 allows faster infrastructure growth for services experiencing rapid customer usage. Microsoft corporate IT efforts are based on a belief that IPv6 support is a cost of business, with returns on investment to be seen only over a very long time frame.

Wells Fargo⁵¹

Wells Fargo & Company is an American international banking and financial services holding company. To Wells Fargo, IPv6 provides numerous benefits, including: greater space for growth; reduced requirement for readdressing duplicate address space in mergers/acquisitions; the ability to support low-functionality end-points that may lack DHCP and static addressing capabilities (IoT, even Android devices); the ability to reduce reliance on NAT (and associated logging complexity); the ability to more universally geo-locate address space (assuming ULA usage is reduced compared to RFC1918); and the simplification of routing tables through improved summarization.

Wells Fargo also observes unexpected benefits of implementing IPv6 include gaining a very detailed knowledge of all the technology used in the organization; Establishing closer working relationships with application and procurement teams; gaining deeper insight into asset/inventory systems and how to establish relationships between elements; opportunity to provide specific, relevant technical training to a wide variety of engineering teams. It also provides a clean-slate for designing from the ground-up.

51 Submission to the NTIA: https://www.ntia.doc.gov/files/ntia/publications/wellsfargo_10_3.pdf

Risk mitigation of the Internet transitioning to IPv6, or avoiding the situation IPv6 will be required without appropriate preparation is the driving motivation for IPv6 implementation. The desire to remain fully connected to the Internet and support all customers as well as employees (i.e. VPN, outbound web proxy, email) is a significant factor driving implementation. Risk mitigation in having to otherwise enable v6 in a rapid, reactive fashion (and possibly root out rogue internal implementations where it was needed but not supported) is another significant factor, as is perception that future mergers and acquisitions will be simpler if IPv6 is the pervasive enterprise communication standard protocol.

Comcast

Comcast is one of the leading providers of communications, entertainment and cable products and services in the United States. According to their presentation at the RIPE72 meeting⁵² in May 2016, the IPv6 program at Comcast began in 2005. The motivation for commercial IPv6 deployment was: IPv4 is not adequate, it could not support near or long term growth requirements, and therefore IPv6 is inevitable.

The IPv6 Program wanted to have everything IPv6 supported, with 98+% of devices managed using IPv6 only. Management use of IPv6 (only) is one of the largest deployments of IPv6 worldwide, and trending towards 100% of all new and existing devices managed using IPv6 only, with no IPv4. For more information, Comcast provides information about its IPv6 deployment on its website “Comcast's IPv6 Information Center”⁵³.

6.3. Asia Pacific

In South East Asia Malaysia has a high IPv6 deployment rate of approximately 14%. In East Asia, Japan has the highest deployment, approximately 15%. India is showing rapid growth in IPv6 deployment (13%) due to major deployments by mobile operators, some of which observe over 70% of IPv6 traffic on their networks. Vietnam is another case showing rapid growth in 2016, the deployment was less than 1% at the beginning of the year, and was reaching almost 5% by the end of 2016. Korea is lagging behind in overall deployment (1.15%) but has a few initiatives ongoing. According to an analysis presented at the RIPE73 Meeting⁵⁴ in Oct 2013, Korea is observed to have quite a significant usage of IPv6 although penetration is small, which means that the few people who use it use it heavily.

Malaysia

Telecom Malaysia (Telecom operator, Malaysia)

⁵² https://ripe72.ripe.net/presentations/63-comcast.ripe_72_plenary.v4.pdf

⁵³ <http://www.comcast6.net/>

⁵⁴ <https://ripe73.ripe.net/archives/steno/26/>

In August 2015, Telecom Malaysia (TM) became one of the top-10 network operators in the world⁵⁵, according to World IPv6 Launch, measuring over 15% IPv6 deployment.

TM's deployment of IPv6 was driven by two primary factors: the responsibility to drive IPv6 adoption as the nation's leading communication service provider; and to ensure business continuity for all the customers, in view of global IPv4 address exhaustion.

TM took the following economic and business factors into consideration

- 1) Ability to offer IPv6 services give competitive edge amongst local ISP;
- 2) Graceful migration of unmanaged customer devices / CPE (no force migration);
- 3) Minimize capex through natural progression of hardware refresh (no drastic network equipment upgrades)

IPv6 used to be something on the network strategy map years ago, but is now considered as done and a pre-requisite and enabler of other potentials.

In addition, the regulatory body (MCMC) in Malaysia developed strict guidelines⁵⁶ that provided the necessary push required for all Malaysian ISPs to move to IPv6. Without the act, ISPs might have preferred to delay IPv6 adoption because of the lack of commercial demand and the associated costs.

For the full story, see: "Championing IPv6 deployment in Malaysia"

<http://blog.apnic.net/2015/12/01/championing-ipnt-in-malaysia/>.

Lessons Learnt:

1. Top-down support and company-wide communication was key to the success.
2. Spread the deployment cost – try to slot in during typical network tech refresh.
3. IPv6 by default for any new network/service implementation.

Japan

NTT East (IPv6 Multicast):

NTT East is the telecommunications services provider that covers Eastern Japan, with 19 million subscribers as of March 2016. With NTT West, which cover the west areas of Japan, they provide nation wide telecommunications services in Japan. They use their platform for their intranet services and adopted IPv6 in their IP based network in 2004. They wanted to provide a platform for image streaming as their business strategy at the time and it was technically challenging to provide the PPPoE service in IPv4. They saw benefit in IPv6 to provide multicast service on a large scale. They also consider IPv6 from mid-short term

⁵⁵ <http://www.worldipv6launch.org/telekom-malaysia-joins-top-10-ipv6-networks/>

⁵⁶ http://www.skmm.gov.my/skmmgovmy/files/attachments/Guideline_IPv6_Compliance.pdf

business perspective: IPv6 eliminates the risk that IPv4 exhaustion impacts in the business continuity.

IPv6 Multicast has greatly contributed for providing videos and image based services. There was no degrading of performance nor scalability issues (this had initially been a concern). There was no impact on cost. The equipment was both IPv4 and IPv6 capable, therefore there was no additional cost. Based on NTT East's IPv6 Multicast Streaming infrastructure, NTT Plala provides image streaming service to its subscribers for optical fiber service .

The NTT group also runs the largest fiber-to-home infrastructure in the country and (http://www.ntt.co.jp/index_e.html), has been deploying IPv6 since around 2012. The IPv6 promotion council and Task force on IPv4 address exhaustion in Japan (<http://www.kokatsu.jp/blog/ipv4/en/>) has worked with NTT to monitor the progress of this deployment activities. By the summer of 2016, about 20% of fiber-to-home connections for residential customers of NTT was IPv6 capable. NTT deployed IPv6 without notifying their customers nor did customers have to make changes to the configuration of their equipment, as shown at http://v6pc.jp/jp/spread/ipv6spread_03.phtml .

Other mobile operators:

Japan has three major Mobile Network Operators: NTT DoCommo, KDDI and SoftBank. In 2015 the Minister of Information and Communication and mobile operators agreed on a "IPv6 Mobile Launch" in 2017. This means that in 2017 all three mobile carriers in Japan will start the full-scale IPv6 service deployment in their commercial mobile networks. See page 8 in http://www.soumu.go.jp/main_content/000388371.pdf .

Sony:

Sony Corporation, based in Tokyo, Japan, is one of the largest and most comprehensive consumer electronics and entertainment companies in the world, and is deploying IPv6 for its network.

In early 2007, Sony began to respond to the challenges presented by the increasing complexity of its enterprise network. The corporation had undergone a global expansion of its business and a rapid increase of its lineup of products, content, and services produced. It urgently needed to increase collaboration aimed at creating synergies between business units and group companies. However, Sony's complex enterprise network based on IPv4 threatened to impede further growth of the business. As a means of fundamentally resolving these issues, Sony decided that an early migration to IPv6 made the most strategic sense. With its virtually unlimited network address pool, IPv6 would clearly be able to support Sony's long-term, next-generation ICT infrastructure strategy and solve their growing business productivity and collaboration challenges. Further, its TV Bravia can be connected with IPv6.

Sony Adopts Cisco Solution for Global IPv6 Project

<https://www.cisco.com/c/dam/en/us/products/collateral/switches/nexus-7000-series-switches/case-study-c36-730671.pdf>

BRAVIA i-Manual Setting IPv6

http://docs.esupport.sony.com/imanual/NA/2013/65S990A/uc_uen/c_cntnet_ipv6.html

Other sectors – smart meters in the electricity grid:

Other examples of IPv6 deployment in Japan are the smart meters for electricity measurement that are used on a nation wide scale. The major electric utility companies are deploying the smart meter system for residential houses in Japan. Especially, TEPCO (<http://www.tepco.co.jp/en/index-e.html>), which is the largest company in Japan accommodating more than 30 Million residential houses, and Kyushu Electric Power Company (http://www.kyuden.co.jp/en_index.html), that accommodates more than 8 million residential house, have been developing IPv6 single stack smart meter access network. TEPCO mainly uses multi-hop wireless network with 6LOWPAN and Kyushu Electric Power Company mainly uses 4G LTE IPv6 service for the access network.

Vietnam

FPT Telecom

FPT Telecom provides Internet services to customer with more than 100k subscribers. The case of FPT Telecom is a great example of a company that by purchasing IPv6 supported equipment for their new network was able to turn on an IPv6 commercial service, when they felt ready.

The FPT Telecom NOC team worked closely with other teams to bring all websites, and contents that belongs to FPT Telecom to run on IPv6. They wanted to be quicker than their competitors. Currently FPT Telecom is a pioneer to provide IPv6 services to subscribers in Vietnam.

There are two main reasons why FPT Telecom has made the decision to deploy IPv6 faster than other players in Vietnam:

- FPT Telecom has only 1.4M IPv4 addresses and had at the moment more than 2M subscribers. On the short term FPT is using CGNAT. IPv6 is the long-term solution to keep FPT Telecom coping with growth.
- FPT Telecom converted most subscribers from xDSL using copper line to optical line. Therefore it had to change all CPE and could replace them by a new model that supports IPv6. This saved a lot of money in the long term.

FPT Telecom started planning to deploy IPv6 in 2013, tested IPv6 in the lab system during 2014, and starting in 2015 they decided to carry out testing on real network infrastructure and

gradually rolled out and increased the number of subscribers. By mid-2015, about 100,000 subscribers, with a total bandwidth capacity of 30Gbps IPv6 traffic was measured. Most of this traffic was to Google and Facebook.

Between 2015 and 2016, they focused on adjusting the parameters and handled issues of customers using IPv6. Almost all these issues had to do with CPE compatibility. In the same period, FPT continued to convert from an IPv4 network to Dual-stack IPv4 and IPv6. Since May 2016, confident that almost all issues are fixed, FPT started offering IPv6 services to all its users.

Experiences and lessons learned:

Actually, the IPv6 deployment plan has started in 2013, when many not felt the need for IPv6 because the IPv4 availability was still redundant. However, the executive had the vision that IPv6 was needed for the further development of the company and they wanted to act quicker than the competitors. Thanks to this vision, FPT Telecom is currently a pioneer providing IPv6 services to subscribers.

Korea

SKTelecom (Mobile, Korea):

The motivation behind the decision to deploy IPv6 is to solve the problem of IPv4 exhaustion and to take technology leadership in the market. As an external factor, there was an IPv6 government project with KISA. As business factor, there were the IPv4 address exhaustion and increase in IoT devices. It was needed to build up infrastructure for the services that require device-to-device communications. There was a 3G government project in 2010 and a LTE government project in 2012. SKTelecom started to commercialize IPv6 service in Mar. 2013 and completed in Sept. 2014. They have launched IPv6 default devices to deal with IP shortage problem for new services. IPv6 traffic was increased through cooperation with Google.

It was relatively easier to deploy IPv6 on the new networks than on the existing networks. Therefore it was decided to deploy IPv6 mainly on the networks for mobile services.

Kakao Talk (Contents Provider, Korea)

Kakao Talk⁵⁷ provides a Messenger service similar to WhatsApp, and a web portal for news, mail and web surfing similar to Yahoo.com. They have undertaken IPv6 deployment activity through cooperation with KISA and ISPs. The motivation behind the decision to deploy IPv6 is to provide Mobile centered services. They saw an increase in end users' IPv6 only devices and a growing need for native IPv6.

57 <http://m.daum.net> , <http://t1.daumcdn.net> , <http://img.daumcdn.net>

Currently, IPv6 is supported in some services – IPv6 deployment is completed in about 10% of the services - and the goal is to provide all the services through Dual Stack. They observe no benefit in early IPv6 deployment without additional supports. As incentive to deploy IPv6, they see changes in users' environment are needed to requiring IPv6 deployment on the Apps such as Apple, Google will be efficient. IPv6 deployment will cause additional cost anyway, and they deployed IPv6 stage by stage solving the difficult cases of IPv6 deployment on application and OS with NAT64 and Proxy.

Observations on the IPv6 Deployment in Korea

The first IPv6 allocation to Korea was made for the KOrea advanced REsearch Network in 1999. Since then a lot of efforts have been made for IPv6 deployment. Korea has a fairly enough amount of IPv6 addresses, 5,245 /32. However, Korea has kept a quite low profile in terms of actual IPv6 usage regardless its multifaceted efforts.

In the private sector, SKT deployed IPv6 on the voice and data of commercial LTE networks in Sep. 2014. Followed by this, in Dec. 2015, in collaboration with KISA, major CATV operators such as CJ helloworld, C&M, and HCN also deployed IPv6 on their commercial services. In 2016, NAVER, one of large local CSP, commenced IPv6 on its commercial service. Now, IPv6 services are being provided for 11 regions with about 6,0000 subscribers in Korea.

From the public sector, the Korean government & KISA set up a national plan to promote IPv6 deployment. All ministries are obliged to procure IPv6 compatible equipments since 2014. And also, they exempted income and corporate tax in IPv6 equipments purchase - 3% for large companies and 7% for SMEs. KISA established 'IPv6 deployment support center' in 2014 and has provided the full range of services such as a helpdesk service, a training as well as a testbed for IPv6 environment. KISA also hosted IPv6 workshops and published guidelines to share technical / managerial know-hows with SMEs.

6.4. Middle East

In November 2016, Etisalat, one of the first telecommunications service providers in the UAE, announced the rollout of IPv6 for all Etisalat eLife customers across the UAE. eLife is the commercial name used for the company's tv, Internet and telephone solutions for consumers.⁵⁸

The IPv6 Strategy for Saudi Arabia identifies a set of milestones to be achieved within a phased time line via an action plan of initiatives categorized into two tracks: Infrastructure and Awareness. The identified objectives are: (1) Prepare for the IPv4 exhaustion by

⁵⁸ <http://www.itp.net/610263-etisalat-rolls-out-ipv6-for-home-subscribers?tab=article>

supporting IPv6 and ensure stability, business continuity and room for continued growth of the Internet in Saudi Arabia; (2) Ensure a smooth adoption of IPv6 by stakeholders so as to minimize risks; (3) Raise overall IPv6 awareness nationwide by approaching stakeholders of both the public and private sectors highlighting the necessity to adopt IPv6.⁵⁹

6.5. Africa

Liquid Telecom

In September 2016, Liquid Telecom a leading provider active in different African countries gave the following update on the plan to deploy IPv6 on its networks⁶⁰:

- we now have over a thousand /48's allocated and active in Kenya;
- IPv6 testing is completed in Zimbabwe;
- Rollout in Zimbabwe will begin to the customers in a phased approach in the next 3 weeks, and is expected to take 2 weeks to complete;
- we're also starting testing V6 on our Zambian LTE rollout.

In Zimbabwe, the rollout of IPv6 by Liquid Telecom had as immediate effect that the IPv6 measurements for the country went up. By the end of October, Zimbabwe was leading on the African continent with 2.75% IPv6 capability, and 5.28 % IPv6 use ratio.⁶¹

Cameroon

A remote participant from Cameroon⁶² to the BPF IPv6 workshop contributed a story that shows that sometimes pressure from the demand side is needed to get the ISPs to provide native IPv6. On his blog (in French) Willy Manga describes his endeavor to convince the ISPs to start working on the IPv6 deployment. – Concretely, the ISP had committed to provide an IPv6 connection, but only started working on realizing this promise after their client put some pressure by putting further payments on hold. While the ISP working on the IPv6 deployment, Willy Manga is using IPv6 via tunneling to the Hurricane Electric network.

He added a clear message to universities in Cameroon: “In Cameroon, if the universities were to raise the need on IPv6, you can increase the usage. The most important ISP in Cameroon got IPv6 blocks from AFRINIC, but they didn't activate, because they didn't see the need.”

On his blog⁶³, he adds a roadmap for administrators in his country:

- Get interested in IPv6, and convince yourself of its use;

⁵⁹ <http://ipv6.sa/ipv6-strategy-for-saudi-arabia-2/>

⁶⁰ <http://www.slideshare.net/InternetSociety/ipv6-rollout-to-the-mass-market>

⁶¹ <https://afnog.org/pipermail/afnog/2016-September/002869.html>

⁶² Willy Manga <https://twitter.com/ongolaboy>

⁶³ <https://ongola.blogspot.be/2015/07/premiers-pas-avec-ipv6.html>

<http://ongola.blogspot.com/2016/05/utiliser-ipv6-au-cameroun-en-tant.html>

- Explain the importance of IPv6 to the decision makers in your organization;
- Engage with your ISP to obtain a (written) commitment for the installation of a IPv6 connection;
- Install a tunnel to be able to learn and experiment with IPv6 on a part of your network;
- Ask your ISP to integrate IPv6 in its services;
 - And if you are a regular client, put some pressure;
- With more can do more than one;
- Don't follow courses (such as the AFRINIC trainings) to then forget what you have learned;
- REMOVE NAT FROM YOUR MINDS AND NETWORKS!!!

6.6. Global Players

Google

Google supports IPv6 in its Google website, YouTube, and android (not in all cases).

It also provides Google Public DNS64 service, which administrators of IPv6-only networks can combine this with locally provided NAT64 using the well-known prefix 64:ff9b::/96 to reach public IPv4-only sites from IPv6-only networks.

LinkedIn (SNS)

Improvement in user experience by adopting IPv6 is observed in LinkedIn, as no large scale TCP timeout in IPv6 compared to IPv4.

Overall, they report that there is increasing adoption of IPv6 and also better performance when visiting LinkedIn if you are visiting the site through mobile carrier networks.

http://cgi1.apnic.net/conference_data/files/APSr107/APNIC_Keynote_2016_LinkedIn.pdf

<https://blog.apnic.net/2016/05/13/linkedin-ipv6-measurements/>

Cisco (Vendor)

Cisco states on its website that they are committed architecturally to IPv6 for all of their devices, all of their applications and all of their services.

It also states that if the challenges of IPv4 are not overcome, this will slow down the growth of the Internet and the industry will lose momentum. IPv6 is important to all, to everyone around the world. It is crucial to Cisco's ability to tie together everyone and every device.

<http://www.cisco.com/c/en/us/solutions/ipv6/overview.html>

Microsoft (OS)

The list of IPv6 supported Microsoft products and other IPv6 related resources are available at: <https://technet.microsoft.com/en-us/network/bb530961.aspx>

See the case study on p.45 for more details.

Apple (Vendor, Mobile Phone handsets, App store for mobile)

Apple made a very clear statement about app availability over IPv6 in 2015.

“Starting June 1st 2016, all apps submitted to the App Store must support IPv6-only networking.” By taking this decision, Apple helped to make the transition to IPv6 easier for mobile providers.

<https://developer.apple.com/news/?id=05042016a>

Facebook

Facebook uses Identifier Locator Addressing (ILA) feature of IPv6, to accommodate large scale mobility within their infrastructure. This allows them to maintain coherent identifiers, even if the physical location of the device moves.

https://www.nanog.org/sites/default/files/20161018_Lapukhov_Internet-Scale_Virtual_Networking_v1.pdf

Netflix (Content provider)

Netflix, the Internet TV streaming service is dual stacked. This means that when devices support IPv6, the Netflix client supports IPv6. When supported devices run on dual stacked networks, the Netflix client uses IPv6 as a default, but can fall back to IPv4 if needed.⁶⁴ In August 2016 around 10% of global traffic was IPv6 based, with traffic in Western Europe and the US higher than this global average and IPv6 traffic in Africa almost non-existent.

6.7. Non commercial deployment

Universidad de Guadalajara (University, Mexico)

The University of Guadalajara deployed IPv6 for its academic network infrastructure (web server, mail server, Internet connectivity to academic network users). Universidad de Guadalajara UDG is a +265,000 students university with 15 university centers (campuses) and +180 high schools; with 95% of its locations connected to the data network and the Internet. UDG’s network is composed of 91 Km of its own fiber optic metropolitan network, leased circuits and microwave deployed all over the state of Jalisco; it is considered a nationwide leader in ITC. The implementation of Internet Protocol version 6 (IPv6) in UDG’s data network, has been a great effort that started in 2001. Since then the university’s ITC staff has promoted IPv6 use within the university and other national entities. Today network traffic of the institution is reaching 90% of hosts with IPv6 addresses in production.

⁶⁴ Based on Nina Bargisen, Netflix, 30 Aug 2016, at AfPIF, Recording & slides : <https://www.internetsociety.org/afpif-2016/day1-presentations-and-livestream>

The motivation behind the decision to deploy IPv6 is that in recent years a change has occurred in the technological paradigm that enables on-demand provisioning, almost in real time, combined with the virtualization of infrastructure of data centers. At the same time, the rigorousness of the networks has become an obstacle to its flexibility and operation. On top of the above comes the depletion of IPv4 addresses as another major limitation in scalability.

The needs of the University of Guadalajara regarding the implementation of Information and Communications Technologies (ICTs) represent a major challenge because of the size of its academic community and territorial dispersion. The data network of the University of Guadalajara, in the main distribution and dorsal, is not exempt from this situation because it is required to be dynamic and have growth in devices and access points to cover the academic demands.

7. Takeaways and next steps

The BPF workshop at the IGF meeting in Guadalajara discussed some takeaways for policy and decision makers. They are summarized here as a concluding chapter for this BPF IPv6 outcome document.

7.1. Takeaways for policy makers

- Request vendors to support IPv6.
For example by encouraging hardware, software and online services providers to have a published IPv6 roadmap and have a clear service level agreement in place for mitigating IPv6 issues when they arise.
(See the section on remaining challenges for more details).
- Reach out to decision makers in the industry.
How a policy maker can best stimulate industry decision makers will depend among other on the local situation and environment. A number of case studies and examples can be found in last year's BPF on IPv6. For example, facilitating a meeting among key players in the industry. Regulating is often not the best option.
- Raise awareness and inform consumers.
For example by sharing information on which products support IPv6 and encourage the purchase of IPv6 supported CPE.

- Support IPv6 training for engineers.
There's a need for training for mid-small scale business and in developing countries. Training could be organized under the form of public-private collaboration. The different RIRs, for example, already provide trainings in their respective regions.

7.2. Takeaways for business decision makers

- Every person, business, government and organization that today depends on the Internet must understand that IPv6 is needed if they want to continue to rely on the Internet in a similar way. Doing nothing hurts, as eventually it will be necessary to use IPv4 translators which impact user experience and cost.
- Consider IPv6 for long term business sustainability.
IPv4 addresses are a limited and finite resource. It is unlikely that you can continue buying all the IPv4 addresses you need. IPv4 address sharing technologies such as CGN cost money as well, and can have higher operational costs than running IPv6. Some applications or services might not work correctly without native IPv6. The IPv4 address sharing technology might have a negative impact on the user experience. Customers are not aware of IPv6 but might complain about a degrading quality of service.
- IPv6 deployment is no longer an "insurance" for an unexpected situation.
Several observations showed that IPv6 is taking off, and this in different fields (mobile, content providers and CDNs, web browsers, etc.) See section 3.3.2 for examples.

Specific takeaways for vendors:

- Have your products support IPv6 !

Specific takeaways for service providers:

- Choose IPv6 supported products when updating or renewing the network;
- When deploying IPv6 commercially, turn it on by default (not as an opt-in).
Do not require your clients to ask for IPv6. Several companies have already done this without major problems of complaints from their clients.
- Training your staff is not hard if they already know how to run an IPv4 network. Make use of the available external training courses. Problems with IPv6 are often caused by simple misconfiguration. Having your staff properly trained will help to avoid them.

- Not deploying IPv6 in new infrastructure and services is a wasted opportunity and ultimately a waste of money. Every purchase decision by an individual, government, company or organization should ask for IPv6, even if the own network is not yet ready. This will save on upgrade and replacements costs in the future.

7.4. Additional questions to be addressed

Further analysis could give a more comprehensive insight in the decision by industry players to deploy IPv6. It could lead to a better understanding of what external factors, if any, played a role in the success stories and if/why these factors are not present in countries that lag behind. For example, in the Asia Pacific and Latin American region there seems to be a greater impact of external factors such as government encouragements and/or joint community initiatives, compared to cases in Europe and the US.

The observation that there is not always a clear link between economic factors or the Internet development and IPv6 deployment leads to the question why similar countries do not observe similar IPv6 deployment rates. More in depth research could explore different dependencies, such as: Does the IPv6 deployment rate correlate with the implementation of other technologies (e.g. DNSSEC)? How do IPv6 penetration rates correlate with IPv6 usage, and are there different scenarios? Is there a link between the IPv6 deployment rate and the length of the operator's cycle for renewal and upgrades? Do newcomers to the industry have a higher IPv6 deployment rate? Also, individual case studies could deliver richer information if there is a follow up with additional questions and interviews.

Such a detailed research and analysis as described above is difficult to realize in the context of a BPF that counts on the voluntary input and contributions from community stakeholders. It requires dedicated professional work, as for example for the study conducted by CAF and LACNIC on "IPv6 Deployment for Social and Economic Development in Latin America and the Caribbean"⁶⁵.

⁶⁵ <http://portalipv6.lacnic.net/wp-content/caf-lacnic/CAF-LACNIC-IPv6-Deployment-Social-Economic-Development-in-LAC.pdf>

8. Contributors

The Best Practice Forum on IPv6 and this BPF IPv6 outcome document is the result of a joint effort involving many people who contributed by participating in the discussions online on the mailing list, during the virtual meetings and at the BPF IPv6 workshop at the 11th IGF meeting in Guadalajara; by contributing and giving feedback on the different drafts of the document; by reaching out to their communities to raise awareness about the survey; by submitting case studies and sharing experiences.

With the risk of not being fully comprehensive the authors identified the following contributors to the BPF process:

Note: The persons below contributed in one way or another to the BPF process and this document. A contribution cannot be seen as an endorsement of this document.

Youssef Abdelrahim, Wanawit Ahkupertura, Eduardo Barasal Morales, Renato Barreto, Nabil Benamar, Anissa Bhar, Einar Bohlin, Constanze Bürger, Cameron Byrne, Susan Chalmers, Billy MH Cheon, Guillermo Cicilea, Olivier Crépin-Leblond, Wafa Dahmani, Owen Delong, Torbjörn Eklöv, Hiroshi Esaki, Azael Fernandez Alcantara, Lise Fuhr, Andrew Gallo, Kate Gerry, Silvia Hagen, Zeina Bou Harb, Afifa Hariz, Ashely Heineman, Marco Hogewoning, Aaron Hughes, Merike Kaeo, Latif Ladid, Martin Levy, Gonzalo López-Barajas, Carlos Martinez, Roney Medeiros, Marc Neuckens, Michael Oghia, Jaime Olmos, Jordi Palet Martinez, Jasper Rappard, Phil Roberts, Mohamed Shawky, Duraid Silarbi, Sander Steffann, Kiaticchai Treerattanpitak, Nathalie Trenaman, Paul Wilson, Jan Zorz, Izumi Okutani, Sumon A. Sabir, Wim Degezelle, and the participants to the workshop of the BPF on IPv6 at the 11th IGF in Guadalajara, Mexico.

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9. Appendix: Monitoring IPv6

Deploying IPv6 means getting the infrastructure ready and starting to use the IPv6 protocol to communicate over the Internet. Both go hand in hand and obviously, the second can't happen if the first hasn't been realized.

Both aspects of the IPv6 deployment are being monitored. Organisations keep track of the readiness of the infrastructure - the core internet infrastructure as well as the user equipment and applications - and of the amount of IPv6 traffic that is sent over the infrastructure by those capable to do so. This section first looks at different ways to assess the IPv6 readiness and then at different ways in which IPv6 traffic is being measured.

9.1. Assessing IPv6 readiness

IPv6 ready means that it is possible to communicate over IPv6. This requires that the infrastructure, the machines and applications are capable of handling IPv6 traffic. IPv6 readiness starts with the sender's and the receiver's equipment and software, and includes everything in between. A detailed assessment of the progress in IPv6 deployment needs to take the whole chain into account. Only when it is technically possible to have IPv6 traffic, monitoring IPv6 traffic makes sense. What follows are frequently used indicators of IPv6 readiness.

* The allocation of IPv6 address blocks

The public Internet is composed of Autonomous Systems (AS) or individual networks that exchange IP traffic, and each network has a unique Autonomous System Number (ASN). Typical examples of an AS are the network operated by an ISP or by a large organization or company.

The first action for a network operator that wants to enable IPv6 on its network – after making sure that the equipment and infrastructure is IPv6 capable – is to get IPv6 address space. Blocks of IPv6 addresses are allocated by the Regional Internet Registries (RIRs) - via Local Internet Registries (LIRs)⁶⁶ - to individual networks (ASes). When making the assumption that an operator will only request IPv6 addresses when his network is capable of handling IPv6 traffic, the number of allocated IPv6 address blocks and the volume of address

⁶⁶ Local Internet Registry (LIR) are responsible for the distribution of address space and registration of the address space on a local level. LIRs also ensure that policies and procedures are followed on the local level. Organisations that become LIRs are mainly Internet Service Providers (ISPs) that assign and allocate address space onto their customers, telecom and enterprise organisations, as well as academic institutions.
<https://www.ripe.net/manage-ips-and-asns/resource-management/faq/independent-resources/phase-three/what-is-a-local-internet-registry-lir>

space of these blocks can serve as an indirect indicator for the IPv6 readiness of network operators.

The RIRs publish statistics on the allocation of IPv6 blocks for their region. The table below gives an overview of the number of IPv6 allocations by each RIR for the last 10 years.

Table – number of discrete IPv6 allocations by RIR per year

Allocations	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
RIPE NCC	88	150	413	595	1,012	1,565	1,661	2,057	2,143	2,206
ARIN	62	196	213	357	567	959	545	523	505	602
APNIC	41	61	158	185	637	610	561	505	503	778
LACNIC	12	38	43	93	212	447	560	683	1,196	1,061
AFRINIC	14	18	14	13	49	119	76	72	60	86
	217	473	841	1,243	2,477	3,700	3,403	3,840	4,407	4,733

Source: Addressing 2015, Geoff Huston, <https://labs.apnic.net/?p=758>

Network operators can choose between different sizes of IPv6 address blocks. The minimum size of an allocation by a RIR is one /32 address block⁶⁷. The below table shows the volume of allocated IPv6 address space, per year and in number of /32 blocks. One /32 block represents an address space of 79,228,162,514,264,337,593,543,950,336 IPv6 addresses. Note that one /32 block is larger than the whole IPv4 space. By October 2016, the total volume of IPv6 space given out was 202,660.02 /32 blocks. Although this is more than 202,600 times the IPv4 Internet space, it only represents 0.038% of the available IPv6 space.⁶⁸ The total volume of allocated addresses shows a different dynamic between the regions.

⁶⁷ The size of a block of addresses is specified by writing a slash (/) followed by a number in decimal which value indicates the length of the network prefix in bits. For example, an address block with 48 bits in the prefix is indicated by /48 and contains $2^{(128 - 48)} = 2^{(80)}$ addresses. The smaller the value of the network prefix, the larger the block: a /21 block is 8 times larger than a /24 block.

⁶⁸ <http://www.bgpexpert.com/addrspace-ipv6.php> accessed on 8 Nov 2016

Table – IPv6 address allocation volumes by RIR in /32 blocks per year

IPv6 Addresses (/32s)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
RIPE NCC	6,550	1,468	964	1,052	2,406	3,174	3,892	6,286	8,217	12,031
ARIN	54	148	14,486	236	780	6,344	1,660	12,558	5,241	641
APNIC	3,224	5,236	139	170	1,335	9,486	3,783	4,442	2,644	2,109
LACNIC	12	51	35	87	197	948	4,605	597	1,359	974
AFRINIC	14	13	10	9	36	147	4,196	51	51	4,471
	9,854	6,916	15,634	1,555	4,754	20,099	18,136	23,935	17,513	20,225

Source: Addressing 2015, Geoff Huston, <https://labs.apnic.net/?p=758>

* Routable IPv6 networks

The first part of an IPv6 address, the *prefix*, specifies the network, while the remaining part specifies a particular address in that network. For a network to be reachable over IPv6, this prefix must be visible on the Internet, i.e. a network must announce an IPv6 prefix in the routing table. RIPE NCC is measuring the percentage of networks that announce an IPv6 prefix. The data is published in an online graph, adaptable per country or per groups of countries: <http://v6asns.ripe.net/v/6>.

* IPv6 RIPEness

[IPv6 RIPEness](https://ip6ripeness.ripe.net) is a tool developed by RIPE NCC to monitor and assess the IPv6 readiness amongst the RIPE NCC members (LIRs). By marking specific milestones in the deployment process, such as requesting an IPv6 allocation and making the prefix visible on the Internet, the organisation itself as well as other stakeholders can see the high-level progress in IPv6 deployment based on comparable criteria.

<https://ip6ripeness.ripe.net>

* End user IPv6 readiness

[APNIC Labs](http://stats.labs.apnic.net/ipv6/) has designed a test system that reports on end-user capability based on daily tests of random internet users.⁶⁹ The APNIC measurements are publicly available. The webpage gives a global overview and statistics on a regional and country by country level. Further, by clicking on a country's link, one can see the deployment rate per operator in the country, in figures and in a graph with historic records.

<http://stats.labs.apnic.net/ipv6/>

⁶⁹ How APNIC developed the test is explained at <http://labs.apnic.net/?p=83>

Note: *The BPF on IPv6 agreed to use the APNIC Labs deployment measurements to compare the state of IPv6 between countries in this BPF document.*

* Deployment ratios

Efforts have been made to develop matrices to define overall IPv6 deployment levels and allow for comparing between countries and regions. Cisco calculates an *overall IPv6 deployment ratio* based on three other matrices: IPv6-enabled transit AS, IPv6 content and IPv6 users.

<http://6lab.cisco.com/stats/information.php#content>

9.2. Measuring IPv6 traffic

* Global operators and content providers

Global content providers, service providers and operators that have enabled IPv6 for their networks and services monitor and report on the IPv6 traffic. *Google* tracks on an ongoing basis the percentage of users that access Google over IPv6. Statistics are published per country:

<https://www.google.com/intl/en/ipv6/statistics.html><https://www.google.com/intl/en/ipv6/statistics.html>

* IPv6 Domain name system

Each Top Level Domain (TLD), like .com, .org or .de, has its own authoritative nameservers which contain the information on their zone. To support IPv6, these nameservers should have an IP address themselves and native IPv6 connectivity so that they can be reached over IPv6, have AAAA records for their IPv6 address (glue records) in the root zone, and be able to return AAAA (IPv6) address records. Daily statistics on these three requirements are generated by Mike Leber:

<http://bgp.he.net/ipv6-progress-report.cgi>

Domain name registries can count the number of domain names in their zone that have an IPv6 address (AAAA-record) and can track the number of DNS queries they receive over IPv6. CZ.NIC, for example, shows these statistics for the .cz domain names on its website:

https://stats.nic.cz/stats/ipv6_domains/?rd=2016-09-30&dr=1y&tp=i-1m&ss=0&ds=normal&da=chart

* Internet Exchange Points (IXPs)

Internet Exchange Points (IXPs) enable the interconnection and exchange of IP-traffic between Autonomous Systems (networks). IXPs can monitor the amount traffic over IPv6 that passes through the IXP. The Amsterdam Internet Exchange (AMS-IX) , for example, has real time IPv6 traffic statistics on its website:

<https://ams-ix.net/technical/statistics/sflow-stats/ipv6-traffic>

3. Places to monitor IPv6 Adoption

Below is a non-exhaustive list of websites and portals monitoring IPv6 deployment.

Akamai: <https://www.akamai.com/us/en/our-thinking/state-of-the-internet-report/state-of-the-internet-ipv6-adoption-visualization.jsp>
Cisco: <http://6lab.cisco.com>
Eric Vyncke: <https://www.vyncke.org/countv6/stats.php>

The websites of the Regional Internet Registries and the Number Resource Organization (NRO):

NRO	https://www.nro.net
AFRINIC	http://www.afrinic.net
APNIC	https://www.apnic.net
ARIN	https://www.arin.net
LACNIC	http://www.lacnic.net
RIPE NCC	https://www.ripe.net