OECD Digital Economy Papers No. 172

Internet Addressing: Measuring Deployment of IPV6: Measuring Deployment of IPV6

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https://dx.doi.org/10.1787/5kmh79zp2t8w-en

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INTERNET ADDRESSING: MEASURING DEPLOYMENT OF IPv6

APRIL 2010

OECD

FOREWORD

This report provides an overview of several indicators and data sets for measuring IPv6 deployment.

This report was prepared by Ms. Karine Perset of the OECD's Directorate for Science, Technology and Industry. The Working Party on Communication Infrastructures and Services Policy (CISP) recommended, at its meeting in December 2009, forwarding the document to the Committee for Information, Computer and Communications Policy (ICCP) for declassification. The ICCP Committee agreed to make the document publicly available in March 2010.

Experts from the Internet Technical Advisory Committee to the ICCP Committee (ITAC) and the Business and Industry Advisory Committee to the OECD (BIAC) have provided comments, suggestions, and contributed significantly to the data in this report. Special thanks are to be given to Geoff Huston from APNIC and Leo Vegoda from ICANN on behalf of ITAC/the NRO, Patrick Grossetete from ArchRock, Martin Levy from Hurricane Electric, Google and the IPv6 Forum for providing data, analysis and comments for this report.

This report was originally issued under the code DSTI/ICCP/CISP(2009)17/FINAL.

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MAIN POINTS

One of the major challenges for the future of the Internet is its ability to scale to connect billions of people and devices. A key part of scalability is the Internet Protocol (IP). The Internet Protocol specifies how communications take place between one device and another through an addressing system. Each device must have an IP address in order to communicate. However, the currently used version of the Internet Protocol, IPv4, is expected to run out of previously unallocated addresses in 2012.[1] IPv4 addresses are nearing full allocation, with just 8% of addresses remaining in March 2010.

When IPv4 addresses are fully allocated, operators and service providers must support the newer version of the Internet Protocol (IPv6) in order to add additional customers or devices to their networks. Otherwise, they will need to employ complex and expensive layers of network address translation (NAT) to share scarce IPv4 addresses among multiple users and devices. For this reason, the timely deployment of IPv6 by network operators and content/application providers is an increasing priority for all Internet stakeholders. In terms of public policy, IPv6 plays an important role in enabling growth of the Internet to support further innovation. In addition, security, interoperability and competition issues are involved with the depletion of IPv4.

Encouraging the deployment of IPv6 is an explicit goal of OECD and of a growing number of non-OECD countries. In June 2008, in the *Seoul Declaration for the Future of the Internet Economy*, Ministers highlighted the importance of encouraging IPv6 adoption, in particular through its deployment by the private sector and by governments.[2] To this end, benchmarking IPv6 deployment at the international level is necessary in order to help build awareness of the scope and scale of the issue, to support informed policy making, and to monitor the impact of various policies.

Previous OECD work includes "*Economic Considerations in the Management of IPv4 and in the Deployment of IPv6*", published in April 2008.[3] The present report builds on this work by investigating various indicators of IPv6 deployment, each of which offers information on a specific aspect of IPv6 deployment and from a particular vantage point. The difficulty of such a measurement exercise and the caveats associated with each indicator are underscored.

By early 2010, IPv6 was still a small proportion of the Internet. However, IPv6 use was growing faster than continued IPv4 use, albeit from a low base. And several large-scale deployments are taking place or are planned. Overall, the Internet is still in the early stages of a transition whereby end hosts, networks, services, and middleware are shifting from IPv4-only to support both IPv4 and IPv6. During a potentially long transition, both IPv4 and IPv6 will co-exist in "dual-stack" operation on most of the Internet. That said, some green-field IPv6-only deployments will also take place for new purposes such as mobile Internet or in the deployment of sensor networks. Key findings are:

- Networks that can run IPv6 and that propose IPv6 services are critical to IPv6 deployment. 5.5% of networks on the Internet (1 800 networks) could handle IPv6 traffic by early 2010. IPv6 networks have grown faster than IPv4-only since mid-2007. Similarly, demand for IPv6 address blocks has grown faster than demand for IPv4 address blocks. Even more encouragingly, Internet infrastructure players seem to be actively readying for IPv6, with one out of five transit networks (*i.e.* networks that provide connections through themselves to other networks) handling IPv6. In practice, several indicators are closely correlated and point to the same countries as having the most IPv6 network services. These include Germany, the Netherlands, the United States, and the United Kingdom.

- As to end-users, the penetration of operating systems that supports IPv6 indicates the number of Internet computers / devices that could potentially run IPv6 if IPv6 connectivity was available. The number of *potential* users is quite high with over 90% of the installed base of operating systems being IPv6-capable, and roughly 25% of end users running an operating system that supports IPv6 by default in January 2010, such as Windows Vista or Mac OS X. However, *actual* IPv6 connectivity by users is very low. A one year experiment by Google estimated that just 0.25% of users had IPv6 connectivity (and chose IPv6 when given the choice) in September 2009, up from less than 0.2% one year before. After France, the top countries by percentage of native IPv6 capable users in September 2009 were China, Sweden, the Netherlands, the United States, and Japan.

- IPv6 support by content providers and low latency of IPv6 websites are critical for end-users to have an incentive to use IPv6. Only 1.45% of the top 1000 websites had an IPv6 website in January 2010, but this figure grew to 8% in March 2010 when Google websites were included. However, only 0.15% of the top 1 million websites had an IPv6 website in January 2010 (and just 0.16% in March 2010). A trend may be emerging whereby large websites are deploying IPv6 alongside IPv4, while the vast majority of smaller websites remain available only over IPv4.

Adequate adoption of IPv6 to satisfy foreseeable demand for Internet deployment would require a significant increase in its relative use, in a short space of time, and require significant mobilisation across all parts of the Internet. Adequate adoption of IPv6 cannot yet be demonstrated by the measurements explored in this report. In particular, IPv6 is not being deployed sufficiently rapidly to intercept the estimated IPv4 exhaustion date. Much more mobilisation needs to occur for the Internet infrastructure to be ready when IPv4 addresses run out in 2012.

This report concludes that recommendations made in 2008 remain valid (ANNEX 1 - Main points, OECD (2008), "Economic Considerations in the Management of IPv4 and in the Deployment of IPv6"). As the pool of unallocated IPv4 addresses dwindles, all stakeholders should anticipate the impacts of the transition period and plan accordingly to gather momentum for the deployment of IPv6 to decrease the pressure on IPv4. In particular, to create a policy environment conducive to the timely deployment of IPv6, governments should consider: *i)* Working with the private sector and other stakeholders to increase education and awareness and reduce bottlenecks; *ii)* Demonstrating government commitment to adoption of IPv6; and *iii)* Pursuing international co-operation and monitoring IPv6 deployment.

INTRODUCTION

The goal of the report is to present to policy makers various data sets being used to monitor IPv6 deployment. The Internet's distributed nature makes measuring IPv6 challenging because many stakeholders and components are involved. No single measurement can indicate the overall level of IPv6 deployment on the Internet, or in private networks, nor how much IPv6 is actually being used. Instead, various indicators are presented in this report, each of which offers information on a specific aspect of IPv6 deployment and from a particular vantage point. A goal of the report is to indicate the relevancy, reliability and representativeness of various indicators.

Most indicators in this document are generated by entities that administer core Internet infrastructure or by network surveys. [4] Many of these data are made available publicly and an examination over time, by country and compared to IPv4, can provide useful indications of IPv6 deployment. It should be noted that sources of relevant data may evolve as new types of actors deploy IPv6. Actors who are not yet able to provide data on IPv6 *usage* from their vantage point include providers of end-user operating systems, industry associations, content distribution networks and large wired and wireless Internet service providers.

The Internet will face significant pressure in the coming years as the unallocated pool of IPv4 addresses depletes. An IPv6-only network is the end-point of a potentially long transition phase where, on most of the Internet, both IPv4 and IPv6 will co-exist in "dual-stack" operation. Some green-field IPv6-only deployments will also take place for new usage models such as mobile Internet or sensor networks deployments. The Internet is only in the early stages of this dual-stack transition whereby end hosts, networks, services, and middleware are shifting from IPv4-only to support both IPv4 and IPv6.[5]

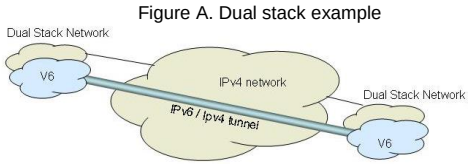
Box 1. Phases of the transition to IPv6

For technical reasons, IPv6 is not directly backwards compatible with IPv4 and consequently, the technical transition from IPv4 to IPv6 is complex. If a device can implement *both* IPv4 and IPv6 network layer stacks, the "dual-stack" transition mechanism enables the co-existence of IPv4 and IPv6. For *isolated* IPv6 devices to communicate with one another, IPv6 over IPv4 'tunneling' mechanisms can be set up. Finally, for *IPv6-only* devices to communicate with IPv4-only devices, an intermediate device must "translate" between IPv4 and IPv6. All three mechanisms – dual-stack, 'tunneling' and 'translation' – require access to some quantity of IPv4 addresses. Bearing in mind that during the entire transition the Internet will continue to grow, experts envisage the transition to occur across three general phases:

Phase 1: In the early phases of IPv6 deployment, since about 2000, there are isolated 'islands' of IPv6 hosts and network deployments, that interconnect using 'tunneling' techniques over a common IPv4 layer.

Phase 2: In the medium term, operating dual IPv4 and IPv6 protocol stacks (dual stack) is required in most cases to underpin the Internet's evolution to IPv6. The use of 'tunneling' techniques should decline.

Figure A. Dual stack example



Phase 3: In the final phase of the transition, IPv4 is expected to be shut down for all but a small number of legacy IPv4-only edge networks that remain where general Internet connectivity is not required.

IPv6 represents a very small proportion of the Internet. However, the relative use of IPv6 in today's Internet as compared to IPv4 is increasing, so that while the IPv4 Internet continues to grow, IPv6 use seems to be growing slightly faster. On balance, it is not yet clear *when* IPv6 will be widely adopted by access and content provider networks nor generally *how* the transition will be supported in the Internet's component networks. There is widespread expectation that the transition to IPv6 is inevitable. However, Internet service providers have different broad strategies to meet future service delivery requirements: *i)* even denser deployment of IPv4 Network Address Translation (NAT), whereby more devices are connected with fewer public IPv4 addresses by using private networks; *ii)* using network middleware IPv4

/ IPv6 protocol translators, and/or; *iii)* likely deploying IPv6 in the medium term to extend IPv6 connectivity services to all end points in the entire Internet.

Several large operators and content providers such as Comcast or Google are deploying IPv6 alongside IPv4. It should be highlighted that beyond providing IPv6 public Internet access or content, service providers, corporations, public agencies and end-users are leveraging IPv6 for advanced and innovative activities on *private networks*. For example, IPv6 is used for network management services to simplify and better control appliances across large and heterogeneous infrastructures with coexistent IPv4 and IPv6 networks. IPv6 is also used in 6LowPAN clouds of smart objects connected with the Internet Protocol within intranets. These advanced and innovative activities use IPv6 as a business stimulator/enabler, rather than just a way to scale existing Internet services. But while promising, services offered and used on private networks are very difficult to quantify and are not included in this report.

This report considers data in three main areas: *i)* indicators of infrastructure readiness, to determine the portion of the Internet that would support IPv6, should it be turned on[6]; *ii)* indicators of actual use of IPv6 on the Internet and; *iii)* Operator survey information.

i) Indicators of infrastructure readiness, January 2010

Experts deem that much of the IPv6 technology set is operationally ready. There is clear evidence that IPv6 hosts and service delivery platforms are being deployed. There is also evidence that a visible proportion of the organisations that manage the infrastructure of the Internet are undertaking various forms of IPv6 deployments. IPv6 interconnectedness is increasing quickly. However, the portion of the Internet that is IPv6-capable is still small compared to the portion of the Internet that is IPv4-only. All the data that follows is dated early 2010.

- Allocations of IPv6 address space show interest in potential IPv6 deployment, since obtaining IPv6 address space is a first step in deploying IPv6.[7]

  Over 4 000 IPv6 prefixes (address blocks) had been allocated/assigned. The top countries in terms of prefix allocations were the United States, Germany, Japan, United Kingdom, the Netherlands, and Australia.

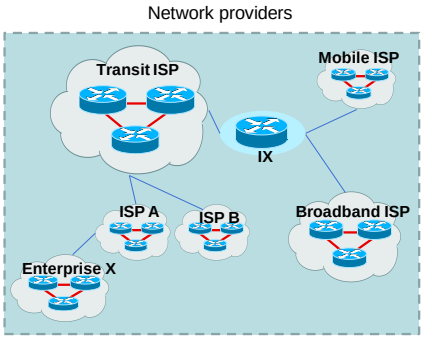
  It should be noted that the IPv6 address space is so large that the 4 000 IPv6 prefixes allocated/assigned to date represent just 0.003% of the total available IPv6 address space.[8]

- The IPv6 global routing tables show the networks ("Autonomous Systems" or "ASes") that are to some extent capable of handling IPv6 traffic. ASes peer with one another to exchange traffic.

  There were 2 500 routed IPv6 prefixes (address blocks) on the Internet, i.e. 60% of allocated IPv6 prefixes were routed.

  Importantly, over 5.5% of networks on the Internet (over 1 800 networks) were IPv6-enabled. IPv6 has had higher growth than IPv4 since mid-2007.

  Even more significantly, 20% of IPv4 transit networks, i.e. networks that provide connections through themselves to other networks, also announced IPv6 prefixes. This signals that Internet infrastructure players are actively readying for IPv6.



The top IPv6 networks were different from the IPv4 networks. The top countries by presence of IPv6 peers were Germany, the Netherlands, the United States, China, and the United Kingdom.

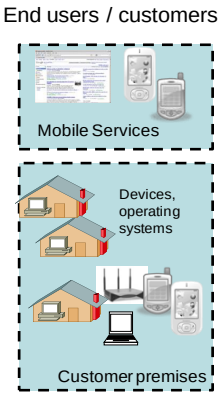
- As key infrastructure to exchange local Internet traffic, Internet eXchange Point (IXP) support of IPv6 is a pre-requisite for fast and inexpensive IPv6 connectivity. Having Internet Service Providers (ISPs) and transit providers offer IPv6 is also key to enabling IPv6 connectivity.

At least 23% of Internet eXchange Points explicitly supported IPv6.

The top countries by number of ISPs offering native IPv6 service were Germany, the United States, Japan, the United Kingdom, and France.

The top countries in terms of service offerings by native IPv6 transit providers were Germany, the Netherlands, the United Kingdom, France, and the United States.

- The penetration of operating systems that support IPv6 by default indicates the number of Internet computers/devices ("end-hosts") that could potentially run IPv6.

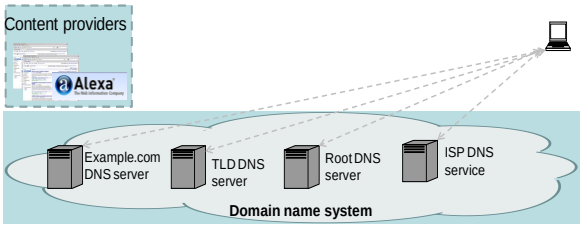


Roughly 25% of end users operated an operating system that supports IPv6 by default, in particular Windows Vista or Mac OS X. Over 90% of the installed base of operating systems is IPv6-ready, but often requires extra configuration.

The top countries by number of products approved by the IPv6 Forum's IPv6-ready logo program were Japan, the United States, Chinese Taipei, Korea, and China.

- IPv6 support in the Domain Name System (DNS) enables IPv6-enabled computers ("hosts") to reach other IPv6-enabled computers. DNS data also helps indicate IPv6 support by content providers.

7 out of 13 of the root DNS servers were accessible over IPv6. In terms of IPv6 support by Top-Level Domains (TLDs), 65% of TLDs had IPv6 records in the root zone file while 80% of TLDs had name servers with an IPv6 address.



At least 1.5 million domain names, roughly 1% of registered domain names, had IPv6 DNS records.

Some 1.45% of the top one thousand websites (ranked by Alexa) had an IPv6 website. Only 0.15% of the top one million websites (ranked by Alexa) had an IPv6 website, of which the content was mostly identical to the IPv4 content.

ii) Indicators of actual use of IPv6 on the Internet, June-November 2009

However, indicators of actual use of IPv6 on the Internet today, in terms of service access, show that IPv6 adoption on the Internet remains very low, although it is growing. Data considered include end-user IPv6 connectivity and observed IPv6 traffic levels in the second part of 2009.

- End-user systems that chose IPv6 when given the choice (dual-stack) and end-user systems that have IPv6 connectivity are two very important indicators of IPv6 uptake by users. They are particularly important for content providers.[9]

  A one year experiment by Google estimated that about 0.25% of users were IPv6 capable by September 2009, of which almost half were using MacOS operating systems and almost half Windows Vista.

  On other, technically-oriented websites, about 0.9% of end-users connected via IPv6 when possible in June 2009.

  Google's experiment finds that the top countries by percentage of native IPv6 capable users in September 2009 were France (1%), China (0.4%), Sweden (0.1%), the Netherlands, the United States, and Japan (under 0.1%) in September 2009.[10]

  Google's experiment also finds that the networks originating most IPv6 traffic are universities or research institutions, with the notable exception of free.fr in France.

  Finally, Google found native IPv6 latency to be comparable to that of IPv4 while latency of IPv6 relay mechanisms was higher than that of IPv4. It should be noted that other research finds IPv6 latency to be much higher than that of IPv4 at this stage.

- The percentage of traffic that uses IPv6 on the Internet is a general indication of uptake of IPv6, although numerous caveats must be stressed.

  At free.fr, a French IPv6-enabled ISP, IPv6 traffic per opt-in customer represented on average some 3% of each customer's global traffic in October 2009 (400 000, or 10% of subscribers, opted in).

  At one of the largest IXPs, AM-IX, 0.3% of the total traffic exchanged was IPv6.

iii) Survey data, June and September 2009

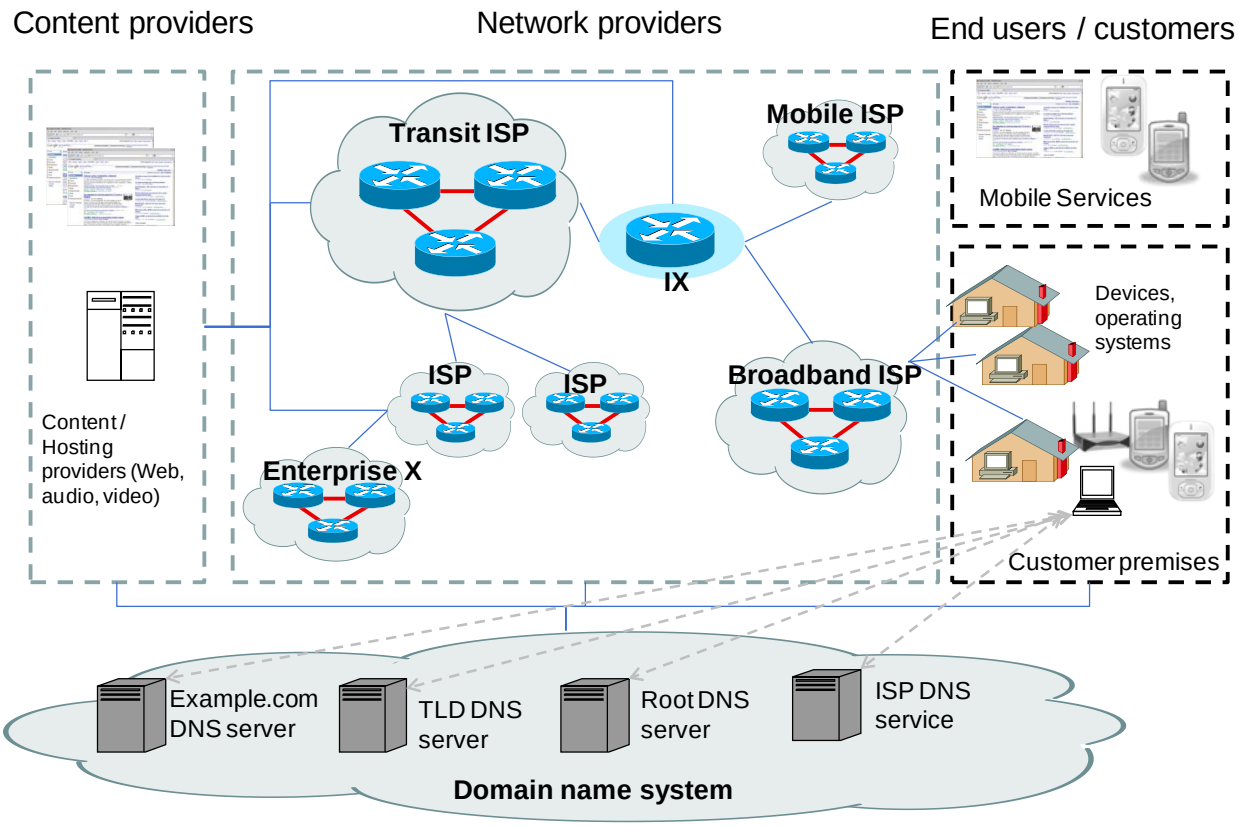
Operator surveys in the RIPE and APNIC service areas were launched by GNKS/TNO on behalf of the European Commission in 2009.[11] They provide some insight on network operators' planned IPv6 deployments and perceived barriers. In particular, levels of deployment seem similar in the Asia-Pacific region and Europe, the Middle East and parts of Central Asia. Lack of vendor support remains a barrier to IPv6 deployment as does the lack of business models.

The European and Asia-Pacific regions had similar levels of IPv6 deployment although there seemed to be more entities with no plan to deploy in the RIPE region than in the APNIC region.

The European and Asia-Pacific regions both found IPv6 traffic to be mostly insignificant (for approximately 80% of respondents). However, 7% of APNIC respondents claimed to have equal or more IPv6 traffic than IPv4 traffic, compared with 2% of RIPE respondents.

Those respondents that were not implementing IPv6 saw cost as a major barrier (over 60%), while for those that were implementing IPv6 it was less of a barrier (about 40%). The primary obstacle for those implementing IPv6 was the lack of vendor support.

Figure 1. Stylised view of the Internet



SUMMARY OF INDICATORS CONSIDERED

	Type of data	Why is it important?	Indicator(s) considered and selected data points
INFRASTRUCTURE READINESS	**RIR allocations/ assignments of IPv6 address space**	RIR allocations/assignments of IPv6 addresses show interest in potential IPv6 deployment, since obtaining IPv6 address space is a first step in deploying IPv6.	- Number of IPv6 prefixes (address blocks) which have been allocated/assigned by the RIRs - Size of IPv6 prefixes allocated/assigned
	IPv6 global routing tables	The IPv6 global routing tables show the networks ("Autonomous Systems" or "ASes") that are to some extent capable of handling IPv6 traffic. ASes peer with one another to exchange traffic.	- Number of routed IPv6 prefixes - Number of IPv6-enabled networks - Top IPv6 networks by interconnectedness (adjacencies)
	IPv6 support by IXPs, ISPs and transit providers	As key infrastructure to exchange local Internet traffic, Internet eXchange Point (IXP) support of IPv6 is a pre-requisite for fast and inexpensive IPv6 connectivity. IPv6 service offering by Internet Service Providers (ISPs) and transit providers is also key.	- Percentage of Internet eXchange Points that support IPv6 - Top countries by number of ISPs offering native IPv6 service - Top countries by number of native IPv6 transit providers
	End-host readiness for IPv6	The penetration of operating systems that support IPv6 by default indicates the number of Internet computers/devices ("end-hosts") that could potentially run IPv6.	- IPv6-capable Operating Systems (OSs) and market penetration. - Top countries by number of products approved by the IPv6 Forum's IPv6-ready logo program.
	IPv6 support in the Domain Name System (DNS)	IPv6 support in the domain name system enables IPv6-enabled computers ("hosts") to reach other IPv6-enabled computers. DNS data also helps indicate IPv6 support by content providers.	- Number of root servers accessible over IPv6 - Top-level domain (TLDs) support of IPv6 - Registered domains returning IPv6 records - Relative latency of IPv6 DNS resolution versus IPv4 - Percentage of the top one million websites (ranked by Alexa) with an IPv6 website
END-USER IPv6 ACTIVITY	**End-user IPv6 connectivity**	End-user systems that chose IPv6 when given the choice (dual-stack) and end-user systems that have IPv6 connectivity are two very important indicators of IPv6 uptake by users. They are particularly important for content providers.[12]	- Percentage of end-user systems in a given population that chose IPv6 if given a choice of dual stack service point.[13]
	Traffic levels	The percentage of traffic that uses IPv6 on the Internet is a general indication of uptake of IPv6, although numerous caveats must be stressed.	- Percentage of IPv6 traffic at an IPv6-enabled ISP - Percentage of IPv6 traffic at an Internet eXchange Point
OPERATOR SURVEYS	**Operator surveys in the RIPE and APNIC service areas**	Such a survey provides information on planned deployments and perceived barriers.	- Surveys of network operators in the RIPE and APNIC service area launched by GNKS/TNO on behalf of the European Commission[14]

1) INFRASTRUCTURE READINESS

IPv6 address allocations/assignments by RIRs

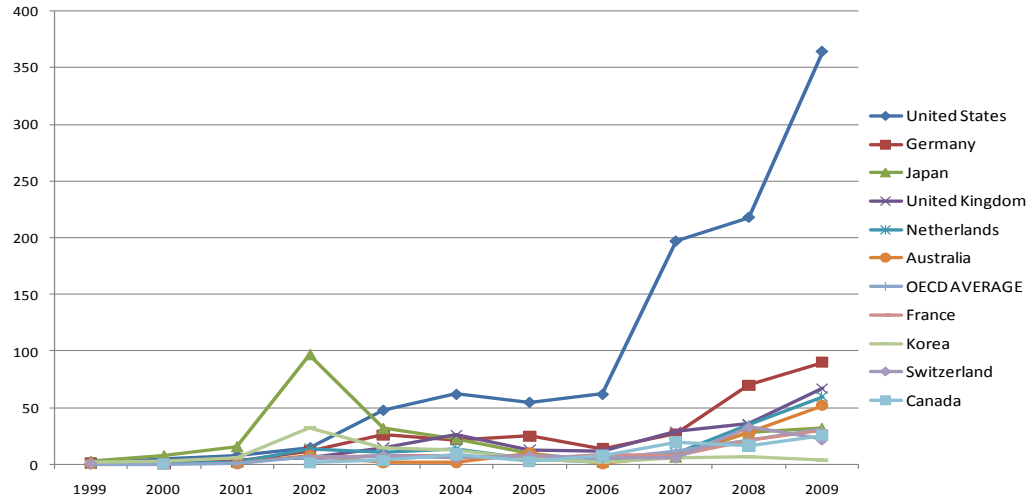
Number of IPv6 prefixes allocated/assigned by the RIRs

Obtaining an IPv6 assignment/allocation from a Regional Internet Registry (RIR) is the first step for an entity interested in deployment of IPv6. Entities can and are going through the RIR processes to obtain IPv6 allocations. The number of allocated prefixes provides an indication of the number of organisations interested in implementing the IPv6 protocol.

Several caveats warrant stressing in using RIR assignment data. First, allocation of prefixes does not indicate actual use of these prefixes. Second, allocations do not show sub-allocations from Local Internet Registries (LIRs) to other entities. [15]

By early 2010, the RIRs had made a cumulated total of over 4 100 allocations. OECD countries accounted for 75% of the IPv6 allocations. The United States was leading, accounting for over 25% of allocated IPv6 prefixes. Next were Germany (7.1%), Japan (6.3%), the United Kingdom (5.1%), the Netherlands (3.8%), and Australia (2.7%).

Figure 2. Numbers of IPv6 allocations per year, top 8 OECD countries, 1999-2009

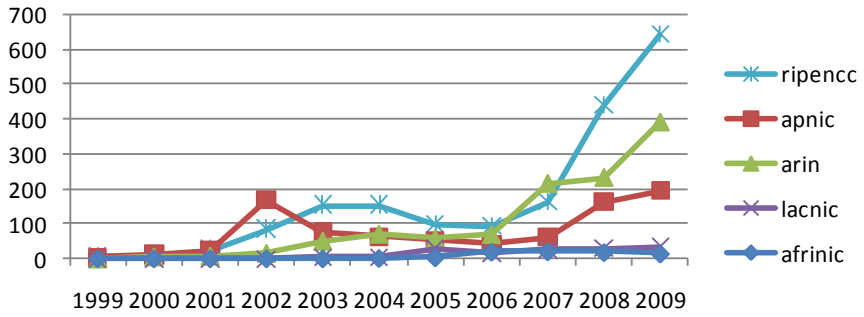


Source: OECD based on RIR assignment data, 1 January 2010.

While Japan had an early lead in IPv6 deployment after its 2001 national strategy for the adoption of IPv6 (e-Japan), other countries have been catching up (Figure 2). In particular, there was a surge in the number of IPv6 allocations in the United States starting in 2007. In 2007, 200 IPv6 prefixes were registered in the United States, followed by 220 in 2008 and over 360 in 2009. This surge, at least at the beginning, was likely linked in part to the mandate of the United States' Office of Management Budget (OMB) for all agencies' infrastructure (network backbones) to be using IPv6 and agency networks to be interfacing with this infrastructure by June 2008. Several other countries have also taken a lead in deploying IPv6 networks and the number of allocations in other countries also increased in 2008. For example, the Australian Government Information Management Office has a revised Strategy for the

Transition to IPv6 which will see Australian Government agencies being IPv6 capable by the end of 2012. Similar initiatives and numerous awareness campaigns exist in other countries.[16]

Figure 3. Number of prefix allocations by region, 1999-2009

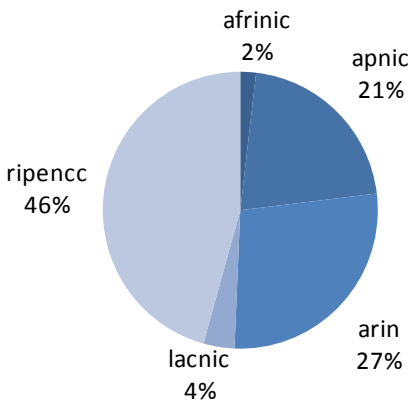


Source: OECD based on RIR assignment data, 1 January 2010.

By number of allocations of address blocks, the RIPE region is clearly leading, and shows extremely large growth in 2008 and 2009 (Figures 3 and 4). In 2009, the RIPE NCC received about 500 requests from carriers for blocks of IPv6 address space, compared to 440 in 2008 and 164 in 2007. Likewise, ARIN allocations are increasing at a very fast rate, and surpassed APNIC in 2006. APNIC has many allocations, but has been growing at a slower pace. LACNIC and AfriNIC have comparatively fewer allocations, with LACNIC growing slightly faster than AfriNIC. Cumulatively, there have been over 4 000 address block allocations and it appears that growth in allocations of IPv6 addresses increased significantly as of 2007.

It should be noted that regional policies have an impact on prefix allocations. In particular, policies relating to provider-independent address allocations by RIRs to end entities vary across regions. Provider-independent address allocations (which are /48 in size) enable end-users to change service providers without renumbering their networks and to use multiple access providers in multi-homed configurations.[17] In total, about 15% of RIR allocations (617 out of 4 000) were provider-independent address allocations to end entities by early 2010 (*i.e.* of a /48 in size). For example, of the 1 037 allocations of IPv6 addresses recorded as being made to country code US, 331 are /48 in size, which may skew somewhat the results for the ARIN region. In addition, the top position of the RIPE region may be due at least in part to the number of countries that are served by RIPE NCC and each country having several ISPs. Policy changes are believed to be responsible for the growth in allocations at RIPE NCC and APNIC in 2002 (mid 2002, RIPE NCC, APNIC and ARIN instituted policy changes regarding IPv6 allocation).

Figure 4. Distribution of IPv6 Allocations by number of allocations, year-end 2009



Source: OECD based on RIR assignment data, 1 January 2010.

Size of IPv6 allocations allocated/assigned by RIRs

The size of IPv6 allocations could in some cases help indicate the scale of planned deployments. By this measure, the Latin American and Caribbean region services by LACNIC would appear to be close to large-scale deployment of IPv6 (Figure 5). However, it is difficult to use at an aggregate level because extremely large allocations were made to some operators, national Internet registries and large users. In addition, the same caveats as for the number of IPv6 allocations apply (addresses are not necessarily used and sub-allocations from NIRs and LIRs are not detailed).

Extremely large allocations were made to National Internet Registries (NIR), for example by LACNIC to the Brazilian NIR in 2008, for further assignment to Local Internet Registries (LIRs), including ISPs (Figure 6). In addition, many large IPv6 prefix assignments were to telecommunication operators. For example, Deutsche Telekom and France Telecom were each allocated a /19 prefix in 2005. To illustrate the size of some of these prefixes, the allocation in 2006 of a /20 to Telecom Italia represented 268 435 456 (2^{28}) customers, under the assumption of each customer receiving a /48 and each customer having up to 2^{16} (65 536) local area networks.[18]

The policy basis under which some of these allocations were made – on the basis of providing sufficient IPv6 addresses to convert existing IPv4 infrastructure to dual stack operation without incremental cost to requesters and without any obligation to demonstrate IPv6 deployed infrastructure – means that requesting and being granted allocations of IPv6 addresses does not necessarily mean actively planning to deploy IPv6 as a customer service.

Figure 5. Size of RIR IPv6 allocations to date

Measured in /32s, year-end 2010

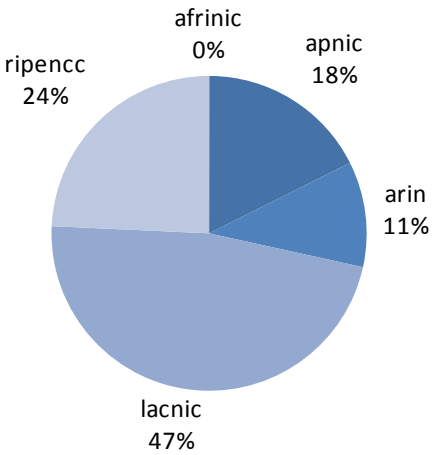
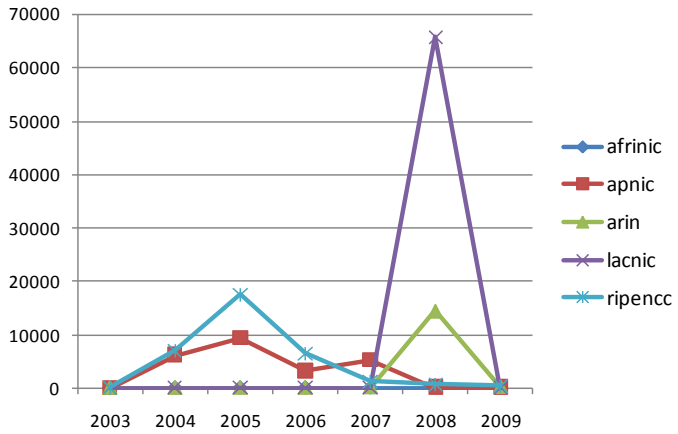


Figure 6. Evolution of RIR IPv6 allocations by size

Measured in /32s, year-end 2010



Source: OECD based on RIR assignment data, 1 January 2010.

IPv6 global routing tables[19]

Once an organisation has been allocated/assigned addresses, for these addresses to be "visible" on the Internet routes to the address blocks (prefixes) used must be published in the routing tables. Therefore, the data in the global routing table provides a better indication of possible use of IPv6, compared to allocated/assigned IPv6 address space.

The routing table reflects the addressable IP networks (called autonomous systems) that can be reached through IPv6, which AS-numbers are being used, which prefixes are being routed and other relevant information. The routers connecting ISPs and businesses connected to multiple ISPs determine how to forward packets based on the contents of the IPv6 routing table.[20] Border Gateway Protocol (BGP) routing tables provide snapshots of Internet topology over time.

Box 2. General caveats associated with data from the global routing tables

- While the routing table may provide a good track of the deployment of "native" IPv6 addresses, it does not take into account the use of "special" types of IPv6 addresses for different transition mechanisms, as in the case of 6to4 and Teredo, where the IPv6 address is synthesised from an IPv4 address.
- As with IPv4, allocated IPv6 address space is not necessarily advertised in the routing system.
- Some public IPv6 addresses may be used in private networks and therefore are not visible in public routing tables.
- The routing tables indicate capability of supporting IPv6 in routing, rather than actual use of IPv6 in services or traffic.
- The RIRs record the country of the entity to which the address was assigned / allocated, and this may be different to the recorded country of the assigned AS number which originates the IPv6 address, and may also be different to the country in which the Internet service is being provided.

Routed IPv6 prefixes

Routed prefixes, which represent part of the prefixes allocated, provide a better indication than allocated prefixes of how many and where addresses are being used.

Analysis of the Internet's global routing table conducted by the NRO shows the number of IPv6 prefixes "announced", *i.e.* routed on the public Internet, over time. Figure 7 shows the number of entries in the global IPv6 routing table from January 2004 through 2009: 2 500 separate IPv6 routes were being advertised by early January 2010, *i.e.* 60% of the total number of prefixes allocated were being advertised.

Figure 7. Routed IPv6 prefixes, total, 2004-2009

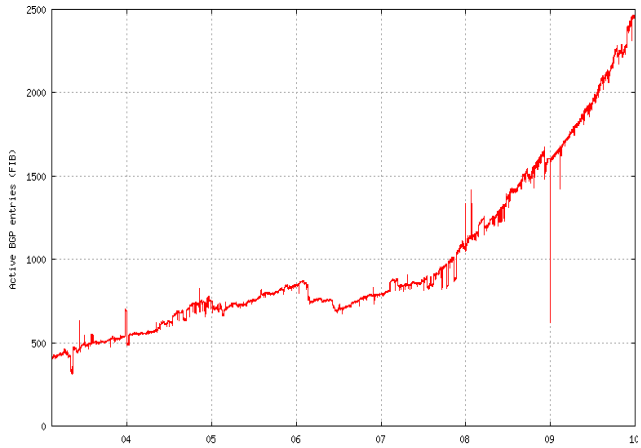


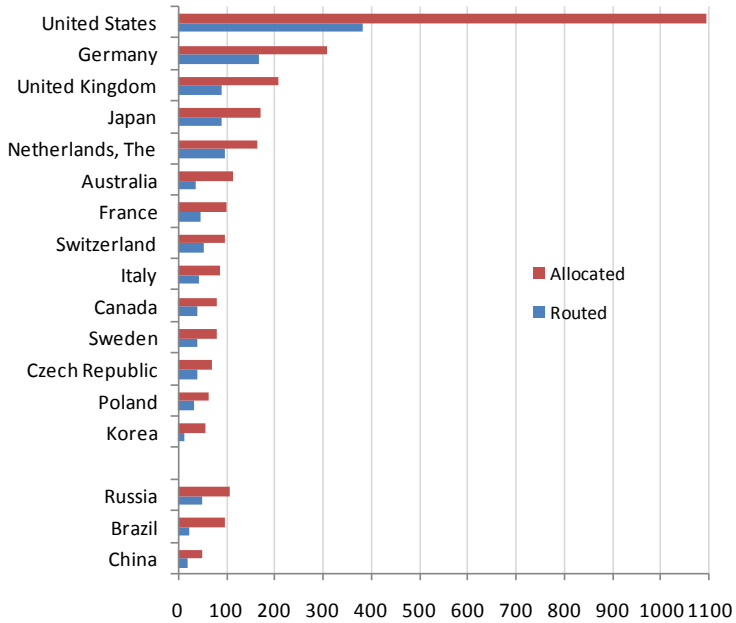
Figure 8. Routed IPv6/IPv4 prefixes, 2004-2009

Source: ITAC/NRO Contribution to the OECD, Geoff Huston and George Michaelson, data from end of year 2009.[21]

These 2 500 advertised IPv6 prefixes compare to some 313 000 advertised IPv4 prefixes early January 2010: some 0.8% of prefixes announced in the Internet routing system are IPv6 prefixes (Figure 8). Figure 8 also shows that the IPv6 network has been growing at a faster rate, in terms of number of routing entries, than IPv4 since mid-2007.

Several strong caveats are in order. Most importantly, experts deem that it is not meaningful to compare the number of IPv6 and IPv4 routes because of the fragmentation of the IPv4 address space: for various reasons, some networks ("Autonomous Systems" or "ASes") advertise several IPv4 routes (known as "fragmentation") and, for the time being, significantly fewer IPv6 routes on a per network basis. Indeed, the average number of IPv4 routing table entries per origin AS is almost 10 compared to 1.3 IPv6 entries per origin AS. In addition, the IPv6 routing tables are very small compared to IPv4, IPv6 'provider-independent' prefixes have not been deployed significantly, and small events or mistakes can trigger large variations in the numbers of prefixes announced.

Figure 9. Number of IPv6 prefixes advertised per country (January 2010)



Source: SixXS, beginning of year 2010.

The number of IPv6 prefixes advertised per country (Figure 9) follows the same pattern as the number of allocated prefixes.

IPv6-enabled networks

As mentioned in the previous section, the routing table also reflects the addressable IP networks, called "autonomous systems" (AS), that can be reached on the Internet, and which autonomous system numbers are being used. Each AS is under a single administrative authority. Usually, an Internet Service Provider (ISP) or a corporate network is counted as one "routing entity".

In this case, it is not the number of entries in the BGP routing table, but the number of individual networks (unique AS numbers) routing IPv6 that indicates how many entities participate in the global IPv6 Internet. The number of IPv6-enabled ASes provides an indication of how many of the distinct entities that compose the Internet are to some extent IPv6 capable.

Caveats that warrant signalling include that while ASes have their origin in a given country, these networks may be offering actual service anywhere in the world. In addition, if an AS originates an IPv6 routing advertisement, this does not mean that its entire network is IPv6-capable, and that all of its end hosts and customers are IPv6-capable, *i.e.* it is a maximum value.

The evolution of the number of AS numbers in the IPv6 routing table since 2004 (Figure 10) shows a more even picture of IPv6 deployment than does the number of advertised IPv6 prefixes (Figure 7 in the previous section). IPv6-enabled networks have more than quadrupled in growth from 2004 through 2009, growing from 400 to over 1 841 over 5 years. In addition, acceleration in growth from mid-2007 is clearly discernable.

Figure 10. IPv6 uniques ASes, 2003-2009

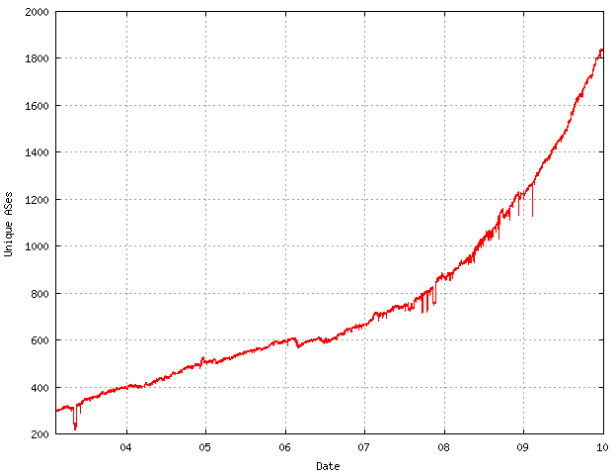
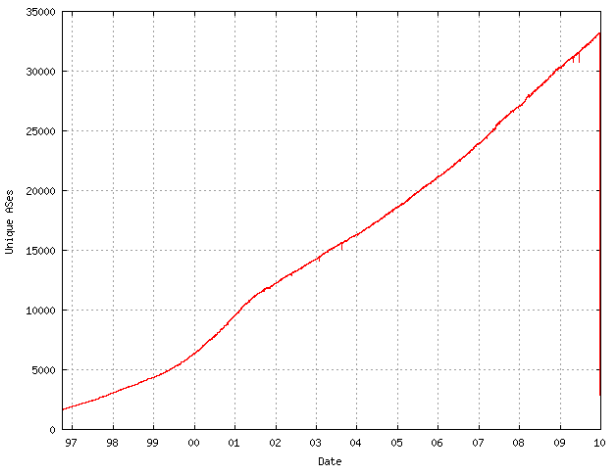


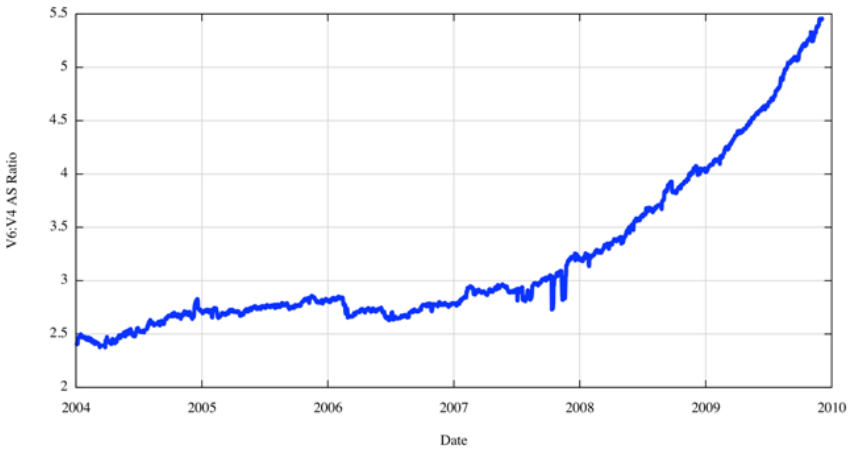
Figure 11. IPv4 uniques ASes, 1997-2009



Source: ITAC/NRO Contribution to the OECD, Geoff Huston and George Michaelson, data from end of year 2009.[22]

IPv6 data can be compared to the number of unique ASes that were visible in the IPv4 routing table over the same period (Figure 11 shows a comparable plot for the number of ASes in the IPv4 network).

Figure 12. IPv6 / IPv4 Relative AS Count Ratio, 2004-2009



Source: ITAC/NRO Contribution to the OECD, Geoff Huston and George Michaelson, data from end of year 2009.

The relative metric of IPv6 as compared to both IPv4 and IPv6 was 5.5% by January 2010, and the number of AS entities actively routing IPv6 has been growing at a faster rate than the IPv4 network and clearly so since 2007 (Figure 12). This would mean that some 5.5% of the Internet was IPv6 capable to some extent by early January 2010, which shows a more advanced level of IPv6 deployment than does the comparison of global routing table entries.

Figure 13. Yearly growth rate of IPv4 and IPv6 ASes (networks), year-end 2009

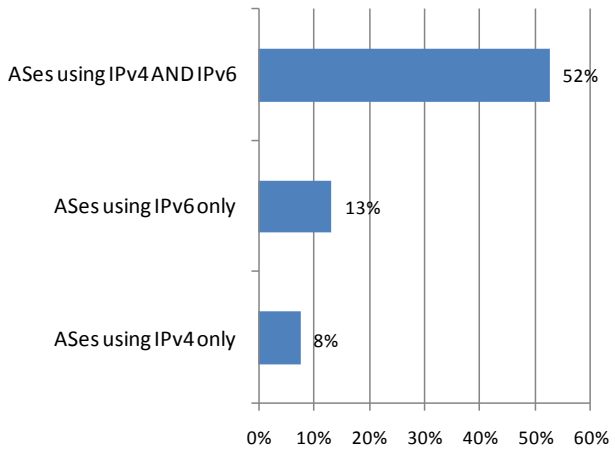
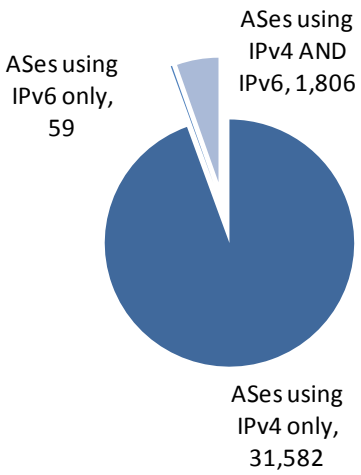


Figure 14. Total number of IPv4 and IPv6 ASes (networks), year-end 2009



Source: Hurricane Electric, 1 January 2010.

Note: yearly CAGR based on period from 24 February 2009 through 5 November 2009.

Huricane Electric measures the percentage of networks running IPv6 by comparing the set of ASes in the IPv6 routing table to those in the combined set of IPv4 and IPv6.

In addition, the highest annual growth rate of networks, of over 50% in 2009, was that of new networks using both IPv4 and IPv6 (Figure 13), reaching a total of about 1 800 by year-end 2009 (Figure 14). This compares to growth of 10% for the total amount of new networks (using either IPv4 or IPv6) that reached 33 000 at the same time.

Adding the component (transit, origin, or mixed networks), 1 865 networks in total supported IPv6 by year-end 2009, *i.e.* 5.6% of the total networks that support IPv4, up from 1 200 at the beginning of 2009 and under 900 at the beginning of 2008. Although the networks supporting IPv6 are still just a small fraction of those supporting IPv4, growth was over 30% in 2008 and over 50% in 2009.

Transit and origin networks

Under most circumstances, networks can be further broken down into either predominantly edge networks that originate or receive traffic ("Origin AS") or predominantly transit networks, which carry traffic for others (transit ASes). To further clarify:

- **Transit ASes** (*e.g.* Hurricane Electric, Tata Communications, NTT/Verio, Level 3 or Cogent) provide connections through themselves to other networks. The number of IPv6 Transit ASes, compared to the combined IPv4 and IPv6 set, indicates the Internet infrastructure players that are enabling themselves for IPv6.

- **Mixed (origin and transit) ASes** (e.g. Google, Comcast, or Free.fr) are edge networks that both originate and receive traffic, and connect to several networks, i.e. they provide some degree of transit.

- **Stub/Origin-only ASes** are edge networks that are connected to only one other AS that provides them with Internet connectivity, to originate or receive traffic. They indicate networks enabled to allow services or clients to run IPv6 and can be compared to 'islands' connected to the rest of the Internet through only one 'bridge'.

Of the 33 039 ASes in IPv4 at end-year 2009, most 86 % (28 596 ASes) were 'stub/origin-only' networks, *i.e.* they were connected to only one other AS each and were not used for transit. The remaining 14% (4 443 ASes) provided some level of transit, *i.e.* provided connections through themselves to other networks (Figure 15). Of the 4 443 IPv4 transit ASes, 20% (910) also announced IPv6 prefixes – double the value of March 2009. Of the 28 596 IPv4 stub ASes, 3% (887) also announced IPv6 prefixes. In conclusion, IPv4 Internet infrastructure players are actively readying for IPv6, with 20% already exhibiting IPv6 capability, and an 80% deployment level by 2013 appears to be a reasonable projection from these numbers.[23]

Figure 15. Numbers of IPv4 transit and stub ASes in global routing table, end 2009

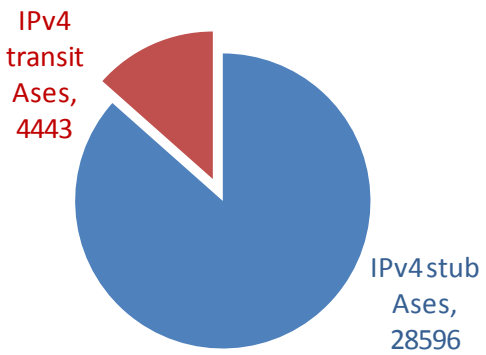
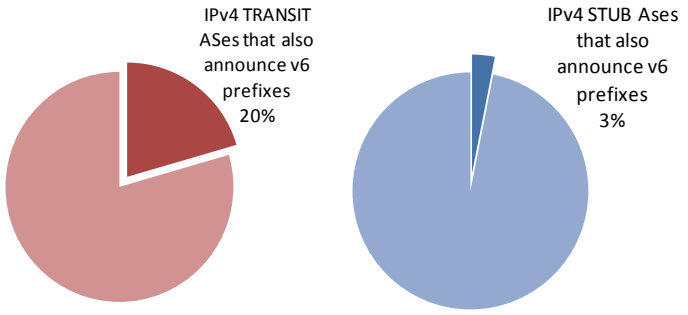


Figure 16. IPv4 transit and stub ASes that also announce IPv6 prefix(es)



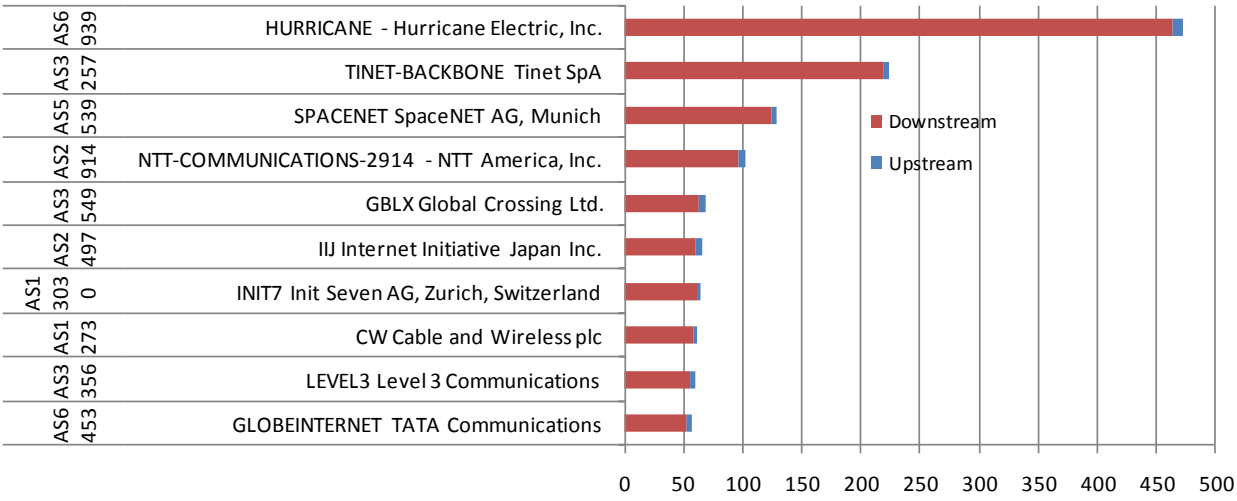
Source: CIDR Report, 1 January 2010, http://www.cidr-report.org/v6/as2.0/.

Top networks by number of adjacencies

The number of adjacent networks an AS has, both upstream and downstream, may provide an indication of the most "interconnected" (and active in terms of pursuing traffic exchange agreements) service providers in the IPv6 world. More IPv6 traffic exchange (peering and transit) agreements help lower latency for IPv6.

It should be noted that the number of adjacencies that a network has does not provide any indication on the amounts of actual IPv6 traffic that a provider carries.

Figure 17. Top 10 networks by number of adjacencies



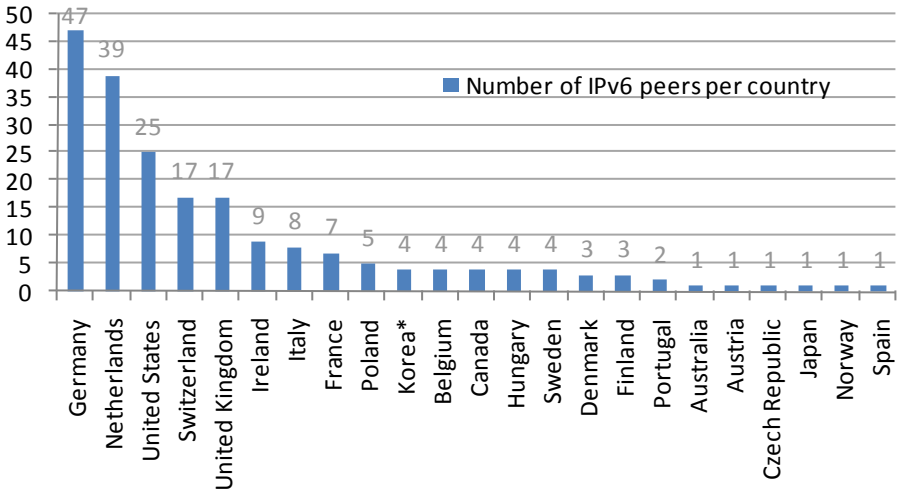
Source: http://bgp.potaroo.net/v6/as2.0/bgp-as-adj.txt, 1 January 2010.

Hurricane Electric, headquartered in the United States, was by far the leading network in terms of IPv6 adjacencies, with nearly 500 IPv6 adjacencies, followed by Tinet, formerly known as Tiscali International Network (Figure 18). The average Connectivity Degree of all IPv6 networks was 2.7 adjacent networks. Among the top 10 IPv6 networks by numbers of adjacencies, only Level 3 and Global Crossing were also in the top 10 IPv4 networks defined by number of adjacencies.

Top countries by number of IPv6 peers

Peering is the arrangement of Internet traffic exchange between networks (*e.g.* Internet service providers or ISPs). Large ISPs with their own backbone networks agree to carry traffic from other large ISPs in exchange for the carriage of their traffic on the other ISPs' backbones. They may also exchange traffic with smaller ISPs so that they can reach regional end points. Peers add value to a network by providing access to the users on their own network, plus the access allowed through the other networks with which it peers. Reasons to peer include reducing transit costs, reducing latencies, billing more traffic to customers, increasing operational stability, localising connectivity and providing roughly equal mutual benefit. Two border routers that directly exchange information are said to have a *peering* session between them, and the ASes they belong to are said to be *adjacent*.[24] Only operators who already run IPv6 can enter into IPv6 peering agreements.

Figure 18. Top OECD countries by number of IPv6 peers



* Korea Communications Commission (KCC).
Source: SixXS, 1 January 2010.

In January 2010, Germany led with the highest number of IPv6 peers (47) as monitored by SixXS, followed by the Netherlands (39), the United States (25 peers) and Switzerland and the United Kingdom (17 peers each). All other countries had fewer than 10 IPv6 peers (Figure 18).

IPv6 support by Internet eXchange Points, ISPs, and transit providers

As key infrastructure to exchange local Internet traffic, support of IPv6 by Internet eXchange Points (IXPs) is a pre-requisite for fast and inexpensive IPv6 connectivity. IXP support of IPv6 is particularly important to increase interconnectedness and decrease latency. Internet exchange points provide a common location where multiple service providers can meet and exchange customer traffic.

A growing number of exchange points is now emerging that are designed to facilitate native IPv6 peering. Research conducted by Packet Clearing House (PCH) shows that at least 23% of Internet eXchange Points (77 IXPs out of 338) supported IPv6 explicitly in January 2010, up from 17% in June 2008.[25] Several caveats warrant noting. IPv6 support by an IXP does not necessarily mean that the IXP has IPv6 peering and transit agreements and IXP-related information excludes private agreements for traffic exchange.

SixXS maintains a list of Internet access providers who can provide native IPv6 to their customers (excluding hosting providers). In January 2010, the list contained 48 consumer and business ISPs and other ISPs that provide access to an end-site (Figure 19). According to the SixXS list, Germany had the most ISPs offering commercial IPv6, followed by the United States, Japan, and the United Kingdom. However, markets vary significantly from country-to-country: the market is more or less concentrated/fragmented and it should be stressed that data on ISPs per country does not provide an indication as to the number of IPv6 end-users.

It should also be noted that the IPv6 Forum launched an 'IPv6 Enabled logo for ISPs' in June 2009. A total of 38 ISPs were validated by the IPv6 Forum by end of early 2010. According to this source, Malaysia had 9 IPv6 enabled ISPs, the Netherlands 6 while China and the United States each had at least 4 IPv6 enabled ISPs.[26]

In January 2010, SixXS also reported that the highest number of IPv6 transit provider offerings were available in Germany (15), followed by the Netherlands, the United Kingdom, France, and the United States (Figure 20). An important caveat is that the largest IPv6 transit services in the world, such as NTT (based in Japan) or Tata Communications (based in India), are international. Therefore a better approach when referring to transit providers in the future may be to compare the largest networks in terms of their points of presence.

Figure 19. Number of ISPs offering commercial native IPv6 service per country

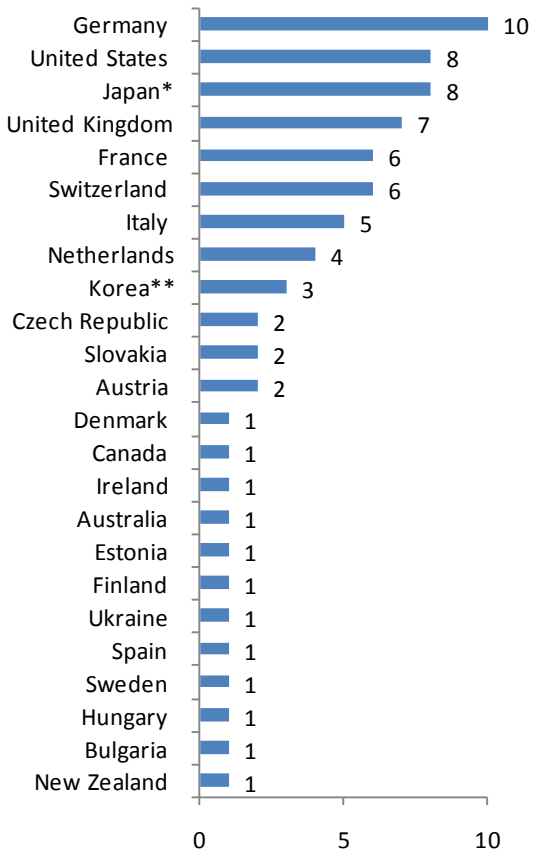
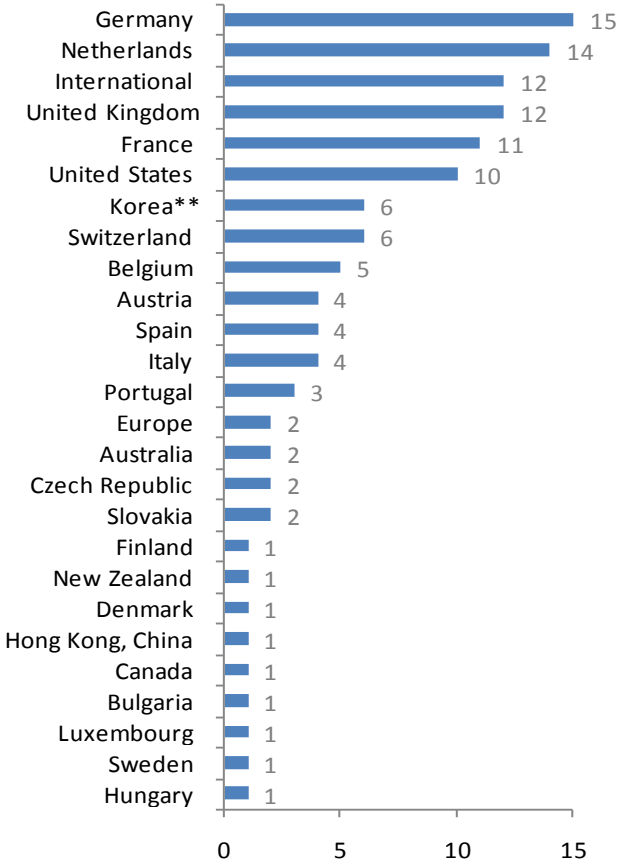


Figure 20. Providers of native IPv6 transit per country



Source: based on SixXS[27], 1 January 2010.

Note: * Number provided for Japan is an estimate. ** Number for Korea provided by Korea Communications Commission.

End-host readiness

Penetration of operating systems that enable IPv6 traffic by default

A pre-requisite to implementation of IPv6 is the availability of supporting operating systems, *i.e.* Windows Server 2008, Windows Vista, MacOS X, Linux, or UNIX, on top of which application and services can then be built. Many experts view widespread adoption of operating systems which support IPv6 by default as a determining factor with the potential to trigger the deployment of IPv6 in earnest. Operating systems that support IPv6 indicate the number of potential IPv6 clients. Data on penetration of top operating systems (Figures 21 and 22) can be compared with these operating systems' support for native IPv6 and for various transitional schemes (which is tracked by some software approval schemes).

It should be noted that IPv6 support by end user device operating systems is not necessarily sufficient for these clients to be able to actually use IPv6. For example, unless an IPv6 client supports IPv6 functionalities such as DHCPv6, Neighbour Discovery and Stateless Address Autoconfiguration, it may not be able to join a new IPv6 network, even if it can send and receive IPv6 packets. MacOSX for instance has no DHCPv6 client.

Figure 21. Top Operating System Share Trend, December 2008 through December 2009

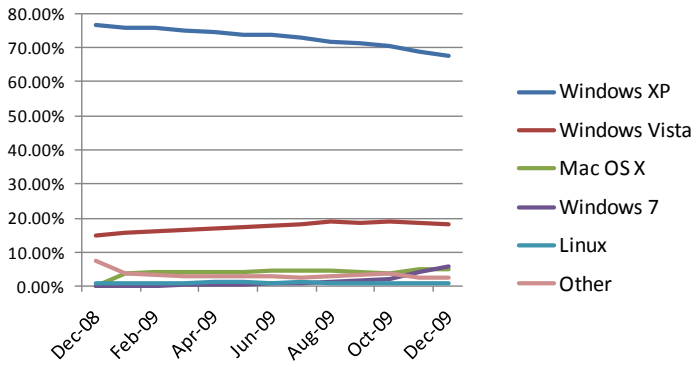
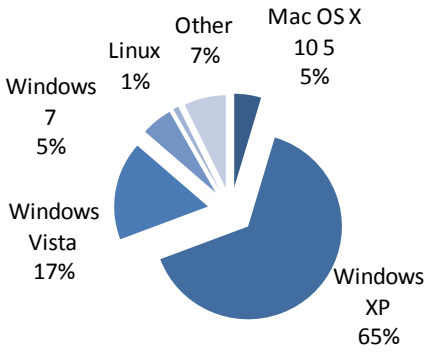


Figure 22. Operating System market share, January 2010



Source: Hitwise Operating System Market Share and list of products that are approved as 'IPv6 ready', January 2010.[28]

Note: The overall trends in operating system data as measured by Hitwise are confirmed by other sources such as W3 Schools.

Over 90% of the installed base of operating systems is IPv6 ready, but often requires extra configuration. It can be estimated that roughly 25% of operating systems would work with IPv6 by default, *i.e.* without needing any extra configuration, if IPv6 is present on the network (Table 1). This default support by Windows Vista, Windows 7 and Macintosh OS X is particularly important as these three operating systems represent respectively 18%, 6% and 5% worldwide. They work with IPv6 by default if IPv6 is present on the local area network (LAN).

Table 1. Operating systems that support IPv6 by default

	January 2010	IPv6 traffic enabled by default	IPv6 support
Windows XP	67.81%	No	Extra configuration line
Windows Vista	17.87%	☑	
Windows 7	5.68%	☑	
Mac OS X	5.11%	☑	
Linux	1.01%	☑	In most configurations[29]
Windows 2000	0.62%	No	
Java ME	0.53%	No	Some APIs enable to specify IPv6 functionality
iPhone	0.43%	No	
Symbian	0.23%	☑	
Windows NT	0.10%	No	
Windows 98	0.09%	No	
iPod	0.09%	No	
X11	0.07%	No	
Windows CE	0.05%	No	Yes, CE 4.2 and Windows Mobile, Windows CE version 7, dependent on product/vendor
Windows ME	0.05%	No	Add-on IPv6 implementation
Unknown	0.05%	No	
BlackBerry	0.03%	No	
PLAYSTATION 3	0.03%	No	
Android 1.6	0.02%	☑, in progress	
FreeBSD	0.01%	No	
		Approximately 25%	

Source: Hitwise, January 2010 and IPv6 Ready Program.

In terms of mobile operating systems, Windows Mobile and Symbian that is used in Nokia phones already support IPv6 and Google is working on IPv6 support in Android. The recently debuted Nexus One from Google has IPv6 enabled by default which, coupled with the IPv6 enabled suite of services, provides an interesting new avenue for end-to-end IPv6. The iPhone and Blackberry do not currently support IPv6.[30]

Box 3. IPv6 support by mobile operators in LTE and WiMAX

Mobile operators have been experiencing very high growth in wireless data usage. Customers' demand for more, faster connectivity is pressuring mobile operators to accelerate the deployment of next generation cellular technologies ('4G' technologies). 'Long Term Evolution' (LTE) and 'Worldwide Interoperability for Microwave Access' (WiMAX) are the most promising 4G technologies. LTE will provide significantly more bandwidth than current 3G systems. In addition to speed, a major difference between LTE and 3G networks is that voice becomes an IP (Internet Protocol) service. In other words, LTE eliminates the distinction between the "phone part" of a smartphone (voice calls, SMS, voicemail), and the "Internet part" (email, web, games, etc). Handsets will become voice over IP (VoIP) devices and will need an IP address all the time, even just to receive voice calls.[31] Meanwhile, WiMAX will provide wireless data transmission using a variety of transmission modes. The bandwidth and range of WiMAX make it suitable for providing data, telecommunications and IPTV services.

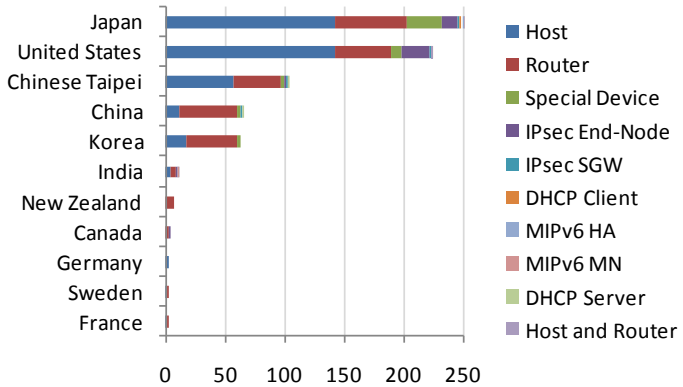
IPv6 is optional in 3G but likely to be mandatory in LTE and WiMAX deployments. According to 3G Americas, growth in the wireless industry has created a requirement for always-available IP addresses that necessitates IPv6. The association advises operators to consider making IPv6 a requirement for LTE deployments from the beginning.[32] As of June 2009, Verizon had posted specifications that require any device on its LTE network to support IPv6.[33] By end of 2009, 130 mobile operators all over the world had indicated a commitment to LTE development.[34] In addition, the WiMAX Forum formed an IPv6 sub-group in 2006 to develop and promote IPv6-based WiMAX technology.[35] Major players such as Bellsouth, Sprint o Korea Telecom are engaged in developing an IPv6-interoperable WiMAX network.

IPv6 product support

The IPv6 Ready (http://www.ipv6ready.org/) Logo Program run by the IPv6 Forum provides conformance and interoperability test specifications based on open standards to support IPv6 deployment across the globe. The IPv6 Ready Program identifies at least 380 hosts and 253 routers that support IPv6 in November 2009.[36] Most products having entered the IPv6 Ready logo approval scheme are manufactured by Japanese, American, Chinese or Korean firms (Figure 23).

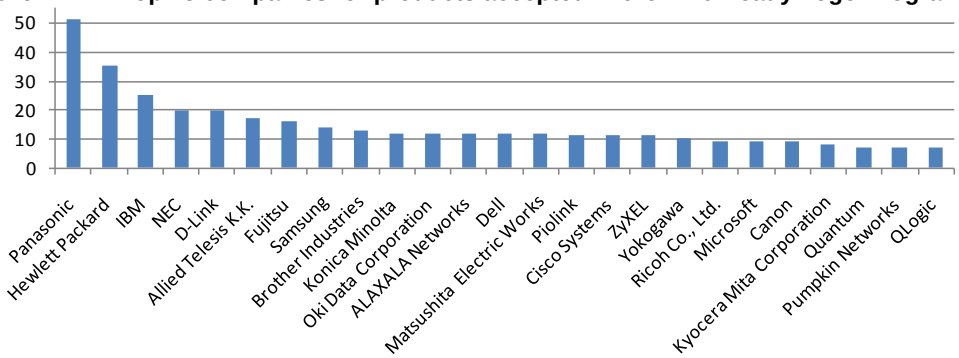
In general, several caveats are in order. First of all, the IPv6-ready logo programme covers few products compared to the quantity available on the market. In general, software certifications are only indicative of a minimum amount of applications which support IPv6 (applications from those companies that undertake to apply for certification). In addition, a large majority of applications do not use or interact with the transport layer underneath and therefore the use of IPv4 or IPv6 is not relevant to them/is transparent to them.

Figure 23. Products approved by the IPv6 Ready Logo Program, by country, year-end 2009



Source: IPv6 Ready (Phases 1 and 2), 1 January 2010.

Figure 24. Top 25 companies for products accepted in the IPv6 Ready Logo Program (Phases 1 and 2)



Source: IPv6 Ready, 1 January 2010.

Equipment manufacturers Panasonic, HP, IBM, NEC and D-Link had the most products having been approved by the IPv6 Ready logo scheme (Figure 24).

IPv6 support in the Domain Name System (DNS)

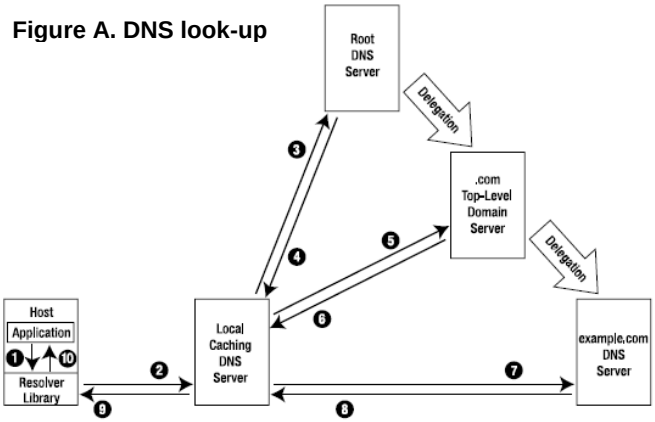
Domain Name System (DNS) support at various levels indicates that DNS operators have set up capability to receive requests for IPv6 records, that they can potentially receive IPv6 traffic and that they can potentially provide services, such as web or file servers, over IPv6 transport. The inclusion of IPv6 support at various levels of the Domain Name System (DNS) is critical to IPv6 adoption because it allows IPv6-enabled hosts to reach other IPv6 hosts and influences performance. For example, an IPv4 website that wants to deploy IPv6 will first obtain IPv6 connectivity and must then add an IPv6 record (known as "Quad A" or "AAAA") in the DNS for its domain name to be resolved to an IPv6 address.

It is important to distinguish between the configuration view and the query and response view of the DNS. The configuration view, discussed in the current section, searches the DNS zone files and counts the number of IPv6 records that are configured into the DNS. Such configuration elements are a necessary precursor to the use of IPv6 for service access.

Box 4. Refresher on looking up information using the Domain Name System

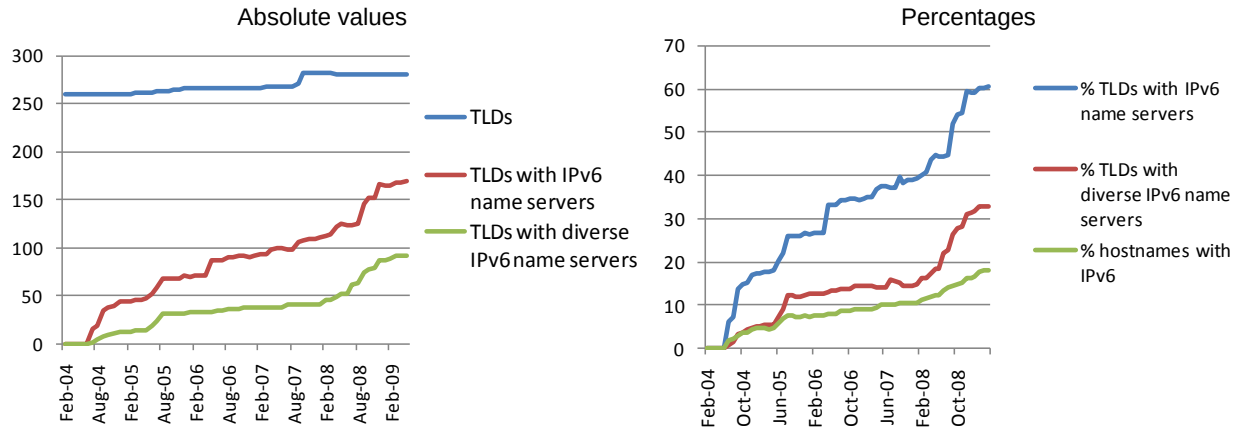
The DNS is a distributed registry system that "resolves" (*i.e.* translates) user-friendly host names (for example www.example.com) into numeric Internet Protocol (IP) addresses (IPv4 or IPv6), to locate content or applications on the Internet. Applications do this by calling on the resolver library (step 1 in Figure A). The resolver library sends a request for the required information to a "caching" or "recursive" name server on the local network: this is usually the ISP's name server (step 2). If the ISP's name server has not yet had the chance to cache the answers to previous requests in its memory, it follows a chain of delegations from the root of the DNS in order to resolve the query. So for a lookup of www.example.com, the local resolver will first consult one of the ***root name servers*** (step 3). The (13) root name servers host the root zone file, which is the single, authoritative root for the DNS that identifies Top Level Domains (TLDs). The root name server will then refer the resolving name server to the **name servers** for the requested **top level domain**, *e.g.* .com (steps 4 and 5). One of the .com name servers will return details of the name servers for example.com (step 6). When one of these is consulted, it returns the IP address of www.example.com to the resolving name server (step 7) which then passes that answer to the clients that originally made that query (steps 9 and 10).

Figure A. DNS look-up



Several strong caveats must be stressed when looking at DNS-related measures. Experts warn that DNS-related measures of IPv6 must be considered with significant caution because of the complexity of the relative roles of authoritative name servers, of DNS forwarders and of cached DNS data, as compared to the rates of queries initiated by end hosts. In addition, the presence of an IPv6 DNS record for a website does not mean IPv6 connectivity (access type and DNS are not linked), nor does it indicate whether a given application on the target host has been IPv6-enabled. Finally, the DNS does not provide any indication about the actual IPv6 activities of network operators who provide IPv6 connectivity from their network.

Figure 25. Trends in the DNS Root Zone, 2004-2009



Source: IANA Contribution to the OECD, June 2009.

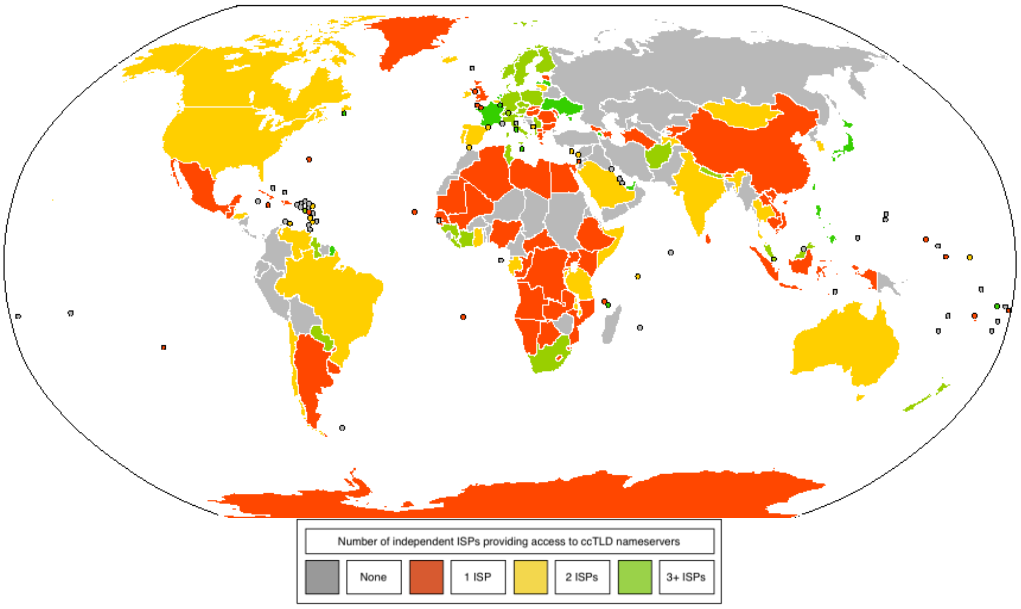
There is increasing deployment of IPv6 in both the root zone and the TLDs (Figure 25). ICANN has been offering IPv6 record publication in the root zone since 2004; however, uptake is still far from universal. The logical outcome to full IPv6 deployment is IPv6 glue records for every name server listed in the root zone.[37] Five years on (January 2010), according to data by the IANA and Hurricane Electric[38]:

- Over half (7 out of 13) of the root DNS servers had IPv6 records in January 2010 (the A, F, H, J, K, L and M root servers, according to the IANA hints file).

The number of top-level domains (TLDs) that have IPv6 glue in the root zone, name servers with an IPv6 address and IPv6 connectivity indicates the ability of TLD registries to resolve IPv6 addresses. It should be noted that the following data is independent of the size of TLD (for example, this indicator gives a large TLD such as .com the same weight as a small TLD such as .tv).

- 65% of TLDs have IPv6 records (IPv6 glue) in the root zone in January 2010, *i.e.* 182 TLDs have IPv6 records while the other 98 do not.
  - 62% (152 out of 248) of the ccTLD name servers have IPv6 records.
  - 75% (15 out of 20) of the gTLD name servers have IPv6 records.
- 80% of TLDs have name servers with an IPv6 address in January 2010, *i.e.* 225 TLDs have IPv6 name servers while 55 do not.
- Only about one third of TLD name servers have diverse (at least 2) IPv6 name servers in early 2010 (figure 26). It should be noted that for IPv4, IANA requires that registries operate name servers in at least two different networks separated by geography and by network topology; each serving a consistent set of data, and reachable from multiple locations worldwide. There was no such requirement for IPv6 early 2010.

Figure 26. ccTLDs with AS diversity over IPv6



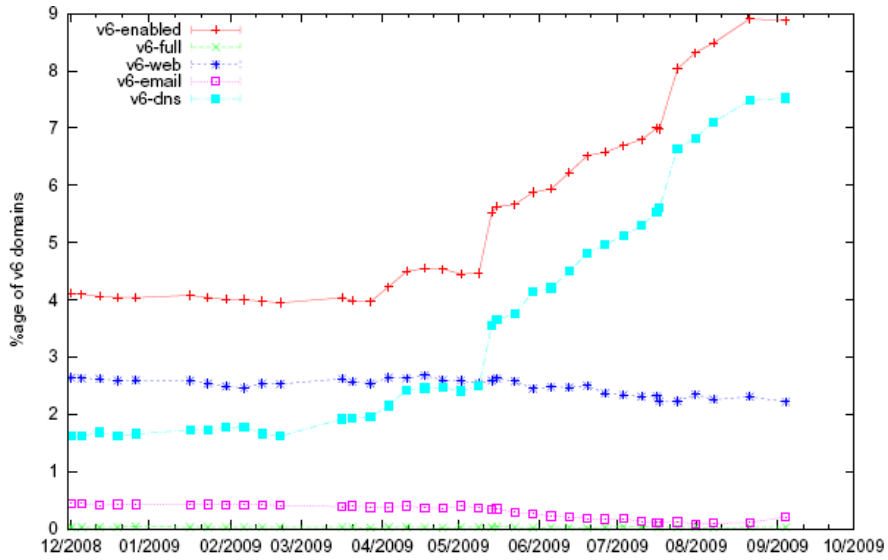
Source: IANA, early 2010.

The number and evolution of registered domains returning IPv6 records is an indicator of the number of websites and other Internet services that are available over IPv6. Hurricane Electric conducts daily queries of IPv4 and IPv6 records for all domains in several selected top level domains (both gTLDs, including .com, .net, .org, .info, and .biz, and several ccTLDs). However, sub-domains such as ipv6.google.com, are not included, which means data is lower bound. In addition, the listing is only partial because only top-level domains that provide Hurricane Electric with access for daily downloads are included. Finally, many domains returning IPv6 records are generated by search engine domain optimisation parking operations so that any conclusions should be received with caution.

- There are almost 1.5 million registered domains with IPv6 records in the DNS by early 2010, among the TLDs queried by Hurricane Electric.
- A gradual increase in the domains that have IPv6 glue in the TLD zone files for their authoritative name servers points to an upward trend in the number of individual companies enabling IPv6 for their websites and other infrastructure.

AFNIC, the registry for the French ccTLD, provides statistics on the use of IPv6 under the .FR extension, by actively querying the domain to determine which domain names in a specific zone support IPv6 for various services. For each "example.FR" domain name, the registries determine whether IPv6 addresses are used for the name server records, whether IPv6 addresses are used for the e-mail exchange servers, and whether IPv6 addresses are used for the Web servers hosting "example.fr". Altogether, 9% of domain names under .FR use a server with an IPv6 address for the domain name system, email exchange, or Web use (about 150 000 out of 1.64 billion). As shown in Figure 27, for .FR most of the increase since end 2008 is due to the DNS, while the IPv6 Web is the next most used IPv6 service. This figure is quite high and compares to just 0.01% of domain names under .KR using IPv6 addresses (141 out of 1 074 771) according to February 2010 data by KISA/KRNIC.[39]

Figure 27. Evolution of the percentage of .FR domain names announcing IPv6



Source: AFNIC, end of 2009.[40]

Support of IPv6 by content providers, as per the top Alexa websites

Comcast and the University of Pennsylvania are conducting a research project that probes websites accessible via both IPv4 and IPv6, based on the list of the top one million sites maintained by Alexa. It includes websites that have an IPv6 DNS entry for their main site, or for a variation of their site (such as ipv6.google.com). It should be noted that the base number on which the percentage is taken is not constant but keeps increasing, *i.e.* it is not always one million. In addition, only the websites visible from the research laboratory are included.

Figure 28 shows the percentage of sites that are accessible via both IPv4 & IPv6. It shows that the content made available through IPv6 is growing but still very low, with only about 0.15% of the top one million websites having an IPv6 website in January 2010 (and just 0.16% in March 2010). Figure 29 shows that by early 2010 out of the top 10 websites, only Google.com was available over IPv6, 3 of the top 100 websites were available over IPv6, while 17 of the top 1 000 websites were available over IPv6 in January 2010. Nevertheless, a growing number of websites such as YouTube or Netflix have been adding support for IPv6. In addition, it should be noted that the percentage of Top 1000 Websites supporting IPv6 figure grew to 8% in March 2010 when Google websites were included. Lack of IPv6 support in Content Delivery Networks (CDN) being an important obstacle to deploying IPv6 on large content sites, Limelight was the first CDN to announce 'production' IPv6 support in June 2009.[41]

Figure 28. IPv6 reachability among top 1M websites, year

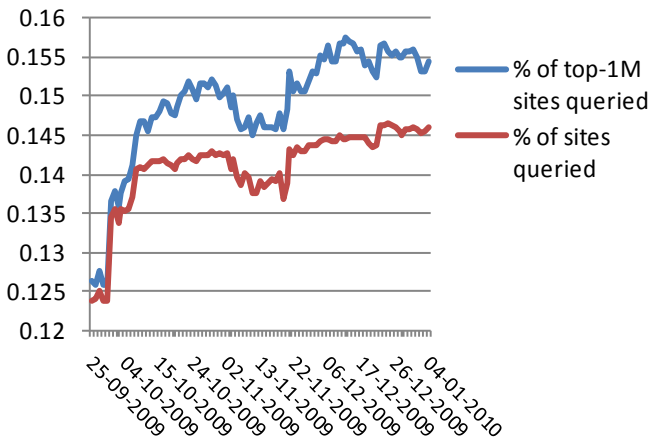
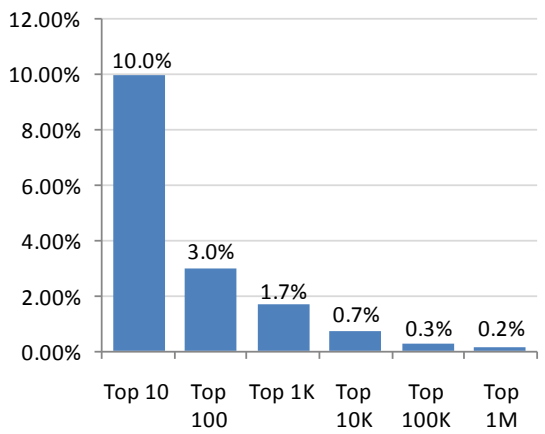
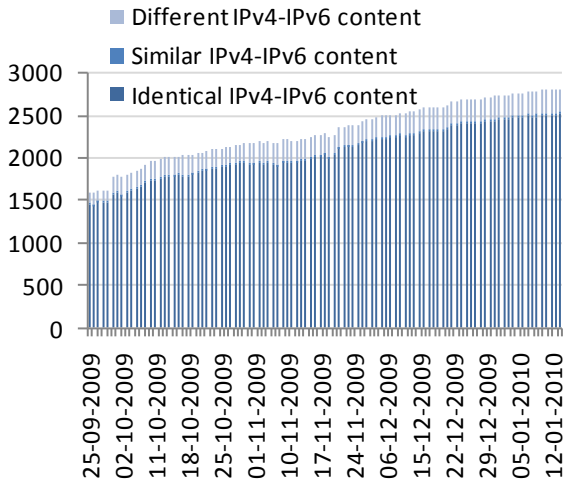


Figure 29. Relative IPv6 accessibility among top-ranking websites, year-end 2009



Source: Comcast and the University of Pennsylvania, http://ipv6monitor.comcast.net, data early January 2010.

Figure 30. IPv4 versus IPv6 content among top 1 million websites reachable over both, early 2010



Source: Comcast and the University of Pennsylvania, http://ipv6monitor.comcast.net, data early January 2010.

Figure 30 shows the number of the top one million sites that are accessible via both IPv4 and IPv6, with the bar broken into three pieces based on the fractions that are providing different, identical, and similar contents to their IPv4 counter-part. IPv4 and IPv6 content is mostly identical.

It should also be noted that the IPv6 Forum launched an IPv6 Enabled Logo for websites in June 2009, which could provide further information in the future.[42] By early 2010, 320 websites had entered the logo programme; the countries with the most IPv6 websites were Japan (68 certified websites), China (40), the United States (34), Germany (28) and Malaysia (15).[43]

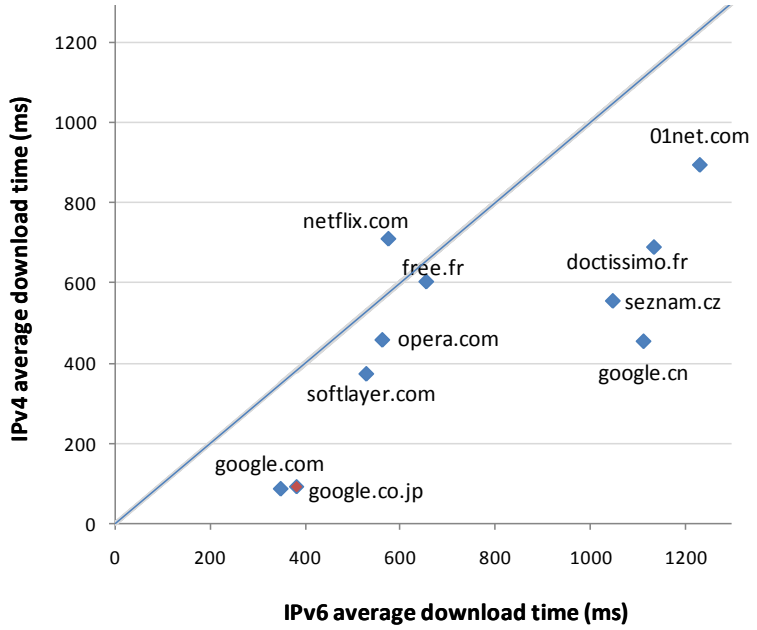
Relative latency of IPv6 versus IPv4 using IPv6 reverse DNS name servers

Latency, the amount of time it takes for a packet of data to get from one designated point to another, is an important indicator of IPv6 Performance evolution as a production service over time. Comcast and the University of Pennsylvania identified servers running both IPv4 and IPv6 by querying all IPv6 prefixes with working reverse DNS servers[44] and working IPv4 and IPv6 addresses. This measures the IPv4 and IPv6 latency to IPv6 reverse DNS servers.[45] Their research showed that in early 2010 the download time

for IPv6 was still higher for most sites (Figure 31). However, their research also showed that some sites were faster in IPv6 than IPv4.

Caveats that should be stressed include that the same domain name may be hosted by two different machines in IPv4 and IPv6, in which case comparing IPv4 versus IPv6 latency would not be meaningful. If the IPv4 DNS address is "anycasted", results would likely be skewed towards IPv4 for technical reasons.

Figure 31. Latency of top 1 000 websites using IPv4 and IPv6, 4-month average year-end 2009



Source: Comcast and the University of Pennsylvania, http://ipv6monitor.comcast.net, early January 2010.

2) END-USER IPV6 ACTIVITY / QUALITY

End-user IPv6 connectivity

End-user systems that chose IPv6 when given the choice of IPv4 or IPv6 (dual-stack) and end-user systems that have IPv6 connectivity are very important indicators of IPv6 uptake by users.

Proportion of visitors that use IPv6 if given a choice of dual stack service point

The growth of the proportion of users who connect via IPv6 to reach a dual stack service point indicates end-user capability to complete an IPv6 connection when there is a choice between IPv6 and IPv4 to reach the service. The choice of using IPv6 depends on whether an application on the user side ("client" side) is configured to use IPv6 (often by default) and whether the target application, target operating system, and the connectivity between the two end-points all allow the use of IPv6.

Some organisations with dual-stack web servers collect usage statistics. They record, over time, the numbers of distinct IPv4 and IPv6 query addresses per day on these dual-homed web servers. For example, APNIC, RIPE NCC, and ICANN collect dual stack statistics.

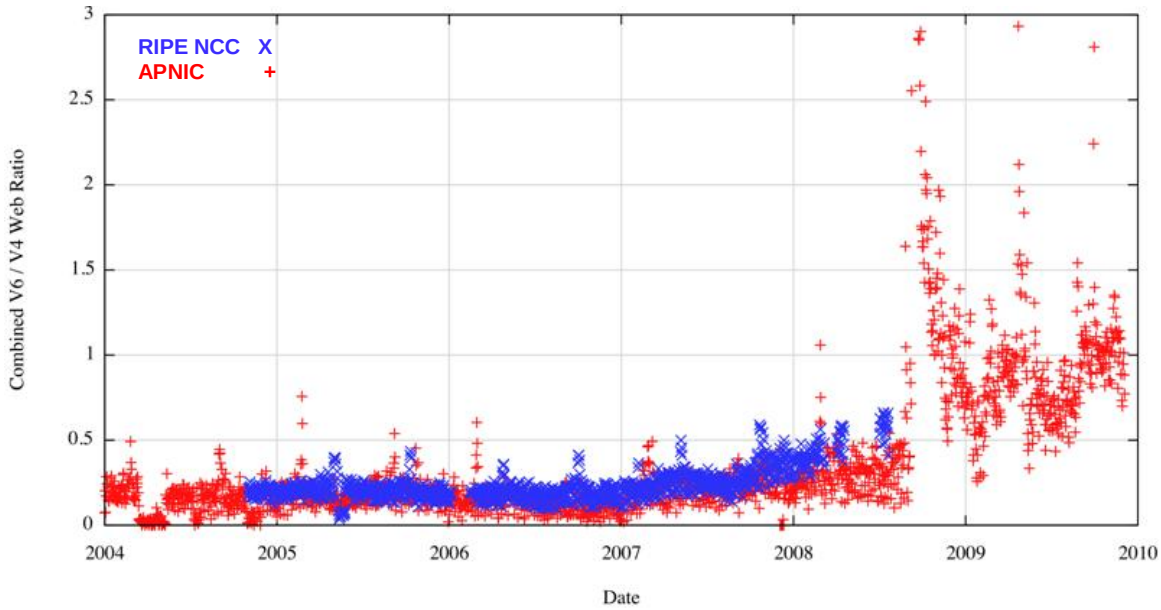
Several caveats warrant noting. Widespread NAT use in IPv4 undercounts IPv4 host counts so that the number comparing IPv6 to IPv4 is a maximum. Visitors to the APNIC and RIPE sites are likely to be more sophisticated technically than average users on the Internet, therefore they are likely to have comparatively more IPv6 clients.

The server will record an IPv6 transaction only if all of the following conditions are met: *i)* the client has an IPv6 stack; *ii)* the client's application is configured with IPv6 support; *iii)* the client's DNS configuration is able to perform an IPv6 address query; and *iv)* the client and server can communicate end-to-end using IPv6.[46] In other words, this measurement will only succeed if all the intermediate components of the connection are configured to support IPv6. Therefore, this metric would be a good indicator of the total level of IPv6 deployment capability across all components of the network.

The data used in this section relate to the use of the APNIC web site, www.apnic.net, and the RIPE web site, www.ripe.net. These web sites have both IPv4 and IPv6 addresses and have been dual homed on both IPv4 and IPv6 networks for over five years. The approach used to measure the relative use of IPv6 to IPv4 was to count the number of unique source addresses visiting these websites each day and to look at the ratio of the number of unique IPv4 source addresses to the number of unique IPv6 source addresses.[47]

Figure 32 shows the daily ratio of IPv6 to IPv4 source addresses that have accessed the APNIC and RIPE websites since 1 January 2004. IPv6 users seem to have started to increase in 2007 and even more so mid-2008, to reach 1% of visits at year-end 2009. Given the considerable variation in the data from day to day, a scatter plot is used to ensure that the trends in the data are visible as well as the day-to-day variation.[48]

Figure 32. IPv6 / IPv4 Web Access Ratio



Source: ITAC/NRO, December 2009.

The APNIC and RIPE sites are oriented towards technologically adept users; more mainstream dual-stack sites, including those of ICANN and IANA, see lower relative numbers for IPv6 access at between 0.2% and 0.3% by mid 2009 (Figures 33 and 34).[49]

Figure 33. ICANN Website v4/v6 comparison, 2009

Ratio of IPv6 to IPv4 unique visits (%)

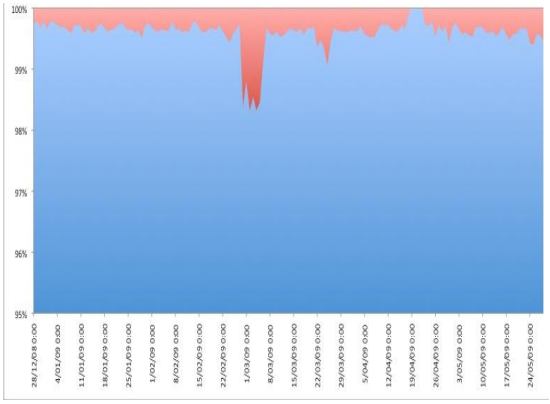
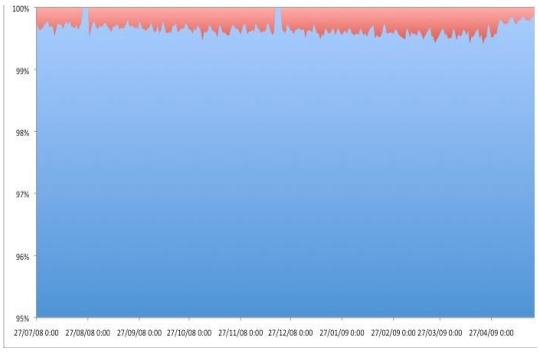


Figure 34. IANA Website v4/v6 comparison

Ratio of IPv6 to IPv4 unique visits (%)



DNS queries

DNS queries under specific top-level domains (TLDs) may help indicate the evolution of user demand for IPv6 websites. DNS queries received by authoritative TLD name servers are passively monitored. Analysis of the relative rate queries for IPv4 address records and IPv6 address records requests over time can help to identify bottlenecks and be compared with other data (*e.g.* ratio of v4/v6 traffic) to verify consistency.

Caveats that should be noted include that data from a specific registry only represents one vantage point and in the case of country-code Top Level Domains (ccTLDs), usually mostly from one country. In addition, this indicator takes into account almost only the requests performed by the recursive name server and does not indicate whether a client (typically, a desktop machine) supports IPv6.

About 0.9% of queries by DNS clients for AFNIC's server a.nic.fr were transported over IPv6 at the end of 2009, *i.e.* about 0.9% of end-users requesting .FR domain names had IPv6 connectivity. This number, at nearly 1% of queries, was consistent with other data, from Google, showing that slightly over 1% of end-users in France had IPv6 connectivity end-2009. In addition, 7% of the actual DNS queries were for IPv6 addresses, 51% were for IPv4 addresses, while most of the other DNS requests under .fr were for mail exchange.

By comparison, 0.42% of queries by DNS clients under KRNIC's server were transported over IPv6 on average in 2009, *i.e.* about 0.42% of end-users requesting .KR domain names had some form of IPv6 connectivity.

End-user systems with IPv6 enabled

Google researchers have developed a methodology for characterising IPv6 adoption, connectivity, and latency from the perspective of a website operator. They performed a large-scale study of IPv6 deployment by applying the methodology to the Google website starting in September 2008. The data helps them to determine what percentage of users would use Google's services over IPv6 if it were enabled, what the impact would be on reliability and latency, and what the degree of IPv6 deployment is in various countries and networks, as well as which transition mechanisms are used.

Google finds that, by September 2009:

- IPv6 adoption, while growing significantly, is still low (Figure 35).
- It seems that IPv6 is more available to users at home than in their workplace (Figure 36).
- IPv6 adoption varies considerably by country (Figures 38 and 39).
- IPv6 adoption is heavily influenced by a small number of large deployments, for example that of free.fr in France.
- The networks (autonomous systems) originating most of the IPv6 traffic are universities or research institutions, with the notable exception of Free.fr in France.
- Native IPv6 latency is comparable to IPv4.

Figure 35. Working IPv6 over time

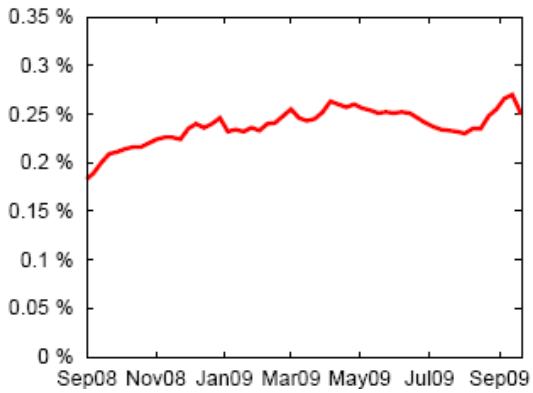
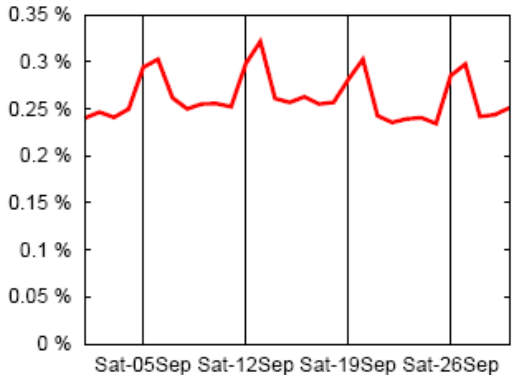


Figure 36. Daily working IPv6 in August 2009



Source: "Evaluating IPv6 Adoption in the Internet", April 2010, Lorenzo Colitti, Steinar H. Gunderson, Erik Kline, Tiziana Refice, forthcoming, PAM 2010.

Figure 37. Working IPv6 by connectivity type

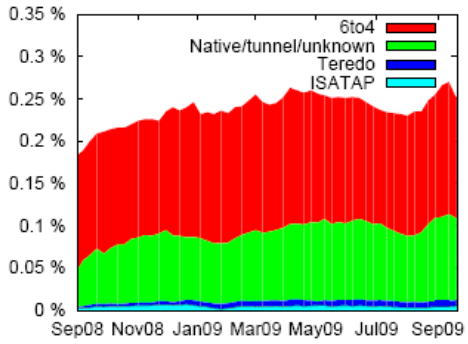
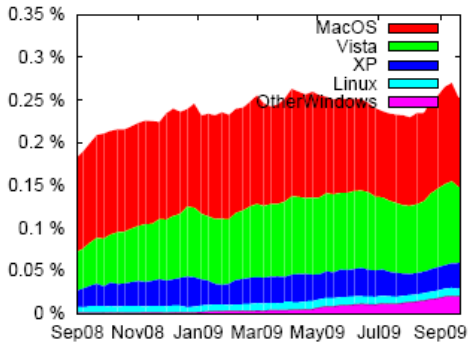


Figure 38. Working IPv6 by operating system



Source: Evaluating IPv6 Adoption in the Internet, April 2010, Lorenzo Colitti, Steinar H. Gunderson, Erik Kline, Tiziana Refice, forthcoming, PAM 2010.

Figure 36 measures the IPv6 'transition mechanisms' that are used to connect to dual-stack Web sites, whereby IPv6 traffic is not native IPv6 traffic, but instead is "tunneled" inside IPv4. Google finds that 6to4 is the most common connectivity type and represents well over half of total IPv6 traffic. ISATAP and Teredo are comparatively rare.[50] This finding is consistent with the fact that 6to4 is used before attempting a V4 connection. Teredo, on the other hand, is configured in Microsoft systems as a last resort, used only after IPv4 access has failed, which means that Teredo traffic is always low.

Figure 39 provides a measure of the availability of IPv6 connectivity in a given country: the countries with the most IPv6 users (native + transit) appear to be Russia (1.5%), France (1%), Ukraine (1%), China (0.4%) and the United States (0.4%).

However, relayed transition mechanisms such as 6to4 and Teredo can be deployed by users and do not require any local network infrastructure. Therefore, the total percentage of IPv6 users is not necessarily a good indication of the presence of IPv6 network infrastructure. Google researchers estimate that a better measure of the deployment of IPv6 in a given country can be obtained by removing relay mechanisms like 6to4 and Teredo. Figure 40 shows that the most significant deployments of non-relay IPv6 are in France (over 1%) and China (0.4%), followed by Sweden (0.1%), and other countries at less than 1% including the Netherlands, the United States and Japan.

Figure 39. Working IPv6 ratio for top-10 countries by connectivity type

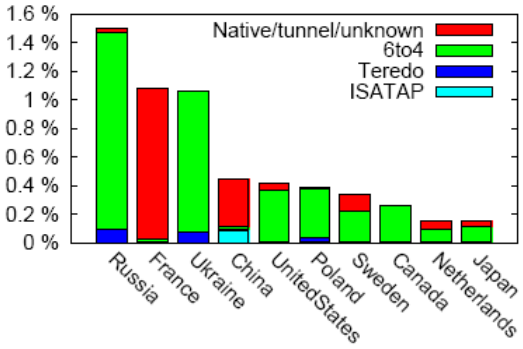
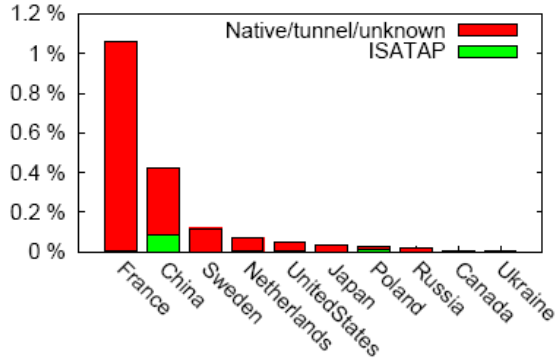


Figure 40. Working IPv6 ratio for top-10 countries, non-relayed only



Source: "Evaluating IPv6 Adoption in the Internet", April 2010, Lorenzo Colitti, Steinar H. Gunderson, Erik Kline, Tiziana Refice, forthcoming, PAM 2010.

Observed IPv6 traffic levels

The percentage of traffic that uses IPv6 on the Internet is a general indication of uptake of IPv6, although numerous caveats must be stressed.

General caveat(s) with traffic measurements:

- Experts warn that traffic measurements of IPv6 must be considered with significant caution. In a similar way to IPv6 DNS queries, traffic numbers that specific entities can collect are often not representative of global Internet use. Traffic numbers may only reflect specific subsets of users and subsets of uses, which entails various biases. For example, if bandwidth-intensive applications such as a peer-to-peer file downloading applications use IPv6 they may cause the level of IPv6 (or IPv4) traffic to appear high, even if very few individual users or applications are using it.
- Organisations may be using IPv6 within internal networks for specific applications. This would not be measured in inter-domain traffic studies. For example, NTT estimates that IPv6 traffic inside its network is very significant because its video-on-demand and video streaming traffic use IPv6 multicast. In another example, Comcast uses IPv6 to manage its cable modems: while the volume of IPv6 traffic is very low, this traffic is extremely important to the company.
- Some measurements may not account for "transition mechanisms" whereby IPv6 traffic is not native IPv6 traffic, but instead is "tunneled" inside IPv4.

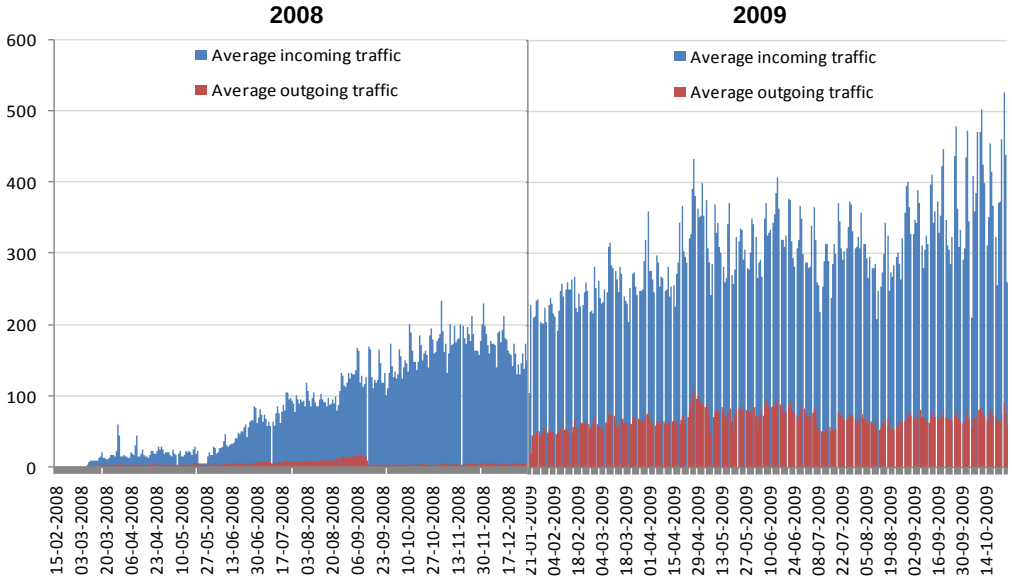
IPv6 traffic at a specific ISP (free.fr).

Free is the second largest ISP in France, with over 4 million broadband subscribers in October 2009. At the end of 2007, Free made available native IPv6 via opt-in, using 6rd technology, to its home subscribers and in March 2008 the ISP launched its first IPv6-only service called 'Telesite', available only to free triple play users.[51]

Some 450 000 subscribers had activated IPv6 by end of 2009, representing 10% of Free's subscribership, up from 320 000 in March 2009. IPv6 traffic per opt-in customer represented on average some 3% of each customer's global traffic (450 000, or 10% of subscribers, opted in).[52] The average incoming IPv6 transfer rate was of 353 Mbps in October 2009 while the average outgoing transfer rate was of 68 Mbps (Figure 41). Outgoing traffic volumes were some 20% on average of incoming traffic volumes.

It should be stressed that these data only represent outgoing traffic from Free's network. This means, for example, that it does not include traffic flows between Free's subscribers.

Figure 41. Daily average IPv6 traffic at Free.fr in 2008 and in 2009 (Mbps)



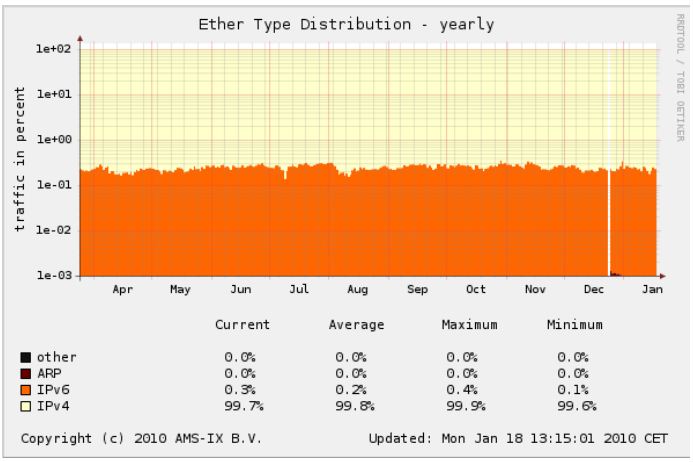
Source: Free.fr. There was a change in the measurement method at the end of 2008.

Percentage of IPv6 traffic at a large Internet eXchange Point, AMS-IX

IPv6 **traffic levels** are low but showing growth. The largest Internet eXchange Point (IXP) in the world, AMS-IX (www.ams-ix.net), tracks the percentage of native IPv6 traffic using s-flow statistics. AMS-IX reports an average of only 0.2% of its traffic being native IPv6 in 2009, with a minimum of 0.1% and a maximum of 0.5% (Figure 42). The average total traffic on AMS-IX in 2009 was 400 Gbps, meaning the average IPv6 traffic was about 800 Mbps.

Caveats that should be stressed include that no private peering points are included. In addition, volumes measured may not include traffic generated by transition mechanisms whereby IPv6 traffic is "tunneled" over IPv4.

Figure 42. IPv6 traffic at AMS-IX, 2009



Source: www.ams-ix.net, January 2010.

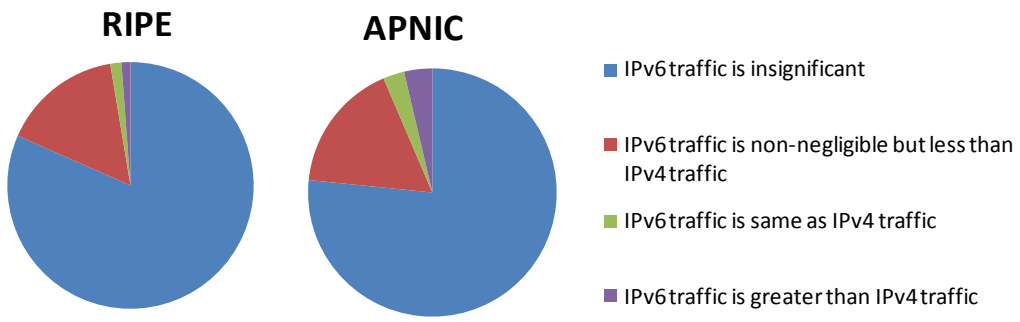
3) SURVEY INFORMATION FROM THE RIPE AND APNIC SERVICE REGIONS

A survey was undertaken by GNKS and TNO in co-operation with the RIPE NCC on behalf of the European Commission DG Information Society in June 2009. It was modelled after a 2008 survey conducted by CAIDA and ARIN in ARIN's coverage area and APNIC ran the same survey in September 2009. The results from the surveys suggest that the RIPE and APNIC regions are at fairly similar level of deployment of IPv6. The surveys also provide some insight into planned deployments and perceived barriers. A full analysis of the survey outcome for the APNIC region will be completed by February 2010. Caveats that warrant noting include the fact that entities choosing to reply to the survey likely had an interest in IPv6 (selection bias).

Of 610 government, educational and other industry organisations surveyed throughout Europe, the Middle East and Central Asia, over half had no IPv6 presence at all, while 37% had some IPv6 presence on the Internet and 23% had some IPv6 presence in internal networks. Nearly 80% of EU respondents have sourced or have considered sourcing IPv6 addresses.

For 82% of RIPE respondents and 77% of APNIC respondents, IPv6 traffic was insignificant in 2009 (Figure 43). However, for a handful of respondents, IPv6 traffic was the same or greater than IPv4, particularly in the APNIC region (in APNIC 7% of respondents have equal or more IPv6 traffic than IPv4 traffic compared with respectively 2% of RIPE respondents).

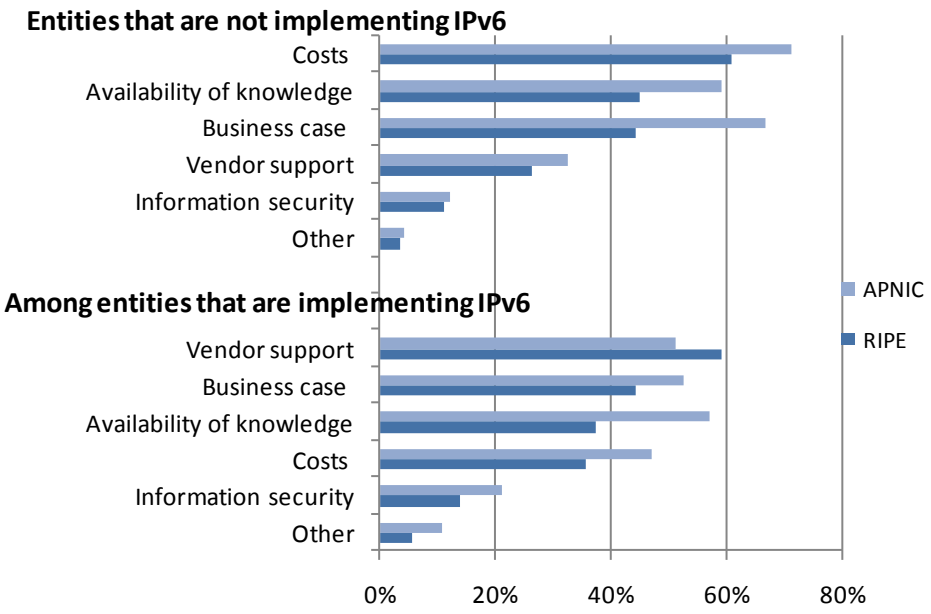
Figure 43. IPv6 traffic compared to IPv4 traffic for institutions that have implemented IPv6



Source: GNKS/TNO 2009, APNIC.

A majority of respondents that had no immediate plans to deploy IPv6 said they did not yet have a business need for IPv6 and some also indicated that they had not yet had time to do so. Cost tends to be seen as a barrier by entities that have not really investigated IPv6 implementation while among those that have implemented IPv6, cost is much less of a barrier. In contrast, among those deploying IPv6, lack of vendor support appeared to be a significant issue. In addition, the availability of IPv6 knowledge/skills appeared to be a large issue in the APNIC service region (Figure 44). It is unclear from the survey whether "lack of vendor support" means current lack of vendor support or rather lack of IPv6 support on products previously purchased from vendors.

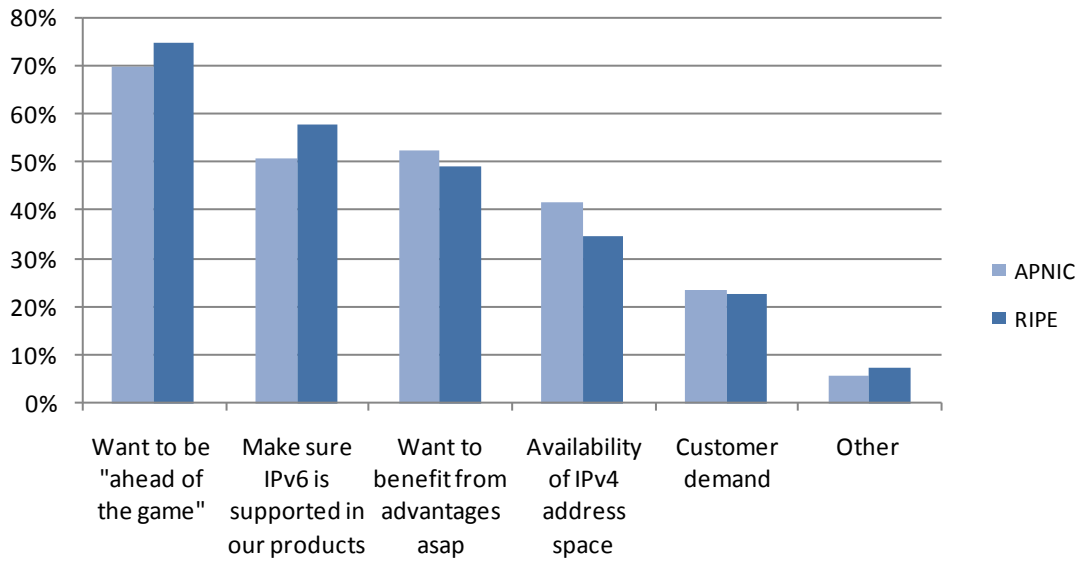
Figure 44. Expected largest hurdle(s) for organizations to deploy IPv6?



Source: GNKS/TNO 2009, APNIC.

A majority of respondents cited 'want to be ahead of the game' as the main driver for IPv6 deployment, followed by the desire to have IPv6 support in products and leveraging the benefits that IPv6 could offer (Figure 45). Lack of availability of IPv4 address space was not a leading issue although it was reportedly a bigger issue for non-EU respondents (48%) than EU respondents.

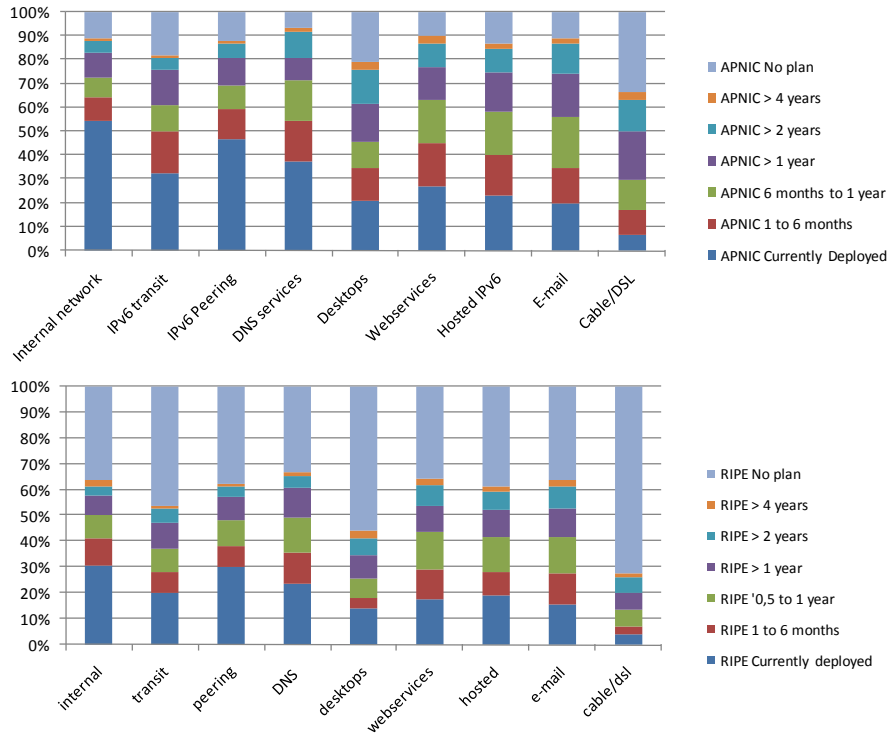
Figure 45. Drivers for IPv6 deployment



Source: GNKS/TNO 2009, APNIC.

There seem to be significantly more entities with 'no plan' to deploy IPv6 in the RIPE region (over 30%) than in the APNIC region (over 10%). The difference is particularly pronounced for cable/DSL service provision (Figure 46).

Figure 46. Planning IPv6 deployment for which services



Source: GNKS/TNO 2009, APNIC.

OTHER POSSIBLE IPV6 DEPLOYMENT INDICATORS

Other IPv6 deployment indicators that some actors may be keeping track of include:

- DNS queries, which may help indicate the evolution of user demand for IPv6 websites through measuring the relative rate of queries for IPv4 and IPv6 address records and relative rate of queries conducted over IPv4 or IPv6.
- Top 1 000 Usenet Servers with IPv6 support
- Breakdown of IPv6 address assignment schemes, in particular, use of privacy extensions.
- Data about applications using IPv6.
- Data about tunnels that carry IPv6 traffic over IPv4 infrastructure.
- Data on registrar IPv6 support.[53]
- Data from DNS forwarders.
- Data relating to the similarity of the IPv4 and IPv6 inter-AS transit network topologies
- Data relating to relative distribution of end user OS for V4 and V6 web queries
- Data relating to the OS-preferred protocol in a dual stack scenario

ANNEX 1 - MAIN POINTS, OECD (2008), "ECONOMIC CONSIDERATIONS IN THE MANAGEMENT OF IPV4 AND IN THE DEPLOYMENT OF IPV6"

One of the major challenges for all stakeholders in thinking about the future of the Internet is its ability to scale to connect billions of people and devices. The objective of this report is to raise awareness among policy makers of capacity and limitations of the Internet Protocol version 4 (IPv4), to provide information on the status of readiness and deployment of the Internet Protocol version 6 (IPv6) and to demonstrate the need for all stakeholders, including governments, to play a part in IPv6 deployment.

The Internet has rapidly grown to become a fundamental infrastructure for economic and social activity around the world. The Internet Protocol (IP) specifies how communications take place between one device and another through an addressing system. The Internet technical community has successfully supported the Internet's growth by managing IPv4 Internet addresses through open and transparent policy frameworks, for all networks to have address space sufficient to meet their needs. It has also developed a new version of the Internet Protocol between 1993 and 1998, IPv6, to accommodate additional growth.

There is now an expectation among some experts that the currently used version of the Internet Protocol, IPv4, will run out of previously unallocated address space in 2010 or 2011, as only 16% of the total IPv4 address space remains unallocated in early 2008. The situation is critical for the future of the Internet economy because all new users connecting to the Internet, and all businesses that require IP addresses for their growth, will be affected by the change from the current status of ready availability of unallocated IPv4 addresses.

IPv6, on the other hand, vastly expands the available address space and can help to support the proliferation of broadband, of Internet-connected mobile phones and sensor networks, as well as the development of new types of services. Beyond additional address space, IPv6 adoption is being driven by public sector procurement mandates, by deployment of innovative products and services, by its better support for a mobile Internet, as well as by the decreased network complexity that it allows.

Today, the latest versions of new popular end systems (*e.g.* Microsoft Windows Vista/Server 2008, Apple Mac OS X, Linux, etc.) fully integrate IPv6, as do parts of the core of the Internet. However, progress in actual usage of IPv6 remains very slow to-date and considerable challenges must be overcome to achieve a successful transition. Immediate costs are associated with deployment of IPv6, whereas many benefits are longterm and depend on a critical mass of actors adopting it. A further major obstacle to IPv6 deployment is that it is not backwards compatible with IPv4: IPv6-only devices cannot communicate directly with IPv4-only devices. Instead, both protocols must be deployed, or sophisticated "tunnelling" and translation systems set-up. Experience to-date with IPv6 also suggests that IPv6 deployment requires planning and co-ordination over several years, that increased awareness of the issues is needed and that, as with all new technologies, finding skilled resources is challenging.

An intersection of economic, technical and public policy factors will determine the strategies adopted by various stakeholders who can pursue three broad paths: *i)* an even denser deployment of IPv4 Network Address Translation (NAT), whereby more devices are connected with fewer public IPv4 addresses by using private networks; *ii)* trying to obtain previously allocated but unused IPv4 addresses, and; *iii)* the deployment of IPv6. It is likely that all three of these options will be pursued by various actors in parallel, according to their business requirements. As an immediate solution, many are expected to pursue denser deployments of NAT. If Internet addressing groups were to liberalise address transfers, some actors would acquire previously allocated IPv4 addresses. Some actors will also implement IPv6. For policy makers, the most important point is that the first two strategies, which extend the life of IPv4, may be useful but are shortterm. The only sustainable solution to deliver expected economic and social opportunities for the future of the Internet economy is the deployment of IPv6.

In terms of public policy, IPv6 plays an important role in innovation and scalability of the Internet. In addition, security, interoperability and competition issues are involved with the depletion of IPv4. Transitioning to IPv6 represents a fundamental change in the Internet Protocol layer, which is necessary to foster an environment for long-term growth and competition across existing players and new entrants. In turn, such an environment is expected to enable the expanded use of the Internet and the development of new networking environments and services.

As the pool of unallocated IPv4 addresses dwindles and transition to IPv6 gathers momentum, all stakeholders should anticipate the impacts of the transition period and plan accordingly. With regard to the depletion of unallocated IPv4 address space, the most important message may be that there is no complete solution and that no option will meet all expectations. While the Internet technical community discusses optimal mechanisms to manage IPv4 address space exhaustion and IPv6 deployment and to manage routing table growth pre- and post-exhaustion, governments should encourage all stakeholders to support a smooth transition to IPv6.[54]

To create a policy environment conducive to the timely deployment of IPv6, governments should consider:

1) Working with the private sector and other stakeholders to increase education and awareness and reduce bottlenecks

IPv6 adoption is a multi-year, complex integration process that impacts all sectors of the economy. In addition, a long period of co-existence between IPv4 and IPv6 is projected during which maintaining operations and interoperability at the application level will be critical. The fact that each player is capable of addressing only part of the issue associated with the Internet-wide transition to IPv6 underscores the need for awareness raising and co-operation. Governments should aim to raise awareness and:

- Establish co-operation mechanisms for the development and implementation of high-level policy objectives to guide the transition to IPv6.
- Develop compelling and informative educational material to communicate and disseminate information on IPv6.
- Target decision-makers in awareness efforts and discussions on IPv6 deployment.
- Support registries and industry groups as they continue to develop policies and technologies to facilitate the management of IPv4 and adoption of IPv6, with a focus on:
  - Policies that safeguard security and stability.
  - Policies that give stakeholders ample opportunity to be ready and operate smoothly during the upcoming period of IPv4 unallocated address space depletion.
  - Ensuring that the deployment of IPv6 and the necessary co-existence of IPv4 and IPv6 safeguard competition, a level-playing field and are careful not to lock-in dominant positions.
- Make specific efforts to ease bottlenecks, by encouraging:
  - Operators to consider IPv6 connectivity in peering and transit agreements.
  - Greenfield deployments to contemplate IPv6 from the outset, to "future-proof" deployments.
  - Vendors and other providers of customer premises equipment to plan for and accommodate future customer needs in terms of IPv6, in recognition of consumer Internet access as the

largest current network-service growth area and the area placing the heaviest demand on IP address resources.

- Telecommunications operators to facilitate IPv6 deployment through training, equipment renewal, integrating IPv6 in hardware and software, developing new applications, conducting risk assessments.
- Software development companies to develop IP version neutral applications where possible, incorporate IPv6 capabilities into new software, and to conduct research and development on new applications that leverage IPv6 functionality.

2) Demonstrating government commitment to adoption of IPv6

As for all other stakeholders, governments need continued addresses to support growth in the public services that they provide online and more generally to meet public policy objectives associated with the continued growth of the Internet economy. They therefore have a strategic need to support transition to IPv6 by taking steps to:

- Adopt clear policy objectives that are endorsed at a high level, to guide the transition effort to IPv6.
- Plan for the adoption of IPv6 for governments' internal use and for public services, by developing a road map and planning time needed to conduct network assessment, infrastructure upgrade, and upgrade of applications, hosts, and servers.
- Set up a steering group to provide strategic guidance on achieving IPv6 implementation objectives.
- Ensure that all new programmes involving the Internet and ICT consider the relevancy of IPv6 and assess public programmes and priorities to determine how they can benefit from IPv6.
- Ensure that all relevant government security entities fully integrate the new dimension that IPv6 brings to security.
- Take pro-active initiatives to include IPv6 training efforts in life-long education cycles.

3) Pursuing international co-operation and monitoring IPv6 deployment

Awareness of the scope and scale of an issue is a key element in support of informed policy making. Benchmarking at the international level is essential to monitor the impact of various policies. With respect to IPv6, governments should:

- Engage in bilateral and multilateral co-operation at regional and global levels, to share knowledge and experience on developing policies, practices and models for coordination with private actors on IPv6 deployment.
- Consider the specific difficulties of some developing countries and assist them with capacity-building efforts to help build IPv6 infrastructure.
- Encourage the participation of all relevant stakeholders in the development of equitable public policies for IPv6 allocation.
- Encourage all relevant parties, including global and regional Internet registries, Internet exchange point operators and research organisations, to gather data to track the deployment of IPv6 in support of informed policy-making.
- Monitor IPv6 readiness, including by monitoring information on national peering points offering IPv6 connectivity, Internet Service Providers offering commercial IPv6 services, volumes of IPv6 transit, and penetration of IPv6-enabled devices in domestic markets.

ACRONYMS / GLOSSARY

AfriNIC	African Region Network Information Centre
Aggregation	Aggregation refers to the distribution of public Internet addresses in a hierarchical manner, to permit the grouping of routing information and limit the number of routing entries advertised in the Internet. It is one of the main goals of Internet administration.
Allocation	Allocation refers to the range of addresses made available to a Local Internet Registry (LIR) that in turn is used by the LIR to make address space assignments to End Users or to the LIR's own network.
APNIC	Asia Pacific Network Information Centre
ARIN	American Registry for Internet Numbers
Assignment	An assignment refers to address space that a Local Internet Registry (LIR) distributes to an End User / organisation that will use the addresses to operate their network(s)
AS	Autonomous System – a group of IP networks operated by one or more network operators that has a single and clearly defined external routing policy
ASN	An Autonomous System Number (ASN) is a unique two- or four-byte number associated with an AS. The ASN is used as an identifier to allow the AS to exchange dynamic routing information with other Autonomous Systems. Exterior routing protocols such as the Border Gateway Protocol (BGP) require ASNs to exchange information between networks.
ASO	ICANN's Address Supporting Organisation
BGP	Border Gateway Protocol
ccTLD	Country Code Top-Level Domain
DNS	Domain Name System
Dual Stack	Concurrent service for IPv4 and IPv6 protocol stacks
End User	An entity receiving assignments of IP addresses exclusively for use in operational networks, not for reassignment to other organisations
gTLDs	Generic Top-Level Domain
IANA	Internet Assigned Numbers Authority
ICANN	Internet Corporation for Assigned Names and Numbers
Interoperability	The ability of two devices, usually from different vendors, to work together
IP	Internet Protocol
IP Whois	Identifies the owner and the IP address of the domain
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
IPv6 capable node	Node that has an IPv6 protocol stack. In order for the stack to be usable the node must be assigned one or more IPv6 addresses
IPv6 enabled node	A node which has an IPv6 protocol stack and is assigned one or more IPv6 addresses. Both IPv6-only and IPv6/IPv4 nodes are IPv6 enabled
ISP	Internet Service Provider
IXPs	Internet eXchange Points
JPNIC	Japan Network Information Center
LACNIC	Latin America and Caribbean Network Information Centre

LIR	Local Internet Registry
NIR	National Internet Registry
Node	Device that is connected as part of a computer network
NRO	Number Resource Organisation
Peer-to-peer	Communication model in which client devices may communicate directly, initiating the data exchange in either direction, without a server system
PI	Provider Independent
Prefix	Hierarchical, aggregated block of addresses for a network
RIPE NCC	Réseaux IP Européens-Network Coordination Centre
RIR	Regional Internet Registry
Routability	A block of addresses being identified as a separate entity in the routing tables and is therefore reachable in the Internet
Routing policy	The routing policy of an AS is a description of how network prefixes are exchanged between that AS and other Autonomous Systems
TLD	Top-Level Domain

NOTES

1 The IANA's free pool of unallocated IPv4 address space is projected to run out in 2011. After then, regional Internet registries will still have remaining address space to last until mid-2012 at current consumption rates. It should be noted that IPv4 address space consumption slowed with the economic crisis. A widely consulted source for projections is Geoff Huston's "IPv4 Address Space Report" available at http://ipv4.potaroo.net.

2 In which Ministers agreed to "encourage the adoption of the new version of the Internet protocol (IPv6), in particular through its timely adoption by governments as well as large private sector users of IPv4 addresses, in view of the ongoing IPv4 depletion" http://www.oecd.org/dataoecd/7/1/40605942.pdf.

3 http://www.oecd.org/dataoecd/49/28/40839436.pdf.

4 Primary sources are the RIR allocations/assignments, the inter-domain routing table, data from the DNS and observed traffic levels.

5 NRO Contribution to the OECD, http://www.nro.net/news/cisp-ipv6.pdf.

6 Data includes entities that have obtained IPv6 address space, IPv6 support by networks as seen by Internet routing tables, IPv6 support in the Domain Name System (DNS), IPv6 support at Internet eXchange Points (IXPs), and data on end-host readiness.

7 The Regional Internet Registries, or RIRs, allocate address space.

8 Even when there is full adoption of IPv6, allocated address space should still be only a small fraction of the available space.

9 To decide whether to make their content available over IPv6 or to offer dual-stack service.

10 Excluding 6to4, Teredo and ISATAP. By percentage of all (native + transit) IPv6 capable users, the top countries were Russia, France, Ukraine, China and the United States.

11 A survey was conducted in the RIPE service area at the initiative of the European Commission and another was conducted in the APNIC service area.

12 to decide whether to make their content available over IPv6 or to offer dual-stack service

13 Dual-stack systems may use IPv6 without knowing it, for example using tunnelling systems.

14 A survey was conducted in the RIPE service area at the initiative of the European Commission and another was conducted in the APNIC service area.

15 Smaller entities generally obtain sub-allocations from a Local Internet Registry (LIR). However, experts consider that the data on sub-allocations as available through the IP Whois protocol is currently not very representative nor very reliable.

16 Further details can be found in OECD, 2008, "Economic Considerations in the Management of IPv4 and in the Deployment of IPv6", Annex 1: Overview of Governmental Initiatives To-Date http://www.oecd.org/dataoecd/49/28/40839436.pdf.

17 Provider-independent address space are blocks of IP addresses assigned by RIRs directly to "Provider independent" end-user organisations. "Provider independent" or "multi-homed" users have redundant interconnection and traffic exchange with two or more independent networks.

18 This is the maximum possible number of assignments but not the number of assignments expected to be made. They needed to have plans for just 3 178 688 /48 assignments and would qualify for additional space after making just 5 534 417 assignments, due to the 'HD'-ratio used to measure network hierarchy. For example, a small network needs to use almost 11% of its 65 536 /48s (in a /32) before applying for additional address space while a network using a /20 needs to use just over 2%.

19 Traffic starting from an AS and directed to a specific prefix traverses an ordered set of other networks/ASes (AS-path). The configuration of such paths on the routing devices is complex and ASes exchange routing information with other ASes using a routing protocol called Border Gateway Protocol (BGP). BGP is based on a distributed architecture where border routers that belong to distinct ASes exchange the information they know about reachability of prefixes.

20 Entries in the routing table consist of: an address prefix, the interface over which packets matching the address prefix are sent, a forwarding or next-hop address, a preference value used to select between multiple routes with the same prefix, the lifetime of the route, the specification of whether the route is published (advertised in a Routing Advertisement), the specification of how the route is aged, and the route type.

21 www.cidr-report.org.

22 www.cidr-report.org.

23 Geoff Huston, Presentation to the Working Party on Communication Infrastructures and Services, December 2009.

24 www.emis.de/journals/JGAA/accepted/2005/Colitti+2005.9.1.pdf.

25 www.ep.net/ep-main.html also provides a list of IXPs.

26 http://www.ipv6forum.com/ipv6_enabled.

27 www.sixxs.net/faq/connectivity/?faq=native.

28 http://marketshare.hitslink.com/report.aspx?qprid=10 and www.IPv6ready.org.

29 ipv6int.net/systems/linux-ipv6.html.

30 http://www.forum.nokia.com/info/sw.nokia.com/id/64fb6b03-5a1d-4048-a849-b68e5a31fc9e/Nokia_Views_on_IPv6_Transition.html.

31 Derek Morr, Living with IPv6, http://www.personal.psu.edu/dvm105/blogs/ipv6/.

32 http://www.3gamericas.org/index.cfm?fuseaction=pressreleasedisplay&pressreleaseid=2150.

33 "LTE devices must support IPv6, says Verizon - IPv4 support for Verizon 4G devices is optional", Brad Reed, Network World, June 10, 2009. C.f. http://www.networkworld.com/news/2009/061009-verizon-lte-ipv6.html?fsrc=netflash-rss.

34 http://www.3gamericas.org/documents/LTE%20Commitments%20Dec%2030%2020091.pdf.

35 The WiMAX Forum is an industry-led organisation comprised of a number of the major operators and equipment vendors in the communications sector. The IPv6 sub-group was formed under the Network Working Group (NWG).

36 As well as many other types of products. C.f. http://www.ipv6ready.org.

37 https://www.dns-oarc.net/files/rzaia/rzaia_report.pdf.

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

39 KRNIC, the registry for the Korean ccTLD, carries out its functions under KISA, the Korea Internet & Security Agency.

40 http://www.ripe.net/ripe/meetings/ripe-59/presentations/bortzmeyer-dnswitness.pdf.

41 Limelight Networks® Introduces Industry's First Content Delivery Service With IPv6 Support, press release, 15 June 2009, http://www.limelightnetworks.com/2009/06/limelight-networks%C2%AE-introduces-industrys-first-content-delivery-service-with-ipv6-support/.

42 http://www.ipv6forum.org/.

43 http://www.ipv6forum.com/ipv6_enabled/approval_list.php.

44 In addition to name-to-number (forward) translations, the Domain Name System provides number-to-name or reverse translations. Reverse DNS delegations allow applications to map to a domain name from an IP address.

45 Through the use of pings and UDP DNS requests.

46 The DNS query can be for an IPv6 address but happen over IPv4. As many end users use resolvers provided by their ISPs it is quite likely that many DNS queries will use IPv4 transport but result in an IPv6 connection to the web server.

47 This approach was used to remove the factors associated with robots and web crawlers (which for these sites are evidently still exclusively using IPv4) and to even out some of the factors of the level of intensity of access and repeat visits to the same site.

48 It is possible that the noise component of day-to-day variation could be lowered by gaining access to the web logs of a dual-stack, dual-protocol-homed website with considerably greater volume levels.

49 Many technical users visit the IANA website, however, as well as many automated queries for tracking changes to IANA registries.

50 6to4 use has a 'signature' source address prefix of 2002::/16 and Teredo has a comparable source address prefix of 2001:0::/32. 6to4 relies on access to a public IPv4 address and does not allow transition across IPv4 Network Address Translators (NATs). More recently, a number of operating systems have been equipped with Teredo, notably Microsoft's Vista. Teredo can tunnel IPv6 across IPv4 NATs. In Windows Vista and Windows Server 2008, most operating system components support IPv6. When both IPv4 and IPv6 are enabled, Windows prefers the use of IPv6

for applications that can use either IPv4 or IPv6. In the case of Teredo, Windows Vista is enabled by default, although the local configuration may disable it and the relative order of use of protocols stacks is to attempt a connection using IPv6 in native mode, then IPv4, then IPv6 using Teredo, unless the application specifically initiates a connection using the local Teredo interface. Thus, for Vista, Teredo is invoked only in the event of failure of IPv4 connectivity, so that a dual-stack server would not trigger a Vista host to use Teredo.

[51] IPv6 Rapid Deployment on IPv4 infrastructures (6rd), draft-despres-6rd-03, April 7, 2009, http://tools.ietf.org/html/draft-despres-6rd-03.

[52] On a global daily basis (5 minute average).

[53] http://www.sixxs.net/faq/dns/?faq=ipv6glue.

1. In parallel, the technical community has to manage complex trends in routing, because of the strong interdependency between addressing and routing. To do this, the technical community is discussing solutions to enable enterprises to be independent from their Internet provider; *i.e.* supporting competition between Internet providers while mitigating its impact on routing table processing