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Assessment of IPv6 Maturity
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Abstract

This document collects and comments on several indicators of IPv6's maturity level as a technology. This data can be used in decision-making processes where many myths regarding IPv6 completeness and deployability persist.

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1. Introduction

While IPv4 has achieved widespread use and acclaim, its intended successor, IPv6, is still facing some hurdles in large-scale deployment. In both aeronautical networking and space networks a move towards network-centric operations and away from application-specific point-to-point links is occuring. In multiple groups that are attempting to define aeronautical or space networking architectures, the use of Internet protocols is well-accepted, but there is considerable uncertainty on whether to use IPv4, IPv6, or a dual-stack.

It is the technical opinion of many that IPv6 is favorable, due to some of its features (mobility and security are particularly important for network-centric operations). Vague notions persist that IPv6 is still ephemeral work-in-progress and not yet ready for widespread use, or that IPv6 has no market support. In this document, we attempt to largely dispel these notions as myths by presenting several sets of hard data that argue to the contrary. Companion documents debunk arguments where IPv4 is brought forward as a favored choice based on the logic that it has lower "overhead" than IPv6 [Eddy06], and provide a comparison of the relative features of IPv6 and IPv4 [EI06].

This document is broken down as follows. Section 2 contains discussion of the available specifications, their status as standards, and other informational materials regarding IPv6. Section 3 describes the availability of IPv6 support in common products, operating systems, and commercial routers. Section 4 contains some information on real-world usage of IPv6 which is currently happening, and Section 5 considers various policy directives and guidance on deploying IPv6. Finally, Section 6 then summarizes the results of this study.

2. Protocol Documentation

The IPv6 standard was the output of the IPng course of action to find a replacement for IPv4, given all of the lessons learned from IPv4 use over the years. While many people have the notion that the significance of IPv6 lies in a larger address space, an examination of the literature shows that this is only the tip of the iceberg, and the IPv4 address size was only one of around a dozen IPv4 aspects that it was seen necessary to change. The search tool on the rfc-editor.org website can be used to find many RFCs that document the history of the IPng process, and archived copies of expired internet-drafts with further details can also be found on the Internet. In April of 2006, a simple search on rfc-editor.org for "IPng" yielded 41 RFC documents, most of which are Informational and contain inputs to the IPng from representatives of various industry segments or researchers.

In December of 1995, RFC 1883 was published as a Proposed Standard for IPv6 [RFC1883]. Three years later, in December of 1998, RFC 2460 was published as a Draft Standard [RFC2460]. This basic specification that covers the IPv6 header format, required extension headers, fragmentation behavior, flow labels, traffic classes, and upper-layer protocol issues has remained unchanged since its publication. Accompanying documents that can be considered the core of IPv6 include the specifications for ICMPv6 [RFC2463], Neighbor Discovery [RFC2461], and Address Autoconfiguration [RFC2462], all of which have reached the Draft Standard level as well. Many protocols that are well-accepted by industry and in widespread use are only Proposed Standards, and not even formally at this level of maturity in the IETF process. All of this demonstrates that the core IPv6 specification is agreed upon and stable and has been for some time now.

Additionally, a very rough search on the rfc-editor.org website for "IPv6", turns up 166 documents. For the most part, these document IPv6 usage and interactions in conjunction with other protocols, or extensions to IPv6. This search is fairly conservative in that a much larger number of documents deal with IPv6 in at least some way, but are not indexed under the term "IPv6", and so do not turn up. We simply use the large number of results that do show up as evidence that integration of IPv6 with numerous link layers and extension of IPv6 has been actively pursued in industry, and a large number of supplementary standards have been produced. Among IETF working groups, the "Mobility for IPv4" group seems to be the only one specifically chartered to provide an IPv4-only protocol, whereas at least 8 others are chartered specifically to provide IPv6-based solutions, including:

- IPv6 over Low-Power WPAN (6lowpan)
- IPv6 Working Group (ipv6)
- Mobility for IPv6 (mip6)
- Mobile IPv6 Signalling and Handoff Optimization (mipshop)
- Mobile Nodes and Multiple Interfaces in IPv6 (monami6)
- Site Multihoming by IPv6 Intermediation (shim6)
- Site Multihoming in IPv6 (multi6)
- IPv6 Operations (v6ops)

Among other working groups, for example those focusing on security, application, or transport protocols, it seems that the vast majority are constructing protocols that will work with either IPv6 or both IPv6 and IPv4 (e.g. Host Identity Protocol). There is a clear sense of support for IPv6 in the standards community based on this survey of current IETF activities. From mailing list archives it can be seen that representatives from several large vendors and operators are active participants in the IPv6 groups, not merely academics.

In addition to the IETF, other bodies exist, such as the IPv6 Forum, to further the use and adoption of IPv6, and produce documentation and reccommendations on the topic. There are widely available training courses and materials, textbooks, and support services for IPv6 deployment, transition, and troubleshooting. A search on amazon.com for IPv6 books turned up 60 results. The next section of this document examines actual IPv6 implementations that are readily available.

3. Running Code

A large number of IPv6 implementations are available from both commercial vendors and the open-source community. The IPv6 Forum has created the "IPv6 Ready" Logo Program which consists of sets of criteria that can be used to assess the features and interoperability of IPv6 products. Phase-1 of this program judges implementations of basic or core IPv6 functions. Over 200 products have been certified to use the Phase-1 IPv6 Ready Logo. The Phase-2 Logo builds upon Phase-1 by adding tests for IPsec and mobility features. Several dozen products are on the approved list for Phase-2.

Major router vendors are serious about IPv6 and provide products that implement many advanced features in addition to the IPv6 base. Cisco, for instance, has a webpage that lists dozens of specific IPv6 services and details which versions of their IOS software implement the features and where documentation on configuring them can be found (http://www.cisco.com/en/US/products/sw/iosswrel/ps5187/products_configuration_guide_chapter09186a00801d65ed.html). Similarly, Juniper has supported IPv6 basic functions since 2001 in JUNOS 5.1 [Shimizu01], and supports IPv6 across their product line [Uze02].

IPv6 support is built into many off-the-shelf end-host operating systems as well. Microsoft's Windows Server 2003, Windows XP (Service Pack 1 or 2), and Windows CE .NET all support IPv6. Apple's MacOS 10.3 and Sun's Solaris 8 similarly have built-in support for IPv6. The Japanese KAME project developed IPv6 support for the open-source BSD-based operating systems, and Linux has had IPv6 support since the 2.2 kernel.

Additionally, many common consumer devices come with IPv6. For instance, the 3GPP and 3GPP2 cellular telephony groups have made IPv6 a part of the IP Multimedia System (IMS). IPv6 capable, or dual-stack cellular handsets have been available for some time (the Nokia 7700 is an example), and a dual-stack takes up only about 15% more space on the device than an IPv4-only stack [Loughney04]. Sony's Playstation 2 and Microsoft's X-Box video game consoles are both IPv6-enabled and widely deployed.

4. Real-World Deployment

In this section, we examine evidence that the IPv6 Internet is currently operational. This evidence comes from four main sources (1) known IPv6 exchanges and peering services, (2) reports from the RIRs on IPv6 allocations, (3) BGP announcements, and (4) measurements of 6-to-4 gateways. All of this evidence suggests that IPv6 is nearing a critical mass of operational use.

The www.v6nap.net web site lists 18 exchanges that support IPv6 throughout the United States, South Korea, the Netherlands, Finland, France, Germany, Japan and the UK. As an example, the MAE exchange (operated by Verizon Business) is really a number of facilities consisting of four main locations in the United States, one in Paris, France, and one in Frankfurt, Germany. Each of these facilities may actually extend to a number of physical sites throughout a number of nearby cities. A customer's routers connect to switches at a MAE site over which they can interface with other customer's routers to exchange traffic. Currently, all of the MAE facilities are capable of exchanging IPv6 traffic. The same switches are used to support both IPv4 and IPv6, accros a number of access types (ATM, Frame Relay, or Gigabit Ethernet). Native IPv6, dual-stack, and tunneled connections are supported at the customer's discretion. New IPv6 native exchange point addresses are available upon request from MAE, and IPv6 addresses are automatically provided to customers with current IPv4 addresses at an exchange. More information can be found at www.mae.net.

IPv6 address blocks are assigned by IANA to the five Regional Internet Registries (RIRs). The RIRs then further distribute smaller blocks of addresses to IPv6 ISPs and other Local Internet Registries (LIRs). Each of the five RIRs publishes some statistics on the prefixes that they have delegated. Examination of some recent reports of these statistics allows us to count the number of IPv6 prefixes delegated, as well as the Autonomous System Numbers (ASNs) assigned (note that the percentage presented that compares the number of IPv6 prefixes to the number of ASNs is not a completely valid way to measure IPv6 adoption for a number of reasons):

AfriNIC (April 24, 2006): 11 IPv6 prefixes (220 ASNs - 5%)

APNIC (April 24, 2006): 436 IPv6 prefixes (2162 ASNs - 20.2%)

ARIN (April 24, 2006): 247 IPv6 prefixes (16729 ASNs - 1.5%)

LACNIC (April 21, 2006): 54 IPv6 prefixes (1060 ASNs - 5.1%)

RIPE NCC (April 21, 2006): 761 IPv6 prefixes (11437 ASNs - 6.7%)

This data indicates that IPv6 addresses have been assigned to a fair number of LIRs, especially in the Asia-Pacific region. The current policies for IPv6 allocation from the RIRs do not allow address blocks to be assigned to end-sites (although this may be changed soon), whereas this is not the case in IPv4, so the number of ASNs reflects a number of IPv4 end-sites that are not eligible for IPv6 address blocks from an RIR, and thus the number of locations where IPv6 is usable is actually much greater than the percentages of prefixes over ASNs reported here. If Provider Independent addressing for IPv6 became popular with the RIRs, then we would expect these percentages to more accurately reflect the penetration of IPv6. Since ASNs may correspond to multiple prefixes, at full adoption, these would go somewhere above 100%.

In April of 2006, Geoff Huston's BGP analysis tool (bgp.potaroo.net/v6/as6447) sshows between 721 active IPv6 BGP entries. Among these, 589 unique AS numbers appear, with 419 origin-only ASes, 12 transit-only ASes, and the remainder mixed. These BGP observations show that there is a global IPv6 routing table with a reasonable number of sites contained in it.

6-to-4 [RFC3056] is a transition mechanism that tunnels IPv6 over IPv4 packets for transit across the network. Pekka Savola has studied the traffic at a public 6-to-4 gateway [Savola04]. This was only considered to be a relatively small, or lightly-used, 6-to-4 gateway, it still was probed by 2 million Windows hosts, and actively used by over 1000 nodes per month in 2004. DNS traffic, as well as SSH, HTTP, SMTP, and BitTorrent file sharing were all observed over the 6-to-4 gateway, indicating that typical Internet applications are functioning over it.

5. Policy Directives

Among US government agencies, the Department of Defense (DoD) was an early recognizer of the benefits of IPv6 and began the deployment and transition process before most other federal agencies even considered IPv6. the DoD has a number of useful resources for IPv6, including a set of feature profiles for judging aquisitions against [Green05]. The DoD has announced plans to fully transition to IPv6 by fiscal year 2008.

In 2005, the Government Accountability Office (GAO) recomended to the Office of Management and Budget (OMB) that other federal agencies should follow DoD's lead and begin planning for a move to IPv6 [GAO05]. Following this, it was announced that June 2008 was the deadline for all agencies to support IPv6 in their operational networks [Evans05].

Plans for the 2008 Olympics in China involve IPv6 as a prominent means of connecting millions of users to various types of multimedia content [Chi-Loong05]. In general, the growth in the "online population" in Asian countries is causing IPv6 to be eager to deploy IPv6.

Since IPv6 several of the features of IPv6 can be back-ported or hacked into an IPv4 architecute through various means, IPv6 has been portrayed as unecessary or lacking a killer-application by many pundits. That these opinions are not very well informed from a standpoint of network architecture, where attempting to make IPv4 do things that it was not designed for make the network more fragile. For instance, the use of NAT to get around addressing limitations in IPv4 is well-known to have poor architectural implications [RFC2993]. Unfortunately, US businesses still seem to be stalling on IPv6 deployment, however, the recent government action in this area may serve to motivate the private sector to some extent.

6. Summary of Findings

The general result of this study is that IPv6 can be used at the present time, and is being deployed in diverse settings (from mobile phones and video games to government systems).

The technical advantages, ease of availability, and policy directives regarding IPv6 combine to make it the strongly favored option for use in present network design efforts.

7. Security Considerations

This informational document only contains data about IPv6 maturity. There are no new security considerations raised by this material.

8. Acknowledgements

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9. Informative References

[Chi-Loong05]
Chi-Loong, C., "China's IT Gold", CMPnetAsia Newsletter , December 2005.

[EI06] Eddy, W. and J. Ishac, "IPv6-IPv4 Feature Comparison", draft-eddy-ipv6-ipv4-comparison-00 Internet-Draft (work in progress), May 2006.

[Eddy06] Eddy, W., "Comparison of IPv4 and IPv6 Header Overhead", draft-eddy-ipv6-overhead-00 Internet-Draft (work in progress), May 2006.

[Evans05] Evans, K., "Transition Planning for Internet Protocol Version 6", Office of Management and Budget, Memorandum for the Chief Information Officers M-05-22, August 2005.

[GAO05] GAO, "Federal Agencies Need to Plan for Transition and Manage Security Risks", GAO report to congressional requesters GAO-05-471, May 2005.

[Green05] Green, D., "DoD IPv6 Standard Profiles for IPv6 Capable Products", DISA draft for coordination, Draft v.06, December 2005.

[Loughney04]
Loughney, J., "IPv6 in 2G and 3G Networks", North American IPv6 Summit 2004, June 2004.

[RFC1883] Deering, S. and R. Hinden, "Internet Protocol, Version 6 (IPv6) Specification", RFC 1883, December 1995.

[RFC2460] Deering, S. and R. Hinden, "Internet Protocol, Version 6 (IPv6) Specification", RFC 2460, December 1998.

[RFC2461] Narten, T., Nordmark, E., and W. Simpson, "Neighbor Discovery for IP Version 6 (IPv6)", RFC 2461, December 1998.

[RFC2462] Thomson, S. and T. Narten, "IPv6 Stateless Address Autoconfiguration", RFC 2462, December 1998.

[RFC2463] Conta, A. and S. Deering, "Internet Control Message Protocol (ICMPv6) for the Internet Protocol Version 6 (IPv6) Specification", RFC 2463, December 1998.

[RFC2993] Hain, T., "Architectural Implications of NAT", RFC 2993, November 2000.

[RFC3056] Carpenter, B. and K. Moore, "Connection of IPv6 Domains via IPv4 Clouds", RFC 3056, February 2001.

[Savola04] Savola, P., "Observations of IPv6 Traffic on a 6to4 Relay", ACM Computer Communication Review, Volume 35, Number 1, January 2005.

[Shimizu01] Shimizu, T., "Juniper Networks IPv6 Implementation", Global IPv6 Summit, Yokohama, Japan, December 2001.

[Uze02] Uze, J., "Juniper IPv6 Solution", RIPE 42, IPv6 WG, May 2002.

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