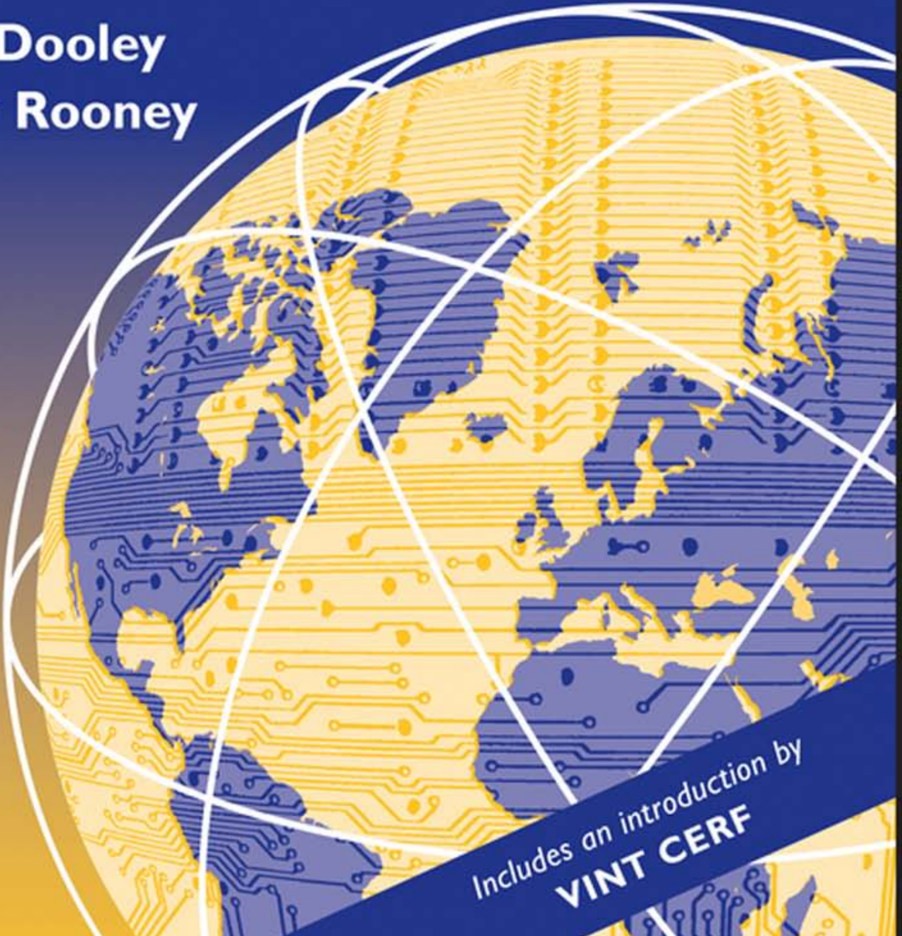
IPv6 DEPLOYMENT AND MANAGEMENT

Michael Dooley
Timothy Rooney



Includes an introduction by
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Michael would like to dedicate this book to his parents

Timothy would like to dedicate this book
in memory of his mother, Kathryn
"Kitty" Rooney

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INTRODUCTION

Nearly 14 years have passed since RFC2460 was published, specifying the IPv6 packet format. Authored by Steve Deering and Bob Hinden, this document represented nearly 8 years of debate beginning in the early 1990s over how the Internet's 32-bit IPv4 address space could be expanded. There were four proposals for what was called "IPng" for IP next generation. I won't catalog them here except to say they varied dramatically in their functionality. There was even a fifth proposal to adopt the OSI connectionless networking protocol format (CLNP) that provoked howls of outrage from many passionate engineers in the Internet Engineering Task Force (IETF) where this problem was near the top of the agenda.

After all the debate, the cochairs of the IPng Working Group, Deering and Hinden, recorded the results in December 1998 and submitted them as RFC 2460 to the Internet Engineering Steering Group (IESG) for release to the RFC editor. Many of us hoped there would be an immediate effort to implement this protocol. There was great concern that the rate of consumption of the Internet address space was accelerating during the period now known as the "dot-boom." New Internet companies were popping up like mushrooms after a spring rain. But at the same time that the IPng debates were taking place, another effort to restrain IPv4 address consumption, through reinterpretation of the bits of the address structure, was in full swing. The so-called classless interdomain routing system made much more efficient use of address space by allowing any bit boundary in the address structure to mark the dividing line between "network" and "host." In addition, the concept of autonomous system (AS) was introduced through which to associate indicators (masks) illustrating where this boundary lay. The Border Gateway Protocol was revised to take into account the masks marking network and host extents in the address format. Together with rules to guide very conservative IPv4 address allocations by the Regional Internet Registries, the rate of consumption of IPv4 address space was substantially curtailed. So much so that the pressure to implement IPv6 generally dissipated.

Network address translation (NAT) functionality was also introduced to allow multiple devices using private IP address numbering to share a single public address space. Port numbers were used in the NAT boxes to map to/from public addresses and the private addresses associated with individual devices in a local network. This practice attracted cable and telecommunications providers who were offering Internet service because they could now maximize the number of devices that could share one "public" IP address. This improved the absolute number of customers they could sign up to be subscribers to their Internet service.

These various practices actually stretched the use of IPv4 addresses until February 2011 when the Internet Assigned Numbers Authority (IANA), operating under the auspices of the Internet Corporation for Assigned Names and Numbers, announced that it had exhausted the supply of IPv4 addresses at the source of its allocation. The Regional Internet Registries (ARIN, LACNIC, RIPE-NCC, AFRINIC, APNIC) still had allocations but APNIC soon exhausted its supply in April 2011 and RIPE-NCC has announced that it has exhausted its supply in September 2012. A market for IPv4 address space has formed but it cannot possibly solve the real need.

The "Internet of Things" is upon us. Mobiles using LTE for data transfer will need end-to-end communication capability. The same may be said for set-top boxes, sensor devices, Internet-enabled automobiles, countless household and office appliances, and, eventually, personal devices that may even be embedded or attached in some way to our bodies. The only sensible solution is to implement IPv6 addressing capability *in parallel* with IPv4. We cannot simply "throw a switch" to convert every device on the Internet from IPv4 to IPv6 addressing. The transition will take years.

This long transition leads to the need for very thoughtful design and implementation of control and management systems that can deal with both IPv4 and IPv6 operating concurrently in the network and in many devices. We cannot even try to form enclaves that are IPv4 only or IPv6 only for "simplicity." Devices that are mobile or portable will regularly encounter both IPv4 and IPv6 and mixed environments. There is also a very good chance that areas of the Internet will be IPv6 only for lack of IPv4 address space. Complex environments involving NATted IPv4 and end-to-end IPv6 will also be encountered. It is no wonder that a book of this kind, written by Michael Dooley and Timothy Rooney, will be needed on every Internet engineer's bookshelf (or in his laptop or pad or mobile, cloud client, and digital reader).

Configuration and network management are hard. Dealing with them in a mixed IP packet format environment is even harder. Error messages will be generated for both protocols even if a common fault, for example, a fiber cut, is the proximate cause. Network management systems will need to become much smarter about filtering, correlating, and sorting various error and status or warning messages emerging from a mixed IP addressing environment. The mere fact that the packet headers are potentially larger in IPv6 will create the potential for fragmentation or at least complicate the discovery of the minimum packet size needed to avoid fragmentation of blockage. These are just a few of the questions that need answering. Any system architect preparing to cope with a dual-stack environment will find this book a useful companion and source of advice.

It is not too late to start implementation but it is surely timely. The rest of this decade will see major changes and extensions to the Internet in many dimensions, not the least of which is a massive increase in the number of devices that can be attached and referenced in the system.

Some ISPs have been heard to say "customers are not asking for IPv6" as an excuse to delay implementation. From where I sit, customers should have to know nothing about IPv6. They should have a reasonable expectation that their ISPs will implement dual stack without their asking. It is irresponsible not to move rapidly to deployment of dual stack before there is no more IPv4 address available, even through NAT mechanisms. We must complete the transition to a fully connected IPv6 network as soon as possible. This does not mean we have to abandon the use of IPv4, only that we need connectivity as complete with IPv6 as we have had with IPv4—and we need it now.

Vint Cerf

VP and Chief Internet Evangelist Google

CHAPTER 1

IPv6 DEPLOYMENT DRIVERS

1.1 THE INTERNET: A SUCCESS STORY

The Internet has come a long way. Invented in the late 1960s as a resilient interconnected network of networks for the U.S. Department of Defense, it has evolved into a global communications phenomenon. With the invention of the World Wide Web by Tim Berners-Lee, defining the hypertext linking of information over a network such as the Internet through the use of a web browser, this innovation of simple point-and-click user interface brought the Internet out of government and science laboratories and into ordinary people's lives. Email was the second key Internet application that contributed to the widespread adoption of Internet services during the mid-1990s. Today's Internet users generally find this ubiquitous availability of wide variety of information and applications indispensable in their day-to-day lives. If popular Internet applications like Facebook, YouTube, Twitter, Google, Blogger, shopping, and news sites, and even good old email were suddenly rendered unavailable, most people would not know what to do with themselves!

But the abundance of information and applications on the Internet is not universally available worldwide today. Figure 1-1 illustrates the statistics reported by Internet World Stats indicating the penetration of Internet users as a percentage of overall population in various regions of the world as of mid-2012. Just over one-third of the world's population has access to and use the Internet from work, home, mobile, or wireline. Penetration in North America is highest among the measured regions at more than 78% with Europe second at 63%. Among the Asian population, penetration is only about 28%.

Looking at the same data from a raw numbers perspective, Figure 1-2 illustrates the distribution of Internet users throughout the world. Comparing Figures 1-1 and 1-2, note that while Internet penetration in Asia is less than 28%, the number of users in Asia tops 1 billion, representing 45% of global Internet users, estimated at 2.4 billion by Internet World Stats.

With worldwide penetration of Internet users at just 34%, there seems to be plenty of room for an expanding Internet population. And with the likelihood of multiple devices required per user, this expansion will create accelerated demand for Internet Protocol (IP) addresses. But what circumstances would facilitate such expansion? A recent study by the World Bank concluded that in low- and middle-income countries, for every 10% increase in Internet penetration, the country's average economic growth increases by 1.12% as measured by gross

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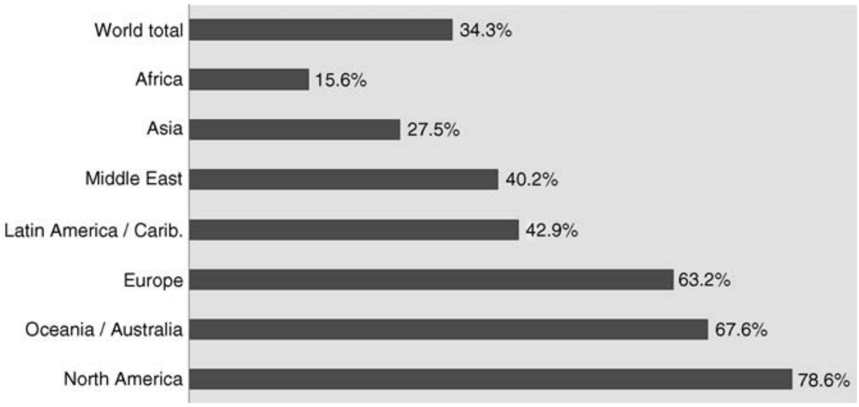

Figure 1-1. Internet penetration by region [1].

domestic product (GDP) [2]. A 10% increase in broadband penetration yields an average GDP increase of 1.38%. The report also extols other socio-economic benefits for broadband deployment including higher employment, expanding entrepreneurial opportunities, providing social contacts, and delivering public information-based services. While some governments may desire to restrict free access to certain content or applications, the economic correlation to Internet growth is difficult to ignore.

And trends leading up to the present time indicate strong growth over the last decade. Figure 1-3 illustrates growth in Internet users and penetration. These appear to be directly proportional. The compound annual growth rate (CAGR) over this time period, by region, is represented in Table 1-1 and averaged 18% worldwide.

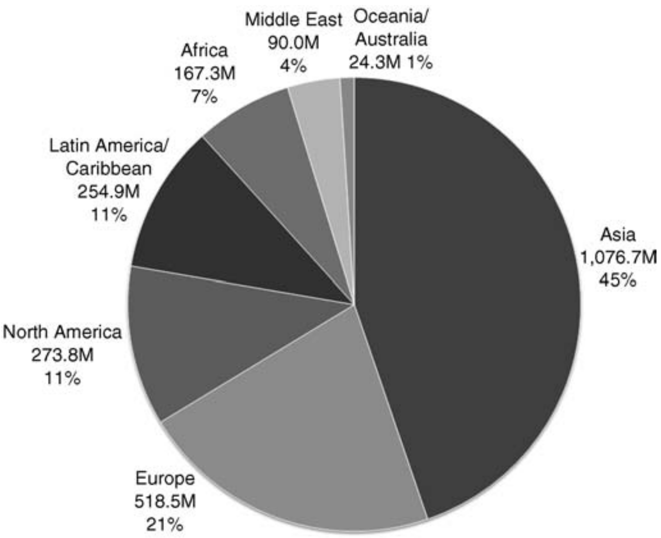

Figure 1-2. Worldwide Internet users by region [1].

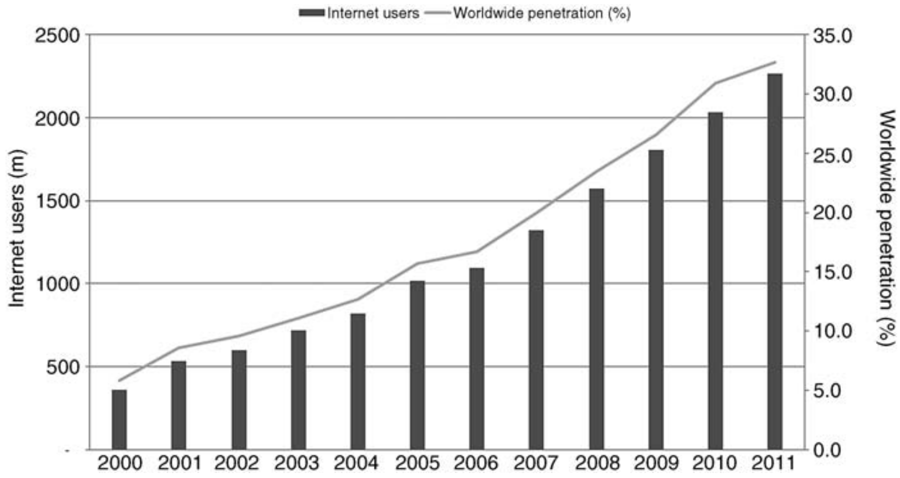

Figure 1-3. Internet users history [1].

The number of content providers or "producers" on the Internet as measured by the number of new websites is also growing at an increasingly rapid rate according to Netcraft [3], an Internet research and security services firm. As of June 2012, the total number of discovered unique website hostnames reached nearly 700 million, while active (non-template, based solely on domain registration) sites approached 200 million as shown in Figure 1-4. Both metrics have increased at an accelerated rate over the past two years. New organizations beyond some point in time desiring to operate their own websites or hosting providers will eventually only have access to IPv6 address space for publishing web content.

1.1.1 Supply-Side Issues

Given this history of sustained growth of Internet users and content suppliers, the relatively modest penetration rates, and the economic benefits of broadband deployment and Internet access, it's reasonable to predict that Internet user and producer

TABLE 1-1. Worldwide Internet User Growth per Region

Internet users (M)	2000	2011	CAGR (%)
Africa	4.5	139.9	37
Asia	114.3	1016.8	22
Europe	105.1	500.7	15
Middle East	3.3	77.0	33
North America	108.1	273.1	9
Latin America/Caribbean	18.1	235.8	26
Oceania/Australia	7.6	23.9	11
Worldwide total	361.0	2267.2	18

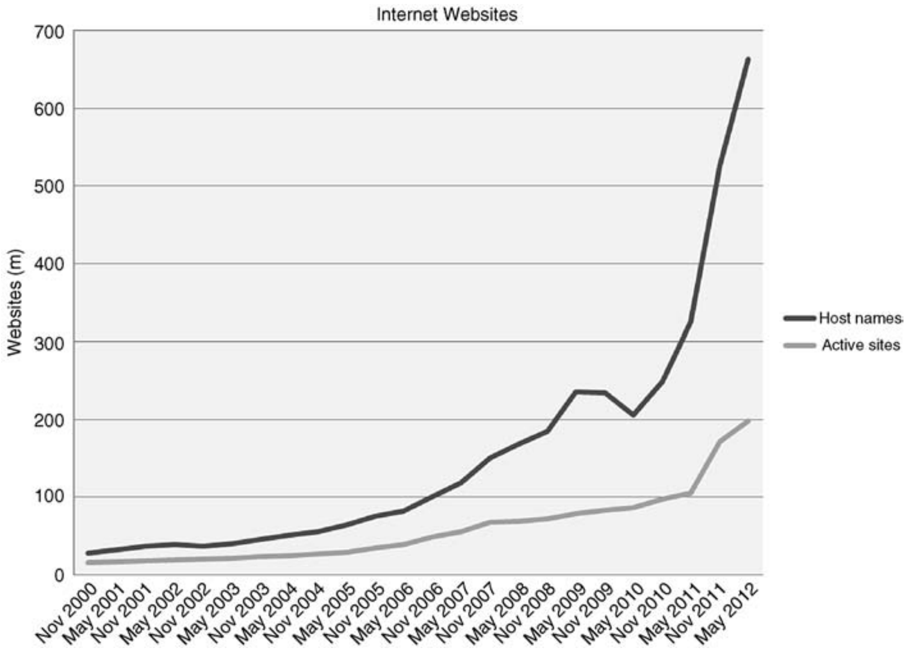

Figure 1-4. Measured quantity of Internet websites [3].

demand will continue to grow. Unfortunately, the currently available capacity of IPv4 addresses to support this growth is insufficient. With IPv4 address space depleted, for all intents and purposes, the only Internet Protocol available to support this demand is IPv6.

When the Internet Assigned Names and Numbers Authority (IANA) announced, on February 3, 2011, that it had allocated its last remaining IPv4 address space to the Regional Internet Registries (RIRs), that day was the beginning of the end of the Internet as we know it. Figure 1-5 illustrates the IP address space "food chain," with IANA allocating base address blocks to RIRs. IANA is a department within the Internet Corporation for Assigned Names and Numbers (ICANN), which itself is a not-for-profit public-benefit corporation with participants from around the world. IANA is the centralized coordinating body for Internet domain names managing the Domain Name System (DNS) root and several other top-level domains, Internet number resources (IP addresses), and protocol assignments (protocol-specific parameters, e.g., Dynamic Host Configuration Protocol (DHCP) option number assignments).

The RIRs are organizations responsible for allocation of address space within their respective global regions from their corresponding space allotments from IANA:

- AfriNIC (African Network Information Centre)—Africa region
- APNIC (Asia-Pacific Network Information Centre)—Asia-Pacific region
- ARIN (American Registry for Internet Numbers)—North America region including Puerto Rico and some Caribbean Islands

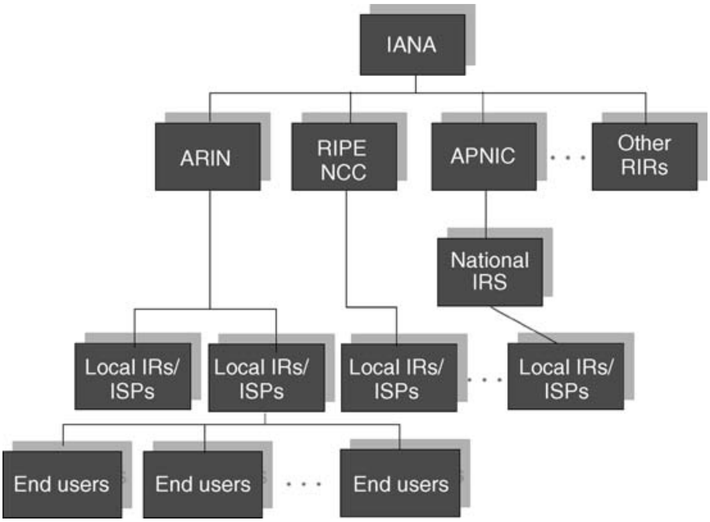

Figure 1-5. The IP address space hierarchy [4].

- LACNIC (Regional Latin-American and Caribbean IP Address Registry)—Latin America and some Caribbean Islands
- RIPE NCC (Réseaux IP Européens Network Coordination Centre)—Europe, the Middle East, and Central Asia.

The RIR system was established with the following goals for IP address allocation to National Internet Registries, Local Internet Registries (LIRs), and Internet Service Providers (ISPs):

- *Uniqueness*. Each IP address must be unique worldwide for global Internet routing.
- *Aggregation*. Hierarchical allocation of address space assures proper routing of IP traffic on the Internet. Without aggregation, routing tables become fragmented which could ultimately create tremendous bottlenecks within the Internet.
- *Conservation*. With IPv4 in particular but also for IPv6 space, address space needs to be distributed according to actual usage requirements.
- *Registration*. A publicly accessible registry of IP address assignments eliminates ambiguity and can help when troubleshooting. This registry is called the *whois* database. Today, there are many whois databases, operated not only by RIRs but also by LIR/ISPs for their respective address spaces.
- *Fairness*. Unbiased address allocation based on true address needs and not on long-term “plans.”

Despite efforts to extend the lifetime of IPv4 through technologies such as Network Address Translation (NAT) and Classless Inter-Domain Routing (CIDR) as well as RIR policies enabling sales and transfers of IPv4 address space, eventually the RIRs will each allocate their last vestige of IPv4 address space to their constituents. The ISPs then in turn will eventually exhaust their IPv4 resources for distribution to their customers, generally enterprise businesses. The APNIC and RIPE NCC RIRs have already exhausted their respective IPv4 space.

1.1.2 Internet at a Crossroads

So what does all this mean? When IPv4 address space runs out among the ISPs within a given RIR's region, any new organization requiring IP address space or existing organizations requiring supplemental IP address space in that region will, by necessity, receive an IPv6 address space allocation. As new organizations initiate web presences, they will be accessible only by IPv6. As new "IPv6-only" organizations join the web, the composition of the Internet itself will slowly change from the homogeneous IPv4 Internet available today to a mixed IPv4/IPv6 Internet in the future. How quickly and to what levels this IPv6 density within the Internet will rise is uncertain.

The growth in number of IPv6-only users is expected to surface initially in Asia. The economies of major Asian countries, particularly China and India, have grown more rapidly in recent years than the rest of the world according to the International Monetary Fund [5] as illustrated in Figure 1-6. From 2000 through 2011, the average annual GDP growth in China was 10.2% and India was 7.1%, while the world average was 2.7%. This in turn has led to rising disposable incomes and government infrastructure investment in communications technologies such as broadband and wireless. Point Topic Ltd estimated that nearly half of the world's broadband net additions for the first half of 2012 were in Asia [6]. Point Topic's report also mirrored that of Internet World Stats, which reported that while Asia boasts the most Internet users at over one billion, its Internet penetration rate is below the world average (33%) at 26%.

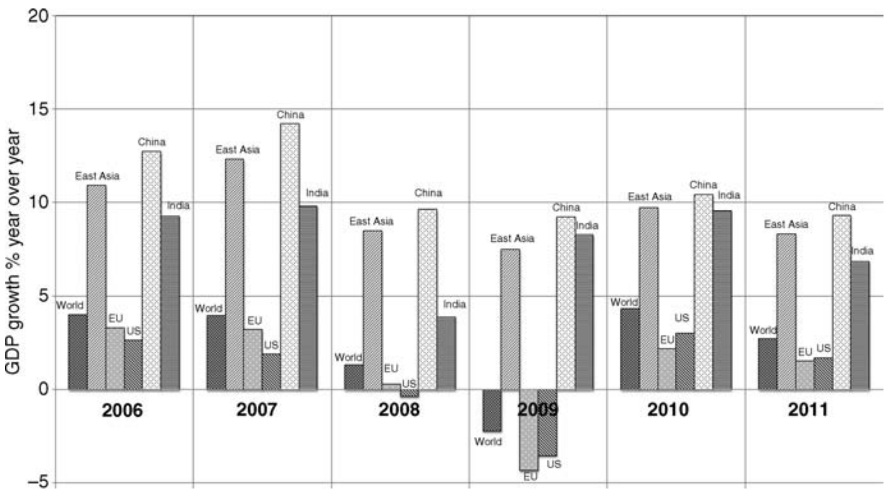

Figure 1-6. GDP growth 2006–2010 [7].