

## Whitepaper

# The Transition to IPv6... the Bottom Line

## Executive Summary

With a skyrocketing population of Internet users worldwide and an explosion of 'smart' Internet-enabled devices ranging from tablets to appliances, global Internet trends are taxing the existing Internet Protocol, IPv4, which has been in place since 1981. On February 4th, 2011, the International Corporation for Assigned Names and Numbers (ICANN) handed out the last remaining IPv4 address blocks.

IPv6 has been designed to supplement and eventually replace IPv4, offering more than enough unique IP addresses for every networked device on the planet. With its vast address capacity, **IPv6 eliminates the threat of IP address depletion, as well as offers numerous benefits, including simpler address management** (no need for NAT or private addresses) **and greater security with IPsec**. This whitepaper discusses the differences between IPv4 and IPv6 versions, provides the latest updates on IPv4 address availability, and explores the transition to IPv6.

## Background: IPv4

IPv4 is the most widely used version of the Internet Protocol today. Designed in the 1970s, IPv4 defines IP addresses in a 32-bit format consisting of four 'octets' (8-bit numbers), separated by a '.', e.g., 192.168.1.1.

Each octet can represent a number from 0 to 255, meaning...

The total number of IPv4 addresses equals 4,294,967,296 (or 2 to the 32nd power)

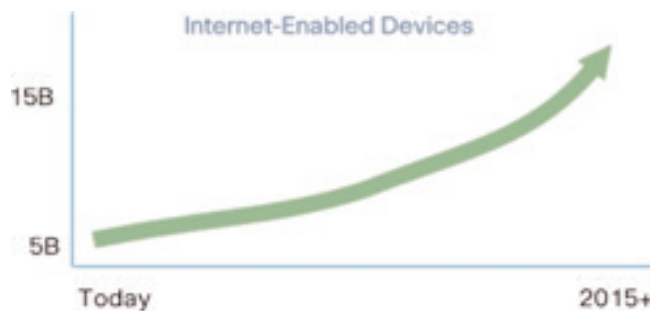
Back in the early 1980's, when the only devices with Internet access were computers associated with the military or research organizations, 4 billion possible addresses seemed like a virtually endless horizon. However, fast forward to today, with a skyrocketing global population of connected users, and we've reached the end of available addresses.

## The Growing Internet: The Next Billion Internet Users

Considering there are well over 6 billion people worldwide and many people already have more than one device connected to the Internet (home, school, work), it becomes quite clear that 4 billion IP addresses is not enough to sustain our global population and the growing demand for IP services. Over the past decade, we've seen an explosion of Internet-enabled devices, from smartphones and tablets, to networked cameras, printers, televisions, and smart grid appliances. In the book *Migrating to IPv6: A Practical Guide to Implement IPv6*, Marc Blanchet wrote,

**"Many experts predict that there will be billions of terminal devices on the Internet, perhaps as many as 100 per user."**

Figure 1: Number of Internet-Enabled Devices



Source: Cisco VNI / Intel Embedded Internet Projections

### IPv4 and Network Address Translation

To help delay the time when the number of addressable IP endpoints exceeds the number of available IPv4 addresses, **Network Address Translation (NAT) emerged as a stopgap measure**. NAT allows a single device (i.e. a firewall, router, or computer) to act as an intermediary between the Internet (public network) and a local network. This means that a single IP address can represent an entire group of computers to anything outside of their network; for example, all devices in a home are typically connected to the Internet using a single IP address by a router which uses NAT.

However, by nature, NAT complicates the Internet's architecture and runs contrary to principles of network openness. Devices that sit behind NATs do not have true end-to-end connectivity, which complicates the deployment of innovative applications, such as Internet telephony, video conferencing, and online gaming.

## Introducing IPv6

IPv6 is the next Internet Protocol version designed to supplement and eventually replace IPv4 altogether (note: IPv5 never became an official protocol...it was designated as Internet Stream Protocol, an experimental real-time streaming protocol that has since been abandoned).

An IPv6 address is four times as large as an IPv4 address, moving from a 32-bit system to a 128-bit. This allows for a theoretical maximum number of 2 to the power 128 address, or:

340,282,366,920,938,000,000,000,000,000,000,000,000,000 unique IP addresses.

It's an unthinkable theoretical maximum: 340 undecillion, 282 decillion, 366 nonillion, 920 octillion, 938 septillion... In short, **IPv6 provides more than enough unique IP addresses for every network device on the planet**, and can meet the requirements of new and emerging Internet applications, such as:

- Internet-enabled home appliances
- Internet-enabled wireless devices
- Sensor networks such as RFID
- Distributed gaming

While IPv4 addresses are 32 bits long, written in decimal, and separated by periods, IPv6 addresses are 128 bits long, written in hexadecimal and separated by colons. For example:

2620:0:1cfe:face:b00c::3 (Facebook's IPv6 address)

IP Version	IPv4	IPv6
Date deployed	1981	1999
Address size	32-bit number	128-bit number
Address format	Dotted Decimal Notation: 192.0.2.76	Hexadecimal Notation: 2001:0DB8:0234:AB00: 0123:4567:8901:ABCD
Number of addresses	$2^{32} = 4,294,967,296$	$2^{128} =$ 340,282,366,920,938,463, 463,374,607,431,768,211, 456
Examples of prefix notation	192.0.2.0/24 10/8 (a "/8" block = 1/256th of total IPv4 address space = $2^{24} = 16,777,216$ addresses)	2001:0DB8:0234::/48 2600:0000::/12

Source: ARIN, IPv4 Depletion/IPv6 Adoption. August 2010.

## IPv6: Each Device Gets a Public IP Address

IPv6 negates the need for Network Address Translation, because each device that needs to be connected to the Internet can now have its own unique IP address. This represents a significant shift in network implementation and will give rise to a new generation of innovative, real-time peer-to-peer applications. In business, new machine-to-machine communications can further automate supply chain and other operational processes. And for consumers, IPv6's vast address capacity supports an "Internet of Things," where everyday objects, from printers to garage door openers and toasters, are equipped with embedded intelligence and the ability to communicate over the Internet directly with any other IPv6-enabled device on the planet.

Contrast this to IPv4, where most devices sit behind a NAT (the home router or firewall), and are assigned a 'private' (non-routable) address. Accessing this device from the Internet can be difficult or impossible using IPv4. Let's consider the example of the consumer who installed an Internet-enabled security camera so she can keep an eye on her home while traveling. With the current IPv4 structure, this camera sits behind a NAT (the home router or firewall) — and port forwarding is required in order to access the camera from outside the home network. **With IPv6, the camera is assigned its own public IP address. From anywhere, the homeowner can simply enter the camera's IP for direct access to the device.**

## IPv6 and Security

Since all devices will have a public IP address, security becomes all the more critical with IPv6. As a result, the IP Security protocol suite (IPsec) is an integral part of the IPv6 architecture. IPsec allows a secure association to be set up between two devices by the exchange of cryptographic keys at the beginning of the session which are used to encrypt and decrypt data exchanged between the devices. **With IPsec, it becomes much harder for hackers to gain access to your devices, or your data.**

## IPv6 Benefits

- Abundance of IP addresses enables each device and object to have its own globally unique IP address — eliminates the need to deploy and manage NAT devices.
- More flexible and simpler address plan management — no need for private addressing (like in IPv4) in the enterprise
- Intrinsic security from use of IPsec
- Native support for mobile devices
- Hierarchical, more efficient routing infrastructure — backbone routers on the IPv6 Internet have much smaller routing tables than IPv4
- Extensibility for new features based on IPv6 header structure

## The End of IPv4 Addresses

In February 2011, the Internet Assigned Numbers Authority (IANA) allocated the last remaining IPv4 addresses. In a ceremony in Miami, the final five blocks of IPv4 addresses were given out to the five Regional Internet Registries (RIRs) who assign IP addresses throughout the world. Of course, **the five RIRs still have tens of millions of addresses as working inventory**, but once those addresses have been assigned, it signals the end of IPv4. While no one can predict the final exhaustion date of IPv4 in each of the five regions, we know it's inevitable and could occur during 2011.

According to Raul Echeberria, Chairman of the Number Resource Organization (NRO), the official representative of the five RIRs, "Each RIR will have its final full /8 from IANA, plus any existing IP address holdings to distribute. Depending on address space requests received, this could last each RIR anywhere from a few weeks to many months. It's only a matter of time before the RIRs and Internet Service Providers (ISPs) must start denying requests for IPv4 address space. Deploying IPv6 is now a requirement, not an option."

### Slow pace of IPv6 Adoption

Work on IPv6 first began in 1993 when IETF forecasts showed IPv4 depletion between 2010 and 2017. Yet while the standard has been available for production since 1999, widespread implementation has been slow. Back in 2006, Marc Blanchet wrote in *Migrating to IPv6*, "The transitional introduction of IPv6 will take place over a period of years if not decades."

In September 2010, the NRO (Number Resource Organization), which represents the world's five regional Internet registries, released the results of a global survey that found that only 25 percent of ISPs are offering IPv6 services to customers, although 84 percent either have IPv6 address allocations or plans to get them. Of those providers offering IPv6 services, 98 percent said that the volume of traffic is negligible to insignificant. Of those not offering the services, most cite a lack of customer demand and lack of expertise in managing IPv6 as the reason.

So, what happens when all the available IPv4 addresses are finally exhausted? Existing devices and networks that already connect to the Internet through IPv4 addresses will continue to work as normal. But network operators and other organizations that rely on Internet numbering allocations will find it increasingly difficult (and expensive) to obtain new IPv4 addresses to grow their networks; they will have to either reorganize their current allocation, or acquire new address blocks from someone else. As a result, managing the remaining IPv4 address space will become increasingly complex and competitive.

## IPv6 Migration: A Technical Overview

**Until the day when IPv6 completely replaces IPv4, several transition strategies have been developed to support a mixed IPv4/IPv6 environment.** For example, IPv6-only hosts will need to reach IPv4 services, and IPv6 hosts will need to reach the IPv6 services over an IPv4 infrastructure. There are three main technology types: Dual Stack, Tunneling, and Translation.

## a. Dual Stack

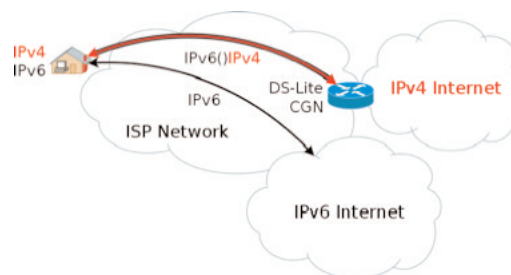
Dual Stack implements both IPv4 and IPv6 protocols in the network layer at the same time. A Dual Stack device can speak equally to IPv4 devices, IPv6 devices, and other Dual Stack devices (where the two devices agree on which IP version to use). The process is typically driven by the DNS; a Dual Stack device queries the name of the destination. If the DNS responds with an IPv6 address, then the Dual Stack device sends IPv6 packets.

This approach offers a very flexible coexistence strategy, by allowing hosts to simultaneously reach IPv4 and IPv6 content. Dual Stack enables networks to support both IPv4 and IPv6 services and applications during the transition to IPv6. However, there is a key drawback: an IPv4 address must be retained by the Dual Stack device; consequently, Dual Stack cannot be considered a long term solution for solving IPv4 address depletion.

### *Dual Stack Lite*

To resolve the issue of deploying both an IPv4 and IPv6 address, Dual Stack Lite was designed to let Internet Service Providers deploy only an IPv6 address to the customer's CPE (omitting the IPv4 address). In this case, the CPE device distributes private IPv4 addresses for any of the LAN clients in the home, much like a NAT device. However, instead of performing the NAT itself, the CPE device encapsulates the IPv4 packet inside an IPv6 packet and delivers the packet to the ISP's Carrier Grade NAT (CGN) which has a global IPv6 connection. The original IPv4 packet is restored, and then routed to the public IPv4 Internet. This scheme is shown in Figure 2.

Figure 2: Dual Stack Lite



Source: File:DSLite.svg, Wikipedia, June 5, 2010

## b. Tunneling

In general, tunneling is used to enable new networking functions while still preserving the underlying network. In the case of IPv6 transition, tunneling enables IPv6 hosts and routers to connect to other IPv6 hosts and routers over the existing IPv4 Internet. The

main role of tunneling is to support the deployment of IPv6 while maintaining compatibility with the vast existing base of IPv4 infrastructure. IPv6 tunneling encapsulates IPv6 datagrams within IPv4 packets, in effect, using IPv4 as a link layer for IPv6.

There are several different tunneling technologies:

### Automatic Tunneling Protocols

- **6 to 4:** Defined in RFC 3056, 6 to 4 is an automatic tunneling method that allows IPv6 sites to communicate with each other over the IPv4 network without an explicit tunnel setup. Tunnel endpoints are determined using a well-known IPv4 anycast address on the remote side, and encapsulating IPv4 address information inside IPv6 addresses on the local side. 6 to 4 is widely deployed today, as it requires no end-to-end reconfiguration and minimal router configuration. This strategy works well when a 6 to 4 router is at the edge of the site.
- **Teredo** is another automatic tunneling technology where IPv6 packets are sent as IPv4-based UDP messages. This enables IPv6 traffic from Teredo hosts to flow across NATs (and this is the main benefit of Teredo).
- **ISATAP** refers to Intra-Site Automatic Tunnel Addressing Protocol. While 6 to 4 and Teredo are inter-site tunneling mechanisms, ISATAP is an intra-site technology. It has been designed to provide IPv6 connectivity between nodes within a single organization. ISATAP enables enterprises to deploy IPv6 within their infrastructure with minimal time and effort. Within a single site, just one ISATAP router is typically needed.

### Configured Tunneling Protocols

In configured tunneling schemes, the tunnel endpoints are either manually configured by a network administrator or through an automatic service called a tunnel broker. Configured tunneling is easier to troubleshoot than automatic tunneling and is often recommended for large, well-administered networks.

Tunnel brokers offer a compromise between the ease of use of automatic tunneling along with the deterministic behavior of manually configured tunneling. To end users, a tunnel broker is a kind of IPv6 ISP, providing IPv6 connectivity to users already connected to the IPv4 Internet.

### c. Translation

**Translation schemes are necessary when an IPv6-only host needs to communicate with an IPv4 host.** This is likely to occur after the regional Internet registries have exhausted their available IPv4 addresses. Address and protocol translation mechanisms such as NAT-PT (Network Address Translation – Protocol Translation) and SIIT (Stateless IP-ICMP Translation) allow an IPv6 host to communicate

with an IPv4 host, by converting IPv6 packets into IPv4 and vice-versa. However, these techniques can be complex and inherit most of the challenges associated with IPv4 NATs.

### Key Takeaways

As shown above, numerous transition mechanisms have been defined. Each technology has its own unique set of benefits and challenges. For example, the dual stack method is flexible and easy to use; however, it requires two IP stacks, two processing tables, and more memory. Tunneling enables the gradual transition to IPv6 (even when the ISP does not support IPv6), but requires the tunnel entry/exit points to perform more work and can represent a single point of failure and bottleneck in the network. These technologies can coexist and can be 'mixed and matched' in a multitude of ways. As the need for IPv6 becomes more urgent in the coming year, you can expect to see more industry consensus around best practices.

## IPv6 Transition: The Bottom Line

So what does all this mean for consumers, or service providers? In this section, we'll take a high level look at what steps consumers, CPE vendors, and broadband service providers should be taking to prepare for IPv6.

### a. IPv6 Transition for End Users

Richard Jimmerson, CIO of ARIN, advises end users on how they can get ready for IPv6. He says, "Call your ISP and let them know you want your mail, Web, and DNS servers on both networks." Next, he advises consumers to determine whether any of their devices aren't IPv6 capable and make upgrades as needed. Any new equipment purchases, particularly routers and servers, should be both IPv6 and IPv4 capable.

### b. IPv6 Transition for CPE Manufacturers

CPE manufacturers need to make sure that their devices are certified as IPv6 Ready. The IPv6 Ready program is an international conformance and interoperability testing program organized by the IPv6 Forum. This program is critical to ensure that devices from different manufacturers can successfully interoperate with each other when they are deployed.

The IPv6 Ready Silver (Phase 1) certification program began in 2003; since this time, nearly 450 products have achieved Phase 1 certification. In an acknowledgement of imminent address depletion, the IPv6 Ready Committee announced in December 2010 that they were retiring the Silver certification, and moving ahead toward Gold (Phase 2) certification

to ensure a higher level of interoperability. The Phase 2 Logo expands the "core IPv6 protocols" test coverage to approximately 450 tests and adds new extended test categories, such as: IPsec, IKEv2, MIPv6, NEMO, DHCPv6, SIP, Management (SNMP-MIBs), and MLDv2.

There are currently five approved IPv6 Ready test laboratories, including the University of New Hampshire InterOperability Lab (UNH-IOL).

Information about the IPv6 Ready program can be found at: <http://www.ipv6ready.org/>

### c. IPv6 Transition for Broadband Service Providers

**For the foreseeable future, the Internet must run both IPv4 and IPv6 versions at the same time.** Broadband service providers will need to give customers full access to both IPv4 and IPv6 websites, applications, mail servers, etc. There are multiple transition paths and technologies available and each provider should make its own architectural decisions.

Regardless of when you plan to implement your migration to IPv6, you should begin discussions with equipment vendors and the IT community now:

- **Equipment Vendors:** Most equipment vendors have plans in place for rolling out software/firmware updates that enable their products to support IPv4 and IPv6. Check with existing and potential equipment vendors on their schedule for IPv6 support and IPv6 Ready certification.
- **IT Community:** There's no shortage of online resources and books published on IPv6. In addition, the IPv6 Forum offers an IPv6 Education Certification Logo program for your company's IT engineers and staff. The program is focused on practical engineering expertise and hands-on knowledge for IPv6 deployment. For more information:  
[http://www.ipv6forum.com/ipv6\\_enabled/ipv6\\_education.php](http://www.ipv6forum.com/ipv6_enabled/ipv6_education.php)

### World IPv6 Day

**June 8, 2011 marks World IPv6 Day, the first global scale 24-hour trial of IPv6.** The Internet Society, a Net standards and advocacy group, is spearheading the event to motivate organizations across the industry (Internet Service Providers, hardware manufacturers, software vendors, and web-based businesses) to show their readiness for IPv6. Google, Facebook, Yahoo, Akamai, and Limelight will be among the organizations to offer their content on IPv6, in participation with Internet service providers such as Comcast, Verizon, and Time Warner Cable.

John Brzozowski, chief architect for IPv6 and distinguished engineer at Comcast said,

**“World IPv6 Day is important to further the deployment and widespread enablement of IPv6. Being able to test our infrastructure at scale and verify our customers’ experience is essential to seamless enablement.”**

Website owners and network operators can learn more about the test event at:  
<http://isoc.org/wp/worldipv6day/>

## For More Information

**IPv6 Forum:**

<http://www.ipv6forum.com/>

**IPv6 Ready Logo Site:**

<http://www.ipv6ready.org/>

**IPv6 Forum Education Certification Logo Program:**

[http://www.ipv6forum.org/ipv6\\_enabled/ipv6\\_education.php](http://www.ipv6forum.org/ipv6_enabled/ipv6_education.php)

**ARIN (American Registry for Internet Numbers):**

<https://www.arin.net/>

**IETF IPv6 Working Group:**

<http://datatracker.ietf.org/wg/v6ops/>

**World IPv6 Day**

<http://isoc.org/wp/worldipv6day/>

## About Actiontec

Actiontec Electronics develops broadband connectivity and broadband-powered solutions that simplify and enrich the digital life – delivering a unified experience that encompasses communications, entertainment, home management, and more. Actiontec offerings range from the market's broadest selection of IPTV-capable broadband home gateways for bringing IP-based video services into the home, to DSL modems, wireless networking devices, routers and digital entertainment devices. The company's carrier-class products are easy to install, manage, and use, and are sold through retail channels and broadband service providers. The company is committed to protecting the environment through energy efficient products and other green-friendly practices. Founded in 1993, Actiontec is headquartered in Sunnyvale, CA, and maintains branch offices in Colorado Springs, CO; Shanghai, China; and Taipei, Taiwan.

## Appendix: References

ARIN, IPv4 Depletion/IPv6 Adoption. August 2010

Cisco VNI / Intel Embedded Internet Projections

"Comcast, Time Warner set for World IPv6 Day." Brian Santo. CED Magazine. February 15, 2011

"Free Pool of IPv4 Address Space Depleted." TMCNet. February 3, 2011

"Get Ready for IPv6." Daniel P. Dern. Processor.com. July 30, 2010

"IPv6 adoption remains slow, survey shows." William Jackson. Government Computer News. September 15, 2010

Migrating to IPv6: A Practical Guide to Implement IPv6 in Mobile and Fixed Networks. Marc Blanchet. 2006.

"Tech giants to enable IPv6 on 'World IPv6 Day' in June." Iljitsch van Beijnum. Ars Technica. February 2, 2011

Wikipedia, June 5, 2010