TECHNOLOGY SERIES

White Paper

Why IPv6?
A Pragmatic Perspective

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1 Introduction

The Internet Protocol (IP) is part of the TCP/IP protocol family. It can be seen as the workhorse of the protocol suite. IP is a connectionless protocol, responsible for addressing and routing packets between hosts and networks.

The version of IP in use in our corporate networks and on the Internet today, is IP Version 4 (IPv4). IPv4 was developed in the early seventies by a number of pioneers who wanted to connect a few educational and governmental computers in the United States. When they started development, a global network with the scope and breadth of the Internet was beyond imagination, yet they managed to create a networking protocol that was able to sustain unprecedented growth and is still—30 years later—capable of running today's Internet!

The "Internet" was migrated to TCP/IP in early 1983, but at that time IPv4 was not the mature protocol we know today. The basics of IPv4 were defined in RFC (Request for Comment) 791 in 1981, but many of the extensions and additions that we use today were developed much later. The capabilities of IPv4 have been expanded over the last twenty years through the development of additional protocols and practices, such as DHCP (Dynamic Host Configuration Protocol), private addressing, NAT (Network Address Translation and CIDR (Classless Inter-Domain Routing). These extensions were defined in international working groups based on the requirements of the market, published as RFCs and implemented by vendors. But today we have exhausted the extensibility of IPv4. Working around the limitations has become increasingly complex, labored and expensive. It is now time for a new generation of protocols to support the growth of the Internet into the future.

The development of IP Version 6 (IPv6) began in the early nineties when it became obvious that the IPv4 address space would be depleted at some point in the future. The working group decided not only to extend the address space of IPv4, but also to include improvements which would enable the successor to more efficiently support larger networks and emerging applications and services. Initial implementations of IPv6 have been available since 1998. Major vendors have incorporated IPv6 into their products, and are continuously updating and optimizing their implementations.

The debate over whether IPv6 will ever come to life has been going on for many years. There are always pioneers and enthusiasts who quickly embrace new technologies, and also skeptics who resist. This White Paper aims to describe the protocol and its impact on our networks and the global economy from a pragmatic perspective.

IPv6 is being adopted by more and more organizations on a wider scale than ever before. It seems clear at this stage that we will all have to deal with it at some point in the near future. We will have to invest in education, strategies, planning and implementation, whether we like it or not. The more we understand about the advantages and business drivers for IPv6, the more prepared we will be to implement it within our own organizations when the time comes.

In the first part of this White Paper, I will lay out some of the aspects of IPv6 that are driving, or may drive, adoption. Some aspects are related to the evolution of the world and the Internet, some to economic or social challenges (such as support for Third World countries); some are related directly to address space, and some to other emerging technologies and services.

In the second part of this White Paper, I will give an overview of the technical features that are new with IPv6, which make it a suitable protocol to support our evolving networks. We are replacing IP with a new version, not replacing the whole TCP/IP protocol family, so many things will remain familiar, or even the same. The developers of IPv6 created a protocol which took the best of IPv4 and added flexibility to extend it, to make it the network protocol of the future. IPv6 is capable of handling the Internet growth rate and supporting the new types of services, especially in the area of mobility, that we expect in the coming years.

2 Non-Technical Reasons for IPv6

This section addresses some of the key business drivers for IPv6 stemming from the growing importance of the Internet in social and commercial areas, the growth of world population, and the Internet penetration rate in different regions of the world. We will not be able to meet the demand of developing countries with the existing IPv4 address space. This shows how important a scalable and extensible protocol is as a foundation for our future networks.

The Internet touches all aspects of society. It has revolutionized the way people communicate, shop, do research, learn and conduct business throughout the world. It creates opportunities for new business models and services, and provides significant opportunities for reduced costs. It allows companies to bring their products to the market faster and at lower cost. E-commerce represents a growing share of the retail market in the U.S. and around the world, accounting for 2.4% of the total retail market in the U.S. in 2005, a total of 88 billion U.S. dollars! Many people also use the Internet to access a variety of educational and medical resources. Citizens use the Internet to interact with governments and commercial organizations. Governments are increasingly using the Internet to provide essential information to their citizens, thereby reducing administrative costs. Industrial sectors are all developing services and devices for monitoring, control and repair.

2.1 Growth of E-commerce in the U.S.

Looking at the growth of E-commerce in the United States in recent years (Table 1), we can clearly see that the share of E-commerce, as a percentage of total retail sales, is increasing substantially every year: (1)

	2002 (billions of $)	2003 (billions of $)	2004 (billions of $)	2005 (billions of $)
Retail sales total $s	3230	3399	3532	3719
Increase compared to past year	2.4%	5.2%	3.9%	5.3%
E-commerce part of retail sales $	44	56	69	88
Increase of E-commerce compared to previous year	29.2%	26.4%	23.6%	27.1%
E-commerce as percent of total retail	1.4%	1.7%	2%	2.4%

Table 1 - Growth of the E-commerce market in the United States

The revised numbers for the first six months of 2006 are as follows:

Retail sales total $	**1909 billion**
Increase compared to previous year	**7.4%**
E-commerce part of retail sales $	**49 billion**
Increase E-commerce compared to previous year	**24.2%**
E-commerce as percent of total retail	**2.6%**

While this data is based on the U.S. E-commerce market, the trends are applicable to many other areas, sectors and regions around the world.

2.2 Mobile Phones and Cellular Services

The growth in number of mobile phone subscribers is of interest with regard to IP. Global telephone service providers are preparing their networks as the global telecommunications industry migrates toward IP-based services. IPv6 offers many advantages over IPv4 in this area, particularly as it involves mobility and increased address space. Let's have a short look at the U.S. cell phone market and keep this in mind when we move on to analyze IP address usage in the next section.

Year	Subscribers (2)	U.S. Population (3)	Penetration Rate
1985	340,000	237,923,795	0.14%
1990	5,283,000	249,464,000	2.11%
1995	33,786,000	262,803,000	12.85%
2000	109,478,000	282,216,952	38.79%
2001	128,375,000	285,226,284	45.00%
2002	140,767,000	288,125,973	48.85%
2003	158,722,000	290,796,023	54.58%
2004	169,467,000	293,638,158	57.71%

Table 2 – Growth of Mobile Phone market

The North American mobile data market (SMS, Internet and e-mail access over Wireless WANs) reached approximately 22.67 million connections in 2002, and, according to Gartner Groups, this market will grow approximately 80% in the next three to four years. (4) At the end of 2002, there were 18.7 million wireless Internet users in North America. This number is expected to grow to 95.6 million by 2007.

2.3 Number of Hosts on the Internet

According to the Internet Systems Consortium (http://www.isc.org), the number of hosts on the Internet has grown as follows:

Year	Number of hosts	
1984	1,000	
1987	10,000	
1989	100,000	
1995	4.8 million	
1999	43 million	
Year	**Number of hosts**	**Increase over 12 months**
2000	72 million	Plus 29 million, +67%
2001	109 million	Plus 37 million, +51%
2002	147 million	Plus 38 million, +34%
2003	171 million	Plus 24 million, +16%
2004	233 million	Plus 62 million, +36%
2005	317 million	Plus 84 million, +36%
2006 January	394 million	Plus 77 million, +24%
Year	**Number of hosts**	**Increase over 6 months**
2006 July	439 million	Plus 45 million

Imagine an IPv6 world...

...in which a device as simple as a wristwatch can save lives. In an IPv6 world, a wristwatch can carry its own IP address and communicate with wireless networks. Similarly, weather sensors of all types—earthquakes, tornadoes, floods, and so on—will also have their own IP addresses. Dangerous weather events can be immediately identified, localized, and forecasted, and severe weather warnings can be sent directly to individuals through their wristwatches. Individuals can choose what types of warnings they wish to receive, and for which locations. In endangered areas, buildings with IPv6-equipped safety systems can arm fire-suppression systems, deactivate elevators in an orderly manner, shut off natural gas lines, and initiate other safety systems. In an IPv6 world, potentially life-saving information is transmitted instantly, to those who have the greatest need to know.

2.4 How many IP Addresses does the World need?

This section begins with a short explanation of the difference between the IPv4 and the IPv6 address space. Next it will discuss the IPv4 address depletion question, and if and when this will happen. This obviously includes the need to address coming requirements for addresses, such as the growth of world population and the evolution of new services.

IPv4 has an address field of 32 bits. This provides a maximum of 2^{32} addresses, or approximately 4.3 billion addresses. The current world population is approximately 6.5 billion people. So even if it were possible to use 100% of the IPv4 address space, it could not accommodate an IP address for everyone living on this planet. Only a small fraction of the IPv4 address space can actually be used. In the early days of IP, nobody foresaw the existence of the Internet as we know it today. Large address blocks have been allocated, without consideration for global routing and address conservation. These address ranges cannot be reclaimed. The consequence of this is that there are many addresses, but they are not available for allocation.

There is one interesting fact, although most people are not aware of it. We talk about address depletion within ten years, and most current speculation places the timeframe to run out of IPv4 addresses between 2010 and 2015. In reality, currently only about 15% of the total world population is connected to the Internet. (5) Many people in developed countries believe that there is no life without the Internet, but, in fact, we are part of an elite group.

The top 5 countries (with the highest number of Internet users) are the United States with 210 Million, China with 132 million, Japan with 86 million, Germany with 51 million, and India with 40 million.

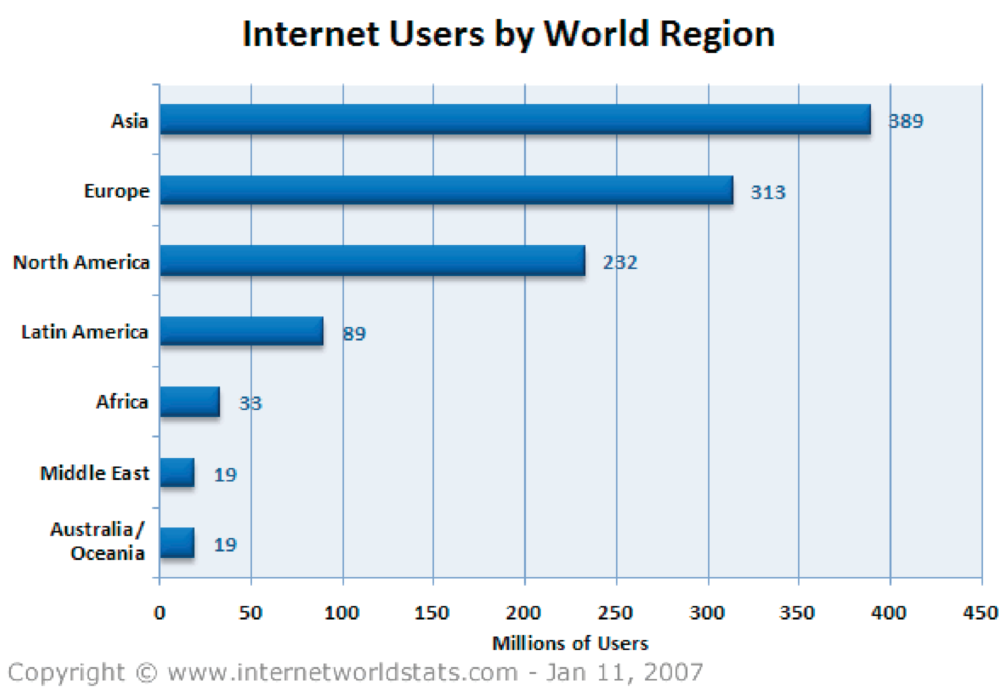

Figure 1 – Number of Internet users by world regions

Another interesting perspective is a comparison of Internet penetration rate in different regions—the number of Internet users as a percentage of the total population. (5)

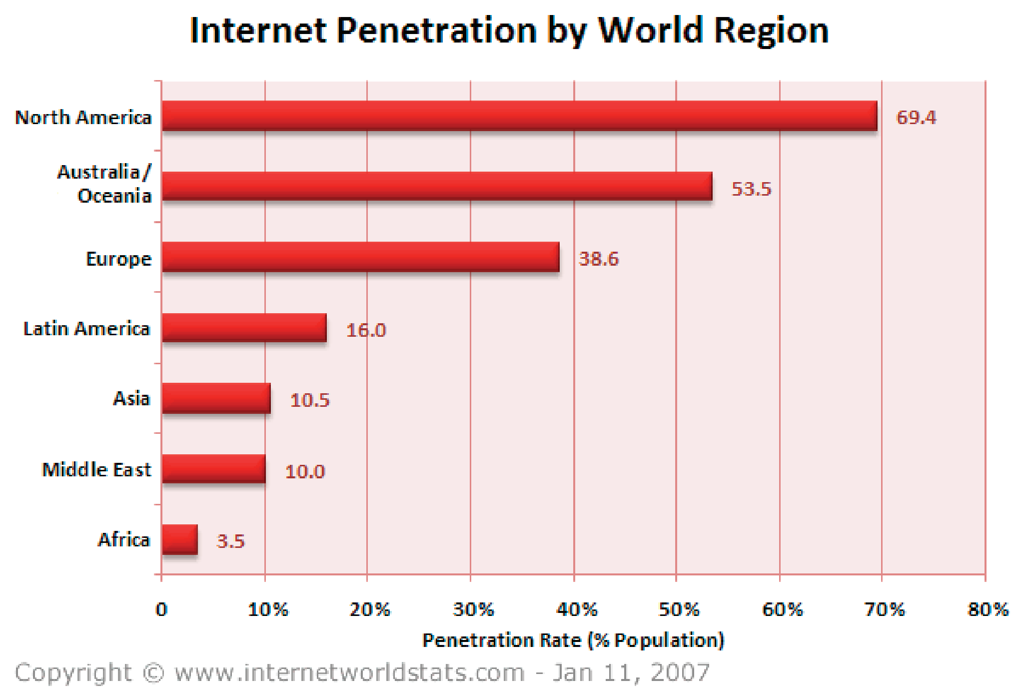

Figure 2 – Internet penetration per world region

Figure 1 shows that Asia has the largest number of Internet users. This is not surprising, as more than half of the world population lives in Asia (3.6 billion people). Asia has 389 million Internet users, but their Internet penetration rate is only 10%, as compared with the 232 million Internet users in North America who represent a 69% penetration rate. The current growth rate of the Internet in Asia is higher than in any other part of the world.

The Web site at http://www.internetworldstats.com/stats.htm offers a more detailed breakdown for each region. For instance, the details from Asia reveal that some regions have a very high penetration rate, such as Hong Kong (69%), Japan (67%), South Korea (66%) Singapore (66%) and Taiwan (60%). These top regions are followed by a region of China called Macao (40%) and Malaysia (40%). The next step is a drop down of the penetration rate to 17% in Vietnam, 14% in Brunei Darussalam, 12% in Thailand and 10% in China. Every other region is below 10%. Now imagine what happens to the demand on IP addresses when Asia wants to pick up only a little bit in the penetration rate chart. As this market continues to grow, there will be a significant impact on the demand for IP addresses.

2.5 When will the IPv4 address space be exhausted?

Opinions vary greatly as to when, or if, the IPv4 address space will be exhausted. Some even jokingly say that we will never run out of IPv4 address space, because nobody will be able to afford that last IPv4 address. There was an article in the *Internet Protocol Journal* in September 2005 written by Tony Hain and Geoff Houston, called "A Pragmatic Report on IPv4 Address Space Consumption." (6) It projects how long the IPv4 address space will last, based on thorough analysis of address consumption in the previous several years. It comes to the following conclusion:

> If there is no change in IP address demand and no change in allocation policy, the IPv4 address space will expire within the next five to ten years.

How did they come to this conclusion? At the time of the article, in the fall of 2005, there were 64 /8 (Class A) blocks left in the IANA pool to be allocated. The actual allocation for a period of 18 months up to July 2005 was 22 /8 blocks. In the article, they project that we will run out of IPv4 addresses in about five years, based on an average allocation rate of 12 /8 per year. And again, this is only true if there is no change in address demand and allocation policy.

Statistics showing IANA's IPv4 allocation and its distribution throughout the world are available at http://www.iana.org/assignments/ipv4-address-space. In 2006, 10 /8 blocks were given out to RIRs (Regional Internet Registries), 3 to APNIC (Asia Pacific Network Information Centre), 3 to RIPE NCC (RIPE Network Information Centre for Europe), and 4 to ARIN (American Registry for Internet Numbers). This information is summarized in the following table:

Total IPv4 allocations from IANA to RIRs	**2063.6 million**
Total IPv4 allocations from RIRs to end users	**1685.69 million**
Number of IPv4 addresses still available at RIRs	**377.91 million**
Number of IPv4 addresses still available at IANA	**922.75 million**
Total number of IPv4 addresses still available	**1300.65 million**
Number of IPv4 addresses allocated in 2006	**167.96 million**

Table 3 – Overview IPv4 allocations

When we project based on these figures (1300 million available addresses, yearly allocation of 167.96 million addresses), we would run out of IPv4 addresss space in seven years.

The U.S. currently holds 57% of the IPv4 address space (down from 60% a year earlier). The statistics show that even though the U.S. allocated approximately one quarter of the IPv4 addresses given out in 2006, its share of the global address space is diminishing as the penetration rate in the rest of the world is increasing. (7)

To link this back to the discussion about world population, there are calculations that show that we would need 390 /8 blocks to provide Internet access to only 20% of the world's population. Growth in Internet penetration throughout the world, coupled with the increase in services such as IP telephony and monitoring and control devices, creates the demand for a protocol with a much larger address space than IPv4 provides.

2.6 IPv6 Allocations

Now let's review the allocation of IPv6 address space through January 2007. Obviously, the pace at which IPv6 addresses are allocated and used has an impact on the allocation rate of IPv4 addresses. The faster IPv6 is adopted, the lower the demand for IPv4 address space will become, increasing the time before the IPv4 address pool is exhausted.

An IPv6 address has a total of 128 bits. The last 64 bits are used for the interface identifier (which we know as host ID in the IPv4 world), and the first 64 bits are the network part of the address. With the current allocation policy, an ISP usually gets a /32 from his registry and allocates /48 blocks to his customers. To analyze the number of IPv6 allocations, we count the number of /32 units. In some cases, larger allocations are distributed. If someone received a /20, we count this as 4096 /32 in our calculation. With one /32 block, an ISP can serve 65,536 customers (2^{16}) with a /48 block each. Each customer with a /48 block can create 65,536 networks. So one /32 equals 4.29 billion networks.

The following table shows the total allocation of IPv6 address blocks as of January 2007, broken down by registry. (7)

Registry	Number of allocations	Number of /32 blocks	Percentage
AfriNIC	24	24	0.05%
APNIC	210	18,883	37.2%
ARIN	223	237	0.5%
LACNIC	66	88	0.2%
RipeNCC	545	31,577	62.1%
Total	1068	50,809	100%

Table 4 – IPv6 allocations per registry per January 2007

Let's try to get a feeling for the magnitude of these numbers in relation to the IPv4 allocations. The table shows that a total of 50,809 /32 blocks have been allocated so far. This allocation would provide a /48 block to each of 3.3 billion customers (50,809 * 65,536). One single /32 has more address space than IPv4 in total.

> The current IPv6 allocation is more than 50,809 times the total IPv4 address space, yet accounts for less than 0.01% of the total IPv6 address space.

And the current total IPv6 address space is only 1/8 of the total IPv6 address space, since with the current policy only addresses out of the binary range 001 are allocated.

These numbers represent the theoretical maximum. In reality, it is not possible to use 100% of the address space. 80% utilitization is generally recognized as a practical maximum, since address management becomes increasingly difficult as the host density ratio increases to these levels. The Host Density (HD) ratio is described in RFC 3194.

Table 4 shows that Europe is leading when it comes to IPv6 allocations. ARIN is second with regard to the number of allocations, whereas APNIC is second in the size of allocations. It will be interesting to see how this develops and whether the U.S. will increase over the course of the coming years. This will largely depend on the development of the market, especially of new services or IP-based devices. For example, the allocation rate is likely to increase dramatically in a short period with increased adoption of IP-based telephony, particularly in mobile phone markets.

The IPv6 world currently is concentrated in two regions: Europe and Asia Pacific. China is developing market power, and with its commitment to building the largest IPv6 network in the world, IPv6 may soon become a technology that can't be ignored.

Another good indicator of the importance of the protocol is the number of ISPs that already have their IPv6 allocations. This shows that ISPs are preparing to deliver IPv6 services. Table 5 gives an overview of the allocations to ISPs per region, including the growth since October 2005. (8)

RIR	Number of ISPs with IPv6 allocation	Number of members	Percentage	Number of ISPs with IPv6 allocations per October 2005
ARIN	212 (+25%)	2,565	8.3%	169
APNIC	263 (+20%)	2,143	12.3%	219
RipeNCC	583 (+17%)	4,471	13%	497
LACNIC	63 (+62%)	564	11.2%	39
AfriNIC	23	350	6.6%	* (see comment)

Table 5 – Number of IPv6 allocations to ISPs per region

* There are no numbers available for AfriNIC for 2005. AfriNIC is a new registry, and this region was previously served by RipeNCC.

2.7 The IPv6 Marketplace

Costs are inevitably associated with the adoption of a new technology, but are there any indications that IPv6 may also save some costs in addition to solving address space issues?

The first independent study about the IPv6 marketplace was published in February 2006 by the U.S. Department of Commerce (DoC). (9) The report was prepared in conjunction with independent research group RTI International. (10) While some of you may want to download this report and study it in detail, here's a summary.

The RTI report examines the costs and benefits associated with the transition from IPv4 to IPv6. The cost estimates are based on likely development and deployment scenarios provided by stakeholders, and includes information by some U.S.-based companies that have already started to leverage the advantages of IPv6. RTI estimates that the total costs for IPv6 deployment over the next 25 years will be approximately 25 billion US$ ($2003), or approximately 1 billion US$ per year. This figure primarily includes increased labor costs associated with the transition. These cost estimates seem large, but are actually quite small compared to overall expected expenditures on IT hardware and software, or to the expected value of potential market applications.

It is difficult to quantify the benefits of applications making use of IPv6's advanced features as they are only beginning to emerge. The stakeholders participating in the study identified several major categories of IPv6 applications (Voice over IP, remote access products and services, improved network operating efficiencies), which in total are estimated to have potential benefits in excess of 10 billion US$ per year. These estimates could prove to be very conservative, as they do not reflect potential next-generation IPv6 applications that have not yet been developed.

In fact, most new hardware devices, including routers, switches and hubs, operating systems and other technologies are already manufactured with IPv6 capability. Microsoft committed to supporting IPv6 several years ago. An IPv6 production stack is currently included in Windows XP SP2, and Windows Vista includes more comprehensive IPv6 support. IPv6 is enabled and configured as the preferred protocol by default in Windows Vista. IPv4 can even be disabled completely. Apple's OS X has supported IPv6 since 2004, as have most versions of UNIX and Linux. It will actually become difficult to buy hardware or software products which do not support IPv6, just the same as it is difficult to buy a mobile phone without a camera, a notebook without a wireless network card, or a car without an air bag.

Based on the report, we can make the following statements:

- IPv6 creates a services market projected to be approximately 25 billion US$ over the next 25 years
- The cost for transition to IPv6 is estimated to be 1 billion US$ per year
- The financial benefits of IPv6 transition are expected to be 10 billion US$ per year
- For every dollar invested in IPv6, you can expect a $10 return in cost savings – a return on investment ratio of 10:1
- Of each dollar invested in IPv6, only about 8% is projected for the actual infrastructure upgrade and the other 92% for leveraging the advantages of IPv6

Cost savings are expected in several main areas:

- Improved security: New E2E security models will help save major enterprise costs, both in reduced downtime and reduced incidents as a result of more effective preventive measures.
- Increased efficiency: The transition from traditional phone networks to Voice over IP could save 20% or more on telephone expenditures. The cost for managing and working around NAT (Network Address Translation) ranges up to 30% of IT expenditures. In the long term, the introduction of IPv6 will eliminate the need for NAT. Clever use of IPv6 autoconfiguration mechanisms will save costs in managing and renumbering networks, particularly in mobile and ad hoc networks.
- Enhancement of existing applications: Remote monitoring and support services reduce service and support costs and increase product life expectancy.
- Creation of new applications: Wireless companies can provide new features through expanded network capabilities (e.g., IP-addressed phones) and need the increased address capacity of IPv6 for mobile P2P applications. Gaming and game console makers envision expanded functionality and opportunities for innovative new products.

One example of an innovative application for remote access and mobility services is OnStar (http://www.onstar.com). OnStar offers in-vehicle security, communications and diagnostics systems. It is available on more than 50 GM models and currently has over three million subscribers. All OnStar-equipped vehicles come with Automatic Crash Notification. If air bags deploy, the system sends a signal to a highly trained OnStar Emergency Advisor, who contacts the vehicle to see if help is needed, and can contact an emergency responder to send for help. If the occupants are severely injured and cannot speak for themselves, OnStar's GPS unit allows Advisors to tell emergency responders the vehicle's location. OnStar responds to at least one air bag deployment in the U.S. or Canada every hour. OnStar currently uses a combination of GPS (Global Positioning System) and cellular technologies. According to several stakeholders of the DoC report, such a service could be enhanced and operated much more efficiently using IPv6.

Most car vendors are working on prototypes of networked cars. Renault's prototype is pictured here. It incorporates a built-in Cisco router with a Mobile IPv6 implementation. The car's network remains connected wherever it goes. In addition to providing monitoring, information gathering and support services, the network provides Internet access to passengers through Bluetooth or wireless interfaces in their mobile phones, PDAs or video sets.

Figure 3 – Renault's networked car prototype includes a Cisco mobile IPv6 implementation

RTI estimates a potential economic benefit in excess of three billion dollars per year, with a one percent increase in life expectancy and a one percent reduction in service costs as a result of the remote-monitoring application.

These are some highlights of the report. So when analyzing and discussing the introduction of IPv6 into your network, don't forget to consider the benefits.

2.8 Summary of Section 2

It is undisputable that the importance of the Internet in political, commercial, private and social sectors will continue to grow substantially in the coming years. The existing IPv4 address space structure and capacity cannot continue to sustain the increasing demands of this growth and the increased penetration into different geographical markets. We will require exponentially more IP addresses to support this growth and support the evolving IP-based services and applications that are beginning to emerge.

The United States has been the leader in development and use of IPv4, where Europe and Asia are the leaders in IPv6 allocation. Many vendors in Asia and Europe are developing IP-based services. These services are likely to become IPv6-based in the near future, in many cases due to the demand for address space and the desire to avoid developing NAT workarounds.

We will run out of IPv4 addresses in the near future. It is best for all organizations and providers to start planning for the transition to IPv6 now and not wait for the inevitable to happen. There are many benefits associated with IPv6—technical as well as business benefits. The experiences of organizations that have already integrated IPv6 show clearly that the cost of migration can be minimized by planning in advance around the regular life cycles of your devices and products, and by doing a step-by-step integration, which allows you to learn as you go.

Imagine an IPv6 world...

...in which inventory tracking and status are up-to-the-minute. In an IPv6 world, a truck leaves Los Angeles for Chicago with a cargo of high definition televisions. Each television carton has its own RFID tag, and the truck is equipped with a mobile IPv6 RFID sensor which is constantly connected to wireless networks. Every RFID tag on the truck is scanned continuously, and as cartons are offloaded their locations are updated in the master inventory system. If a carton leaves a truck in an unexpected location, the time and location of the anomaly are immediately recorded, and corrective action can be taken. In an IPv6 world, things get where they're going or we know what went wrong.

3 IPv6 in the World

The oldest IPv6 network in the world was the 6bone (http://www.6bone.net). The 6bone was created in 1996, and by 2004 connected more than one thousand hosts in about 50 countries all over the world. It was started as a testbed for the IETF IPv6 working group, and became an informal worldwide collaborative project. A special address prefix had been allocated to the 6bone, the prefix 3FFE. Now that the official address allocation is specified, the 6bone was phased out by June 2006 and integrated into the official address space. The 6bone not only proved that IPv6 works, but it provided a great infrastructure for testing IPv6 protocol implementations and experimenting with routing and operational procedures. It was finally used as a platform to develop and test IPv6 applications and transition mechanisms. The old 6bone Web site can still be found. It isn't updated anymore, but it may provide some interesting historical information.

One major requirement to fully leverage the advantages of IPv6 is the support by the world's tier one telecom providers. More than 50% of these providers already route IPv6 packets, and the number is expected to grow to over 90% by the year 2008.

The IPv6 Ready Logo program was initiated in 2003. This program approves products and applications which have passed IPv6 conformance and interoperability tests. Information about the test criteria and the procedures, as well as updated lists of approved products and applications, is available at http://www.ipv6ready.org

There are several organizations that coordinate IPv6 efforts around the world. The International IPv6 Forum (http://www.ipv6forum.com) coordinates the efforts for IPv6 deployments on a worldwide scale. There is an International IPv6 Task Force Site at http://www.ipv6tf.org, which connects all national and regional task forces. There is a North American IPv6 Task Force (http://www.nav6tf.org), a European Task Force (http://www.ipv6.eu) and different task forces in Asia. They each coordinate the activities of national or regional task forces in their regions/countries.

3.1 Asia

IPv6 is a reality in Asia today. There was a relatively small percentage of IPv4 address space allocated to Asian countries, in many cases requiring Internet connections to sit behind multiple layers of NAT (up to four or five layers). The population of Asia, combined with the rapidly increasing Internet penetration rate, made IPv6 a logical choice.

Japan has taken the lead in promoting IPv6. They announced the "e-Japan Priority Policy Program" in 2000—an initiative to build the largest IPv6 network by 2005. The focus of the Japanese IPv6 Promotion Council is to fund different projects to develop applications such as tele-control applications (http://www.live-e.org), the InternetCAR project (http://www.sfc.wide.ad.jp/InternetCAR), Digital IP-TV multicasting, and digital buildings, among others. The construction industry is looking at using IPv6 for remote maintenance and control, using SIP (Session Initiation Protocol) as a key technology in these projects. Vendors demonstrate a wide variety of IPv6-enabled devices and applications, such as microwave ovens and refrigerators that can be operated through Web access and e-mail. IPv6-capable digital cameras and home gateways allow the upload of digital images to your home gateway from any public network, so they can be watched simultaneously by different people from different locations. Internet terminals combine wireless, RFID and Mobile IPv6 technology to show that it is possible for mobile devices to use services over the Internet in a secured, certified way. The "Galleria v6" showroom, accessible through their Web site (http://www.v6pc.jp/en/index.phtml), lists vendors and the appliances they represent.

Japan's decision to adopt IPv6 has been followed by South Korea, China, Taiwan, Malaysia, India and other countries. The China Next Generation Internet (CNGI) project was started in 2001, with China's five major telecommunication operators playing a key role. IPv6 Mobility was built into the CNGI from the beginning. Metropolitan Area Networks (MANs) will be deployed gradually in each city, with IPv6 playing an important part in this deployment. IPv6 will also be used in other industries, such as the military, meteorology, seismology, intelligence, architecture and digital home networking. Many of China's giant industry companies, such as Lenovo and Konka, have begun to focus on IPv6. China has made it clear that they plan to build the number one information infrastructure in the world by 2008, while working toward becoming an economic superpower.

Most Asian countries offer governmental support for organizations that support the introduction of IPv6, because they recognize the potential economic benefits. As a consequence, you will find the most examples and the richest variants of implementations in Asia. There is clearly a need for the additional address space provided by IPv6, but these countries also leverage many of the other advantages of IPv6, such as lower cost of deployment and management, greater security and privacy, better connectivity, and faster speeds for real-time data such as voice and video.

Companies that do business with, or may acquire, companies in Asia should pay particular attention to the need to integrate with IPv6 networks and applications in these areas.

3.2 Europe

The European Commission believes that IPv6 is vital to the European economy and competitiveness in the global marketplace, and it has been actively promoting IPv6 since 2000. It has funded many IPv6 research projects, such as 6net (http://www.6net.org) and Euro6IX (http://www.euro6ix.org).

There is a European IPv6 Task Force (http://www.ipv6.eu) which coordinates the activities throughout Europe, with many countries having their own national task forces. Currently, 14 European countries are active, with additional countries becoming increasingly involved.

Telia Sweden was one of the first ISPs starting to offer IPv6 POP (Point of Presence) in 2001. Today, many ISPs, despite not advertising a full range of services, have been testing capabilities and are prepared to support IPv6 in some capacity. The number of backbones and IEX (Internet Exchange Points) with IPv6 access/transport is growing. Some recent activities worth noting are listed here:

- TeliaSonera has a /20 allocation and introduced IPv6 in 2006. They are using Lucent's VitalQIP solution. TeliaSonera currently has more than 8 million fixed lines, 15 million mobile phone customers, and more than 2 million Internet customers
- Deutsche Telekom received a /19 in 2004 and already had two /35, one /34 and one /33. They are currently running a pilot
- Cable & Wireless runs fully dual-stacked and has a /21 allocation
- Géant, a European high-speed network, is fully dual-stack
- In Greece, the DIODOS Project was realized. It provides IPv6 connection services over xDSL to university students with the objective of enhancing tele-teaching, collaboration, video conferencing, access to digital libraries, multimedia content and virtual labs. Their Web site can be found at http://diodos.gsrt.gr—but you'll have to get a Greek friend to read it to you
- ETSI, the European Telecommunication Standards Institute, started a joint ETSI-eEurope Standardization Project for the Development of Test Specifications for IPv6. IPv6 is an integral part of several ETSI technologies. One ETSI project creates IPv6 testing specifications for interoperability to support efficient deployment of IPv6 (project time frame: 2005 to 2007). More details are available at http://www.ipt.etsi.org
- IPv6 is available in every country in Europe. 33 out of 40 European IEX (Internet Exchange) points support IPv6. (11)

The IST (Information Society Technologies) and the European IPv6 Task Force compiled a "European IPv6 Roadmap" in March 2006 (12) which provides more detailed information on the status of IPv6 in Europe. It includes a great summary and overview of worldwide activities and then goes into detail regarding business drivers, strategies and deployment, technology and application requirements.

3.3 North America

Initially, it was expected that the U.S. would be the last part of the world to be interested in IPv6, because it owns the largest part of the IPv4 address space. This has begun to change since the U.S. DoD (Department of Defense) announcement in 2003 of the requirement to purchase only IPv6-capable hardware and software, and plans to migrate the whole DoD network to IPv6 by the year 2008. With an annual IT budget exceeding 30 billion US$, this has a major impact on the market and will greatly accelerate the introduction of IPv6. The Office of Management and Budget (OMB) announced in July 2005 that all government agencies have to integrate IPv6 by 2008. The DoD budget for IT alone is impressive, but the stated intention of the entire government to adopt IPv6 provides even more incentive for vendors to develop their IPv6 offerings.

The NAv6TF (North American IPv6 Task Force), http://www.nav6tf.org, coordinates activities across North America. The NAv6TF started the MetroNet6 Project, which is a 24x7x365 ad hoc mobile network. They are currently building a prototype in California. The goal of MetroNet6 is to provide emergency services through a command and control center using the Moonv6 network. You can find more details about this project at http://www.metronet6.org

The Moonv6 Project (http://www.moonv6.com) was started as a collaborative effort between the North American IPv6 Task Force, the University of New Hampshire-InterOperability Lab, the Joint Interoperability Testing Command (JITC) and various other DoD agencies, and Internet2 (http://www.internet2.edu). The Moonv6 project takes place at multiple locations across the U.S. and represents the most aggressive collaborative IPv6 interoperability and application demonstration event in the North American market to date. It serves as an opportunity for equipment and application vendors to demonstrate the maturity and robustness of their IPv6 implementations to prospective users and adopters of IPv6.

NTT Communications (formely NTT/Verio), a US/Japan-based ISP, extended their global IPv6 services in all areas: tunneling, native IPv6 and dual-stack. They were the first to offer a wide variety of commercial IPv6 services, more than six years ago, and have two 24x7 NOCs (Network Operation Centers), one in the U.S. and one in Japan. Here's a picture of international IEX points and how the NTT backbone connects to them:

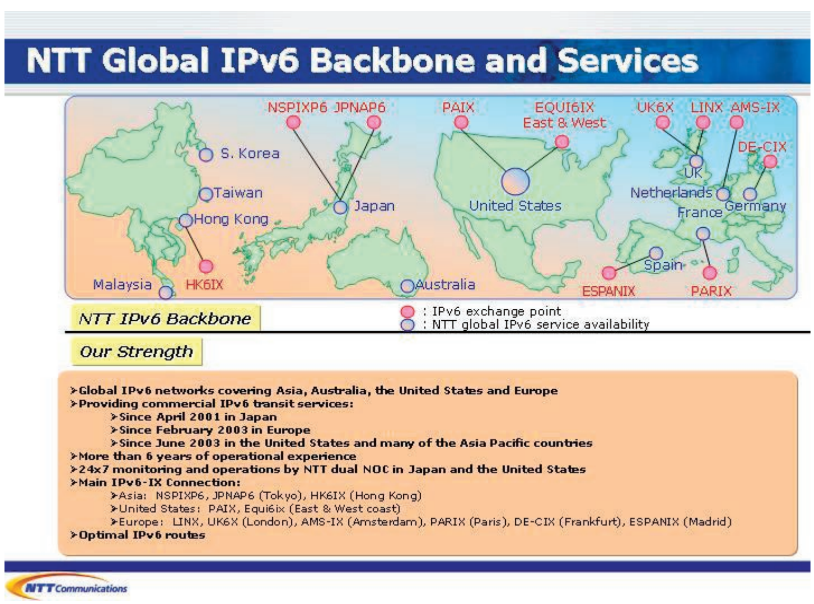

Figure 4 – NTT Communication's Global IPv6 Backbone and Services

Summary of recent activities:

- Moonv6 (http://www.moonv6.org)
- Internet2 (http://www.internet2.edu)
- Global Crossing introduced IPv6 in the whole global IP network. The MPLS infrastructure has been fully IPv6-enabled
- NTT Communications runs a global dual-stack backbone and has offered a variety of commercial IPv6 services for more than six years
- San Francisco-based Bechtel Group, Inc., will migrate to IPv6 by 2008

3.4 Summary of Section 3

The examples in this section show that IPv6 is much more than a new standard on paper. There are many functional implementations that prove that IPv6 works. In Chapter 10 of "IPv6 Essentials" published by O'Reilly, there are some case studies of IPv6 deployments. To write these case studies, I interviewed the network architects and engineers who were responsible for these projects. The case studies show that there are many different ways to introduce IPv6, depending on what the goal and the requirements are. But the important bottom line was that everyone interviewed agreed that IPv6 is mature enough to be introduced, and that the advantages clearly outweigh any issues. Some issues, such as those with Windows XP's IPv6 stack, have already been resolved with Windows Vista. It is also significant to note that most people interviewed mentioned that the introduction of IPv6 was less difficult and less costly than they had expected.

4 Technical Overview of IPv6

IPv6 is a technical evolution of IPv4. Many things that are familiar from IPv4 will remain or be similar, with the addition of new features designed to make IPv6 more efficient to handle the growing requirements of our future networks and services. Let's examine what the new key features are.

4.1 Extended Address Space

The most obvious difference between IPv4 and IPv6 is the address format.

An IPv4 address has 32 bits or 4 Bytes and is written in decimal notation. For example: 192.168.0.1

An IPv6 address has 128 bits or 16 Bytes and is written in hexadecimal notation.

For example: 2001:DB8:0000:0000:0202:B3FF:FE1E:8329

There are rules that allow the address to be abbreviated by omitting leading zeros and replacing a series of zeros with two colons. So the IPv6 address above can be written as 2001:DB8::202:B3FF:FE1E:8329

The following figure shows the format of an IPv6 address:

Global Routing Prefix n bits	Subnet ID 64 - n bits	Interface ID 64 bits

Figure 5 – Format of the IPv6 address

The Global Routing Prefix is assigned to a site and is, according to the current allocation policy, usually a /48 or smaller. The Subnet ID identifies a link within a site, and the 64-bit Interface ID is what we know as the host identifier in IPv4. Currently IPv6 addresses are only allocated out of the binary prefix 001.

There are several types of special addresses, such as the link-local IPv6 address, which is automatically configured for every active IPv6 interface (stateless autoconfiguration) and is used for communication on the local link. Other special addresses include the Unique Local IPv6 address, which can be used for corporate communication but is not to be routed to the Internet. We still have an all-zero address (::0) and a loopback address (::1). All multicast addresses have a prefix of FFXX. XX is used to configure a scope for the multicast address. There are various scopes defined; for instance, FF02 is a link-local scope, and FF05 is a site-local scope. Multicast functionality has been greatly enhanced, with the larger address space and the scoping option making it much more scalable. MLD Version 2 (Multicast Listener Discovery) introduces support for source-specific multicast. Source-specific multicast allows registration for a specific multicast group address, as well as specification of one or more sources from which you want to receive the multicast stream, or certain sources to specifically exclude.

We have discussed the IP addressing issues at length in this White Paper. The IPv6 address space is big enough to assign multiple addresses to every grain of sand on the planet. Some, however, argue that solutions such as NAT are sufficient, and even desirable in some cases, through the inadvertent "security" provided by hiding internal networks.

There are several misconceptions behind this viewpoint. The first is that the latest studies show that the IPv4 address pool will be exhausted soon, as described in Section 2.5, and NAT imposes severe limitations when it comes to scalability and end-to-end security. A device behind a NAT can initiate a connection to a global host, but someone from outside cannot initiate a connection to someone behind a NAT. When it comes to services like real-time banking applications with high security requirements, or services like Voice over IP, NATs can be a major obstacle. As you have seen in the summary of the RTI report in Section 2.7, the cost for workarounds to overcome NAT limitations is estimated to be 30% of total IT expenditures. The almost unlimited global address space of IPv6 will resolve these issues and let us re-establish the end-to-end paradigm. This was a fundamental design rule of the Internet, and it was broken with the introduction of NAT. There are other features of NAT that some like, such as the fact that it allows the internal topology of networks to be hidden, thus preventing someone outside from initiating a connection to hosts within our corporate network. There are other features of NAT that some of us like, such as the fact that it allows us to hide the internal topology of our networks and prevents someone from outside initiating a connection to hosts within our corporate networks. These features—which are sometimes perceived as security features—will be replaced by new mechanisms called "Local Network Protection" (LNP, RFC 4864).

4.2 ICMPv6

ICMP has always been a networker's best friend. Many of the new features of IPv6 are based on ICMPv6, such as Stateless Autoconfiguration, Path MTU Discovery, Neighbor Discovery and Multicast Listener Discovery (MLD).

ICMPv6 is much more powerful than ICMPv4 and contains new functionality. For instance, the IGMP (Internet Group Management Protocol) function that manages multicast group memberships with IPv4 has been incorporated into ICMPv6 (MLD). The same is true for the ARP/RARP (Address Resolution Protocol/Reverse Address Resolution Protocol) function that is used in IPv4 to map layer 2 addresses to IP addresses (and vice versa). Neighbor discovery (ND) is introduced; it uses ICMPv6 messages in order to determine link-layer addresses for neighbors attached to the same link, to find routers, to keep track of which neighbors are reachable, and to detect changed link-layer addresses. New message types have been defined to allow for simpler renumbering of networks and updating of address information between hosts and routers. ICMPv6 also supports Mobile IPv6.

4.3 Autoconfiguration

Perhaps the most intriguing new feature of IPv6 is its stateless autoconfiguration mechanism. A booting device in the IPv6 world comes up and asks for its network prefix by sending out a Router Solicitation message (ICMPv6 message). It can get one or more network prefixes from a router on its link. Using this prefix information, it can autoconfigure for one or more valid, global IP addresses by using either its MAC identifier or a private random number to build a unique IPv6 address. In the IPv4 world, we have to assign a unique IP address to every device, either by manual configuration or by DHCP. You can still use DHCP with IPv6 if you wish, but stateless autoconfiguration provides other options.

Autoconfiguration provides advantages in cost and efficiency in business implementations, but the functionality it provides seems indispensable when we consider the potential for IPv6-based home networks in the future. Stateless Autoconfiguration also allows for easy connection of mobile devices (your mobile phone or handheld) when moving to foreign networks.

4.4 Simplification of the Header Format

The IPv6 header is much simpler than the IPv4 header and has a fixed length of 40 Bytes. This allows for faster processing. All unnecessary fields have been removed, and additional options can be added in the form of extension headers, which are inserted into the packet only if they are needed. So, for instance, all the fields in the IPv4 header for fragmentation are removed from the basic IPv6 header. If a packet needs to be fragmented, a Fragmentation Extension header is inserted.

There is a basic set of six Extension headers defined in the current specification, but the model makes it easy to create specifications for additional Extension headers without changing anything in the basic IP header. This is one of the main changes that will allow IPv6 to expand and adapt to future services when the need arises. Figure 6 shows an IPv6 packet which has been encapsulated in an IPv4 header to be forwarded over an IPv4 infrastructure. The figure shows at a glance how much leaner the IPv6 header is.

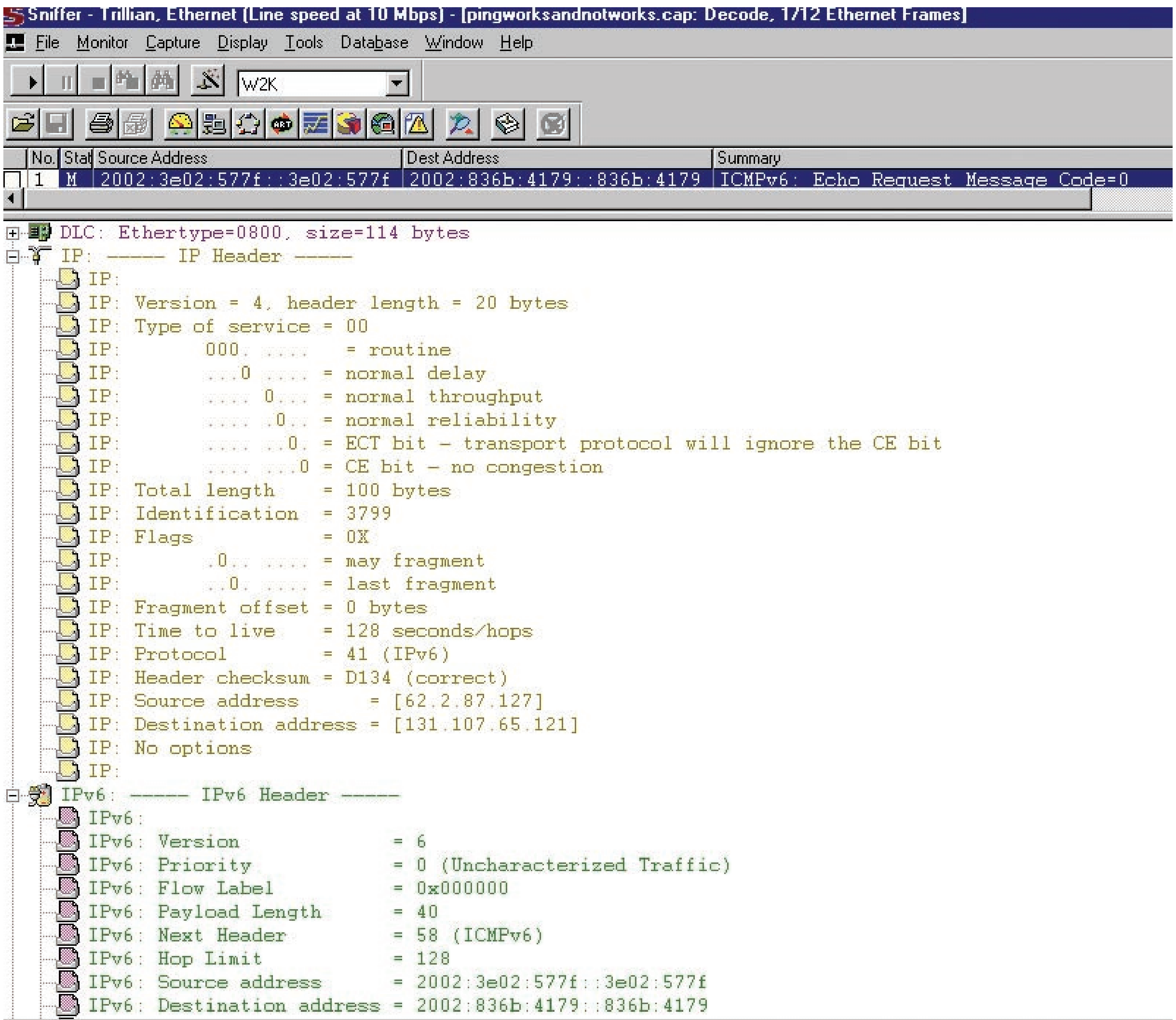

Figure 6 – Comparison of IPv4 and IPv6 header

The currently defined Extension headers are used for routing information, for RSVP (Resource Reservation Protocol), for Mobile IPv6, for QoS (Quality of Service, Flow Labelling), and for Security Options like authentication and privacy options. Some additional extension headers have already been defined—for mobile IPv6, for example.

IPv6 Header Next H. = Routing Value 43	**Routing Header** Next H. = Fragment Value 44	**Fragment Header** Next H. = TCP Value 6	**TCP Header and data**

Figure 7 – IPv6 packet with extension headers

Figure 7 shows how Extension headers are inserted into packets. Each header has a field called "Next Header." It is similar to the Protocol Type field in IPv4 and indicates the type of the next header. This field has been renamed, because with IPv6 the next header does not necessarily have to be a protocol header, but can be an Extension header. The value numbers for Extension headers have been inserted into the values for protocol types used with IPv4. So the next header value for UDP is still 17, and the value for TCP is still 6, just as with IPv4. In the figure, you can see that the value for a Routing header is 43 and the value for a Fragment header is 44.

4.5 Interoperability

It is expected that IPv4 and IPv6 will co-exist in our networks for many years to come. Therefore, the developers put a lot of attention into developing co-existence and transition mechanisms to make the transition as smooth as possible.

The mechanisms available today fall into one of three categories, and they are:

• Dual-stack techniques
Dual-stack techniques allow IPv4 and IPv6 to co-exist in the same devices and networks. This will probably be the most frequently used and easiest technique. It involves dual-stacked hosts—hosts that have both IPv4 and IPv6 stacks installed. Dual-stacked hosts access IPv4 applications using their IPv4 stack and access IPv6 applications using their IPv6 stack. It is improbable that all applications can be ported to the new protocol at the same time. This scenario allows use of the new protocol where it makes sense, while still supporting older applications that haven't been ported.

• Tunneling techniques
Tunneling techniques allow the transport of IPv6 traffic over the existing IPv4 infrastructure. These techniques allow an organization to migrate parts of the network to IPv6, even while the backbone is still running IPv4, or to migrate to IPv6 internally and connect to the outside world through a provider (ISP) that is still IPv4-only. This means that for building islands of IPv6 networks, you do not need to immedately replace your backbone routers. You can replace your backbone routers with IPv6-capable devices as the need arises, and you do not have to wait until your ISP offers commercial IPv6 services. So tunneling techniques provide flexibility in the order of your infrastructure upgrade. You can start anywere—in the core or at the edge of your network. As IPv6 becomes more widely available, we will increasingly be tunneling IPv4 packets over an IPv6 infrastructure. A variety of tunneling techniques supports all different types of transition scenarios. For instance, there are techniques that support IPv6 applications in an IPv4-based network, and others that support IPv4 applications in an IPv6-based network. For any transition scenario, you can choose the set of techniques that best fits your requirements, and you may use different combinations of techniques during the transition.

• Translation techniques
Translation techniques allow IPv6-only nodes to communicate with IPv4-only nodes. With these techniques, it is even possible that an IPv4 host can talk to an IPv6 host and vice versa through an ALG (Application Level Gateway). This technique is generally not recommended, since it does not really let you take advantage of the advanced features of IPv6, and the ALG creates a bottleneck and performance hit, but it may help in specific scenarios.

4.6 Security and Quality of Service

IPsec was originally developed for IPv6. When security issues became more and more pressing, IPsec was adopted for use in IPv4 networks, and since then has been widely implemented. The main difference with IPsec is that it is mandatory in IPv6 implementations. It is implemented as Extension headers, the Authentication Header (AH) and the Encapsulating Security Payload Header (ESP). Together with the extended address space and the fact that each IPv6 interface will have multiple IPv6 addresses, new security concepts will emerge, with more of the protection mechanisms moving away from a central device to the end host.

The need for real-time applications is growing. Voice over IP is in high demand and offers many business advantages, but improvement in quality is still needed. Streaming video is supported in many devices and offered by many providers, but again, the quality is still unsatisfactory. IPv6 has several features that allow traffic classification to provide Quality of Service (QoS). There are two fields in the IPv6 header, the Traffic Class field and the Flow Label field. In addition to this, there are two Extension headers which help prioritize traffic, the Routing Extension header and the Hop-by-Hop Extension header. To implement QoS on a larger scale, operators will need to cooperate in terms of strategy, policy, rules and accounting.

4.7 Mobile IPv6

I always tell people not to wait for a killer application to introduce IPv6, because there may be no killer application. But if anything can substantially drive the deployment, it will be the advantages that we gain in mobility, provided through the new structure of the protocol. Let's examine what this means.

The requirements for mobility are constantly growing. We want to be connected always, even when we are on the move. When we change our connection from our current network (let's call it the home network) to a new network (which we will call the foreign network), we also change our IP address. Any TCP connection we had based on the home network will be lost, because a TCP connection is always based on our IP address. So when we move to a foreign network, we have to re-establish our TCP connections. To solve this challenge, Mobile IP was defined. It solves the problem through a so-called Home Agent in the home network. This home agent will maintain my TCP connections while I am on the move. It will forward all packets to me wherever I am. I will keep the home agent updated about my current address. The mobile node now has two IP addresses, the home address and the so-called care-of address, which is the address I use in the foreign network. The service or the application, any host to which I was connected while on the home network (called a Correspondent Node in the specifications), will not know

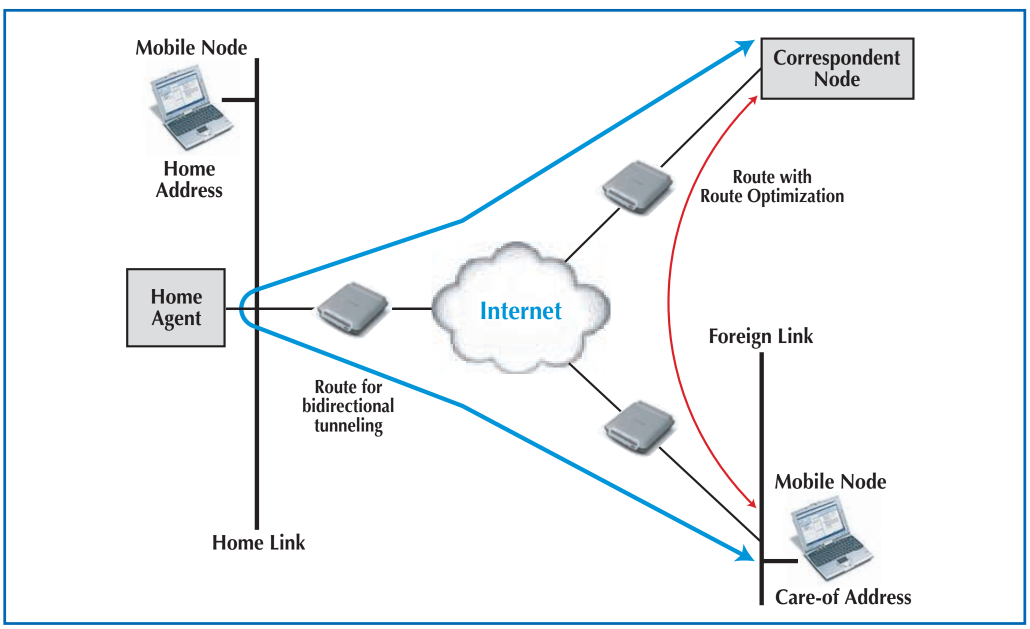

Figure 8 – Overview of mobile IPv6

that I am not connected to my home network and will continue sending its packets to my home address. The home agent forwards all packets to my care-of address. The correspondent node may also be a mobile node.

This works with both IPv4 and IPv6. The problem here is that the home agent creates a bottleneck and, in many cases, inefficient routing. All packets sent to me have to be forwarded by the home agent. If there are only a few mobile nodes that need to be supported, this may work just fine. But imagine global mobile phone communication being IP-based, or other services which have large numbers of users moving around. This is where Mobile IPv6 offers great advantages. Through the use of the Destination Options header and the Routing header, it is possible that after the exchange of some initial packets through the home agent, direct routing between the mobile node and the correspondent node is possible. This is called Route Optimization and cannot be done with IPv4.

The Mobile IPv6 specification was published in 2004. Since then, many additions and extensions have already been developed to cover future needs, especially in the area of scalability. This proves what we mentioned in the introductory section, that the protocol is open and flexible and will be extended as needs arise, just like IPv4.

One new extension that was defined is NEMO (Network Mobility), which allows a whole network to be mobile. In this case, the border router is the mobile node, using all the features of Mobile IPv6, while every node in this network, whether it supports mobility or not, remains connected while the network moves around. This specification allows configuration of nested mobility, where one mobile router is connected to another mobile router.

Another extension is Hierarchical Mobile IPv6. It is designed to significantly enhance performance of Mobile IPv6 and to reduce the number of messages a mobile node sends over a link in order to update its bindings with the home agent and the correspondent node. It also allows mobile nodes to hide their location from correspondent nodes and home agents when using route optimization. This specification introduces a new node type, called a Mobility Anchor Point (MAP). This is essentially a local home agent in the geographical region of the mobile node. The mobile node now sends its address updates to the local MAP rather than to its home agent.

Another extension is the Fast Handover, which has been specified to reduce the mobile node's handover latency when moving from one network to another.

Imagine an IPv6 world...

...in which critical information is sent instantaneously and reaction is swift and precisely pinpointed. In an IPv6 world, firefighters wear biometric monitoring harnesses that are also IPv6 devices. Heart rate, internal temperature, and other key factors are monitored centrally and a firefighter in danger is immediately identified, his location targeted, and assistance is directed through IPv6-enabled communications—the closest firefighters with the ability to respond are those directed to assist. Police, military, and all types of public service systems serve the public better in an IPv6 world.

5 Your Action Plan

Now we know that IPv6 has many advantages. It solves our address issues. Through the analysis of world population, Internet penetration rates and evolving new services, we can now be certain that we really will need more addresses in the near future. IPv6 allows us to move on to more flexible, scalable, mobile and secure networks by providing a large address space and many advanced features. There is also a reasonable ROI, as shown in the DoC report, so we can justify the cost of introduction. Now the question arises: What should you do today?

Well, if you are an enthusiast when it comes to embracing new technology, you probably have your lab running and are into advanced testing, playing with the advanced features and exploring all the new possibilities for managing and securing your network. If you are a skeptic, you are probably not even interested in reading this White Paper. So let us outline the best action for the pragmatic position.

One thing we learned from interviewing the project managers of our case studies is that you provide the best scenario for minimizing costs and problems if you introduce IPv6 while there is no time pressure. This provides time to plan carefully, to use the regular life cycles of your devices and applications, to test thoroughly and run pilots.

The most important thing you should do when preparing to migrate to IPv6 is to obtain a thorough education in all levels of network design, management and operation. Once you have a complete understanding of the architecture and features of IPv6, you can determine how you want to introduce it, and how you want to handle address management and security issues—especially in a dual-stacked world, which is probably what you will be maintaining for a long time. Then you can create a transition plan, talk to your vendors and give them a list of RFCs that you need to be supported, and find the products that support your transition. For instance, it is advisable to require IPv6 as a major evaluation criteria whenever you buy hardware or software which has a life cycle of more than a year.

There are different levels of IPv6 implementation, depending on what RFCs your vendor supports. You should consider your transition scenario when purchasing new equipment, even if you don't plan to implement IPv6 right away. You need to understand the advanced features, available transition techniques, and changes that may come from advanced management and security features, so that you can make informed decisions.

Learning about IPv6 in a class or by reading books is your best starting point. But this doesn't replace the test lab. You should test your scenarios before you finalize your transition strategy. You can test different transition scenarios, find out where the issues are, and find out which applications can be supported in an IPv6 network. You can also test different combinations of vendor products to identify interoperability issues and perhaps solve them in the lab. Operating the test lab will also give you the experience needed to find the optimal strategy for your requirements.

The bottom line is that you should prepare to introduce IPv6 sometime in the near future, perhaps within two to five years. The exact timing will be determined by market and business demands. Vendors and ISPs who depend on selling IP-based products and services should be getting ready. If you wait until the market requires IPv6, you will have less time to thoroughly research and prepare. If you are a customer/end-user, I would recommend that you educate yourself about IPv6 and start working on your transition strategy, including the setup of a testing environment. You should become IPv6-sensitive when it comes to buying hardware and software. Then you'll be prepared to quickly adopt applications that require or would benefit from IPv6.

If you watch the history of how new technologies emerge, you will find that, in many cases, a technology suddenly floods the market seemingly overnight. I remember back in the early eighties, a leading management center in Switzerland did a detailed study to find out whether it would be likely that at some point everyone would have a computer on his desk. The conclusion was that this scenario didn't make sense and was very unlikely. Only five years later, computers were sitting on every desk. A similar thing happened with mobile phones. In the early nineties, there were many people who believed that mobile phones (which then resembled a sewing machine more than a slim phone) would never be able to reach a good market penetration rate. Only a few years later, almost everyone had a mobile phone. Incidentally, the use of mobile phones is forbidden in schools in Switzerland because the kids have used SMS (Short Message System) to exchange answers during their exams. Even so, SMS is a great example of how a technology is sometimes adapted for uses beyond its initial projected applications. SMS creates lots of revenue. As far as I know, nobody foresaw any business case for SMS. It was simply a byproduct of other technologies, and then the market discovered it overnight. This reminds me of the following words by Victor Hugo: "Nothing is more powerful than an idea whose time has come."

Enjoy the ride.

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World Internet Users and Population Statistics: http://www.internetworldstats.com/stats.htm

IANA's IPv4 address allocation statistic: http://www.iana.org/assignments/ipv4-address-space

RipeNCC statistics of IPv6 allocations per RIR: http://www.ripe.net/rs/ipv6/stats

The 6bone homepage: http://www.6bone.net

The IPv6 Ready Logo Web site: http://www.ipv6ready.org

The IPv6 forum: http://www.ipv6forum.com/

The IPv6 portal: http://www.ipv6tf.org

The North American IPv6 Task Force: http://www.nav6tf.org

European IPv6 Task Force: http://www.ipv6.eu

The 6net Project: http://www.6net.org

The Euro6IX Project: http://www.euro6ix.net

DIODOS, Greek University Network: http://diodos.gsrt.gr (Greek Web site)

IPv6 Promotion Council Japan: http://www.v6pc.jp/en/index.phtml

Live E! Project in Japan: http://www.live-e.org

The InternetCAR Project in Japan: http://www.sfc.wide.ad.jp/InternetCAR/

Moonv6: http://www.moonv6.org

Internet2: http://www.internet2.edu

MetroNet6: http://www.metronet6.orgl

Fun Link:
And finally, after you have mastered all these challenges, visit: http://www.shibumi.org/eoti.htm

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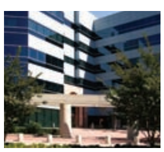

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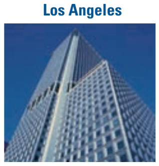
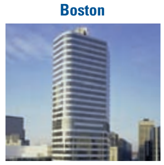
Boston

Chicago

Washington, DC



New York City



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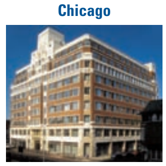
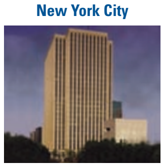
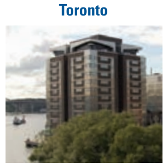


London

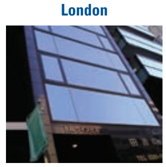
Paris



Ottawa



Stockholm



Tokyo

About the Author

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Silvia Hagen has been in the networking industry since 1990. She began her career as a successful instructor, and has trained hundreds of system engineers. Today she is CEO of Sunny Connection AG in Switzerland and works as a professional consultant and analyst for many mid-size and large sized companies. Her expertise is in Directory Services, Identity Management and Protocol Analysis. She is the author of several successful books, such as *Novell's Guide to Trouble-shooting TCP/IP* and *IPv6 Essentials*, published by O'Reilly. She presents internationally on various networking topics for Universities, Burton Catalyst, Cisco Conferences, Novell's Brainshare, NetWare Users International Conferences and offers customized corporate presentations and courses. She is a founding member of the Swiss IPv6 Task Force.

About the Editor

Erica Elam Simms

Erica Elam Simms has been in the networking industry since the mid 1980s. She began her career implementing systems and providing training and technical support to U.S. Federal Government clients in the Washington D.C. area. Erica has architected and implemented numerous IP networks, written multiple networking courses, and is a top-ranked instructor, having taught networking, IP and network security topics to thousands of clients in the U.S. and Europe. Her areas of expertise include IP networks, protocol analysis and network security. She is the founder and principal of Phoenix Technology Consulting, Inc., in Virginia, and is currently the CEO of Convergent Technology Alliance, an IT technology solutions consulting firm.

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