The Case for IPv6

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Introduction

The IP version we are all using today, in our corporate networks and in the Internet, is IP Version 4, short IPv4. It has been developed in the early seventies by a number of pioneers who wanted to connect some educational and government networks in the United States. At the time when they started development, a network like our Internet today was beyond imagination and therefore to meet such a requirement wasn't part of their design goals. All the more fascinating it is, that they managed to create a networking protocol, which is still - 30 years later - capable of running today's Internet! But now it has reached it's age and can't be pushed any further. Time for the next generation to take over!
When the Internet was switched overnight to use TCP/IP instead of the formerly used NCP in 1983, IPv4 was not exactly the protocol we know today. It was, in the core. But many of the extensions and additions that we use today, have been developed much later. The basics of IPv4 were defined in RFC (Request for Comment) 791 in 1981. Path MTU Discovery was defined in RFC 1191 in 1990, Supernetting, which was designed to help ease the issue with overloaded routing tables, was defined in RFC 1338 in 1992, DHCP, which was designed to help manage the addresses in a larger IP network, was defined in RFC 1531 in 1993 and Private Addresses which we use to build our NATs (Network Address Translation) today were defined in RFC 1597 in 1994.

The reason I am mentioning this, is not to bore you with numbers of papers that you never want to read. What I would like to point out is, that when IPv4 was first introduced, it was not the mature protocol we know today. Many of the extensions to IPv4 that help us manage and maintain our IPv4 networks, were introduced later, when the need arose. Based on the need, the extensions were defined in the international working groups and defined as RFCs.

So when people argue today, that IPv6 is not mature and cannot do what IPv4 can, this is only partially true and above all, not a reason to not use IPv6. Development for IPv6 started in 1991. The core of IPv6 was standardized in 1995 and updated in RFC 2460 in 1998. Based on that standard we have many implementations around since many years. Most hardware and router vendors have implementations since the late nineties and have tested them intensely. 6to4, a main transition mechanism, that makes co-existence and transition much easier, has been standardized in 2001. DHCP Version 6 has been standardized in summer 2003. Mobile IPv6, which is going to be one of the technologies that makes you choose IPv6 over IPv4, is in the process of being standardized in early 2004. The same is true for ISATAP, another example for a transition mechanism.

IPv6 has been developed based on the rich experience we have with IPv4. IPv6 is an evolution of IPv4, it is mature in the core, it has been implemented and tested intensely up to the network layer. The developers created a protocol, which takes everything that was great about 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 to support the new types of services, especially in the area of mobility, that we have to expect in the coming years.

There are things that we are missing in IPv6 today, that is true. But you do not need to switch today and all these additions will be defined in the coming years, just as it happened with IPv4. But you ought to become aware of how IPv6 will impact your business and your network. If you plan early, you will save money and headaches. You will be ready when it is time for you and more importantly, you will be able to determine the right moment for not extending your IPv4 infrastructure anymore, but putting your investments into the future technology.

Technological Advantages of IPv6

IPv6 is a technical evolution of IPv4. Many things that are familiar from working with IPv4 will remain or be similar. We do not have to master a completely new technology. The driving reason to develop a new protocol, was the expected address depletion. But the working group determined in the early

nineties, that they had enough time to not only extend the address space in the protocol, but build in additional features which would make it a more efficient protocol to meet the growing requirements of future networks and services. So let us examine what the new key features are.

1. **Extended Address Space**
   An IPv4 address has 32 bits or 4 Bytes.
   Example: 192.168.0.1 (decimal notation)

   An IPv6 address has 128 bits or 16 Bytes.
   Example: FE80:0000:0000:0000:0202:B3FF:FE1E:8329 (hexadecimal notation)

   There are rules, to abbreviate the address, by omitting leading zeros and replacing a series of zeros by two colons.

   So the address above can be written as: FE80::202:B3FF:FE1E:8329.

   Many people argue, that we have enough IPv4 address space and that with technologies like NAT, where many users with private IP addresses can hide behind a single globally routable IP address, there is no issue about address space. There are several misconceptions behind this viewpoint. 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. We also have to consider that more than 70% of the global IPv4 address space belongs to corporations and organizations within the United States. There are providers in the US that have almost as much address space as the whole of Asia today. If countries like China, Japan, India and many others want to connect their people to the Internet, imagine what numbers of addresses they need. They are using IPv6 today, they have no choice.

   When it comes to services like real-time banking applications with high security requirements or services like Voice over IP, NATs can be killers. The almost unlimited global address space of IPv6 will resolve these issues.

   In addition to this, we do not only need more address space to connect more people to the Internet. In the future all sorts of always-on devices like mobile phones, sensor devices, tv-sets, digital radios, refrigerators, air conditioning devices, cars, and many more to imagine, will need a permanent IP address. This growth of address demand can only be met with IPv6.

   The almost unlimited IPv6 address space will let us reestablish the end-to-end paradigm. This was a fundamental design rule of the Internet, which was broken with NAT.

2. **Autoconfiguration**
   Perhaps the most intriguing new feature of IPv6 is its autoconfiguration mechanism. A booting device in the IPv6 world can come up and ask for its network prefix. It can get one or more network prefixes from a router on its network. Using this prefix information, it can autoconfigure for one or more valid, global IP addresses by using either his MAC identifier or a private random number to build a unique IP 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 you have other options.

   Autoconfiguration will facilitate the lives of network managers and save substantial cost in maintaining IP networks. But not only this. If we imagine the number of devices we may have in

our homes in the future, that need an IP address, this feature becomes indispensable. Imagine reconfiguring your DHCP server at home when you bought a new tv-set! Autoconfiguration also allows for easy connection of mobile devices, like for instance your mobile phone or handheld, when moving to foreign networks.

3. **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 only inserted into the packet, 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, when the need arises, without changing anything in the basic IP header.

   The currently defined headers are used for routing information, for RSVP (Resource Reservation Protocol), for Mobile IPv6, for QoS services (Quality of Service, Flow Labelling) and for Security Options like authentication and privacy options.

4. **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 to developing co-existence and transition mechanisms to make the transition as smooth as possible.

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

   - **Dual-stack Techniques**
     Allow IPv4 and IPv6 to coexist in the same devices and networks. This will probably be the most used and easiest technique. It allows to set up dual-stacked hosts, that can 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 to use the new protocol where it makes sense, without neglecting older applications that haven't been ported.

   - **Tunneling Techniques**
     allow the transport of IPv6 traffic over 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 and connect to the outside world, while the provider (ISP) is still IPv4-only. This means, for building islands of IPv6 networks, you do not need to rip out your backbone routers. You can wait until the backbone routers fulfill their life cycle and then replace them by IPv6 capable devices. And you do not have to wait until your ISP offers commercial IPv6 services (although many of them are 'sort of' ready, only they do not announce it yet).

   - **Translation Techniques**
     allow IPv6-only nodes to communicate with IPv4-only nodes. With this technique, it is even possible that through an ALG (Application Level Gateway) an IPv4 host can talk to an IPv6 host and vice versa. This is your last resort, if everything else fails. 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.

5. **Common Myths About IPv6**
   There are several misconceptions circulating in discussions about IPv6. Let us explore the most common of them:

   - **All devices need to be upgraded to IPv6.**
     With all the transition techniques available, IPv6 can be introduced independently at any point and on any number of hosts in the network. Single hosts can start using IPv6 and talk to each other directly, if on the same link, or with ISATAP in a network without IPv6 aware routers. They can talk to hosts outside their network by using any of the transition mechanisms like 6to4, a Tunnel broker or Teredo, if sitting behind a NAT.

   - The core of the network is too difficult and expensive to upgrade to IPv6.
     Again the transition mechanisms make it possible to migrate to IPv6 at the edge of the network with no depency on the backbone. IPv6 packets traveling over the backbone to reach another IPv6 segment within the company, can be tunneled in IPv4 packets. You do not need to upgrade the backbone first.

   - **Our ISP doesn't offer IPv6 services, so why should we upgrade?**
     Same answer, you do not have to wait for your ISP to upgrade to IPv6. As long as he does not offer IPv6 services, tunnel your IPv6 packets over his IPv4 network.

   - **It would be too hard to upgrade all applications to IPv6.**
     Basically the statement is true, it is not realistic to expect that all applications can be switched to use IPv6 at the same time. But there are enough transition scenarios and techniques, which make it possible to live in a dual-stacked world and have access to some applications over IPv4 and to other applications over IPv6. We expect this to become the most used transition scenario in the real world.

   A side note: the effort needed to port applications to IPv6 is often overestimated. It depends on the quality of the application code.

IPv6 in the World

The longest-lived IPv6 network in the world is the 6Bone (www.6bone.net). It was created in 1996 and today connects more than one thousand hosts in about 50 countries all over the world. It was started as a testbed for the IETF working group that worked on the development of IPv6 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 has been specified, the 6bone will be phased out and integrated into the official address space of 2001: by June 2006. The 6Bone not only proves, that IPv6 works, it provided a great infrastructure for different purposes. In the beginning it was used to test the IPv6 protocol and the first implementations, then to experiment with routing and operational procedures and finally it was used as a platform to develop and test IPv6 applications and transition mechanisms.

When we look at the global usage of the IPv6 protocol, we find different scenarios per continent. There is the International IPv6 Forum (www.ipv6forum.com) which coordinates the efforts for IPv6 deployment on a worldwide scale. There is an international IPv6 Task Force Site at www.ipv6tf.org, which connects all national and regional Task Forces. There is a US IPv6 Taskforce (www.nav6tf.org), a European Task Force (www.eu.ipv6tf.org) and different Task Forces in Asia. They each coordinate the activities of national or regional task forces in their region/countries.

Asia

In Asia, IPv6 is alive and used widely. The people in Asia had no choice. With the small percentage of IPv4 address space allocated to Asian countries (less than 20 % of the global address space), people that wanted to connect to the Internet, would sometimes sit behind multiple layers of NAT (up to four or five layers). And this in a situation, where most people wouldn't even have Internet access yet. Today the growth rate for Asian ISP's is very high and they had no choice than to start using IPv6.

Japan has taken the lead in promoting IPv6 back in 2000. They have announced to build the largest IPv6 network by 2005. Their decision was followed by Korea, China, Taiwan, Malaysia, India and other countries. Most countries offer government support for organizations that support the introduction of IPv6, because it is vital for their economy. As a consequence you will find most examples and richest variants of implementations in Asia.

If you are a European or US-based company, watch out if you buy companies in Asia. The day may come soon, where you buy a company that has an IPv6 network, which you will have to integrate somehow.

Europe

In Europe, the European Commission has taken a lead and promotes IPv6 since the year 2000. They have funded many IPv6 research projects such as 6net (www.6net.org) and Euro6IX (www.euro6ix.org). They believe that IPv6 is vital to the European economy and competitiveness.

There is a European IPv6 Task Force (www.eu.ipv6tf.org) which coordinates the activities throughout Europe, with many countries having their own national Task Forces. Currently there are nine European countries very active, Belgium, Denmark, France, Germany, Luxembourg, Portugal, Spain, Switzerland, and UK.

Telia Sweden was one of the first ISPs starting to offer IPv6 POPs (Point of Presence). This started back in the year 2001. Today, one can say that, although most ISPs do not announce it officially yet, they have worked on scenarios and tests to offer IPv6 services and are sort of ready. The number of backbones and IEX (Internet Exchange Points) with IPv6 access/transport is growing. On the 6Net website, there is a map that shows the layout of the 6Net backbone and it connects most countries in Europe. The Euro6IX backbone also connects many European countries and the two backbones are interconnected.

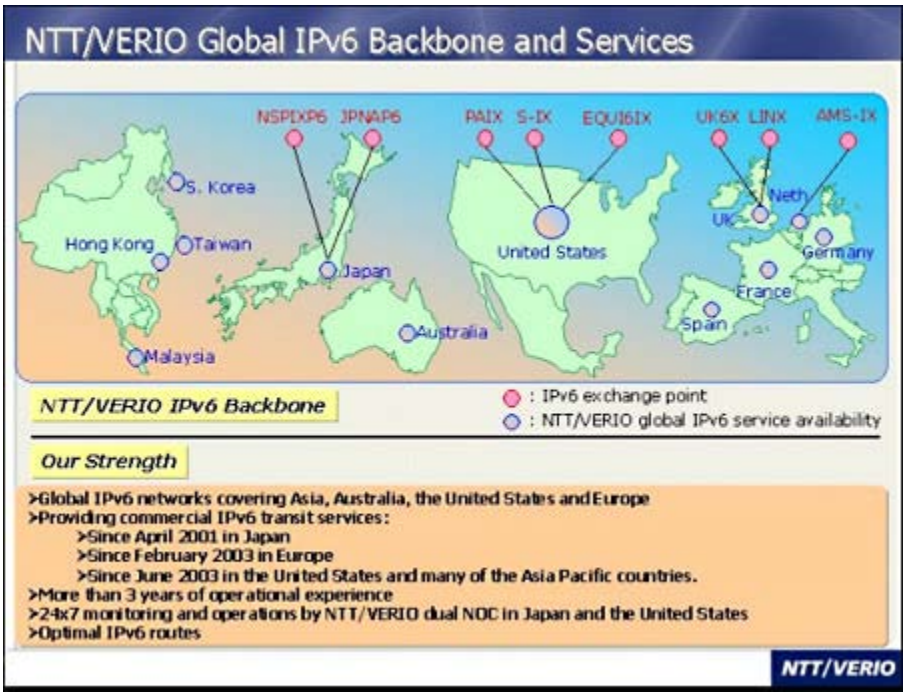
North America

Initially it was expected, that the US would be the last part of the world interested in IPv6, because, due to historical reasons, they own the largest part of the IPv4 address space. This has changed in summer 2003, when the DoD (Department of Defense) surprisingly announced, that they would migrate the whole DoD network to IPv6 by the year 2008 and starting October 2003, would only buy hard- and software which supports IPv6. With their annual IT budget exceeding $30 billion, this has a major impact on the market and will greatly accelerate the introduction of IPv6.

The US IPv6 Task Force can be reached at www.nav6tf.org. The Moonv6 Project (www.moonv6.com) was started, which is 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. Taking place across the US at multiple locations, the Moonv6 project represents the most aggressive collaborative IPv6 interoperability and application demonstration event in the North American market to date. It will serve 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/Verio, a US/Japan-based ISP, recently announced the extension of their global IPv6 services in all areas, tunneling, native IPv6 and dual-stack.

Here's a recent picture of international IEX points and how the NTT/Verio backbone connects to them:



This is not all there is, just an example. And it shows that IPv6 transport is much more than a new standard on paper.

IPv6 Status and Vendor Support

- IPv6 works on the infrastructure level (packet structure, routing, integration, transition, DNS). DHCPv6 was standardized in summer 2003 and first implementations will show up soon.

- Work in progress: QoS, Security Implementation, IPv4/IPv6 MIB integration, Mobile IPv6

- Missing tools: Network Management, Firewalls, Proxies- all in the pipeline. HP, Cisco, Checkpoint, only to name a few, are working on it and implementations are available which will be extended soon.

- Applications emerging

For the status of IPv6, the main thing to be said is that the announcement of the DoD will greatly accelerate the vendor market to work for IPv6 support, so this area is changing very fast these days. Major announcements have been made at the US IPv6 Summit in December 2003 (www.usipv6.com), which took place in Arlington. To get a feeling for the vendor support available, visit the Web site where you can also download the presentations by different vendors.

IPv6 will be everywhere soon, worldwide development is moving beyond infrastructure these days. IPv6 is available today in Gaming Devices (Sony), Mobile Phones (Nokia, Sony Ericsson), Digital

Cameras (Sanyo, Canon), Cars, Refrigerators, TVs, Internet Phones and many more devices. IPv6 is specified as IP of choice for 3GPP networks. Did you know that most car vendors are heavily developing for IPv6? They are all involved in projects and say that a car in the future will have some 15 IP addresses.

A Gartner Group report in 2002 (before the DoD announcement!) estimated, that by the year 2006 approximately 50 % of the ISPs will offer commercial IPv6 services. So in the beginning, IPv6 packets will travel over the IPv4 Internet tunneled within IPv4 packets. At some point the number of IPv6 links in the Internet will exceed the number of IPv4 links. The amount of IPv4 traffic, which will be tunneled within IPv6 in order to traverse IPv6 links, will then increase.

IPv6 - Is There a Business Case?
Now that you have seen that IPv6 is maturing and that it is used globally, even though on a small scale yet, compared to IPv4, your next question will be, why should I invest in it, is there a business case?

The Business Case

Obviously, while introducing IPv6 into a network, cost will initially rise. You will have to educate your IT staff for IPv6, you will have to build testbeds, that let you test IPv6 related issues and you will go through the cost of implementation.

And what is your return on investment? Why should you invest in IPv6, while you have a running IPv4 network? In this area many heated discussions are going on and it is important to ask the right questions in order to get meaningful answers.

There are some facts to be noted:

- IPv6 is inevitable in the long term
- Supporting IPv6 will be a minimum requirement for hardware and application vendors soon
- If you plan for IPv6 early you will save money and headaches

It can be compared to the situation where you had to introduce NAT (Network Address Translation) into your network in order to solve address limitation issues. What is the business case for a NAT? What is the business case for your whole IPv4-based infrastructure?

An infrastructure does not create a business case in itself. You need an infrastructure, in order to be able to use and run applications and services which create a business case for your company. So you have to invest in your infrastructure, because you need a well developed and state-of-the-art infrastructure as a foundation for efficient business processes. You cannot use the newest and coolest applications, if your server runs an old-fashioned version of the operating system. You cannot use the newest and coolest applications and services that build on the advanced features of IPv6, while you still run IPv4.

Our business processes and our private lives more and more depend on connectivity and mobility. The demand for mobility has been exploding in the last years and will continue to grow. Remember in the early eighties, when it was unimaginable, that soon we would have a computer at every desk? Remember in the early nineties, when it was unimaginable that soon everyone would have a cell phone? Today, we have to forbid kids to use their cell phones at school, because they exchange exam results by SMS (Short Message System). Remember in the early sixties, when it was unimaginable, that man would ever put his foot on the moon?

Evolution means that suddenly something is common, which was unimaginable a short time beforehand.

This is what is going to happen with IPv6. It feels new today, you cannot imagine migrating your network to IPv6 yet, but tomorrow you will use it naturally, just like your cell phone. And the advanced services, applications and enhanced mobility, all based on IPv6, will create your business advantage!
In a different perspective, IPv6 can be an enabler for new markets and services. You may be able to create business opportunities with new and innovative services, that use the advanced features of IPv6.

When is it time for IPv6?

The question is not, whether you should consider IPv6. IPv6 is a due upgrade to the existing Internet protocol the question is, when is the right time for you?

If the rest of the world is moving toward IPv6 and you remain on IPv4, the day comes, when you are not really connected anymore. You may loose customer base due to this or you may wish to have a business critical application, which would greatly enhance your business, but it only runs with IPv6.

We do not recommend organizations to go IPv6 tomorrow. What we recommend is, to start to include IPv6 into strategic planning and to start to build some expertise internally in order to be able to determine the right moment in time for you to move on. And most importantly, put IPv6 support as a minimum requirement on your hard- and software shopping list. This will preserve your investments.

The golden rule still applies: do not touch a running system. As long as your IPv4 infrastructure runs well and covers your current needs, let it run. But when your IPv4 infrastructure hits the limits for some reasons and you need to make substantial investments in extending or fixing it, consider IPv6 for a moment, before you spend money on IPv4. Maintaining and extending an IPv4 infrastructure will become more and more expensive. Especially, stop building or extending NATs. NATs are killers, and should be avoided. NAT was a strategy to avoid a crisis (address depletion) and should not be considered as long term strategy, as it does not solve the underlying problem, it's just a quick-fix. Any investment that you put into IPv6 will have a better protection, because it is an investment into the future Internet protocol. Also in the long term, maintaining and supporting an IPv6 infrastructure is less costly.

No flag-day for IPv6!

There will be no flag-day for IPv6, like there was one for IPv4 in 1983. No chance we could switch our Internet to a new protocol over a weekend. So don't wait for the flag-day, and don't wait for the killer application.

Take the step by step approach, according to the above mentioned guidelines, and IPv6 will naturally be there the day you really need it.

The step by step approach is also the most cost effective one. It does not disrupt your current infrastructure, it lets you learn step by step and integrate the learnings into your strategy. And remember: the largest journey begins with the first step.