IPv6: Drivers and Barriers for Adopting

Research mentor

ing. Emile Bons
Department of Information Management
Tilburg University

dr. H. Weigand
Associate Professor
Department of Information Management
Tilburg University

Abstract

Industry stakeholders, specialists and scientist generally agree to the fact that the adoption of IPv6 is not a matter of 'how', 'why' or 'who' but only of 'when'. Since the design of IPv6 in 1996, the adoption of this 'next generation Internet protocol' is far from widespread. This paper deals with the most valuable drivers and most considerable drivers of the adoption of IPv6. This paper is based on other papers and some personal interviews with enterprises specialists.

Besides the drivers and barriers in adoption of IPv6, this paper also gives an overview of important stakeholders in adoption and the role of local governments in adoption of IPv6.

Keywords: IPv6, drivers, barriers, economic approach, adoption

Contents

1. Research plan

1.1 Introduction

The Internet is mainly based on one protocol; the Internet Protocol. (Lundsten, 2002) Version 4 of the Internet Protocol is developed in the 1970's and is the protocol that is common at the moment for Internet traffic. After examining a number of proposals, the Internet Protocol version 6 is settled in January 1995 and since then also known as the "next generation Internet Protocol". Although widespread implementation over the world is necessary within a couple of years mainly because the address space of the Internet Protocol version 4 is almost running out of addresses, we don't see many companies taking consideration about implementing version 6 of this protocol.

Because of this, I was wondering if this lack of consideration is caused by the lack of a serious business case for implementing the Internet Protocol version 6. Since it is hard to define exact costs and exact benefits for every kind of enterprise or organization in the world, I will discuss the drivers and barriers for adopting IPv6 in this bachelor thesis.

1.2 Thesis statement

When considering the adoption of IPv6 from an economic approach, what are the most valuable drivers and most considerable barriers for adopting IPv6?

To conduct an answer to this statement, several sub questions can be stated:

Which stakeholders' can be defined regarding the adoption of IPv6?

What possible drivers can make adoption of IPv6 economical attractive?

Which barriers can be defined for adopting IPv6 within organizations?

Which advantages can be defined for IPv6 compared to IPv4?

Which new business opportunities can be defined when adopting IPv6?

What is the role of local governments in the adoption process of IPv6

1.3 Approach / methods

This research will be based on other papers. Outcomes of research in the past will be compared and collected within this research. Searching for answers on the research question and its sub question will be done from an economic point of view.

Besides the use of papers, this bachelor thesis will also be built upon interviews with managers in the Internet Service Provider (ISP) area. The results from these interviews will be used to reflect on statements or conclusions from other papers.

1.4 Preliminary results and discussion

The adoption of IPv6 is not taking big steps forward at the moment. We see not many early adopters and many organizations struggling with the right moment to start adopting IPv6. We know that adoption should take place; it is a ‘when question’, not an ‘if question’. We also know that there will be a moment that there is no space left in the current IPv4 address space and we can almost expect when this moment will take place.

1.5 Implications of Research

Out of research done before, conclusions will be drawn about the business case and business drivers for adopting IPv6. This research should give an overview of the most valuable drivers and most considerable barriers for adopting IPv6. Besides that, this research will give more information about important stakeholders in adoption of IPv6 and the role of local governments in the adoption.

2. Introduction

Courcoubetis and Weber (2003) discuss the high economic value of the Internet protocol. They recognize that the fundamental characteristic of the protocol is due to it's complementarily and openness. As the authors clearly indicate:

"The added value of the IP is the efficient provision of end-to-end connections of arbitrary duration between any points on the globe. Once information is converted into IP packets these can run over any access and link technology connecting the IP routers. This is the definition of a truly open technology." (Courcoubetis & Weber, 2003)

During the rapid expansion referred to as the 'dotcom boom', the need for adoption of the next version of the Internet Protocol (IPv6) was much discussed and promoted. The reason given was that the explosive growth of Internet companies, bandwidth, and services required a greater address space than possible with the current version, IPv4. (Cooper & Yen, 2004) Many of the Dutch Internet Service Providers (ISPs) are now analyzing when the complete IPv4 address space is used. This moment could be further in time then the moment that is used in many papers, because many ISPs still have their own blocks of unused IPv4 addresses at the moment of worldwide exhaustion. (de Graaf, personal communication, March 18, 2009)

2.1 IPv4

Defined in RFC 791, IPv4 is the first version of the protocol to be deployed on ARPANET, which then became the Internet. As such, IPv4 was widely called simply "IP" and only came into wide discussion as "IPv4" once IPv6 came into common conversation. IPv4 includes 32 bits in the header for address space, which at 4,294,967,296 addresses seemed sufficient for the conceivable number of computing devices at the time. (Cooper & Yen, 2004)

2.2 IPv5

According to RFC 1819, IPv5 describes the Internet Stream Protocol, Version 2 (ST2), an experimental connection-oriented protocol to support data streams to single or multiple destinations. This RFP states that "ST2 is part of the IP protocol family and serves as an adjunct to, not a replacement for, IP". As such, IPv5 is not a replacement for IPv4, so requires no further consideration within this text, but is mentioned here for completeness. (Cooper & Yen, 2004)

2.3 IPv6

IPv6 is the replacement for the protocol commonly known as "IP." RFC 2460, the most recent standards document regarding IPv6, states the following with regard to IPv6: IPv6 is a new version of the Internet

Protocol, designed as the successor to IP version 4 (IPv4) [RFC-791]. The changes from IPv4 to IPv6 fall primarily into the following categories:

- Expanded Addressing Capabilities;
- Header Format Simplification;
- Improved Support for Extensions and Options;
- Flow Labeling Capability;
- Authentication and Privacy Capabilities.

(Cooper & Yen, 2004)

2.3.1 Current status

While much of the Ipv6 technology set could be described as operationally ready, IPv6 hosts and service delivery platforms are being deployed, and a visible proportion of the network operating entities on the Internet are undertaking various forms of IPv6 deployments, the real level of uptake of IPv6 in the Internet today in terms of services and, by inference, packets, remains quite small. The metric that could be regarded as perhaps the best pointer of the current level of IPv6 usage is the web server access data, and the actual value of the relative rate of IPv6 use appears to be around 0.3% of the IPv4 use, or a relative level of 3 parts of IPv6 per 1,000 of IPv4. (Huston & Michaelson, 2008)

The encouraging observation is that the relative use of IPv6 in today's internet as compared to IPv4 is increasing, so that while the internet continues to grow it appears that IPv6 use is growing at a slightly faster rate. (Huston & Michaelson, 2008)

On the other hand, it also appears that while the relative numbers are increasing, IPv6 is still a very small proportion of the IPv4 Internet, and by whatever metric one would claim is a "critical mass" of IPv6 usage, we've yet to achieve and, and it may still be quite some years off yet. (Huston & Michaelson, 2008)

2.4 Advantages v6 compared to v4

IPv6 is more than just a large address space. IPv6 has been streamlined over its predecessor. (Roese, 2004) But the 128 bit length address not only solves the problem of exhaustion, it also restores the end-to-end Internet transparency (Blumenthal & Clark, 2001). IPv6 enforces geographic and regional addressing, where organizations will have common “prefixes” based on where they are located and the provider through whom they are connecting. This is similar to the way public phone networks operate, where companies in the state of Massachusetts, U.S., for instance, have a regional telephony area code of 978 or every company in Great Britain has a telephony country code of +44. (Roese, 2004) IPv6 actually offers solutions adapted for all encountered problems: almost unlimited addressing space, end-to-end secure access for P2P applications, automatic terminal and router configuration, and terminal mobility. (Cocquet, 2004)

Ken Cheng of Foundry Networks states the main difference between IPv6 and IPv4 is the obvious increase in IP addresses. The need for more IP addresses has become a huge issue for a variety of reasons: because intelligent devices increasingly require unique IP addresses; because electronic devices have increased dramatically in highly populated countries such as India and China; and because of "always on" mobile devices whose addresses change as they transition between connection points. (Gomez, Mancin, Richardson & Weiler, 2008) Auto configuration is another big difference between IPv4 and IPv6. Currently, configuration is done either manually or using DHCP (Dynamic Host Configuration Protocol), which adds operational costs due to management difficulties and additional network complexity. (Gomez et al., 2008)

Anycast addressing—also available in basic IPv6 specifications—compared to traditional multicast techniques, constitutes a very effective way of locating a DNS server and, generally, all types of servers. IPv6 also brings an immediate solution to end-to-end security of transmission that is not always possible through NAT-based IPv4 architectures. (Cocquet, 2004) IPv6 has also brought security to the forefront by requiring IPSec for host-level end-to-end security. (Roese, 2004)

The address space is a major step forward and the major driving factor for the technology. Nearly everyone understands that IPv6 has a bigger address. Routing will be simpler, but it forces the end devices to do Path MTU Discovery. While the users may not care much about byte alignments, the engineers look to the details like 64-bit aligned packets to help improve efficiency and ease of implementation. This means faster and cheaper network devices in the long term. (Roese, 2004)

IPv6, however, added features like Neighbor Discovery and local addressing to make IPv6 more plug-and-play. Many in the IT community believe that the inherent auto configuration capabilities in IPv6 will make the network easier to operate and manage so that the migration will pay for itself in the long run. (Roese, 2004)

Table 1 describes some of the key differences between current implementations (IPv4) and IPv6. (Gomez et al., 2008)

Feature	IPv4	IPv6
IP address space	4 billion	$3.40282367 \times 10^{38}$
Configuration	Manual	Plug & Play, automatic node discovery
Security	Optional	Mandatory. Embedded encryption & authentication
Mobility	Mobility need to be configured	Integrated Mobility
Network Management	Expensive and complex	Cheaper and simple
Address Format	Multicast & Broadcast	Unicast, Anycast and Multicast
More Applications	No support for future applications	3G applications and beyond

Table 1: Key differences between IPv4 and IPv6

3. IPv6 adoption

3.1 Stakeholders in adoption

We can define several stakeholders within the process of adopting IPv6. Because of the curved partitioning of IPv4 address space over the world, Asia, Europe and the Middle East are experiencing the greatest shortage of IPv4 addresses. For that reason, these regions are known as early adopters in the IPv6 adoption process. (Hovav & Schuff, 2005) In the world today, an area with a great drive to move toward IPv6 is Asia, followed by Europe. (Ladid & Telebit, 2001)

For the study of this research, we can define the supply chain into four major stakeholder groups: infrastructure vendors, application vendors, Internet Service Providers, and Internet users. (Gallaher & Rowe, 2005) It is interesting to note that home users will probably adopt IPv6 as well. Home users will likely begin to adopt IPv6 earlier than private enterprise. (Roese, 2004) The organizations and groups in which IPv6 will be adopted are the following: Universities, Carriers, Governments, Private enterprise and Home users. (Roese, 2004) Usually an operator has two separate customer categories; private consumers and companies. Both of these segments should be willing to pay for IPv6. (Anttila, 2005) As a result, the Internet Engineering Task Force (IETF) began work on the next generation IP. Their efforts led to the development of IPv6. (Gallaher & Rowe, 2006)

National backbone ISPs (e.g., MCI, AT&T, and Sprint) provide connectivity to larger companies, some institutional users, and national and regional ISPs (e.g., AOL and Earthlink) that provide Internet connectivity to home and small business users. Internet users represent a diverse group of entities ranging from corporate, institutional, and government organizations to independent users including small businesses and residential households. (Gallaher & Rowe, 2006) Most people who are making applications do not know what the IP address space looks like. If anybody should be paying attention to this, it's the ISPs. (Ladid & Telebit, 2001)

The international community has experimented with IPv6 and the new IP protocol has been implemented in large scale tests in some countries around the world. (Gomez et al., 2008) China, Japan, Taiwan, and Korea are among the most advanced adopters of IPv6. Japan has a strong motivation to embrace IPv6 due to both a shortage of addresses and the demands of a technical savvy population. (Gomez et al., 2008)

The IETF has done its part in developing IPv6 protocols. The Internet Corporation for Assigned Names and Numbers (ICANN) has published the policy document on IPv6 address allocation and assignment. (Ladid & Telebit, 2001) The redesigned header structure in IPv6 (which includes new flow labels) and the enhanced capabilities of the new protocol could provide significant security benefits to Internet users, network administrators, and applications developers. (Gallaher & Rowe, 2005)

3.2 Role of local governments

Government regulations reduce the level of risk and uncertainty about the future of a new standard. In cases where a government mandates the implementation of a new standard, that standard will become dominant (at least in that country or region), ensuring some market for related products. For example NX, an ISP that lacks slack funding, is adopting IPv6 relatively early. NX believes that the European Union mandate will force the widespread adoption of IPv6 – in this environment, by adopting early they are positioning themselves to be opinion leaders. NX intends to leverage their knowledge in providing service and support for late adopters. (Hovav & Schuff, 2005) Additionally, the governments of Japan and the European Union have mandated that in the near future, network devices must support IPv6. Given that the U.S. government is the single largest IT customer in the world and the EU and APAC markets represent substantial portions of the IT market, the reality is that the customers exist for "IPv6 capable." (Roese, 2004)

Among other suggested ways of government support for IPv6 were pushing more advanced aspects of IPv6, including support of WLAN rollouts, best practice guidelines and promotion of IPv6 in academia through engineering programs, a government IPv6 Web site, tax incentives to carriers/ enterprises that deploy IPv6, and coordination with other governments to develop international coalitions. (Rowe & Gallaher, 2006) The European Union Commission (EU) mandated the implementation of IPv6 as a long-term goal to increase the competitive position of the European community. The EU provided over 180 million Euros for research and development. (Hovav & Schuff, 2005)

Government sponsorship offsets the costs and the uncertainty associated with early adoption. Government support can reduce the economic risk involved in early adoption. None of the cases we studied received direct financial incentives from their respective governments. However, ST received subsidies in employee training. NX and CL, through the EU, received financial backing in the form of information, test environments, and technical support. (Hovav & Schuff, 2005) In addition, most of the respondents saw value in government support of new application development through funding research, providing a leadership role (i.e., government R&D for new applications), or the sponsorship of real life applications development (e.g., funding university-sponsored research projects focused on developing applications that require IPv6). (Rowe & Gallaher, 2006)

For its part, the European Commission (EC) in 2001 funded a joint program between two major Internet projects—6NET and Euro6IX—to foster IPv6 deployment in Europe. The Commission committed to contribute up to e17 million over 3 years to enable the partners to conduct interoperability testing, interconnect both networks, and deploy advanced network services. (Rowe & Gallaher, 2006) In general, infrastructure vendors and users were more enthusiastic about government involvement as compared to application vendors and ISPs. Infrastructure vendors and users differed in the type of activities and technical areas in which they believed government should be involved. (Rowe & Gallaher, 2006) The European Union is completing its second phase, contracting international cooperation agreements to help set up IPv6 task forces at national and regional levels. (Childress, Cathey & Dixon, 2003)

When asked more specifically what role government should play, 63% indicated government should provide support for R&D and participate in the markets as a consumer. Forty-seven percent indicated that government should be active in endorsement and provide technical guidance. (Rowe & Gallaher, 2006) Subsequently, interview participants were asked more specific questions related to the three possible roles for government. For respondents who indicated the government should have a role in supporting R&D, respondents were asked about specific activities. Support for new applications, compliance and interoperability testing and testbed infrastructure were the most commonly cited activities for government involvement. (Rowe & Gallaher, 2006)

Most respondents indicated that government should play some role as a consumer. Stakeholder groups were split with respect to IPv6 training opportunities. While some desired government participation in private industry, others saw it as unnecessary to spend government money on corporate training. In contrast, most of the respondents agreed that government should promote IPv6 and work with the industry on IPv6 promotion. (Rowe & Gallaher, 2006) Most of the respondents identified government's cooperation with industry standard bodies as being particularly important. (Rowe & Gallaher, 2006)

4. The Economical Approach

Although this chapter does not give a business case in terms of net present value of adopting and implementing IPv6, it gives an overview to the most valuable drivers and most considerable barriers for adopting IPv6. This chapter also defines the new business opportunities that arise when adopting IPv6 within an organization.

4.1 New business opportunities

IPv6 has the potential to lower costs associated with application development for software vendors and to reduce the costs of network management and the installation and testing of new applications for all enterprises. These represent long-term efficiency gains (net cost reductions) after the transition from IPv4 to IPv6 is complete; however, they are contingent on the removal of NAT devices and the restructuring of organizational networks, including the evolution of firewalls to be more versatile to allow seamless connectivity. (Gallaher & Rowe, 2005) IPv6 has the potential to change the way we view computing and communications. IPv6 has been designed to facilitate pervasive mobile computing and information sharing on a worldwide scale. (Roese, 2004)

Voice over Internet protocol (VoIP) is a very good example of killer application that has two intrinsic properties. The first one is that gives an alternative way of communication with personal computers and PDA's as well as with landline telephone numbers. Under this notion it acts as a complementary service to the installed base of telephone users but also exploits the positive feedback loop of the large network of TCP/IP compatible devices. It links two different installed bases: the telephone network and the devices that are already plugged into the Internet. The communication from computer to computer is without charge and the only cost associated with it, is the fixed cost of the broadband connection. Under the notion that IPv6 and 3G networks will start gaining power in the market, everyone with an Internet connection can run a VoIP application and talk for free with everyone in the globe. In this way, VoIP applications start to face at a first level critical mass and after some time the user will be locked in this service as it faces lower charges from the old costly services of GSM mobile networks. According to Brian Carpenter, IETF Chair, VoIP applications challenge "all the cost models of telecoms" (Alafouzos, 2006)

Secondly, VoIP applications are based on the information infrastructure of already existing technologies. This is not the first time that such a thing happens in telecommunications industry. The Internet was built upon the old telephone network. However, the diffusion of Internet as a means of communication was not limitless due to this fact. In some geographic areas the already installed base of Private Branch Exchange (PBX) boxes was a reason for early diffusion of Internet technology because Providers did not accumulate the sunk costs of new infrastructure (although this was not for high speed connections). This aspect is critical for the growth of companies that did not need to invest in infrastructure and exploit the IP protocol for growing their earnings. Internet service providers and mobile telephony companies face extremely costs for upgrading their infrastructure. At the same time companies, like Skype, start taking share of their market. This will force ISP's to enable Ipv6 capabilities in order not to lose customers. (Alafouzos, 2006)

Devices that are globally addressable so that they can be remotely accessed and controlled via the Internet represent a potential application of IPv6 addresses. Automobile components or subsystems, refrigerators, cameras, home computers, and other home appliances could be assigned IP addresses, linked together on home networks, and connected to the Internet. Home owners could control such devices remotely, and automobile and appliance manufacturers, for example, could offer remote service and support packages. (Gallaher & Rowe, 2005) Some experts believe that IPv6 could spur increased research and development (R&D) of, and interest in transitioning to a new network security model, in which techniques such as Internet Protocol Security (IPsec) could be more commonly and effectively used. (Rowe & Gallaher, 2006)

Some IPv6-only applications will provide obvious benefits, such as blood-analysis chips, personalized response from household gadgets, single address for emails and phone calls because these innovations are appearing around the world. However, other innovations cannot be known until they are created, which will only happen once an IPv6 infrastructure is in place. Key fields of innovation may include: streaming video, weather, transportation, health, and many others. (Gomez et al., 2008)

However, it is less clear if other near-term IPv6-dependent applications will emerge. For example, teleconferencing quality and implementation simplicity could improve (through the use of IPv6, the removal of NATs, and network restructuring) and potentially decrease the need for companies to incur large travel expenses. However, it is unclear to what extent improved teleconferencing will replace in-person interactions in the near future due to quality enhancements. VoIP represents an increasing share of the telecommunications market, and IPv6 could allow companies to move to VoIP more easily and enable more extensive use of VoIP capabilities. In a recent study, SouthTrust Bank indicated that installation of VoIP resulted in a 30 percent reduction in annual communications costs. (Gallaher & Rowe, 2005)

Despite these caveats, stakeholders participating in this study indicated that widespread adoption of IPv6 could lead to a world of connected devices. In a "virtual home" individuals could manage their heating and cooling systems, take stock of their refrigerator or access files from their home computer while from another country. Companies could offer constant monitoring services to automobile and appliance owners to determine the best possible time to get certain services performed. (Gallaher & Rowe, 2005) Meteorologists could use sensors with IP addresses on cars to more accurately predict and report current and future weather. (Gallaher & Rowe, 2005)IPv6 will facilitate a worldwide infrastructure to support public mobile computing, so users can utilize their mobile IP phones or laptops or PDAs anywhere in the world. (Roese, 2004)

4.2 Barriers for adoption

The problem with being an early adopter (as an organization) is that the leading edge of using new technologies is often also referred to as the 'bleeding edge' due to the risk of failure. New technologies will have bugs, may integrate poorly with the existing systems, or the marketing benefits may simply not live up to their promise. Of course, the reason for risk taking is that the rewards are high – if you are using a technique that your competitors are not, then you may gain an edge on your rivals.
It may be also useful to identify how rapidly a new concept is being adopted. When a product or service is adopted rapidly this is known as 'rapid diffusion'. The access to the Internet is an example of this. In developed countries the use of the Internet has become widespread more rapidly than the use of TV, for example. It seems that in relation to Internet access and interactive TV, Internet-enabled mobile phones are relatively slow-diffusion products. (Chaffey, 2007)

4.2.1 Early-adopter

The barriers to private enterprises moving to IPv6 are many; cost, complexity and business value are a few. (Roese, 2004) One of the issues facing early adopters is the risk associated with the adoption of a new standard. This is caused by the fact that relatively little information exists regarding IPv6 (Hovav & Schuff, 2005) According to Rowe and Gallaher (2005), many experts have noted that using IPv6 networking could result in decreased network security for a certain period during which network operators become more familiar with the new protocol and hackers identify flaws in initial IPv6 implementations. Unfortunately there appear to be no clear "early adopter" rewards for IPv6. (Huston, 2006) The scarcity of information on the subject of IPv6 migration costs, merged with the reality that many organizations are not sold on the supposed benefits offered by the Internet Protocol version 6, is making the case for upgrading difficult to argue. (Arifin, Abdullah, Berhan, & Budiarto, 2006)

The negative repercussions of successful standards are most visible in issues of "lock-in", where an old standard is so widespread and entrenched that switching costs are sufficiently high to dissuade agents from adopting a new standard. Apart from switching costs, the network effects involved may also cause coordination problems, as agents will have to coordinate a move to a new standard. In spite of the advantages that IPv6 offers, network operators have yet to shift from IPv4, both due to switching costs, induced by the scale of the network, as well as coordination problems. Since IPv6 network traffic cannot flow over an IPv4 network, all machines connected to, and running, the Internet must be upgraded at the same time (Ashwin, 2008)

4.2.2 Application legacy

Another economic factor is marinating IPv4 application, which is also a technical issue. It is very important that current applications which run on IPv4 can also run on IPv6. Most probably it will be some applications cannot be ported to IPv6 and end user will not be motivated to implement IPv6, since the interested applications cannot work on IPv6 network but the need for IPv6 features may affect the legacy of marinating IPv4 application. (Arifin et al., 2006) Some other application based barriers for adopting IPv6 are caused by the fact that many of the back office applications of ISPs (i.e. Enterprise Resource Planning applications) are used to check constraints in IPv4 form, where the input is expected to be an IP address. These applications have to be changed in order to accept IPv6 form IP addresses as input. (de Graaf, personal communication, March 18, 2009)

Today, there are only a few enterprises that need worldwide host-to-host connectivity, and in fact, many enterprises utilize NAT as a security mechanism, and will not likely change that any time soon. (Roese, 2004) Furthermore, experts generally agree that implementing any new protocol, such as IPv6, would be followed by an initial period of increased security vulnerability and that additional network staff will be necessary to address new threats posed by a dual network environment (DoC, NIST, and NTIA 2004).22 (Rowe & Gallaher, 2006) During this period, more security holes would probably be found in IPv6 than in IPv4, and IPv4 networks would continue to have, at a maximum, the same level of security issues as they do currently. (Rowe & Gallaher, 2006)

4.2.3 Dual-stack

IPv4 is expected to remain until IPv6 deployment has made it unnecessary. Given the lack of urgency for American companies to migrate, many providers will need to offer service over both protocols for the foreseeable future. This will increase, not decrease, costs in the short-term as the work that provides routing and other infrastructure will be duplicated. (Cooper & Yen, 2004) For many enterprises, the lack of enterprise-specific applications and the administrative overhead of running dual-stack networks can override the benefits of IPv6. (Roese, 2004) Some providers, especially those not geared towards consumers, may determine this expense is unnecessarily and only provide service over IPv6, which will restrict their markets. Other businesses may find themselves forced to deploy IPv6 as a result of partner demands despite not feeling the limitations of IPv4 themselves. (Cooper & Yen, 2004) The return on investment in the IPv6 business case is simply not evident in today’s ISP industry. (Huston, 2006)

ARIN and CAIDA conducted a survey in March 2008 to capture community input from the ARIN region. This survey led to an overview of the biggest hurdles to IPv6 deployment, from the view of the respondents. These results are shown in table 2.

Biggest hurdles	Number of responses	Percentage of responses
Cost, Time, Business Case	79	36.41%
Vendor support, Back office	51	23.50%
Knowledge, education	40	18.43%
User demand	39	17.97%
Upstream transit	38	17.51%
Dual-stack interoperability	31	14.29%
Multihoming	9	4.15%
Allocation policy	5	2.30%
Performance	4	1.84%

Table 2: CAIDA and ARIN survey

Because major applications for IPv6 have yet to emerge, it is more difficult to quantify their potential benefits. (Gallaher & Rowe, 2005) Besides that, many companies are used to see the adoption of IPv6 as an expensive project and are not putting any effort in performing research to the business opportunities. (de Graaf, personal communication, March 18, 2009) In fact, there is no way to launch a business off of IPv6 until a “fair amount” of IPv6 infrastructure is put in place. The problem with the search for a “killer application” is that there will not be any until after at least some IPv6 infrastructure is implemented and it becomes an easy way to simply dismiss IPv6, since transition costs are nontrivial. (Gomez et al., 2008)

4.3 Drivers for adoption

Although the shortage of IPv4 address space is often seen as the main driver for adoption of IPv6 (Hovav & Schuff, 2005), many Internet Service Providers still have an own reserved free range of IPv4 addresses, enough to use for the next several years since Internet Service Providers are used to request addresses with thousands at a time. (de Graaf, personal communication, March 18, 2009)

4.3.1 Address space

Added address space is not interesting, since enterprise networks can well be run with RFC 1918 private addresses. This fact remains as long as there is no need to give all hosts an address that can be reached from outside one's network. However, when IP-based telephony really takes off, communications need to done end-to-end between participating hosts. This might be a problem with IPv4 and private addresses since there is a need to use NATting devices which could disrupt communication flow. (Anttila, 2005) Many potential benefits hinge on removing and/or changing the management of middleboxes, such as NAT devices and firewalls, because they currently disrupt certain types of host-to-host connections. (Gallaher & Rowe, 2005)

IPv6 addressing space opens a new field that simplifies access for the final user. Consequently, it is no longer necessary to create complex solutions to get around NAT-type mechanisms that no longer have a place. (Cocquet, 2004) Near-term benefits include increased use of Voice over IP (VolP) and new mobile data services. Long-term benefits potentially include increased Internet security and efficiency gains from removing NATs. (Gallaher & Rowe, 2005) In addition, IPv6 will reestablish the end-to-end model that was lost with the introduction of network address translation (NAT) in the IPv4 world. The problems that protocols like SIP and H.323 encounter today with NAT will be eliminated. (Roese, 2004)

4.3.2 Security

IPv6 is a lot more secure than IPv4, even the makeup of IPv6 with its almost unlimited addresses makes it less vulnerable to attacks as Spelman (2008) points out, "That because the IPv6 address space is so large, randomly scanning for systems that are vulnerable is completely infeasible. The story goes that at the height of the self-propagating malware explosion a few years ago, an unpatched Windows system would be infected faster than it could download the necessary security updates. With IPv6, that is simply impossible: even with a billion infected hosts each scanning a billion IPv6 addresses per second, it takes more than a hundred million years to scan just the IPv6 address space that's given out to ISPs right now, which is about 0.01 percent of what's available. (Spelman, 2008) IPv6 has also brought security to the forefront by requiring IPSec for host-level end-to-end security. End-system addressing has been greatly simplified with the advent of address auto- discovery. (Roese, 2004) IPv6 adoption could be a significant driver (and potentially a necessary step) for networks to move to a more secure networked environment. (Gallaher & Rowe, 2005)

IPv6 offers a great increase in Internet scalability, but this scalability is not limited to the increase in addresses that first comes to mind. In fact, as can be seen, this is not even an immediate reason to consider IPv6. IPv6 removes the need for NAT and the barriers it imposes. IPv6 also offers other advantages that could save businesses money, especially in terms of bandwidth. The journey to full IPv6, however, will be a long one. Many businesses whose primary function is not content creation, Internet services, or telecommunications may not see why it is even necessary, but once IPv4 can be disabled, new services will be possible in a much less hostile landscape. (Cooper & Yen, 2004)

IPv6 has the potential to lower costs associated with application development for software vendors and to reduce the costs of network management and the installation and testing of new applications for all enterprises. (Gallaher & Rowe, 2005) The per-address cost can be reduced dramatically through the elimination of various forms of dynamic address translation technologies, as well as the elimination of the scarcity premium factor in IPv4 address mechanisms. Application complexity can also be reduced, and the diversity of application models can be broadened. This model of universal addressing allows for many forms of peer-to-peer networking models as well as supporting communication transaction security models that reply on end-to-end coherence. (Huston, 2006) Increased security is a frequently mentioned benefit associated with IPv6. (Gallaher & Rowe, 2005)

In addition, longer-term benefits may be realized from a decrease in IT costs for internal network operations (accruing throughout the supply chain) and from simplified R&D for new products and services developed by vendors. (Gallaher & Rowe, 2005)

4.3.3 Voice over IP

Cooper and Yen describe the effect and position of 'Voice over IP' (VoIP) as enabler for IPv6 adoption within their paper. "The tactical response to the need to acquire the minimum number of addresses for a business is Network Address Translation. Not only did this allow a business to setup multiple systems under one address, but also it provided a security benefit in obfuscating addressing from outside the business. (Cooper, Yen) Next generation Voip networks based on IPv6 address current problematic issues such as lack of inherent Quality of Service (QoS) in many IP networks, and end-to-end integrity of the VoIP signaling and bearer paths, Minoli (2005) states that IPv6 offers the potential for achieving the scalability, targeting, end-to-end interworking, QoS and robustness necessary if VoIP is to replace the Transportation Demand Management (TDM [8]) infrastructure worldwide." Protocol limitations and NAT issues make it difficult to carry Voip packets across firewalls in the current IPV4 based set up, along with security vulnerabilities, IPv6 deals with these and QoS issues.

One of the protocols most seriously affected by this translation is Voice over IP (VOIP) [28, p. 195]. Although intra-organization VOIP would unaffected (unless NAT is deployed in the intranet), replacing the Public Switch Telephone Network (PSTN) interface to the outside would be prevented as interorganization communication would need to be converted to regular telephony. With the presence of a NAT device, the flow VoIP telephone to external VoIP telephone is broken. Because many organizations use standard nonroutable addressing, it is not unlikely that telephones in both organizations might have the same IP address, resulting in confusion for the devices as shown in Fig. 2. Therefore, even initiating a conversation would not be possible because there is no globally unique identifier by which the remote VoIP telephone can be contacted by another device. Even if the IP addresses are not identical, however, the presence of the NAT makes initiating a connection from the outside impossible, preventing directly dialing the remote telephone device.” (Cooper & Yen, 2004)

Other capabilities have also been developed in direct response to critical business requirements for scalable network architectures, improved security and data integrity, integrated quality-of-service (QoS), automatic configuration, mobile computing, data multicasting, and more efficient network route aggregation at the global backbone level. (Ladid & Telebit, 2001) Multicasting is an important feature of IPv6 that replaces the IPv4 broadcast feature by supporting both unicast and multicast functions. (Ladid & Telebit, 2001)

5. Conclusions

The key differences between IPv4 and IPv6 can be found in an increased IP address space, plug & play configuration options, mandatory and embedded security, integrated mobility, cheaper and simple network management, unicast, anycast and multicast address format and the possibilities for 3G applications.

Although the adoption of IPv6 should lead to a number of new business opportunities, the adoption of IPv6 is far from widespread. A basic approach from an early-adopter point of view could lead to the conclusion that there is a known risk in being an early-adopter. This could lead to competitive advantage but also to the possibility to lose the gain on your competitors because of bad implementation or bugs within this new technology.

The unwillingness for being an early-adopter can be strengthened by the fact that relatively little information exists regarding IPv6. That, together with the fact that no clear 'early-adopter awards' exists is making the case for adopting difficult to argue. Since the adoption of a new network standard involves actions for all parties related to the network, the Internet, we also see the existence of network effects. Only if all parties will adopt IPv6, IPv6 matters at the long run.

Besides a potential risk in being an 'early IPv6-adopter', there are high costs that arise when adopting IPv6. These costs are caused by the training of people, the changes in infrastructure and – more important – the changes of applications. Besides costs for adopting, the adoption of IPv6 will also cause the (temporary) need of a dual-stack network for most enterprises. This will increase short-term costs.

The increased IP address space is often seen as the main driver for IPv6 adoption. This increased address space causes NATting devices to become unnecessary since they are used to overcome the shortage of IPv4 address space. This will reestablish the end-to-end communications model that was lost by the use of Network Address Translation.

Another driver for adoption of IPv6 can be found in security. Since the address space of IPv6 is that large, scanning for addresses will become almost impossible and IPv6 includes mandatory IPSec, an important security protocol.

Integrated quality-of-service, automatic configuration, mobile computing and data multicasting are some of the small drivers for adopting IPv6. These drivers are not often seen as enablers for IPv6.

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