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Internet Protocol Version 6 (IPv6)

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Forward

This paper is the sixth to be released in the ODTR's Briefing Note series and, like the briefing notes on Optical Access[1] and Potential Applications for Next Generation Networks[2] before it, expands on our Next Generation Networks briefing note[3] issued in November 2001. These briefing notes, which form part of our 'Forward-looking Programme', are primarily aimed at non-technical readers with some background knowledge of telecommunications technology. The main purpose of the Briefing Note series is to raise awareness of new or developing technologies that could have important implications or present significant opportunities in the telecommunications sector in Ireland.

This briefing note concerns the basic workings of the Internet itself: the Internet Protocol (IP). In moving towards next generation networks it is widely viewed that a new generation of IP is needed. The particular standard currently being proposed, and the topic of this briefing note, is known as IP version 6 (IPv6). Emerging Internet applications in areas such as 3G mobile and e-commerce could potentially outgrow the Internet in its current form. This briefing note outlines some of the related problems network operators are currently facing or are likely to face shortly, most of which stem from a shortage of Internet addresses, and offers IPv6 as a possible solution. IPv6 is already being deployed to a limited extent in networks in Ireland and around the world, and has recently been nominated for widespread adoption in European networks by the European Commission[4].

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[1] www.odtr.ie/docs/odtr0229.doc

[2] www.odtr.ie/docs/odtr0245.doc

[3] www.odtr.ie/docs/odtr0188.doc

[4] '*Next Generation Internet – priorities for action in migrating to the new Internet protocol IPv6*', Communication from the Commission to the Council and the European Parliament, Feb. 2002

The Internet has become a key enabling technology to many sectors of the Irish economy, and competitive telecommunications networks to support it are essential to achieving and sustaining economic growth. IPv6 is presented here as a technology that could help to advance telecommunications networks, thus enabling the development of new communications applications.

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Comments on this briefing note

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1 Introduction

The Internet uses Internet Protocol (IP) to allow individual terminals (e.g. PCs, Laptops, Palm devices etc.) to communicate with one another across various different types of telecommunications networks (e.g. fibre optic, copper, wireless). Since the early 1980's and the emergence of the Internet the particular type of IP used has been IP version 4 (IPv4)[5]. A more advanced version of IP –IPv6[6] or IPng (next generation) – designed for the modern Internet has been under development since the early 1990's and is starting to be deployed in networks around the world.

IPv6 was identified as a key technology in the Next Generation Networks Briefing Note[7]. The present Briefing Note outlines the importance of IPv6 as a potential solution to some of the shortcomings of IPv4 and in relation to the further development of Internet applications and services. The implications of when and how IPv6 is implemented are assessed and highlighted here also. Furthermore, this briefing note is in line with the European Commission's call upon EU member states to help raise awareness and encourage the development of IPv6[8].

[5] As defined by the Internet Engineering Task Force (IETF) which is 'a large open international community of network designers, operators, vendors, and researchers concerned with the evolution of the Internet architecture and the smooth operation of the Internet': www.ietf.org

[6] IPv5 is a little used protocol designed for audio and video multicasting that was abandoned for Resource ReSerVation Protocol (RSVP) – IETF RFC 2205.

[7] Next Generation Networks Briefing Note – www.odtr.ie/docs/odtr0188.doc

[8] '*Next Generation Internet – priorities for action in migrating to the new Internet protocol IPv6'*, Communication from the Commission to the Council and the European Parliament, Feb. 2002. ftp://ftp.cordis.lu/pub/ist/docs/ka4/mb_com_parlipv6.pdf

2 IP Address Shortages

Terminals that are connected to the Internet have IP addresses, so that they can be uniquely identified by other Internet devices (e.g. PCs, routers) allowing traffic to find its way between terminals. It is useful to think of an IP address as being like a postal address on an envelope or even a telephone number[9]. Physically, an IP address is a number that is attached to each individual Internet message. This number indicates to Internet routers (devices responsible for passing traffic around the Internet – similar to sorting offices in our postal analogy) which network, section of a network, or terminal a packet is destined for[10].

The Internet was originally developed as a 'network of networks' designed to interconnect a relatively small number of main-frame computers at research institutions and large corporations. To this end the developers of IP designed the Internet with approximately 4 billion individual addresses, although in practice only a portion of these are useable[11]. However, due to a combination of developments, this resource has now become limited with restricting consequences for further development of Internet applications and services.

Some of the key developments that led to the rapid consumption of IP addresses were:

a) The development and widespread uptake of personal desktop computers (PCs) greatly increased the number of devices requiring Internet connection.

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[9] A closer 'telephony' analogy for an IP address would be a circuit identifier in the PSTN. IP addresses contain routing information.

[10] The address of the sender (i.e. source address) is also attached to every IP packet.

[11] 240 Million is thought to be the practical limit of useable IPv4 addresses on the Internet – IETF: RFC 3194. This is because in a hierarchal addressing system, losses in efficiency at each hierarchal level multiply resulting in a significant overall loss in efficiency.

b) The emergence of the World Wide Web brought the Internet to a far larger user base than was originally envisioned.

c) Early IP address allocation policies allowed large portions of IP address resources to be allocated to a relatively small number of companies and organisations.

Looking forward, it is likely that there will be even greater levels of demand for IP addresses:

a) There are currently over 6 billion people in the world and this number is continuing to increase – a population of 9 billion is forecast by 2050[12]. It is reasonable to expect that any new Internet addressing scheme would be capable of accommodating everyone in anticipation of future needs.

b) Many people will soon probably require multiple IP addresses for numerous personal devices and applications, as is already the case in parts of the developed world (e.g. mobile phones, PDAs, Laptop computers, PCs). Some devices may require more than one IP address (e.g. roaming mobile IP such as 3G).

c) The number of automated devices that are connected to the Internet is accelerating and eventually is likely to far exceed the number of people using it – e.g. an abundance of IP addresses could assist the development of new applications including machine to machine communications.

2.1 When will IP addresses run out?

Opinions vary as to the rate at which IPv4 addresses are running out, with dates between 2005 and 2010 typically predicted for total address exhaustion[13]. Techniques to extend IPv4 such as NAT (see Section 2.2.1) and the migration of some users to IPv6

[12] http://www.census.gov/ipc/www/worldpop.html

[13] In the early to mid 90's, before the introduction of Classless Internet Domain Routing (CIDR - see Section 2.2.1), it was predicted that IP addresses would run out by 1998.

are likely to prevent IP addresses from ever running out completely. However, a scarcity of addresses can slow the potential development of the Internet in areas such as mobile and always-on residential applications (i.e. many ADSL users do not have their own permanent IP addresses).

2.2 Current Solutions

The approaching IP address shortage has been dealt with in various ways:

2.2.1 Technology Solutions

- Classless Internet Domain Routing (CIDR) was introduced by the Internet Engineering Task Force (IETF) in 1994-95 to conserve IP addresses[14]. This allowed the allocation of more suitably sized segments of IP addresses to match individual network needs instead of the comparatively wasteful Class A, B and C[15] system that has previously been used.
- Network Address Translation (NAT[16]) –This is analogous to private branch exchanges in a telephony system, whereby a small number of external lines can serve a larger number of terminals, based on the premise that not all of the terminals will be in use at any one time. In this situation a limited number of IP addresses can be temporarily allocated to devices as needed. Apart from the possible shortage of IP addresses here, the main problem is that terminals are likely to have different IP addresses (not static) each time they connect to the Internet, and are therefore not uniquely identifiable to other devices on the Internet. This breaks the end to end concept of the Internet causing difficulties for applications such as peer to peer networking, secure services, and telephony.

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[14] Part of the reason for CIDR's introduction was to deal with exponential growth in Internet routing tables due to large numbers of Class C allocations (see Footnote 15). CIDR is also know as supernetting.

[15] These classes, introduced in 1978, allowed addresses to be allocated in blocks of 254 for class C, 65534 for class B, and 16777214 for class A. Using this system a network of 500 hosts could require a class B allocation, wasting over 65000 IP addresses.

[16] Originally described in IETF RFC 1631.

- Private IP addresses[17] –Terminals that are connected to networks (e.g. PCs on an office local area network) which are not connected to the Internet or other IP networks can be allocated IP addresses independently of other networks. Therefore, addresses can be used which may also be allocated on the Internet without fear of conflict. However, address conflict problems can arise here if private IP addresses are allowed to 'leak' into the public Internet, or other private networks (e.g. if a private network is accidentally connected to the Internet).

2.2.2 Policy Solutions

- More recently, tighter allocation policies from IP address registries (e.g. RIPE[18]) have been implemented which require applicants for IP addresses to justify their address needs.

[17] IETF RFC 1918

[18] RIPE (Réseaux IP Européens) – organisation responsible for allocating IP addresses in the European region. www.ripe.net

3 IPv6

In 1993 the IETF began work on a new version of IP – IPv6 – to attempt to solve among other things the IP address shortage problem, and an initial standard was published in 1995[19].

3.1 Solution to the IP address shortage problem

IPv6 offers up to 340 x 10^{36} (340 followed by 36 zeros[20]) possible Internet addresses. This equates to many billions of addresses per person –more than enough for the foreseeable future. IPv6 has enabled a fresh start for IP address allocation, ensuring that IP addresses are allocated according to the layout of the Internet. This simplifies the task of routing in increasingly complex networks with numerous peering arrangements (see Section 4.4).

On the other hand, the huge amount of IP addresses that comes with IPv6 could potentially create large traffic overheads for IP networks. For example routers will have to store and transmit more details about the networks they are connected to than previously.

3.2 Mobile IP

An abundance of IP addresses is particularly important for mobile communications. A mobile terminal that moves between coverage areas presents major technical problems to NAT type addressing approaches. Roaming mobile Internet terminals need to be allocated forwarding IP addresses to enable them to be contactable at any time in any location. The growing mobile market presents a potential demand for current IP

[19] 'The Recommendation for the IP Next Generation Protocol', IETF RFC 1752. The current version of the IPv6 specification was published in 1998, 'Internet Protocol, Version 6(IPv6) Specification', IETF RFC 2460

[20] 340 undecillion

addresses[21]. To overcome this IPv6 has been selected for 3G mobile systems by the Third Generation Partnership Project[22] (3GPP). Indeed, the mobile market could potentially drive demand for IPv6 based services, since many mobile applications (e.g. security applications for m-commerce) require the end-to-end connectivity that IPv6 can provide to operate effectively. Other mobile and portable systems, such as wireless local area networks (WLANs), could also benefit from a greater availability of IP addresses.

3.3 Security and service provision

The Internet was originally designed to allow applications to communicate directly with one another over IP. Many Internet security applications are based on this premise of end to end connectivity enabling an individual terminal to be uniquely identified and addressed. As already described, increasing numbers of IP devices requiring unique IP addresses place significant demands on the remaining IPv4 address reserves. This has resulted in the adoption of techniques such as NAT which typically break the end to end model. The provision of secure connections from the Internet to IP devices can be difficult without static IP addresses[23]. The preservation of the end to end model facilitated by additional IP addresses, allows security protocols such as IPSec to operate. Furthermore, IPv6 addresses can be authenticated so that the source of a packet can be identified, reducing the opportunities for malicious attacks (e.g. 'spoofing'[24]). IPv6 also facilitates encryption in IP networks through the use of specific encryption headers on IP packets.

[21] Strategy Analytics forecast worldwide cellular subscribers to reach 1.9 billion by the end of 2006: http://www.3gnewsroom.com/3g_news/jan_02/news_1796.shtml

[22] http://www.3gpp.org –A collaborative body including ETSI (European Telecommunications Standards Institute)

[23] Network administrators can often exploit a NATs interruption of end to end connectivity to enhance security alongside their firewalls. However, this enhanced security denies the benefits of end to end connectivity to network users.

[24] Spoofing is a technique that can enable unauthorised users to gain access to computer systems by disguising data so that it appears as if it is coming from a trusted terminal.

3.4 Class of Service/Quality of Service

Quality of service guarantees and capacity reservation can be difficult to implement using Internet technology. This has implications for many traditional carrier type services where traffic is real-time or mission critical (e.g. voice, video). IPv6 can prioritise IP data enabling service level guarantees to be applied to IP traffic, thus making it more suitable for carrier type applications. Furthermore IPv6 can provide extra facilities to control the flow of IP traffic[25].

3.5 Automatic Configuration

IPv6 can enable devices to automatically configure themselves on a network, making them more user friendly and accessible to domestic markets ('plug and play'). Furthermore, this auto configuration feature enables network managers to avoid manual re-configuration of IP addresses (e.g. when changing from one Internet service provider to another, or following company mergers). This is a significant time and cost saving benefit of IPv6 particularly where large networks are involved[26].

[25] '*The case for IPv6*', IETF, IAB, December 1999

[26] A limited level of auto-configuration can be achieved with IPv4 using Dynamic Host Configuration Protocol (DHCP).

4 Migration Paths

4.1 When to implement IPv6?

For telecommunications networks to remain competitive they must consistently offer advanced features while retaining scalability and efficiency. For some network operators this will probably mean adopting IPv6. However IPv6 will not suddenly replace IPv4, and some applications which make use of IPv4 are likely to be present on the Internet for many years even if there is an overall changeover to IPv6. The decision as to when to start migrating to IPv6 is as much a commercial question as a technological one[27]. It is likely that many service providers will only begin deploying IPv6 networks once such solutions become less expensive than IPv4 alternatives (e.g. NAT). Furthermore, local area network administrators are unlikely to adopt IPv6 until sufficient applications are available to them[28]. On the other hand applications developers are only likely to develop IPv6 applications in environments where IPv6 is commonplace.

Network operators who delay adoption of IPv6 risk increased migration costs as their changeover may have to be done in a far shorter time frame and on larger scale networks without as much control as is afforded to earlier adopters. For example, by delaying adoption and continuing to implement IPv4, operators may be investing in technology that could rapidly become obsolete, hence incurring upgrade costs that could have been avoided. Early adopters, on the other hand, risk investing in a technology that is not adopted on a widespread basis, or which may require modifications (e.g. early software releases often require upgrades to deal with bugs and other flaws).

[27] Some of the technological advantages of IPv6 are outlined in Section 3.

4.2 Where will the implementations come from?

Initially it was commonly thought that IPv6 would be adopted in edge networks first, i.e. in corporate or university local area networks, before making its way into core networks. However, to date edge implementations of IPv6 have been limited and it is now more likely that growth will occur from core networks outwards. A third form of IPv6 implementation is also emerging in the form of isolated IPv6 islands. These islands have already begun to form on a geographical basis (e.g. Japan), and are also likely to from on technological (e.g. 3G) and enterprise basis.

4.3 Implementing IPv6

IPv6 is not directly backwards compatible with IPv4, leaving operators who choose to migrate to IPv6 with two main approaches[29]:

a) implement a method of inter-working or converting between the two standards

b) implement both variations

These broad approaches can be taken using the following methods:

a) *IP Tunnelling* – one type of IP traffic is encapsulated and carried by another[30], e.g. an IPv6 packet is given an IPv4 wrapper so that it can be passed over an IPv4 network. Similarly, IPv4 traffic can be passed over IPv6 networks. These 'tunnels' usually need to be manually configured by network administrators, although more automated and dynamic tunnelling methods are being developed e.g. *IPv6 Tunnel Broker*[31] for small networks or individuals and *6to4*[32] for larger networks.

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[28] The adaptation of IPv4 applications to IPv6 networks is a relatively trivial task.

[29] The IETF working group *ngtrans* is concerned with the transition from IPv4 to IPv6; www.ietf.org/html.charters/ngtrans-charter.html

[30] This is analogous to a car-ferry transporting cars across the sea i.e. one type of vehicle transporting another over unsuitable terrain.

[31] IETF RFC 3053 'IPv6 Tunnel Broker'

[31] IETF RFC 3056 'Connection of IPv6 Domains via IPv4 Clouds'

b) *Dual Stack* – network equipment can operate both IPv4 and IPv6 allowing traffic to pass over the two different types of network.

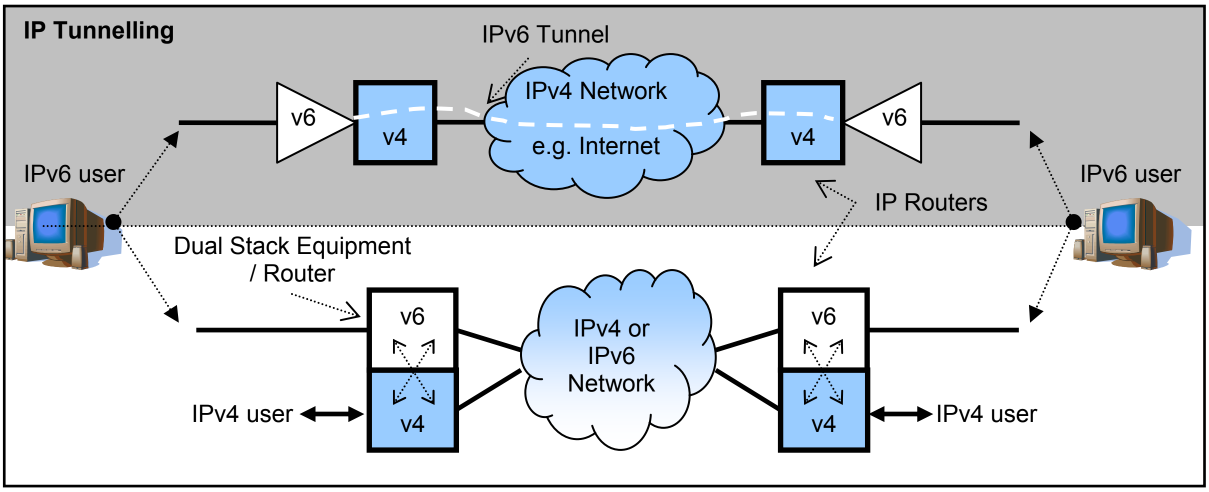

Figure 1. Inter-working between IPv4 and IPv6 networks.

4.4 Peering[33]

Peering is an important issue for network operators since better peering arrangements yield more connectable networks. If IPv6 emerges from the core out (see Section 4.2) it is likely that many core IPv6 networks will present attractive peering opportunities, thus further encouraging IPv6 adoption. Current peering practices can limit the connectability of smaller operators and ISPs, since larger ISPs often prefer not to peer with smaller operators due to the increased routing complexity they can cause.

[33] Peering describes the mutual interconnection of IP networks, typically without charge, e.g. the Internet Neutral EXchange (INEX – www.inex.ie). See also www.v6nap.net for a list of major IPv6 peering points.

5 Current Adoption

IPv6 has been adopted to varying degrees by various networks around the world. For the most part IPv6 has been initially implemented in education and research networks, although it has also been deployed commercially to a limited extent.

5.1 Adoption in Ireland

In Ireland IPv6 has been deployed on the HEAnet (www.heanet.ie)[34]. Some other Irish sites that have connected to the 6BONE IPv6 network[35] are:

- Broadcom
- Dublin Institute of Technology
- eircom multimedia
- Ireland On-Line IPv6 Test Network
- Computer Science, Trinity College Dublin
- TRC, ECE Dept, University of Limerick

Source: (http://www.cs-ipv6.lancs.ac.uk/ipv6/6Bone/Whois/bycountry.html)

5.2 Adoption in Europe

Major European IPv6 projects funded by the European community include 6NET[36] and Euro6IX[37]. Most member states have some level of IPv6 development, typically in government and research networks (National Research and Education Networks – NRENs or NRNs). The GÉANT[38] initiative is a pan-European research network that can facilitate pan European IPv6 trials. Funding for such IPv6 networks and development of applications was granted under the European Union's Fifth Framework

[34] HEANet have deployed both tunnelled IPv6 and pure (i.e. native) IPv6.

[35] The 6BONE is an international IPv6 test network, originally developed under the IETF in 1996.

[36] www.6net.org

[37] www.euro6ix.org

[38] The GÉANT initiative is a successor to the TEN-155 network - www.dante.net/geant/about-geant.html

Programme. Further funding is expected under the Sixth Framework Programme. The European Commission is urging timely implementation of IPv6 and issued a communication to the Council and the European Parliament on the topic in February 2002[39]. In this communication the Commission has called upon EU member states to help raise awareness and encourage the development of IPv6.

5.3 Adoption in Japan and US

The Japanese government took the lead in IPv6 initiatives by declaring in September 2000 that all public sector and business networks must be IPv6 enabled by 2005. The Japanese have also established an IPv6 promotion council.

Widespread adoption of IPv6 could potentially be slightly slower in the US due to its large share of IPv4 addresses. However, there are some large IPv6 networks in the US such as ESNet. Furthermore, the US hosts more of the world's major IPv6 peering points than any other country (e.g. 6TAP, 6IIX), and many US companies are heavily engaged in IPv6 product development and equipment manufacturing (see Annex 1). Other IPv6 peering points[40] are located in Japan, UK, The Netherlands, Germany and South Korea[41].

[39] *Next Generation Internet – priorities for action in migrating to the new Internet protocol IPv6,* Commission of the European Communities, COM(2002) 96 Final, February 2002

[40] Internet peering points are also know as Internet Exchanges (IX)

[41] see http://www.v6nap.net/ for a list of major IPv6 peering points/exchanges.

6 Market Development in Ireland

The Internet has become a key enabling technology to many sectors of the Irish economy. Therefore, competitive telecommunications networks are essential to achieving and sustaining economic growth. IPv6 can help enable efficient and scalable delivery of secure and reliable telecommunications services (e.g. e-commerce, voice over IP). Timely deployment of IPv6 in Ireland could potentially have a significant impact for Irish businesses, affording them a competitive advantage through access to advanced telecommunications services.

It is possible that if IPv6 networks are implemented on a widespread basis globally, good peering arrangements for IPv4 networks could become increasingly difficult to acquire (see Section 4.4), thus making them less attractive to customers. With the implementation of IPv6 enabled 3G networks, it is conceivable that the mobile communications industry could stand to benefit more quickly from IPv6 than the fixed line sector, for whom IPv6 deployment may not be seen as such an urgent priority. The provision of mobile IP services can be technically challenging for operators which may in some cases be more difficult and costly to provide with non IPv6 methods.

IPv6 presents potential opportunities to telecommunications applications developers in the Irish software industry. An important factor that has delayed the roll-out of IPv6 networks worldwide is the lack of IPv6 applications.

7 Conclusions

If the Internet is to continue to grow, with applications such as e-commerce and peer to peer computing, an abundance of readily available IP addresses is essential. Although IPv4 addresses are unlikely to ever become completely exhausted, their increasing scarcity could potentially restrict development of the Internet and its applications (e.g. Voice over IP). For future 'always on' Internet technology to work effectively each connectable device needs to be individually addressable. 3G mobile and other wireless Internet systems are likely to depend on readily available IP addresses to enable mobility.

IPv6 can provide more than enough IP addresses for the foreseeable future, along with more secure, scalable, and easily configurable networks. Operators of IPv4 networks can adopt IPv6 technology and provide IPv6 services using a variety of methods to suit various migration strategies. IPv6 equipment, networks and applications have begun to emerge around the globe including Ireland, and the European Commission has called upon member states and the industry to promote and adopt IPv6 so that the Internet and the ICT sector can continue to develop.

Finally, IPv6 can help restore simplicity to the Internet by reducing the need for additional protocols and equipment to overcome some of the Internet's growing problems. This could result in reduced operational costs, enabling operators to deliver new applications and services.

8 Annexes

1 Some IPv6 Equipment Manufacturers and Software Developers

Microsoft http://www.microsoft.com/windows.netserver/technologies/ipv6/default.asp

CISCO http://www.cisco.com/warp/public/732/Tech/ipv6/

Motorola http://e-www.motorola.com/collateral/IPV6-AN.pdf

IBM http://www-3.ibm.com/software/network/commserver/library/publications/ipv6.html

Nokia http://www.nokia.com/ipv6/press_release_6.html

Nortel http://www.nortelnetworks.com/corporate/technology/ipv6/

Ericsson http://www.ericsson.com/infocenter/news/ipv6_trial.html

HP/Compaq http://www.hp.com/products1/unixserverconnectivity/software/ipv_print.html ,
http://www.compaq.com/ipv6/
http://www.tru64unix.compaq.com/internet/ipv6ready.pdf

Sun Microsystems http://wwws.sun.com/software/solaris/ipv6/faqs.html

Intel http://www.intel.com/support/network/adapter/1000/whatsNew.htm

Novell http://www1.novell.com/resourcecenter/ext_item.jsp?itemId=7189

Lucent http://www.lucent.com/knowledge/documentdetail/0,1983,inContentId+0900940380008954-inLocaleId+1,00.html

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