IPv6: Current Deployment and Migration Status

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***Abstract*:** Although there appears to have been increased interest in routing IPv6 over the public Internet since mid 2007, the adoption and deployment of IPv6 has been relatively limited. This paper investigates the reasons for the slow rate of progress, as well as the debate surrounding the demand for IPv6 technology. The issues relating to IPv4-to-IPv6 migration will be re-addressed, from where respective solutions will be proposed along with decision-making guidelines. This article does not focus on IPv6's contribution to wireless and mobile networks; attention is placed on its deployment in the Internet backbone and enterprise networks. The findings aim to evaluate the needs and requirements of IPv6 in order to ascertain the extent to which it can be made common place.

***Keywords*:** IPv4 to IPv6 Transition, IPv6 Deployment, Migration Strategy

1. Introduction

IPv6 was first invented by Internet Engineering Task Force (IETF) in the mid 1990s due to the then urgent need to supplement the rapidly diminishing IPv4 addressing space. It was thought that IPv4 would be totally exhausted therefore a successor was designed. With the majority of networks still utilizing IPv4, there are currently no serious motivational factors to move over to a new method of working when the current provision is still adequate for the majority of users. The debate has been ongoing for years in terms of whether IPv6 should be deployed [1], [2], hence very few migration plans have been made in the industry [3].

The use of IPv4 has changed dramatically over the last 30 years, and the protocol was never designed to deal with the stress and strains it has to endure over the last few years. The initial design specification did not take into account the need for the protocol to handle video-on-demand services, or other types of large scale data, also with the advent of mobile communications, set top boxes that have Internet access taking presence in the home, each device requires an IP address.

However, the need for a new technology is not paramount; the current 30-year-old technology has been modified to coincide with new ideas and ways of working. For a sustainable network to be developed and evolve over the next few years a seamless migration over to IPv6 needs to be made. It would be foolish to believe that this could be done overnight n the infrastructure of the Internet along with the associated cost of upgrading hardware and software.

This paper first reviews the current worldwide IPv6 deployment, and compares the technical aspects of the available IPv4-to-IPv6 migration solutions, then discusses the debate on the demand for IPv6 technology. In the following section, the difficulties and challenges of IPv4-to-IPv6 migration will be addressed together with suggested solutions. Migration strategy will be given as well as proposed decision-making guidelines. The last section will conclude this paper.

2. IPv6 Deployment in the World

In June 2006 Market Connections completed a market analysis commissioned by Cisco Systems [4]. The study was used to reveal the way in which federal agencies in the US viewed the mandates and their progress towards achieving the goal which was setup by the Department of Defense (DoD) to be a fully sustained IPv6 environment. The DoD stated that its intentions were to move over to a complete IPv6 environment by 2008. This plan has not been implemented as it was initially expected. 2% of those questioned in the survey have completed their IPv6 planning process, and only 14 participants had begun their IPv6 implementation. Although this survey was carried out

TABLE 1. IPV6 DEPLOYMENT IN FIVE CONTINENTS (BY APRIL 2009)

Continents	Deployment Ratio	Leading Countries
Europe	8.8%	Vatican – 100% Monaco – 33% Estonia – 28% Isle of Man – 25% Czech Republic – 19% Luxembourg – 19%
America	7.6%	Cuba – 60% Fiji – 50% Uruguay – 35% Costa Rica – 18% Virgin Islands – 18%
Asia	3.6%	Bhutan – 20% Qatar – 17% Japan – 15% Vietnam – 15% Taiwan, China – 15%
Africa	3.4%	Tunisia – 33% Senegal – 33% Mali – 33% Madagascar – 20% Ivory Coast – 17%
Australia	6.3%	New Zealand – 18% Australia – 7%

TABLE 2. IPV6 VS. IPV4

		IPv6	IPv4
Address	*Format*	128 bits	32 bits
	Hierarchy	Multiple global address, link-local addresses	Primary and secondary
	Auto-configuration	Stateless and stateful	Stateful (DHCP)
	Broadcast	No (replaced by multicast)	Yes
	Anycast	Yes	No
Components	*Header Structure*	Fixed base header (optional extensions)	Variable size (to support options)
	Header Checksum	No checksum	Included
	Flow Labeling	Yes	No
	Fragmentation	Done by the source node	Done by routers & source node
	IGMP	Replaced by Multicast Listener Discovery	Yes
	ARP	Replaced by neighbor discovery	Yes
	Routing Protocols	Static, RIPng, OSPFv3, MP-BGP4, ISISv6, EIGRP. Based on IPv4, with enhancements [9].	Static RIP, OSPF, BGP, ISIS, EIGRP
Services	*IPSec Support*	Required	Optional
	Domain Name Service	Use host address (AAAA) resource records	Use host address (A) resource records
	Quality of Service	Use traffic classes & flow labels	Differentiated services
	Mobility	Mobile IPv6 with route optimization and fast handover	Less efficient comparing to Mobile IPv6

on the DoD and strict guidelines had been put in place for the implementation of IPv6 to be completed, 30% of respondents have not commenced any level of implementation of IPv6.

The United States is not playing a leading role in the IPv6 deployment in the world. Results from [5] has shown that the Vatican has first reached 100% IPv6 deployment ratio, next to which is Cuba that has got 60% deployment ration as assessed in April 2009. The IPv4 leader United States has only received a 2% level which is well below the global average.

The contents of Table 1 is based on the statistics of [5]. It shows the IPv6 deployment ratio for five continents on country-counting basis, as well as the leading countries in each continent. From Table 1, it can be seen that small countries are ahead of the IPv6 deployment schedule as compared to bigger, more developed countries. There are different rates of uptake depending on the necessity and requirements of the network that will be implemented. With regard to different plans and time frames, it is uncertain as to precisely how long a full implementation of IPv6 will take to complete. A government has many resources and instruments that can be leveraged to stimulate and accelerate the adoption of a technology or the deployment of an infrastructure that is deemed strategically important to the national economy. There may be other reasons for governing bodies and other American industries taking a lax approach to this next generation protocol.

Throughout the world, every country is allocated a certain number and range of IP addresses in order to track traffic flow on the Internet. To date, a large portion (almost 40%, or 1481.694 Million) have been allocated to the USA [6]. This observation may attribute to the lax approach the US has taken to the adoption of IPv6. In contrast, other developing nations such as India and South Africa are keen to implement new technology.

Twenty-one percent of IP addresses are currently unallocated [6]. It is a common mistake to think that these could be redistributed to ease the need for IPv4 addresses, however a certain amount have to be kept for reserve. It can be argued that creating a new infrastructure within the developing world is easier than modifying an existing older infrastructure. Careful planning can ensure that migration will be smooth; however there will be issues in terms of migration which need to be addressed and appropriate action taken to rectify any foreseen problems.

Big web companies such as Google who are at the forefront of technological development have already started to offer IPv6 services. IPv6.google.com can be used in any browser given that a connection to an IPv6 enabled internet is available. The front end appears identical to users, but when the cache for these pages is reviewed, the link is pointing to an IPv6 address.

3. Debate on IPv6

In the past few years, the usual debates on IPv6 implementation mainly cover two subjects: IPv6 vs. IPv4, and IPv6 vs. Network Address Translation (NAT).

Table 2 compares the main differences between IPv6 and IPv4. Users are far less interested in what particular service is available via either or both IP protocols, than ensuring that it makes no difference to them [7]. Smooth migration plans can lead to outstanding performance. A report made in August 2009 [8] stated that South Korea which has implemented IPv6 to an extent and has an average internet speed of 20.4mb/sec. Their infrastructure can be deemed superior when compared to those of western countries such as the UK and USA.

Table 3 displays the common arguments for IPv6 vs. NAT. With much of the IPv4 addresses reserved or in use, the scalability options for IPv4 are slightly limited. New methods of working have been introduced to try and extend the life of IPv4; however some of these new methods such as NAT have implications on applications in some networks. Communication

TABLE 3. IPV6 VS. NAT

	IPv6	NAT
What does it offer?	Greater address space with fewer intermediary proxies; Plug-and-play services	Short-term, pragmatic, and incremental approach of increasing the number of network connections via NAT over IPv4
Deployment Impact	Multiple segments may get affected.	Purely local decisions
Cost	Can be expensive; Includes hardware & software upgrades, staff training, etc.	Nearly free
ETE Transparency	Yes	No
Third Party Devices	Users can authorize which addresses can be reached and which should stay inaccessible.	Forces a third-party service model into what should be peer-to-peer communication
Standards	Standardized by IETF	Lack of standardized ways to deal with how NAT hide addresses
Ease of Use	Staff training is mandatory.	IPv4 is already well-known.
Limitations	Many challenges for the migration have been raised.	Single point of failure; Limited NAT gateway functionalities.

TABLE 4. IPV6 MIGRATION: PROS AND CONS

What drive the migration?	What hold back the migration?
• IPv4 address depletion	• Interoperability with software and hardware
• Lack of IPv4's scalability	• Equipment upgrades worthwhile?
• IPv6 product maturity	• Massive leftover of legacy office equipments
• Mobile IPv6	• People resilient to change
• End-to-end network model	• Experience with the new protocol is limited
• Applications such as VoIP and video that require good end-to-end networks	• Difficulty of time scheduling
• IPv6 capabilities are present on most networks	• Business return on investment is uncertain
• New protocols ease network administration	

used by applications such as VoIP and Video conference normally enjoy an end-to-end network, while adding extra components breaking the end-to-end (ETE) model can introduce extra latency to these applications. NAT is after all one of the major reasons that IPv6 deployment is so slow in coming. It has played a major role in meeting the IP address requirement that arose out of Internet growth, and has at least deferred the demand for a new IP with the provision of the much needed address space to enable sustained Internet growth.

Table 4 summarizes what drive the IPv6 migration forward and what hold back the migration. The migration over to IPv6 is a necessity in the long term as the Internet and other large scale networks acquire more users and the scalability of IPv4 will undergo previously unseen pressures. Moreover, IPv6 is not just about IP address space, there are some other advantages to this which would be classed as cost saving for the network. If IPv6 were to be implemented on a large scale network with a DHCP server, then as a cost saving measure, this could be replaced and used for another application. IPv6 has built-in auto-configuration mechanisms that allow clients to communicate with one another without any human intervention. This will not only save the network administrator time, but also the company money as less hardware is needed to administer the network.

As time goes on, the cost of implementing IPv6 will ultimately rise as labor and materials continue to rise and networks start transferring over to IPv6. The penultimate desiccation for network administrators is to weigh the benefits of transferring now to being forced to do so in the future; if investments were made in IPv4 NAT, they would have limited use in IPv6 networks since NAT do not play an integral part in the IPv6 network architecture.

Mobile applications have recently had a significant influence on the adoption and interest with IPv6. Mobile IP aims to give users connectivity whilst away from their central home agents. From the emergence of this technology until its current rapidly-developed stage, the adoption of IPv6 has been made relatively easier compared to the case in the Internet backbone network. This paper does not cover the details of IPv6 usage in mobile or wireless networks.

TABLE 5. COMPARISONS OF DIFFERENT TRANSITION APPROACHES

	Dual Stack	Translation	Tunneling	IPv6 over WAN Links
Equipments	Clients and Servers have to support both IPv4 and IPv6	Great for connecting IPv4-only end nodes and IPv6-only nodes	Great for using older legacy equipments	No need for hardware or software upgrades in the core
Complexity	Easy to implement, but complex management	Simple network design	Easy to implement over existing IPv4 infrastructure	High management overhead
Scalability	Same as pure IPv4 networks	Limited	Good	Good
Performance	Can be slow with stacked protocol on the network	High capacity translators are required	Depend on tunnel speed	Depend on the WAN performance
Security	IPSec	Classic NAT security issues; End-to-end security impossible	IPSec	Depend on the security of the WAN technology
Cost	Can be high	Low initial costs	Creation of a tunnel over the internet may be a high cost	Relatively low cost
Weakness	Asymmetric paths are not supported	Services cannot be supported on end-to-end basis; Single point of failure	Tunnel breakdown will fail the network	Complex implementation

TABLE 6. COMPARISONS OF DIFFERENT TUNNELING TECHNOLOGIES

	6to4	6over4	Teredo	ISATAP
Performance	Good	Good	Bottlenecks can occur with large volumes of traffic	On par with every other mechanism
Complexity	Little or no maintenance	Automatically sets tunnels for ease of use	Complex due to programming of servers	Slightly more complex than 6to4
Advantages	No end reconfiguration	No end reconfiguration	Can utilize NAT	No need for NAT
Weakness	Cannot be used with NAT	Cannot be used with NAT	Security may be left to end nodes	No multicast support
Scalability	Good	Good	Fairly scalable	Good

4. Comparisons of Transition Technologies

The technical transitions from IPv4 to IPv6 have been proposed and investigated for several years. There are four types of transition technologies: dual stack, translation, tunneling and IPv6 over WAN links. All the approaches are devoted to facilitate the co-existence of IPv4 and IPv6.

Dual Stack is a basic mechanism which implements both protocols in the network layer at the same time. Translator works in the similar way as NAT. Tunneling sets up data tunnels for IPv6 traffic to run over IPv4 or vice versa. IPv6 over WAN Links is for IPv6 to run over dedicated data links that uses WAN technologies such as Multi-Protocol Label Switching (MPLS), Asynchronous Transfer Mode (ATM), Frame Relay and Wavelength Domain Multiplexing (WDM). Extensive researches have been carried out to evaluate the performance of these approaches [10], [11], [12].

Table 5 summarizes the features of the four transition technologies through comparison methodology. As tunneling is mostly discussed among the three transmission approaches [13], Table 6 compares all the common tunneling techniques.

5. Performance Validation

A network model has been built as shown in Figure 1 using OPNET Modeler [15]. The network consists of three major segments: one core network and two edge networks (i.e. server farm and customer site). Core network is implemented merely either with IPv4 or with IPv6, so there are four scenarios in the whole network to be modeled: IPv4-only, IPv6-only, IPv4-over-IPv6, and IPv6-over-IPv4. These four scenarios are representative examples of IP network generations, and they all carry identical traffic profiles.

In the modeling and evaluation process, TCP is designated as the transport layer protocol for the evaluation of network layer protocol performance. Automatic tunneling is chosen as the transition technique for the overlaid networks. RIP/RIPng is chosen as the routing protocol in the core network which selects the fewest number of hops as the best route. One router within the core network is scheduled to fail at 150s simulation time and recover at 550s.

Figure 2 shows the average TCP segment delay of IPv4-over-IPv6 and IPv6-over-IPv4 networks, which is

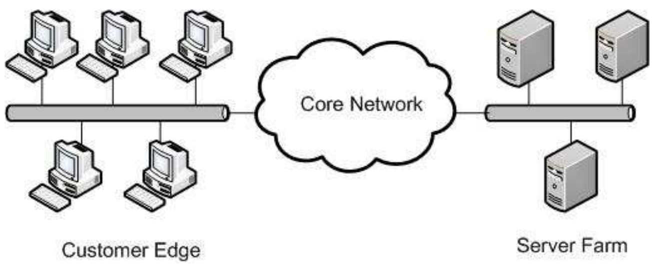

Figure 1. Network simulation model

measured from the time a TCP segment is sent from the source TCP layer to the time it is received by the TCP layer in the destination node. The statistics indicate very steady TCP performance supported by the IP core network despite the node failure in a short period, which validates the excellence of the transitional approaches between IPv4 and IPv6. Figure 3 shows the average TCP segment delay of IPv4-only and IPv6-only networks. By comparison, IP-only network is more advantageous with the performance in the failure status, due to the additional features of RIPng [16].

In order to further evaluate the fault tolerance ability of the network, a different network topology is used in the core network where two equivalent-merit paths are established upon network connection and one of them is scheduled to fail. Figure 4 shows the IP packet drop rate in the network. Packet drop reflects the network routing efficiency. This figure shows that IPv4-only and IPv6-only networks encountered close-to-zero packet loss during the node failure, which indicates highly efficient network re-convergence upon failure. Overlaid networks add additional administration overheads to the data delivery process which compromises network efficiency. Moreover, the tunnel breakup imposes extra burden on the routing re-convergence procedure. Hence, although transitional approaches are a short-term solution for the IP protocol evolvement, networks implemented with single routing policy are more agile and flexible with response to network status changes.

6. Migration Challenges and Solutions

6.1 Overview of the Roadblocks

The roadblocks that hold back the IPv4-to-IPv6 migration are listed in Table 4, which includes interoperability with software and hardware, whether equipment upgrades are worthwhile, massive leftover of legacy office equipments, people resilient to change, limited experience with the new protocol, difficulty of time-scheduling, and uncertain business return on investment. These elements can be categorized into four issues: Interoperability with Software and Hardware, Technology Education, Planning, and Business Return on Investment, which are discussed in the following subsections, together with some proposed solutions respectively.

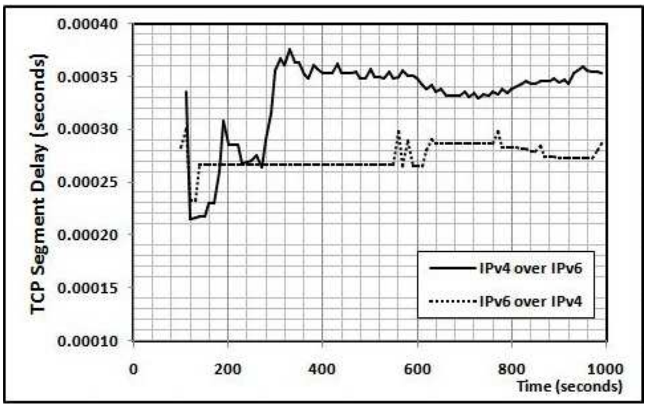

Figure 2. Average TCP segment delay for overlaid networks

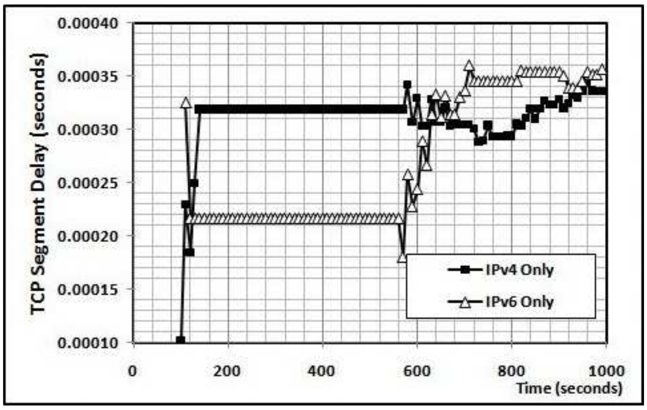

Figure 3. Average TCP segment delay for sole-protocol networks

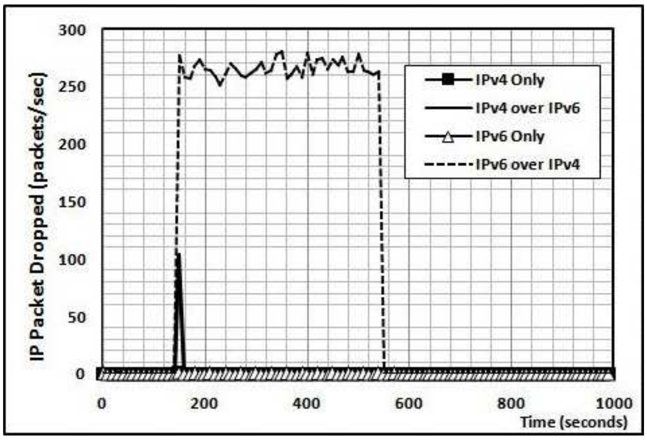

Figure 4. IP packets loss

6.2 Interoperability with Software and Hardware

Interoperability problems with both software and hardware covers a wide area of issues from legacy hardware such as Windows 98 machines that need adaptations to be able to use the new protocol, to software that uses IPv4 style addresses and is unable to work with new format of IPv6 addresses.

Figure 5 illustrates a process that can be followed to ensure that both hardware and software is IPv6 compliant. IPv6 is not part of the hardware and can be installed as part of the operating

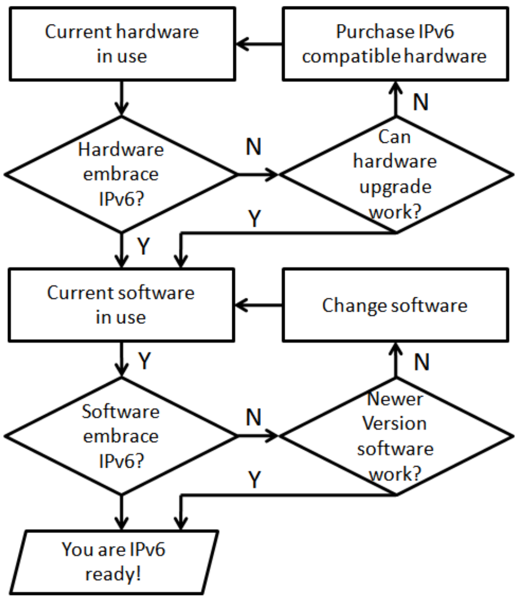

Figure 5. IPv6 compatibility check

system. While the majority of hardware post 2000 is IPv6 compliant, older legacy hardware may have compatibility issues.

Time and effort should be spent to port applications to run over IPv6 depending on how the application is written and how it accesses the IP layer. If the application strictly separates the application layer from the communication layer, the porting is simple and quick. If the application uses complex middleware and customized Application Programming Interfaces (APIs) to communicate with the IP layer, the time and effort needed for porting is in direct relation to the complexity of middleware [14].

Newly developed applications or commonly used applications made by large vendors already offer support for IPv6. Bespoke applications made by small software vendors also need to be tested for conformance and analyzed to find the best and most efficient way to port them, or to find out whether they are too complex to be ported and need modification. Any costs must be included in any planning or implementations considered by individuals or organization considering an upgrade to IPv6.

6.3 Technology Education

Learning about the protocol is necessary for everyone that it will affect. Ultimately IPv6 change will have an impact on everyone in the years to come, however the amount of knowledge and inner workings will not be applicable to everyone. The key benefits of the protocol need to be well publicized and explained. Every technology upgrade requires education for developers about vendor's services and the infrastructure. Home users have been excluded from this list because it will be down to their ISP to make the transition as smooth as possible.

Planning education for users should be done according to job responsibilities to support a smooth introduction of IPv6. System Administrators who are responsible for implementing the new protocol will have to invest much more time and effort than regular users. There are new concepts and possibilities in IPv6 which need to be assessed before implementation, therefore time to familiarize with these new ways of working is essential in order for a smooth transition. Once system administrators have a sound understanding of the new infrastructure, the knowledge can be transpired down to end users when needed.

6.4 Planning

One of the most important aspects of integration is the planning. Building on an existing infrastructure poses a number of problems and requires a considerable amount of investment during the research stage. Planning new network architecture can be a huge task, therefore knowledge of the protocol is a fundamental requirement, and therefore the education of all those involved needs to be assessed to ensure sufficient knowledge is shared between teams or departments that are implementing change. The planning stage should not focus on how to make IPv4 services available for IPv6. Instead it should include an understanding as to how the new features of IPv6 and making use of them to create new concepts of architecture, security, mobility and administration. This will ensure that the introduction of IPv6 is smoother, on time and on budget. A step-by-step integration plan can be devised as this will allow timescales to be created allowing for clear and concise time keeping throughout the project.

There are many solutions that can be used to solve the change over to IPv6; however as most modern day businesses are dependent on the Internet for commerce, large unplanned downtime is simply not an option. As a result of this, migration from IPv4 to IPv6 should be completed on a node-by-node basis. The advantage of this is that IPv6 implements its own auto-configuration illuminating the need for DHCP servers in many instances. Work in [17] is an inspiration for this step-by-step strategy. In their case, dual stack is implemented in the initial phase which only requires a minimum upgrade of software and hardware, and then the transition plan gradually moves forward to a more mature IPv6 deployment status until the entire network infrastructure is shifted to the pure IPv6 state.

6.5 Business Return on Investment

For any investment, a suitable return must be made. There is no urgency for major upgrades as the migration to IPv6 will be a gradual process. However newly developed hardware and software will mostly be IPv6-capable, hence the existing resources on networks needs to eventually support both protocols in order to keep up with up-to-date developments and products in the field. The longer the implementation is delayed the more expense is needed to upgrade the network.

Implementing a new protocol within a small enterprise may cost a considerable amount of money depending on the age of equipment and how sustainable their current infrastructure is. State-owned organizations normally follow the guidelines from the government in terms of technology evolvement. Private organizations may be reluctant in the amount of money that

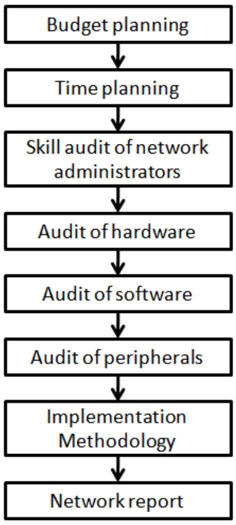

Figure 6. Migration guidelines

needs to be invested on the technology migration, especially since IPv4 NAT provides a short-term solution and is virtually cost free.

Another typical example of this investment plan is school entity. Consider a large campus network of around 500 computers, with 100 Windows98 machines, 300 Windows XP machines and 100 Windows Vista machines. Both Windows Vista and Windows XP have IPv6 support built in; therefore there is no pressing need for that hardware to be replaced. As for the 100 Windows 98 machines, although they can be adapted to run IPv6, it would not make financial sense to outlay money on machines that are relatively old.

6.6 Migration Guidelines

Figure 6 shows a generic guideline for the IPv6 implementation process. A budget plan should be processed prior to technical implementation, followed by a detailed time-planning schedule for each stage. Network administrators need to have the knowledge as to how the new protocol works along with any new services that are introduced on the network. This must be completed in a skills audit and can be done in the form of a simple questionnaire or an informal interview to validate the knowledge of key personnel. If skills are not available from the current IT team, training may then be necessary. This must be added to the budget as extra expenditure.

An audit of hardware needs to take into consideration the hardware and its support for the new protocol. Upgrading hardware that does not support IPv6 may not be financially viable. If it is the case that hardware obsolescence is proving problematic, direct replacement may be a better alternative. Software will need to be checked to establish whether it is compatible with IPv6. Large manufacturers such as Microsoft may have already published updates to ensure compatibility, which must be tested and confirmed with no conflicts. Although older operating systems can support IPv6 with adaptation, it may not make sense if the software is dated; therefore the budget should be adapted for extra expenditure. Peripherals used on the network such as printers need to be checked to ensure their compatibility with IPv6. Older printers made pre-2000 may not have any compatibility and support from the manufacturer.

As for the methodology of implementation, an appropriate approach needs to be selected from the options mentioned in the previous sections, based on the circumstance of each individual. A report should conclude and document the network upgrade. The report should consist of relative costs, problems encountered and cost-savings found on the network along with any recommendations needed or any problems that may arise in the future.

7. Conclusions

The migration over to IPv6 is a necessity in the long term, but IPv6 is not just about IP address space - there are some other advantages including long-term cost savings and better performance. Although transitional approaches are the short-term solution for the IP protocol evolvement, network implemented with single routing policy is more agile and flexible with response to network status. As for the IPv6 migration, currently small countries are ahead of the IPv6 deployment schedule as compared to 'larger' or more developed countries. Problems arise with hardware differences around the world, and it would be unfeasible to recommend a change in a short period of time. Companies and individuals should be cautious with any sustained investment in IPv4 networks, since older technologies such as NAT devices cannot bring long term benefits. With backing and drive from the government, specific time frames should be decided for a partial or regional switchover as a temporary trial to investigate the sustainability of IPv6 where the current IPv4 network dominates. Awareness needs to be made before the implementation. One difficulty of this approach is there is no clear understanding to how long IPv4 will last. Challenges for the IPv6 migration have been summarized in this paper along with proposed solutions and guidelines. IPv6 will provide the entire Internet community with clear benefits, which will eventually become the mainstream.

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