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Inter-mobility and interoperability between IPv4 and IPv6 networks

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ABSTRACT

Transitioning IPv6 takes several challenges and hurdles. Significant work has been carried out to different transition scenarios to prove their suitability is under research. It is observed in the literature that the Internet infrastructure still has not significantly migrated from IPv4 to IPv6, even after the introduction of IPv6 in 1995. While IPv4 and IPv6 Internet infrastructures co-exists together, IPv4 mobile users should not be restricted to utilize only IPv4 based networks and IPv6 mobile users should not be restricted to utilize only IPv6 based networks. The current Internet protocols IPv4 and IPv6 adopted for the Mobile Internet connectivity provide facility for roaming of IPv4 mobile node into IPv4 based networks and facility for roaming of IPv6 mobile node into IPv6 based networks. This paper highlights the need of mobile Internet connectivity while roaming of IPv4 mobile node into IPv6 based networks and similarly while roaming of IPv6 mobile node into IPv4 based networks by providing inter-mobility and interoperability between IPv4 and IPv6 mobile nodes when they are in each other's IP networks. This paper also emphasizes that more research have to be carried out, to design an integrated architecture addressing, inter-mobility and interoperability for IPv4 nodes in IPv6 networks and to design an integrated architecture addressing, inter-mobility and interoperability for IPv6 nodes in IPv4 networks.

Introduction

The popularity of Internet has become ubiquitous and pervasive all over the world. Internet plays a pivotal role in all walks of human life especially in Governmental Organizations, Science and Technology, Industry, Business World, Education and Day-to-Day affairs of every human being. The Internet was originated by US Department of Defense (DoD) and Advanced Research Project Agency NETwork (ARPANET) in the year 1969 and was used with Network Control Program (NCP) during 1969-1982. The researchers in Great Britain and Norway tried to collaborate with the researchers in US using Internet Protocol (IP) in 1982.

Realizing the importance and the advantages of the Internet Protocol, in 1983, Internet was implemented with Internet Protocol. IP version 0 was reserved and IP version 1, 2 and 3 were unassigned. IP version 4 (IPv4), the widely used Internet Protocol has proven remarkably popular, robust and easily implementable, serving the Internet with tremendous durability for over 25 years [Miguel *et al.*, 2001]. This is a tribute to IPv4's initial design with 32-bit address capable of providing 4.3 billion addresses.

The power of the Internet springs from its ability to route information between machines all over the world. Accompanying the evolution of the Internet, Institutions were created to manage Internet resources and adapted Internet resource policies as and when needed. Due to the rapid growth in the Internet, several Internet Registries were created and used all over the world [Gerich, 1993]. The first regional Internet registry was created in 1989 for Europe and named Reseaux IP Europeans Network Coordination Centre (RIPE NCC). The Asia Pacific Network Information Centre (APNIC) was created in 1993 for the Asia-Pacific region. The American Registry for Internet Numbers (ARIN) was created in 1997 for the United States and Canada. In 2002, the Latin American and Caribbean Internet Addresses Registry (LACNIC) was created for Latin America and the Caribbean. In 2005, African Network Information Centre (AfriNIC) became the RIR for the African region. Allocating IP addresses to RIRs came to be known as one of the Internet Assigned Numbers Authority (IANA) which is responsible for allocating unique IP address and Autonomous System (AS) numbers to each RIR to meet the needs of their region [IANA, IP Address Services]. These Registries manage the allocation of blocks of IP addresses to networks in the corresponding geographical regions.

IPv4 and its Growth

Due to the mobile penetration and the Internet access through the mobile devices, the growth of broadband access, the convergence of voice, data and video; the proliferation of potential IP-enabled devices; massive growth of web; and the burgeoning popularity of Voice over Internet Protocol (VoIP), there has been a heavy demand for the IP addresses [Lambrinos *et al.*, 2007]. But the availability of IP addresses in IPv4 is very less to meet the demand for IP addresses. Presently more than 75% of the global population is connected in the network through IPv4.

Over the last two decades, IPv4 addresses have been freely allocated to growing public and private internetworks [Huston, 2007]. The Internet users were 1000 in number in the year 1984; 10000 in 1987; 100000 in 1989; 1000000 in 1992; 16 millions in 1995; 361 millions in 2000; 1018 millions in 2005; 1802 millions in 2009; and 1966 millions in June 2010 [Internet World Users, 1995 - Jun 2010], [Internet World Users, 1984 - 1989].

On an average, approximately 5% of the total IPv4 address space has been consumed every year since 1990. Study reveals that in January 2010, only 10% of the IPv4 address space was

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available for allocation. In February 2010, that number had shrunk to 8.5% and in October 2010, less than 5% of the IPv4 address space remains unallocated. The American Registry for Internet Numbers announced in November 2010 that the available IPv4 addresses are less than 2.73% [Remaining IPv4 Address Space, 2010]. Figure 1.1 illustrates the IPv4 address space allocation over a period of time.

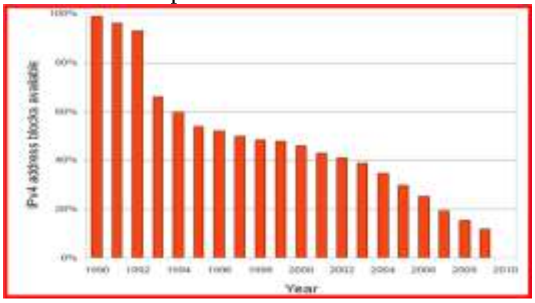

Figure 1.1: Consumption of IPv4 Addresses Over Time

Limitations in IPv4

The remaining IPv4 address blocks may cause tribulations for enterprise and Internet Service Provider (ISP) network operators when they are put back into use, while many ISPs have already had experience with routing inconsistency. At the end of the 1980, the Internet Engineering Task Force (IETF) evaluated the consequences of the Internet's escalation on the IPv4 protocol, with particular emphasis on addressing. The IETF identified the two major issues such as address space exhaustion and the expanding routing tables and formed the ROuting and ADdressing (ROAD) Working Group (WG) in November 1991, to analyze and deliver guidelines in order to meet out the issues. In March 1992, the ROAD WG provided its recommendations in two categories namely (i) Immediate Short Term Solution and (ii) Long Term Solution.

ROAD WG - Recommendations

As short term solutions, the protocols such as Classless Inter Domain Routing (CIDR), Dynamic Host Configuration Protocol (DHCP) and Network Address Translation (NAT) protocol were proposed. These protocols were standardized in September 1993, October 1993 and May 1994 respectively [Egevang *et al.*, 1994], [Rekhter *et al.*, 1993], [Droms *et al.*, 1993]. A new routing protocol, Border Gateway Protocol version 4 (BGP-4) was implemented for the support of CIDR. However, CIDR effectively managed the explosive growth of routing tables in Internet routers and the transition was fairly smooth. DHCP automatically allocates the reusable network addresses. NAT provided the private addresses in a network. However, these protocols temporarily provide solutions for the IPv4 address limitations and it is also a proven fact that these protocols CIDR, NAT do not seem to scale well in the next generation networks [Nawaz *et al.*, 2009], [Kamis *et al.*, 2007], [Vegoda, 2003], [Stallings, 1998].

Knowing well the IPv4 address depletion, the Engineering and Computer Science community conducted several analyses on IPv4 address consumption rates and lifetime projections. Most notable studies are the "IPv4 Address Space Report" submitted by Geoff Huston, the Chief Scientist at APNIC, in 2003 and "A Pragmatic Report on IPv4 Address Space Consumption" submitted by Tony Hain's, in the year 2005 [IPv4 Address Report, Potaroo], [Huston, 2003], [Hain, 2005]. Based on these analyses, the Internet registries have warned the Internet Users Community about the IPv4 address space exhaustion between 2011 and 2013 and have issued reports advising the community to migrate to a new Internet Protocol and ensure that all applications continue to work [Plzak, 2007].

Several Internet Protocols (IP) were proposed by various researchers. A few are IP Encaps, Nimrod, simple Connectionless Network Protocol (CLNP), P Internet Protocol (PIP), Simple Internet Protocol (SIP), TCP and UDP with Bigger Addresses (TUBA), IP Address Encapsulation (IPAE) and the next Internet (TP/IX) which was then changed to Common ArchiTecture for the INternet Protocol (CATNIP).

As per the review report on the strengths and weaknesses of the submitted proposals, the Internet Protocol Directorate recommended the protocol described in the Simple Internet Protocol specification, with the modifications such as (i) SIP should be the basics for the next generation, (ii) modifying the address lengths from 64 bits to 128 bits, (iii) renaming as Internet Protocol version 6 (IPv6), (iv) keeping all aspects and features of IPv4 that were proven to work and continued to make sense, (v) removing or making optional all features of IPv4 that were infrequently used or shown to be problematic and (vi) adding new solutions to patch up existent problems or add new features that enable the protocol to address new needs. The IETF included a new working group named Internet Protocol Next Generation or IPng in December 1993. This IPng protocol was approved by the Internet Engineering Steering Group (IESG) and was documented in RFC 1752, as a proposed standard, on 17^{th} November, 1994. IPng is referred to as the Internet Protocol Version 6 (IPv6). This new version of IP is considered as an evolutionary step rather than a revolutionary step in the development of IP all over the world.

The IPv4 was not premeditated to be configured with the stateless auto configuration of a node. Moreover, IPv4 provides no features for site renumbering. Further, the addresses in IPv4 are difficult to configure with its configuration mechanisms. Private communications over a public Internet requires security services and are provided through Internet Protocol Security (IPSec), which is optional. While standards for IPv4 Quality of Service (QoS) exist, real-time traffic support relies on the Type of Service (ToS) field in IPv4 protocol header. However, the IPv4 ToS field has limited functionality and over time there were various local interpretations. In addition, payload identification using a TCP and UDP port is not possible when the IPv4 packet payload is encrypted. However, IPv6 was designed by taking into considerations of all the limitations in IPv4.

Next Generation Internet Protocol (IPng / IPv6)

The IPv6 was standardized in the year 1995. The suite of IPv6 protocols were finalized by the IETF and updated in RFC 2460 in 1998 [Robert, 1999]. This IPv6 has many significant features and enhancements over IPv4. Since IPv6 was published as an IETF Draft Standard in 1995, the IPv6 Working Group has published several RFCs and Internet Drafts. Many of the protocols specifications on IPv6 are still being discussed by researchers. Many vendors and organizations have established IPv6 research projects laboratories to test and implement IPv6 in order to have IPv6 as a complete standard.

Technical Features and Business Benefits of IPv6

IPv6 has many significant features and enhancements over IPv4 such as header format simplification, extended header, extended address space, efficient hierarchical addressing, address auto-configuration and renumbering, duplicate address discovery, new protocol for neighboring node interaction, efficient routing, built-in security, better support for prioritized delivery in quality of service, route optimized mobility and end-to-end connectivity etc. IPv6 has 128 bits in address length that uniquely addresses 2^{128} networks interfaces which is about 340 sextillion addresses or actually 340, 282, 366, 920, 938, 463, 463,374,607,431,768,211,456addresses. The Earth's surface area is about 510 trillion square meters. IPv6 has 3.4×10^{38} unique addresses and therefore provides over 1000 addresses per square meter in the Earth [Han *et al.,* 2004]. The number of IPv6 addresses is 1028 times larger than the number of IPv4 addresses. Further, IPv6 provides simplified header, stateless configuring of addresses and improved techniques of Duplicate Address Detection (DAD). The classless IPv6 larger address space provides end-to-end global reachability and the addresses are not case-sensitive. The header format of IPv6 has many new features when compared with the header format of IPv4 [Hinden *et al.*, 2006], [Walton, 1999], [Bradner, 1995]. IPv6 includes an improved option mechanism which is placed in separate extension headers. IPv6 extensions are processed only by the destination so that the packets are routed to the next node at a greater speed whereas in IPv4, options are processed in each router thereby slows down packets routing [Gregory *et al.*, 2001]. IPv6 provides a new mechanism called stateless address auto configuration in which a node may also be configured without the need of a server [Donze, 2004]. This feature in IPv6 enables a node to freely roam into other network and get connected on the IPv6 Internet.

Further, IPv6 supports easy network renumbering, Neighbor Discovery (ND) and address auto-configuration functionalities. IPv6 provides a node to be more secured; provides a value of Time-To-Live (TTL) field upto 255; and prevents against outside sourcing of Neighbor Discovery packets or duplicate addresses [Arkko *et al.,* 2002]. Intermediate IPv6 routing nodes do not recompute checksum, fragment/reassemble packets or parse through headers. These features reduce the processing overhead for routers, hardware complexity and enables faster packet processing [Satoshi *et al.*, 2006]. Also, hierarchical addressing feature in IPv6 results in smaller routing tables and more efficient routing in the overall network. In addition, IPv6 makes it easier for network administrators to assign and track addresses. IPv6 offers a more scalable routing system than IPv4. The IPv6 Internet routing system is also more robust and responsive to change than the IPv4 Internet routing system [Deering *et al.*, 1998].

Unlike in IPv4, in IPv6, the Security protocol (IPSec) is enabled and is available for the use on every IPv6 node. This security feature makes the IPv6 Internet more secure. And the IPv6 header extensions support network-layer authentication, data integrity and data confidentiality. Further built-in component of IPv6 security provides end-to-end security [Carlos *et al.*, 2009]. New fields in the IPv6 header define how traffic is handled and identified. Traffic identification using a Flow Label field allows IPv6 routers to identify and provide special handling for packets belonging to a flow, a series of packets between a source and destination. IPv6 provides further enhancements for mobile communication by providing the addition of scope field for multicast has improved the framework for multicast traffic [Han *et al.,* 2004]. IPv4 networks need NAT in certain situations in order to conserve scarce IP addresses [Nawaz *et al.,* 2009]. IPv6 networks eliminate the need for NAT and restores end-to-end connectivity. As a result, peer-to-peer applications work well with IPv6 [Mackay *et al.,* 2003], [Raicu *et al*., 2003], [Phifer, 2000]. Application protocols such as File Transfer Protocol (FTP) can be enabled much more easily with IPv6 [Chena *et al.*, 2009]. Voice-over-IPv6 (VoIPv6), remote sensing and the host mobility are the three critical applications which have been identified, requiring IPv6 for effective and ubiquitous use by the military [Lambrinos *et al.,* 2007]. Certain products, such as 3G cellular phones are commercially available which are only capable of IPv6 communications [Thomas *et al.*, 2005]. Recently, Microsoft researched and announced a new capability for the Windows XP (Windows eXPerience) Operating System (OS) called the Personal Area Network (PAN), supported only by the IPv6 protocol [Jayanthi *et al.*, 2010d]. PAN enables a group of devices to automatically form an ad-hoc network in a small area [Jayanthi *et al.*, 2010e].

Deployment Status of IPv6

Realizing the need and the significant features of IPv6, several countries have started initiating IPv6 deployment in their countries. In 1996, Japan's Nippon Telephone and Telegraph (NTT) was the first Japanese commercial ISP to offer IPv6 service. This service was offered in Japan, Europe and the US. In 1999, Internet Initiative Japan (IIJ) launched Japan's first commercial IPv6 trial service for high-end Enterprise customers. In 2001, an "IPv6 Promotion Council" was established by the Japanese Government and Industry Stakeholders to coordinate IPv6 planning for the Government's e-Japan initiatives, Research and Development programs, Applications Development and Product and Services Trials involving Carriers and ISPs, Customer Premise Equipment (CPE) and Infrastructure Equipment vendors. IIJ is the one of Japan's largest domestic Internet Backbones and provides networking between Japan and the U.S. Japan's Government allocated $18 million in 2003 to rollout IPv6 capable networks by 2005.

In 2000, Countries such as Europe and China, took the lead for deploying IPv6 in their networks. Early 2001 witnessed several Asian countries allocating Internet addresses for IPv6 capable networks. Many countries took steps in funding to promote more IPv6 research and IPv6 deployment in their countries resulting the commercial vendors to provide IPv6 services in their network.

Several research projects on IPv6 are being carried out all over the world. Europe's 6INIT project, US's 6REN, 6TAP project, Japan's KAME project, TAHI project and WIDE project are a few of the IPv6 projects [Ning, 2004]. The IPv6 research center was established at Birla Institute of Technology and Science (BITS), Pilani in India. In 2000, the Sun Micro-Systems included both IPv4 and IPv6 in Solaris 8. In 2002, the Micro-Soft Corporations introduced IPv6 in Microsoft Windows 2002. IPv6 has been already deployed in JAPAN in 1996, CHINA in 2005, EUROPE in 2007, FRANCE in 2008, INDIA and USA in 2009 and KOREA in 2010 [IITG Final Report to ISACC, 2010].

In 2005, China's major carriers deployed the China Next Generation Internet (CNGI) [Ning, 2004]. In 2008, the Chinese Government published the Olympic Games in Beijing using the IPv6 addresses 2001:252:0:1::2008:6 and 2001:252:0:1::2008:8 [Olympic Games, 2008].

In March 2008, NTT announced an IPv6-based IPTV (Internet Protocol TV) service called "Hikari TV" for Japanese subscribers. It provides standard and high definition TV programming over a dedicated IPv6 network.

As the IPv6 support was included in almost every new computer operating system, several industries deployed IPv6. The content provider, Google enabled IPv6 access to YouTube in February 2010 and created 30:1 increase in IPv6 traffic in at least one global ISP [Colitti *et al.*, 2010]. US Government drafted a roadmap for IPv6 transition between 2010 and 2011; and targeted to have its network services to be available over IPv6 by the year 2012 [USEOP, 2005], [USGCIO, 2009]. Australian Government has prepared a draft for IPv6 deployment by the end of the year 2013 [Cisco White Paper, 2010].

In India, the Ministry of Communications set up a ten point agenda for the modernization of telecommunications and the transition to IPv6 in the year 2004. The Indian Government decided to facilitate the use of IPv6 in the country in June 2009. Accordingly the Government of India finalized IPv4 to IPv6 transition strategy in June 2009. The National IPv6 Deployment Roadmap was released in July 2010. Salient features of this roadmap include action plan for telecom service providers, formation of Task Force (TF) for the implementation of IPv6, formation of Indian IPv6 Centre for Innovation and development of standards and specifications for IPv6 conformance and interoperability etc. A few of the steps taken for transition from IPv4 to IPv6 by stakeholders are (i) Telecom Engineering Centre (TEC) in Department of Telecom is coordinating with all stakeholders for transition from IPv4 to IPv6 and (ii) Central Government Ministries/Departments, State Governments and Telecom operators have been advised to procure IPv6 complaint equipments. As a result, Internet Service Providers (ISPs) Ernet, Sify, Hughes Network Systems (HNS) and Tata Communications, started incorporating IPv6. Tata Communications which provides the most extensive IPv6 support in India using 6PE (IPv6 on the Provider Edge Routers) technology deployed international dual stacked IP gateways at various locations. Now, IPv6 access is available in India in 16 cities.

As per the study, during February 2010, more than 915 million "/48" sized IPv6 address blocks were allocated. Each "/48" can support 280 IPv6 addresses. The growth of announced IPv6 Internet and the IPv6 address prefixes grew at a steady rate until 2008 and then the growth incline started in 2008. IPv6 traffic doubled during 2009. The global IPv6 deployment rate increased from 5% in April 2010 to 7.95 % in December 2010. Figure 1.2 shows the growth of IPv6 address space actually in use, on the Internet from 2005 until March 10, 2010 [Carolyn, 2010], [Colitti *et al.*, 2010], [IPv6 Distribution Reports, 2010].

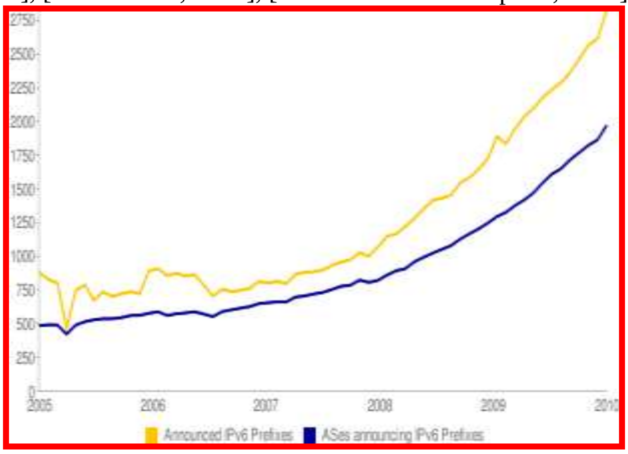

Figure 1.2: IPv6 Addresses in Use on the Internet (As seen by RIPE NCC's Routing Information Service, as of 10 March 2010)

Many countries have not yet initiated IPv6 transition and deployment in their countries [Popoviciu *et al.*, 2006], [Lawton, 2001]. Therefore, IPv4 to IPv6 transition will take some time and during these period, both IPv4 and IPv6 will co-exist [Bush, 2008].

Inter-Mobility and Interoperability Between IPv4 and IPv6 Networks - Issues

During the co-existence period of IPv6 and IPv4, the IPv6 nodes may enter and roam into IPv4 networks and similarly the IPv4 nodes may also enter and roam into the IPv6 networks. The major limitation in the IPv6 deployment is the incompatibility of IPv6 with IPv4 networks and therefore IPv6 devices cannot directly communicate with IPv4 devices and vice versa [Yan-ge *et al.*, 2009], [Hiromi *et al.*, 2006]. In order to overcome this limitation and to provide communication between IPv4 and IPv6 networks, the IETF Next Generation TRANSition (NGTRANS) WG has proposed three transition mechanisms to provide communication between IPv6 and IPv4 networks such as dual stack, tunneling and translation [Dunn, 2002].

Several architectures have proposed by researchers in implementing the IPv6 transition mechanisms but each one has its own limitations [Geer, 2008]. Few of the notable research are the Network Address Translation – Protocol Translation (NAT-PT) architecture, the Bi-Directional Mapping System (BDMS) architecture, and Mobile Internet Protocol - Application Level Gateway (MIP–ALG) architecture [Mellor *et al.*, 2008a], [Choi *et al.*, 2003], [Tsirtsis *et al.*, 2000]. The NAT-PT architecture implemented address translation mechanism. This NAT-PT allows IPv6 nodes roaming in IPv6 networks, to communicate with IPv4 nodes in IPv4 networks and does not provide facility for IPv4 nodes to communicate with IPv6 nodes. The BDMS architecture introduced DNS46 server and V4-V6 Enabled gateway. DNS46 server has been implemented with dual stack mechanism to maintain all IPv4 and IPv6 public Internet addresses. The MIP–ALG architecture has implemented both translation and dual stack mechanisms. These researches have provided the communication between IPv4 and IPv6 devices, considering the IPv4 nodes roaming in IPv4 based networks and IPv6 nodes roaming in IPv6 based networks [Chena *et al.*, 2009].

The mobility of nodes is supported with Mobile Internet Protocol (MIP) at the network layer according to each IP version, i.e. MIP/MIPv4 nodes mobility and MIPv6 for IPv6 nodes mobility. However, MIPv4 and MIPv6 cannot support the mobility of nodes when nodes move between two different IP networks. The mobile IP can be used only when the mobile node moves within the same IP network because the MIPv4 protocol is not compatible with the MIPv6 protocol. The existing IPv4–IPv6 mobility protocols do not provide solutions for scenarios such as (i) when mobile node roams into different IP network; it should be attached to the new IP visited network by means of address configuration, (ii) for Inter–mobility of nodes between different IP networks and (iii) for Interoperability of mobile nodes with other IP networks. Until now, there is no standard technique for interoperability, inter-mobility services and addressing management between IPv4/IPv6 networks. Hence there is a need to design an integrated architecture incorporating the much required transition mechanism for the deployment and migration of IPv6.

Conclusion

Transitioning IPv6 takes several challenges and hurdles. Significant work has been carried out to different transition scenarios and to prove their suitability is under research. Moreover the Internet infrastructure still has not significantly migrated from IPv4 to IPv6, even after the introduction of IPv6 in 1995. Hence more researches have to be carried out, to design an integrated architecture addressing, inter-mobility and interoperability for IPv4 nodes in IPv6 networks and to design an integrated architecture addressing, inter-mobility and interoperability for IPv6 nodes in IPv4 networks.

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