The deployment of IPv6 in an IPv4 world and transition strategies

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Abstract

It is stated that the new version of the IP protocol, IPv6, is the answer to the majority of the problems that were raised during the enormous expansion of the Internet and its transformation to a global communication platform with commercial scope. At the same time it is also stated that IPv6 dominance will not be easy and there will be a period when the two versions of the protocol will co-exist. In this paper we describe some of the main transition mechanisms that can be deployed in order to facilitate the transition process to the new version of the IP protocol. Furthermore, the presented mechanisms are discussed regarding their usability, usefulness and manageability. Describes the way some of these mechanisms were applied to the Greek Research & Technology Network (GRNET).

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Introduction

The IP protocol and its current version, IP version 4, is the most widely used protocol in computer networks at present. The big change that happened to the character of the Internet, from a rather academic network with low demands on resources to a commercial network with a variety of intensive applications running over it - considering also the integration of other communication services on it, e.g. VoIP - showed the weakness of the fourth version to support the new networking applications. The reasons that led the Internet community to adopt the development of a new IP version are summarized below:

- *Lack of addresses*. The address space of IPv4 is 232. This space is decreasing because of the sub netting procedure and the dedicated areas in the IP space for several operations like private networks and multicasting. The IP space that has been left is running out. There are new demands for IPs, while new devices tend to connect to the IP networks, such as home devices and mobile phones.
- *Performance-manageability*. The lack of hierarchy levels in IP addresses results in the existence of too many hard-to-manage routing entries to the routers. Also, several applications demand quality of service (QoS) support from IPv4 and this shortcoming is overtaken by the use of protocols in higher levels with uncertain results.
- *Security*.Considering the wide spread of the Internet and its use for several transactions, like financial ones, security is an issue that has to be supported by the IP protocol, which must be able to provide reliable and efficient security mechanisms.
- *Automatic address assignment*. The configuration procedure in IPv4 hosts is complex and requires human interference. Users would prefer a procedure of the type "plug and play". When a computer is plugged to the IP network, the connection parameters may be configured automatically without human interference. This capability is suitable enough for mobile users.

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The new version of IP protocol, IP version 6, seems to be a satisfactory solution to the above limitations (Deering and Hinden, 1998). It is foreseen that the deployment of IPv6 is probably inevitable and it is only a matter of time to see exactly when ipv6 will become the basic Internet-working protocol. Since the number of network applications that IPv4 currently supports is enormous, and the porting procedure will cost much in terms of money and time, the only applicable solution that will lead to a global dominance of IPv6 is the coexistence of IPv4 and IPv6 for a reasonable period of time. In a mixed situation, where both protocols co-exist, communication between IPv4 hosts over an IPv6 network, IPv6 hosts over an IPv4 network and IPv6 host and an IPv4 host must be achievable.

The rest of the paper is organized as follows. In the next section the most widely adopted mechanisms are presented and discussed. They are divided into three main categories according to the way that they work:

(1) dual stack mechanisms;
(2) tunnelling mechanisms; and
(3) translation mechanisms.

In the following section we present the way that we deployed some of the presented mechanisms in the GRnet IPv6 pilot network. Finally, we present the conclusions we came to during the deployment of these mechanisms and give indications about our future work in this area.

Transition mechanisms

The transition mechanisms are considered as a toolset to enable the smooth transition to the new version of the IP protocol. These mechanisms are divided into three main categories depending on their operation and the way of their implementation: dual stack mechanisms, tunneling mechanisms and translation mechanisms.

Dual stack mechanisms (DSM)

This mechanism is the deployment of a quite simple idea. Any host that desires to participate in both IPv4 and IPv6 networks has to maintain both stacks on its network interface(s). It enables a full IPv4 end-to-end communication between a dual stack host within an IPv6 only network and an IPv4 only host. The DST mechanism is based on a tunneling mechanism using a dynamic tunnel interface combined with temporary IPv4 address assignment provided by a DHCPv6 server.

The dual stack transition mechanism (DSTM) is based on the usage of a DHCPv6 server, which temporarily assigns global IPv4 addresses to IPv6 hosts that wish to communicate with an IPv4 only host (Tsirtsis, 2000). The IPv4 packets are encapsulated into IPv6 packets through a DTI interface and are transferred within the IPv6 network to the Border Router, which interconnects the IPv6 network with the IPv4 network.

One critical issue for the implementation of the DST mechanism is the support of the domain name service (DNS) and the impact of this service to the preference of a host to the IPv4 and/or the IPv6 protocol (Gilligan and Nordmark, 2000). In order that a network host be capable of communicating with other hosts by the use of both protocols, this host has to dispose of the appropriate libraries and ask the DNS for the address of IPv4, IPv6 and IPv4/IPv6 hosts. This means that the libraries have to be able to handle both A records (IPv4) and AAAA/A6 records (IPv6). It is concluded that the DNS support in DST mechanisms is a parameter that affects the network performance.

The operation of the DSTM is bi-directional, which means that the initialization of the communication may take place either from the IPv6 host side or the IPv4 host side. This is a major advantage of DTSM compared to other mechanisms, which allows the initialization of the communication only from the IPv6 host side. The DSTM requires the usage of a DHCP server and optionally the usage of a DNS server for the dynamic import of the temporary IPv4 address into the DNS database. Thus, the implementation of the DSTM matches more to small and medium network sizes that already use a DHCP server for the sharing of global IPv4 addresses. The main limitation for the implementation of DSTM focuses on the non-availability of a DHCPv6 server, because the standardization process has not yet been completed.

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Tunneling mechanisms

The tunnelling mechanisms may be used for the IPv6 communication over the existing IPv4 infrastructure and vice-versa. They are based on the encapsulation of IPv6 packets into IPv4 packets and the transmission over the IPv4 network. The two endpoints of the tunnel need to be dual stack routers or hosts.

The tunneling mechanisms are mainly divided into two main categories according to the way they are created: either by direct configuration on the endpoints of the tunnel or by coding of the address of the endpoint into the IPv6 address.

The first category supports the following two mechanisms:

(1) *Configured tunneling mechanism*. The term "Configured tunnel" refers to the explicit definition in each endpoint of the tunnel of the IPv4 address of the opposite endpoint. According to this mechanism, the IPv6 packets are encapsulated into IPv4 packets. The destination address of the IPv4 packets has been indicated in the creation of the tunneling interface on the router, while the source address is the IPv4 address of the interface. In this way routers build point-to-point links over the IPv4 infrastructure and these links are used for the transmission of the IPv6 packets. The implementation cost of the configured tunneling mechanism is low because it allows the parallel development of the IPv6 infrastructure without the usage of separate physical links.

(2) *Tunnel broker mechanism*.Tunnel broker is a mechanism designed for users who want to participate in the IPv6 network but are isolated from any native IPv6 network, or for users who wish an early IPv6 adoption (Durant *et al.*, 2001). It provides quick connectivity to the IPv6 network in addition to low administration cost. The tunnel broker assigns an IPv6 address to the dual stack host, which returns, along with its DNS name and client configuration information. The main components of this mechanism are the tunnel broker entity and the tunnel broker server. The tunnel broker entity is used for the registration of the user and the tunnel activation for the connection to the IPv6 network. The tunnel broker server is an IPv4/IPv6 router connected to both networks.

The tunnel broker mechanism is targeted to the connectivity to the IPv6 network of remote users and small sites. However, it offers high scalability and can support a large number of remote users. This mechanism presents a limitation for the support of users who use private IPv4 addresses (NAT mechanism). Also, it is aimed more at short-term periods of native IPv6 connectivity rather than providing long-term access.

(1) The second category supports the following three mechanisms:

- *Automatic tunneling mechanism*.This mechanism utilizes the IPv4 compatible IPv6 addresses (Gilligan and Nordmark, 2000). The application of this mechanism requires only the installation of a software module to the hosts. This module is a pseudo-interface, which is responsible for the encapsulation of IPv6 packets into IPv4 packets and their forwarding over the IPv4 interface. This mechanism requires globally routable IPv4 addresses and excludes private addresses.

  Usually, this mechanism is used in combination with a configured tunnel, in order to make the IPv6 host able to communicate with the total of IPv6 hosts (native IPv6 hosts and hosts using the 6to4 mechanism) and not only with hosts using automatic tunneling. As the automatic tunneling mechanism allows remote hosts to have access to the IPv6 network and operates in a simple and flexible way, this mechanism can be combined with other mechanisms in order to achieve end-to-end communication.

(2) *6to4 transition mechanism*. The 6to4 mechanism enables IPv6 sites to connect to other IPv6 sites over the IPv4 network (Carpenter and Moore, 2001; Tsirtsis, 2000). It does not employ any manually configured tunneling mechanism, neither does the host need to have an IPv4 compatible IPv6 address. The only requirement is that the IPv6 router has a

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routable IPv4 address. This mechanism uses the IPv4 infrastructure for the interconnection of remote IPv6 hosts. It faces the IPv4 network as a unicast point-to-point link layer and implements the IPv6 network using encapsulation techniques. 6to4 mechanism has been assigned the IPv6 prefix 2002::/16.

The main aim of this mechanism is to allow isolated IPv6 sites/hosts, which are attached to an IPv4 network with no IPv6 support, to communicate with other IPv6 domains. Another advantage is that the 6to4 mechanism may be used in networks that have private IPv4 addresses and only one routable address, while it is not affected by the presence of firewalls and NAT boxes. The 6to4 mechanism supports the progressive migration from IPv4 to 6to4 and later to native IPv6.

(3) *6over4 mechanism*. The 6over4 mechanism allows isolated IPv6 hosts to act like fully functional IPv6 hosts even without direct contact with an IPv6 router (Carpenter and Jung, 1999). This mechanism utilizes the IPv4 multicast domain, that is considered as the link layer over which the IPv6 stack is built. In this case, the IPv4 domain has to support multicast operations. Also, if connections with external IPv6 sites have to be supported, then it is required that a router applies the same mechanism to the link connected to the multicast domain. The 6over4 mechanism does not use IPv4 compatible IPv6 addresses or configured tunnels. Also it provides independence of the technology of the used links and the topology of the IPv6 network. Usually the 6over4 mechanism is called a "virtual Ethernet".

Translation mechanisms

The translation mechanisms aim to allow the communication between hosts that support different protocols. They may be applied in networks where only one protocol is used, while it is desirable to maintain the support of services of the other protocol, for example support of IPv4 services in IPv6 hosts. The most well-known translation mechanisms are described briefly below:

- *Header conversion*. According to this mechanism the IPv4 headers are translated to IPv6 headers and vice-versa. It is similar to the NAT protocol (IPv4-to-IPv4 Header Conversion). Although this mechanism is fast enough, it appears that there are some limitations to its application, for example it does not support translation in the application layer.
- *NAT-PT (Network address translation-protocol translation)*. The NAT-PT mechanism allows native IPv6 hosts and applications to communicate with IPv4 hosts and applications respectively. The host that makes the translation lies on the borders between the IPv4 and IPv6 networks. Each host acting as an address translator keeps a pool of addresses that are assigned dynamically to IPv6 hosts and a session is generated between two hosts supporting different protocols. The NAT-PT mechanism supports both address and header translation. The implementation of the NAT-PT mechanism is simple and does not require any extra configuration to the hosts. However, this mechanism does not support the implementation of end-to-end security strategies and requires the usage of a large IPv4 space.
- *Address mapping*. This technique refers to one-to-one correspondence between IPv6 destination addresses and IPv4 source addresses and vice-versa.
- *Socks*. Socks is a gateway mechanism implemented by a "Socks server", that acts as a relay mechanism in TCP or UDP sessions between two hosts supporting different protocols (one IPv4 host and the other IPv6 host) (Toutain and Afifi, 2000). Socks is considered a unidirectional mechanism and may be used for the connection of an IPv4 network to an IPv6 network and vice-versa. Its main disadvantage is that the connections have to be initialized by the hosts lying behind the Sock server.

Table I summarizes the transition mechanisms (EuresCom Project P1009 results, 2001). The Table presents the main implication on the

Table I Overview of transition mechanisms

Mechanism type	Implication on application	IPv4 address requirements	Hosts/site mechanism	Comments
Dual stack	None	Permanent or pool of addresses allocated by a DHCP server	Site/host	Very simple to set up, available to every node supporting IPv6 stack
DSTM	None	Pool of addresses required for AIIH server	Site/host	Allows host to run end-to-end IPv4 application within an IPv6-only network. Allows IPv4/IPv6 of IPv6-only host application to communicate with either IPv4 or IPv6 end point without need of specific ALG
6to4	Applications need to be ported to interface with the IPv6 stack	IPv4 address of border routers	Site/host	Allows automatic joining of IPv6 network separated by an IPv4-only network Each IPv6 network needs to have a 6to4 border router
Tunnel broker	Applications need to be ported to interface with the IPv6 stack	One for the dual stack host. At least one for the tunnel broker implementation	Site/host	Allows an isolated IPv4 host within an IPv4-only network, to reach an IPv6 wide network
6over4	Applications need to be ported to interface with the IPv6 stack	One per host	Host	Allows automatic joining of IPv6 network separated by an IPv4-only network The IPv4 network needs to support multicast Each IPv6 network needs to have a 6over4-border router
NAT-PT	Applications including IP addresses in the packet payload need the availability of a dedicated ALG into the NAT-PT router	Pool of IPv4 addresses needed	Site	Needs specific ALG for DNS, FTP, IPSEC, ... Mechanism located in a single point
SOCKS64		The Socks server must have an IPv4 address	Site	Allows IPv4 applications to communicate with IPv6-only hosts and vice-versa

application of each transition mechanism. In other words it is posited that the main changes have to be done in the networking applications in order to co-operate with each mechanism. Also, the Table shows how many IPv4 addresses each mechanism needs in order to operate and is categorized according to its scope.

Transition scenarios applied on the Greek Research & Technology Network (GRNET)

GRNET is the Greek Research & Technology Network, providing Internet services to the Greek academic and research community. It interconnects universities and research centers in Greece, as well as other R&D departments of industrial organizations through an advanced high-speed network. Like many other NRNs, GRNET maintains a pilot IPv6 network in order to enable its users to familiarize themselves with the new protocol. The IPv6 network was built over the IPv4 infrastructure so that the core IPv6 links are not actually native IPv6 links but IPv6 over IPv4 tunnels that interconnect the IPv6 routers of the participating organizations and the core IPv6 router of GRNET. The topology implemented is a star one. Figure 1 shows the topology of the IPv6 network of GRNET.

Figure 1 IPv6 network topology of GRNET

Address assignment

GRNET is the administrative authority of a pTLA, the 3FFE:2D00::/24 that have been assigned to it by the RIPE for the needs that will arise during the deployment of the IPv6 protocol in the east Mediterranean area. Following the guidelines of RFC 2450 an address plan was designed so as to distribute the allocated address space to the possible clients (universities, technology and research institutes, etc.) (Hinden, 1998). The decision was to allocate three bits for sharing between the Mediterranean countries, the next five bits for the big ISPs in each country, leaving the total of 96 bits to be consumed by the customers. This leads to eight countries, 32 big ISPs in each country and each ISP can support up to ~65,000 clients. Since the last 64 bits comprise the host part, each client disposes 16 bits for the internal sub netting.

Motivation

The IPv6 backbone of GRNET comprises an IPv6 router that is connected through IPv6 over IPv4 tunnels to each client and with 6bone too. Initially in each academic institute there was a small IPv6 LAN that was connected to the local IPv6 router. This small IPv6 LAN was the test bed where the new protocol had been tested and a knowledge base obtained by technicians so they could support the expanding procedure to the end user. The last one was the challenge that had to be taken: How could the IPv6 network reach the end user? The main goal was to use the IPv6 backbone in a manner similar to the use of the IPv4 backbone, meaning that all IPv6 traffic from every institute should cross the local IPv6 router. The reasons that enforced this policy were mainly administrative in terms of traffic measurement and accounting; so we focused on transition

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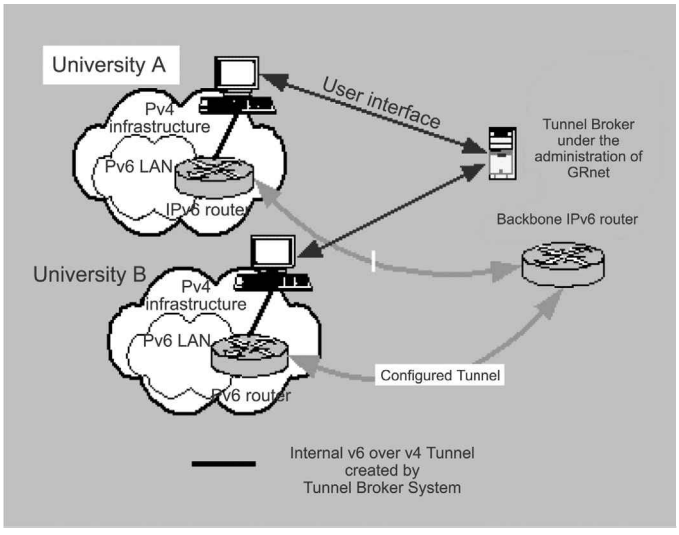
techniques that could provide this characteristic. Although it is commonly accepted that the IPv6 will be the Internet working protocol of the future and the users have to get familiar with it, there were certain reasons that kept us from enabling the protocol to the entire network and making it a full dual stack network and thus providing end-to-end communication with both protocols.

In the following we describe the techniques that were proposed to the Network Operation Centers of the academic institutes in order to provide IPv6 services to the end users.

The tunnel broker solution for GRNET

In order to provide IPv6 services to the end users without investing many resources or making changes to the network, one of the apparent solutions is the deployment of the tunnel broker. Our approach is described in Figure 2. We set-up a server that implements the user interface and also has permission to change the router's configuration in order to set up the tunnels. The tunnel broker software checks the IPv4 address of every user, determines in which institute the user belongs and set-up a tunnel between the user and the local IPv6 router. If the institute does not maintain an IPv6 router then the tunnel is established between the user and the backbone IPv6 router.

Figure 2 Tunnel broker operation in GRNET



The configured tunnels solution for GRNET

The second solution, in order to provide IPv6 connectivity to the end user, was to deploy configured tunnels between specific routers and the local IPv6 router. Each university used the IPv6 space that had been assigned to it by GRNET. The topology that is implemented inside the campus networks is a mesh one, meaning that there is a tunnel between each pair of routers participating in the IPv6 network. Each router with an IPv6 interface activated on it has been configured with a static route for all native IPv6 addresses pointing to the local IPv6 router, which is connected to the 6bone through the tunneling interface of the backbone IPv6 router.

Employing the 6to4 mechanism

As IPv6 employment is increasing among academic institutes and other organizations (enterprises) in Greece, we considered that the next step towards better support in IPv6 services was the employment of the 6to4 mechanism.

We enabled the 6to4 service on the backbone IPv6 router and, considering the fact that this router is connected to the 6bone too, in this way we offered 6to4 relay service. This service is open to everybody who wants to get involved with IPv6 and does not have any registered IPv6 address space or cannot have a permanent connection to an IPv6 enabled service provider. This service is suitable for small and medium enterprises or other organizations that want to try Ipv6 and need some connectivity to the 6bone but their ISP does not support any IPv6 services.

Future work

Using the mechanisms described above any network could provide IPv6 services to its customers. However, the variation of network architectures, technologies and demands that exist in each different customer, mostly enforces network administrators to deploy a mixture of the described techniques. The main target is to select the appropriate technique for each customer in order to provide better IPv6

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service and smoother transition procedure for the end user. Our future work includes the evaluation and performance measurement of each mechanism in a real-life, heavily loaded networking environment.

Conclusions

The transition to the next version of the IP protocol inside the GRNET, as in almost any network, is a long-term procedure that is considered to consume a lot of resources. The whole toolset of transition tools that have been defined and tested will provide the "middle step" in order to make the whole procedure smooth for the end users and the administrators. Surely there isn't only one solution for every network. The final strategy that will be followed in most cases is a mixture of the presented mechanisms and varies accordingly to the special needs, architectures and technologies that are deployed in each network.

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