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6DEPLOY

IPv6 Deployment and Support

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D2.1.1: Report of 1st Deployment Use Case

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Executive Summary

This deliverable presents IPv6-related activities in the Greek School Network. It discusses the drivers for the deployment of IPv6 services and the operational experiences from the deployment of services based on IPv6 technology during the last 5 years.

Project co-funded by the European Commission within the 7th Framework Programme		
Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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1. Introduction

This deliverable presents IPv6-related activities in the Greek School Network (GSN). Section 2 presents the GSN, the characteristics of its users, the provided services and the current networking infrastructure. Section 3 discusses the drivers for the deployment of IPv6 services and how new technologies may reduce the operational costs and allow the deployment of future services. In section 4, we present in detail the deployment phases of IPv6 technology over the last 5 years. The last two sections present our experiences and conclude this deliverable.

2. Presentation of GSN

The Greek Schools Network (GSN - www.sch.gr) is the educational intranet of the Ministry of National Education and Religious Affairs (www.ypepth.gr), which interconnects all schools and provides basic and advanced telematics services. Thus, it contributes to the creation of a new generation of educational communities, which take advantage of the new Informatics' and Communication Technologies in the educational procedure. GSN is the largest network in Greece regarding the total number of its users.

2.1. Users

In order to maintain the educational orientation of the network, its users are certified individuals, educational or administrative entities of the National Education. In particular, the users are divided in the following categories:

- **Schools**: At least one user account has been provided to all middle grade education schools and first degree education schools.
- **Administrative units**: At least one user account has been provided to more than 2.996 administrative units of National Education.
- **Educational staff**: The Greek Schools Network offers fully personalised access to all educational staff, with the dial-up service being broadly used under certain terms.
- **Students**: Network access is provided to students through the school laboratories. In addition, pilot personalised access is offered to second grade students of Achaia and Corinthian Prefectures.
- **Administrative staff**: as with educational staff

2.1.1. Diagrams & Graphs

The provision of network connectivity to the school units constitutes the main objective of the GSN. Through this accounts it is feasible the acquisition of access in the Internet and the services of the GSN from the computing infrastructure of each school unit, provided that a local area network is deployed in each school unit. In Table 1, the connected sites and the percentage of the schools that are connected to the GSN are presented per category of schools.

Category	Connected Sites	Percentage of Connectivity
Kinder Gardens	4.227	74,75%
Primary Schools (ISCED[1] 1)	5.950	100%
Secondary Schools (ISCED 2)	1.955	100%
Secondary Schools (ISCED 3)	1.203	100%
Technical Schools (ISCED 3)	639	100%
Institutes of education (ISCED 4)	140	100%
Others	86	-

Table 1: Number of Schools and Percentage of Connectivity (1/12008)

In a similar way as with the schools, the Ministry of National Education and Religious Affairs has recognised the need of provision of access to advanced services in its administrative and supporting units. Thus, GSN provides also network connectivity to more than 2.996 other units (administrative units, school libraries, public libraries, etc.) as shown in Table 2.

Connected Administrative Units (01/11/2008)[2]	
Administrative Units for ISCED level 1	548
Administrative Units for ISCED levels 2 & 3	1080
School Libraries	562
Professional Training & Support Units	424
Public Libraries	46
Local Libraries	29
Governmental Units	65
Other	242

Table 2: Connected Administrative Units

The GSN beyond the provision of one or more connectivity accounts, depending on each unit needs, in the educational and administrative units of the Ministry of National Education and Religious Affairs, has gone ahead in the provision of personalised accounts to the teachers of primary and secondary schools. These accounts are activated after certification of each teacher.

[1] http://www.unesco.org/education/information/nfsunesco/doc/isced_1997.htm
[2] http://www.sch.gr/statistics

The provided services with the most extensive use are the dial-up, the e-mail and the web hosting services, however progressively the educational community embraces also the other Internet services. In Figure 1, the registrations of new teachers to the GSN are shown per year.

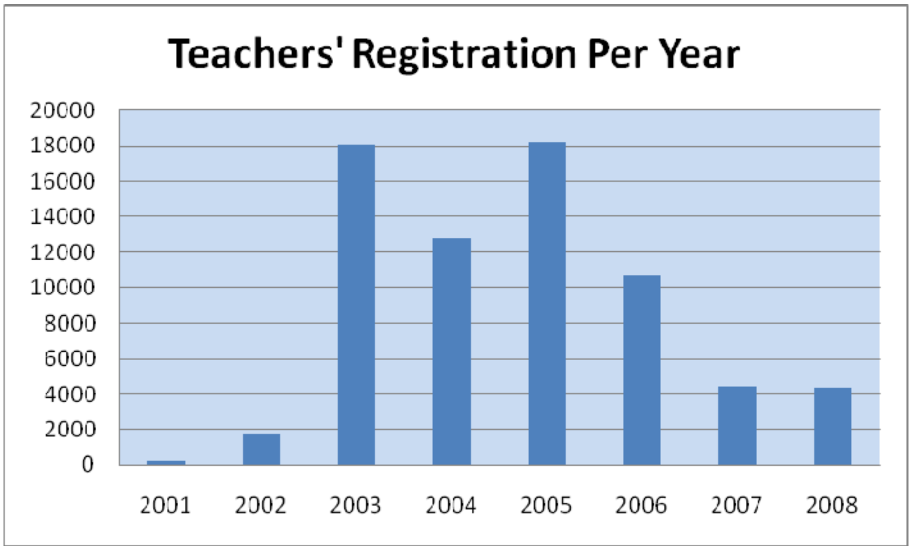


Figure 1: Teachers' registrations per year

The personalised accounts that have been provided in students do not constitute a metric for the acceptance of the GSN from the educational community, due to the particularities that are present in the provision of these accounts. More specifically, the personalised accounts of students allow the personalised access exclusively to the e-mail service. It is important to refer that already by 2007, 5521 students were registered to the GSN.

	Students' registrations per year						
Month / Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
January	0	1	0	55	0	0	2454
February	0	0	2	13	15	0	947
March	0	0	3	2	0	0	537
April	0	0	11	97	2	2	211
May	0	0	45	77	0	0	214
June	0	0	4	0	0	0	11
July	0	0	0	5	1	0	0
August	0	0	0	0	0	2	0
September	0	0	0	0	5	0	72
October	0	0	255	1	0	0	439
November	2	0	757	94	0	3398	284
December	0	0	211	16	0	3113	352

Table 3: Students' registrations per year

2.2. Services

The provided services constitute an exceptionally important dimension of GSN. It is reasonable that the users of a network services provider do not aspire exclusively at the acquisition of access to the Internet, but also to a group of provided services. Each desirable "group of services" differs considerably depending on the profile of the final user. In the case of GSN, services are provided in a wide community of users (regarding their requirements), some of which have increased and specialised requirements. Moreover, it is imposed the development of a group of administrative services (not visible to the users), aiming at the operation and management of the Network. Based on the above, the services of the GSN can be divided in the following three categories (each one of them is described in detail in the following subsections):

- Basic Services
- Advanced Services
- Infrastructure Services

2.2.1. Basic Services

The main services are provided immediately to the final users and concern all or most of them. The guarantee of the proper function of the basic services allows the planning and development of higher layer services. The basic services serve the formal needs of GSN users and the educational and administrative units. Following is provided a short description of the basic services that are provided by the GSN:

E-mail: The GSN provides in its certified users, e-mail account with electronic address username@sch.gr. The prefix of the e-mail is selected by the user and is determined strictly by well defined rules. This service (http://www.sch.gr/mail) is accompanied by a number of additional characteristics, such as virus protection and anti-spam filters.

Mailing lists: The mailing lists service (www.sch.gr/lists) aims at the creation and the maintenance of electronic lists in order to make possible the distribution of messages to large numbers of users. The GSN maintains central, prefectural and administrative mailing lists.

Web Portal: The content of the GSN portal (http://www.sch.gr) is constituted exclusively by services. Even the informative material, as well as the frequent questions or the guidelines for the use of services, is part of the provided services:

- *News and announcements*: The main announcements are uploaded in the main page by the administrators, while the administrators of each school unit can send material in the news service.
- *Services for the GSN*: they contain informational material for the GSN, statistics and guidelines for the use of the services.
- *Electronic magazine (e-emphasis.sch.gr)*: it allows the publication of articles from one simple web interface that do not presuppose knowledge of HTML, as well as the periodical submission of a newsletter with summaries of published articles.
- *Personalised services*: a user through its personalised services can manage his personal account (e.g. change password, secret question, view personal statistics), acquire access

to the guidelines for the automatic creation of web pages, maintain a list with its favourites network places, and manage its personal web page.

- *Educational Web Pages*: these pages allow access in the web pages of the educational and administrative units as well as the teachers' web pages, through a functional menu. Furthermore, the visitor can mark these web pages.

The Web Portal provides links to the following services: webmail (www.sch.gr/webmail), forums (www.sch.gr/forums), e-learning (www.sch.gr/e-learning), video on demand (www.sch.gr/vod) and videoconferences (www.sch.gr/rts). It is very popular in the educational community, as it concentrates – according to official statistics[3,4] – very high visibility (e.g. more than 110.000 visitors in February 2008).

Web-Hosting / Creation: The web-hosting service and the corresponding guidelines for the automated creation of web pages, serve the wish of GSN's users to acquire a presence in the WWW, provided that this is conform to the corresponding terms of use of this service. The web-hosting service provided by the GSN is accessible via the web page http://www.sch.gr .

Safe access to the WWW (block inappropriate content): The GSN, in order to protect the students from illegal and inappropriate content, provides the service of safe access to the Internet. Through this service, the access to websites that are considered inappropriate is blocked. GSN also promotes the safe use of Internet (www.sch.gr/safe) with directives and proposals to parents, teachers and students.

Remote Management: the service of remote management of the electronic infrastructure of the GSN (http://www.sch.gr/rc) provides remote functionality to services such as the management of the available processing and storing resources, the distribution of software and the remote control of systems and applications.

RSS – feed: It constitutes a modern and alternative way of briefing that is provided from the GSN to the educational community, for his following services:

- News from the web page www.sch.gr: http://www.sch.gr/sch-portlets/postings/rss.php
- Briefing on events by the web page www.sch.gr: http://www.sch.gr/sch-portlets/reservations/rss_events.php
- Briefing on the new video registrations in the GSN video server http://vod.sch.gr/rss.php
- News from the web page students.sch.gr: http://students.sch.gr/students-portlets/studentsNews/rss.php

e-magazines: Within GSN several electronic magazines are published. e-Emphasis (http://e-emphasis/) aims at informing all the educational community about news and current actions of the GSN and also which of them are best practices and can be used by each school unit. Furthermore, in each school unit, there is given the possibility of creating an electronic magazine (www.sch.gr/periodika) in which only certified users of GSN (teachers and students) will be able to participate as authors.

[3] http://www.alexa.com/data/details/traffic_details/sch.gr
[4] http://www2.sch.gr/awstats/awstats.pl?config=www.sch.gr

In addition to the above services, the GSN provides also services such as participation to Forums (www.sch.gr/forums), web page for sending e-cards to other users (www.sch.gr/e-cards) and announcements for news and events.

2.2.2. Advanced Services

The services of this category are exceptionally innovative and modern and usually concern a limited number of users. The GSN, corresponding to the increasing requirements and needs of its users, continuously designs and implements new services. The development of advanced and pilot services allows the GSN to constitute a completed educational intranet with important domestic added value and minimal dependence from other institutions and commercial products. The advanced services that are provided through GSN are the following:

Multimedia Services: The multimedia services allow the users to retrieve and access sound and video material. The retrieval of the available material is realised as streaming audio and video or as multimedia files, therefore the user can store the material in his computer for later processing. According to this discrimination, the GSN provides access in the following services of multimedia retrieval:

- Real Time Streaming (RTS) (www.sch.gr/rts): the RTS service allows the GSN to record and transmit via the Internet relative events or workshops. For this aim, GSN allocates specialised equipment in order to record and digitalise the captured information in audiovisual flows (video and audio streams) and furthermore to serve webcasting purposes.
- Video on Demand (www.sch.gr/vod): this service provides informative and educational content to GSN users. In its framework is offered digitalisation of the available material, while there are under development advanced characteristics such as search and certification of users. Still, via this service there is available archival material from past recorded events.
- Tele-learning and Videoconference (http://www.sch.gr/lms): This service implements a process of exchange of learning that is done synchronously and remotely allowing the creation of virtual classes. It supports the bidirectional communication of users in real time with exchange of picture (video) and sound, while it allows sharing of the educational material and applications among the participants. It is a modern tool that facilitates the communication and collaboration of teachers with their colleagues in Greece or abroad.

Educational Blogs (http://blogs.sch.gr): Educational blogs is a tool that can be used in the pedagogic process and strengthen the teaching method, due to the interaction and collaboration that it offers. The creation and maintenance of a blog helps the announcement of new ideas, thoughts, opinions and transfer of knowledge between teachers and students.

e-Learning: Aiming at the encouragement of pedagogic exploitation of Information Technologies, GSN has deployed the e-Learning service, which is provided via the web page (www.sch.gr/e-learning). This service in its current phase is in pilot operation. It has been installed using the open-source software Moodle (www.moodle.org). This platform provides the instructors with a bunch of capabilities and characteristics, which allow the creation of courses with a wealth of activities and informative material.

Voice over IP - VoIP: This service aims at the implementation of phone calls using the IP network. The coding and decoding of the communication signals is feasible through the use of special material (phone appliances) or software.

Instant Messaging: The instant messaging service exceeds the restrictions that are placed from the electronic mail service of. This service (www.sch.gr/im) is based on the open protocol Jabber.

2.2.3. Infrastructure Services

This category includes services that are necessary for the proper operation of the network. These services are self-existent (their operation does not depend on other services) and formally support/allow the operation of upper level services. The fundamental services are transparent or not to the final user or they are addressed to the administrators of the network, something that constitute the main criterion of segregation from the rest. The fundamental services that are provided from the GSN are the following:

Domain Name Service (DNS): DNS manages the IP range of addresses that has been allocated to the GSN, as well as maps these addresses to DNS names. More specifically, it watches the relative needs in IP addresses, it answers on demands and it records the IP addresses that are essential for the operation of the Distribution and the Access Network.

LDAP Directory Service: This service is the central repository where the profiles of GSN users and the network equipment are stored. This service does not constitute simply a index of users used in order to find their communication elements, but a middleware in which all the services of the GSN that require authorised access are supported. Thus, this is one of the more critical services of GSN.

User Management: This service aims at the management of users (schools, teachers, students) of the GSN as well as the definition of services and rights of each user, depending on his role.

Public Key Infrastructure (PKI): PKI service (http://ca.sch.gr) was developed in the framework of GSN in order to provide secure services to its users. This infrastructure was developed based in public key cryptography and the existence of confidence to a recognised entity called Certification Authority. The Certification Authority resolves issues of identification, authorisation, integrity and confidentiality, as the identity certification of a user or a server, the guarantee of integrity of a message or document and the encryption of the content of a message in order to be accessible only from the right receiver (confidentiality).

SLA Monitoring: The GSN SLA monitoring (http://sysmon.sch.gr/nagios) is in charge of the syntax and permanent briefing of the rules that describe the above agreements, so that is ensured the agreed level of provided services. Furthermore, it provides continuous follow-up of the services via the use of suitable metrics that allow the easy examination of the conformity of the services with the agreed SLA.

CERT and Network Abuse Handling: This service aims at the development of mechanisms for handling incidents of abuse of network resources, network services or digital content, as they are recorded by CERT®/CC (Computer Emergency Response Team Coordination Center).

Helpdesk: User support in GSN is implemented via technical support of equipment that exists in the points of access in the network, as well as via the support of telematics services.

- Support of Access Network: The support of Access Network ensures the right operation of the active network equipment of schools (“nodes of Access Network”) and includes (a) monitoring of the operation of the network that connects schools and administrative units, (b) the control of the operation of telecommunications circuits of the Access Network, (c) the installation of hardware and software and the regulation of security issues (access lists) in the active network equipment of the school units, (d) the repressive actions in the Access Network in case of a malfunction, (e) phone and mail support.
- Support of telematics services: The technical support of telematics services ensures on one side their right operation, and on the other side their exploitation from the users, via operations relative with (a) the monitoring of the operation of services and the implementation of suitable actions in case of a malfunction, (b) phone and mail support, (c) ticketing system in cases where a direct solution is not feasible, (d) announcements for scheduled maintenance of the network or its services and (e) creation or modification of users accounts.

2.3. Network Architecture & Topology

GSN is a nationwide network that spans all fifty one (51) prefectures of Greece. A three layered architecture was selected in order to manage the complexity that comes with the large number of sites that are covered. The three layers are:

- **The Backbone network**: GSN has not built its own backbone network but it uses GRNET (the Greek NRN) as a backbone. Because of its geographical distribution GSN consists of eight (8) individual parts, each having its own connection with GRnet. GRNET will provide native IPv6 connectivity between the main PoPs of GSN and connectivity to the rest of the internet. The connection to GRNET is implemented via Gigabit Ethernet of Fast Ethernet connections.
- **The Distribution Network**: As mentioned above, GSN maintains a PoP in every prefecture of Greece. The nodes in each PoP provide the ports on which the remote sites (Schools, Administration Units) are connected. These nodes together with the links that interconnect them constitute the Distribution Network (DN). The nodes of DN are hosted in the premises of OTE (National Telecommunication Operator). Besides the networking equipment the DN also hosts eight (8) datacenters all over Greece that provide the GSN services. The DN speeds vary from 256kbps to 5 Mbps implemented by fractional E1, E1 and ATM technology.
- **The Access network**: It is used to directly and efficiently interconnect the schools to the prefecture's access point. The telecommunication junctions used to interconnect each school are selected on the basis of financial and technical criteria from an array of available options:
    - ADSL circuit (1Mbps/256 Kbps – 8Mbps/384Kbps)Analog leased line (0,512 - 2 Mbps)
    - Wireless link (10 - 54 Mbps)
    - VDSL circuit (10 - 15 Mbps)
    - Digital ISDN circuit (bandwidth: 64 - 128 kbps)

2.3.1. Public Switched Telephone Network circuit (56 kbps)Backbone Network

The backbone Network of GSN is the core network of GRNET, thus the GRNET3 network. GRNET3 signals the transition from the model of renting telecom circuits to the long-standing leasing of optical fibers of total length of more than 8.000 kilometers, which will be used exclusively from the GRNET owned equipment of optical transmission, providing broader geographical coverage. GRNET3 supports the circuit switching of great capacity for e-science applications, along with the packet switching for classic Internet usage. At the same time, it is an advanced network that will facilitate the experimentation in all network technologies which are expected to come to the fore within the following years. GRNET3 allows the data transmission at really high speeds (at 16 wavelengths of 10 Gbps, initially), making possible, in a wider scale, the usage of advanced network applications in real time. The tele-education, the teleconference and the multimedia communications are just some of the applications that will facilitate the everyday activity of the Research and Educational Institutions of the country. In parallel, e-science and GRIDs applications are supported. Achieving the acquirement of the rights for the usage of optical fibers, GRNET will provide and administer autonomously the practically inexhaustible capacity of the network, attaining its best usage.

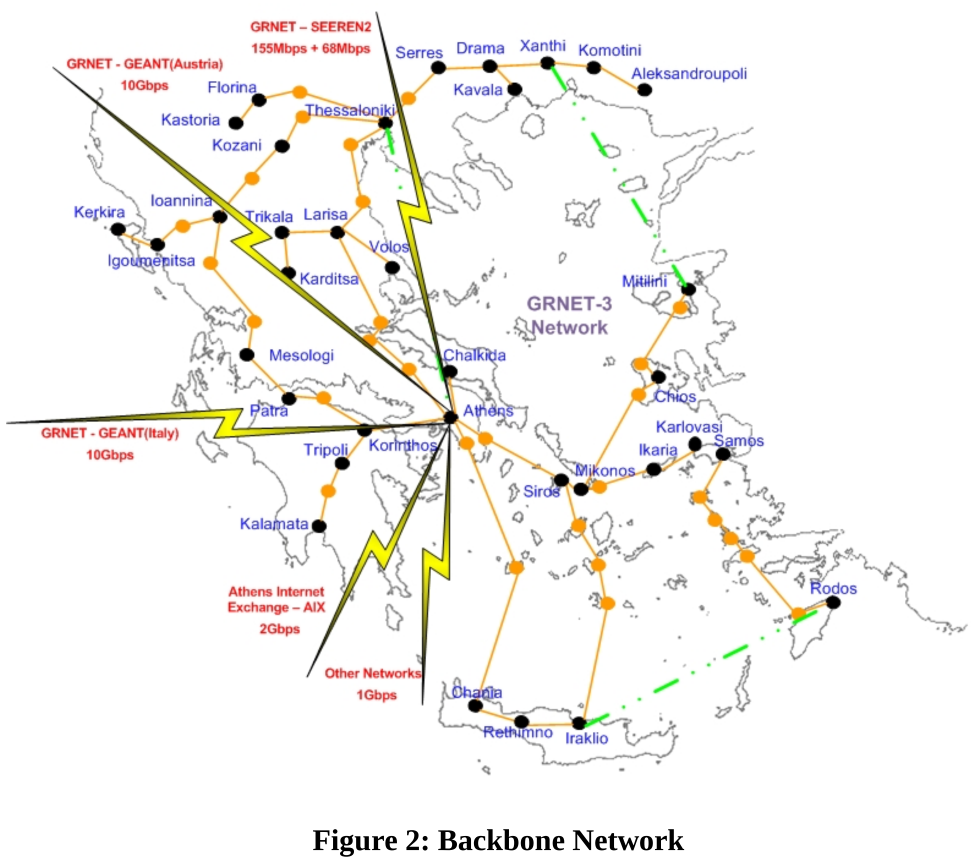


Figure 2: Backbone Network

2.3.2. Distribution Network

The Distribution Network constitutes the main network infrastructure of GSN. In interconnects users and units of GSN, as well as the available computing equipment. Still, it is interlinked with the Backbone Network, rendering feasible the connection of GSN with the Internet.

The Distribution Network is composed from 51 nodes and is distinguished in two levels:

- First level, which is composed from 8 nodes (Athens, Thessaloniki, Patras, Heraklion, Larissa, Ioannina, Xanthi, and Syros), that represent the main nodes of the Distribution Network.
- Second Level, which is composed from 43 nodes installed in the remaining prefectures of Greece and represent the secondary nodes of the Distribution Network. The nodes of second level are not connected directly with the Backbone Network, but with first level nodes, and through them with GRNET.

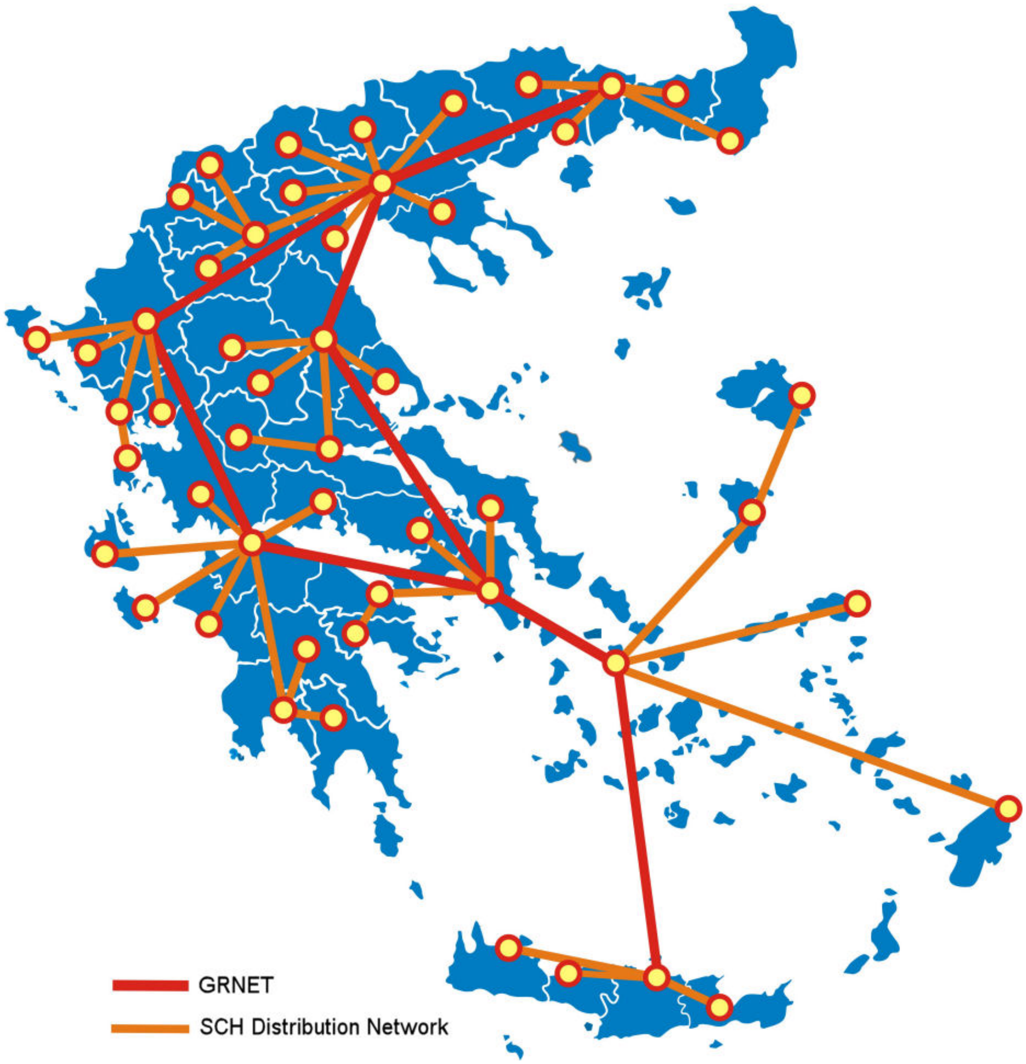


Figure 3: Distribution Network

In the nodes of the Distribution Network there is installed the network infrastructure of GSN, which provides access to the network, and the computing infrastructure, which provides various telematic services. The installed network and computing equipment is analyzed in the following tables:

Model	Number	Role
Cisco 7604	8	Router
Cisco 7206VXR	8	Router
Cisco 7206/7301	4	ADSL Aggregator
Cisco 3845	43	Router
Cisco 5400/5350/3660/3640	51	Aggregator
Cisco Catalyst Switches	60	Fast/Gigabit Ethernet Switch
Cisco VSDL Concentrators	10	VSDL Aggregator
Cisco 2509	10	Terminal Servers
Total	194	

Table 4: Network equipment installed in the Distribution Network

Equipment	Number
Media Servers	2
Portal Servers	2
Sun Enterprise 450	3
Sun Enterprise 250	7
Sun v120	12
Cache Boxes	14
Sun Ultra 10	32

Table 5: Computing equipment installed in the Distribution Network

2.3.3. Access network

The Access Network interconnects the users of GSN with the Distribution Network and thus with the Internet. For the Access Network it has been selected a number of telecommunications circuits of different technologies, based on concrete economical and technical criteria and protractor the benefit of higher possible bandwidth in the lower cost. The Access Network in its current state is changing from ISDN technology to ADSL technology. The wide scale interconnection of the educational and administrative units of the Ministry of National Education and Religious Affairs in the Access Network is feasible via telecommunications circuits of the following technologies:

- **ADSL**: The ADSL connections allow relatively high speeds of access in permanent base with low monthly cost, but they presuppose the existence of PSTN or ISDN telephone line with the corresponding constant cost.

- **PSTN and ISDN**: The PSTN and ISDN connections offer, with proportionally higher cost in comparison to ADSL connections, access to the network in low speeds. These connections will remain in use only in the regions where broadband access is not available.

Particular indications require alternative technologies in the Access Network that are used by the GSN, and more concretely wireless and satellite connections. The exploitation of these technologies is conducted mainly in pilot level, aiming at the examination of the advantages they offer and their likely future use in wide scale.

Finally a limited number of educational and administrative units are connected to the Distribution Network via dedicated circuits. The dedicated circuits provide permanent connections in high and guaranteed speeds. However, the high cost of hire of these connections renders prohibitory their use in wide scale and thus their use is limited in selected administrative and school units with justified high requirements in connection speeds.

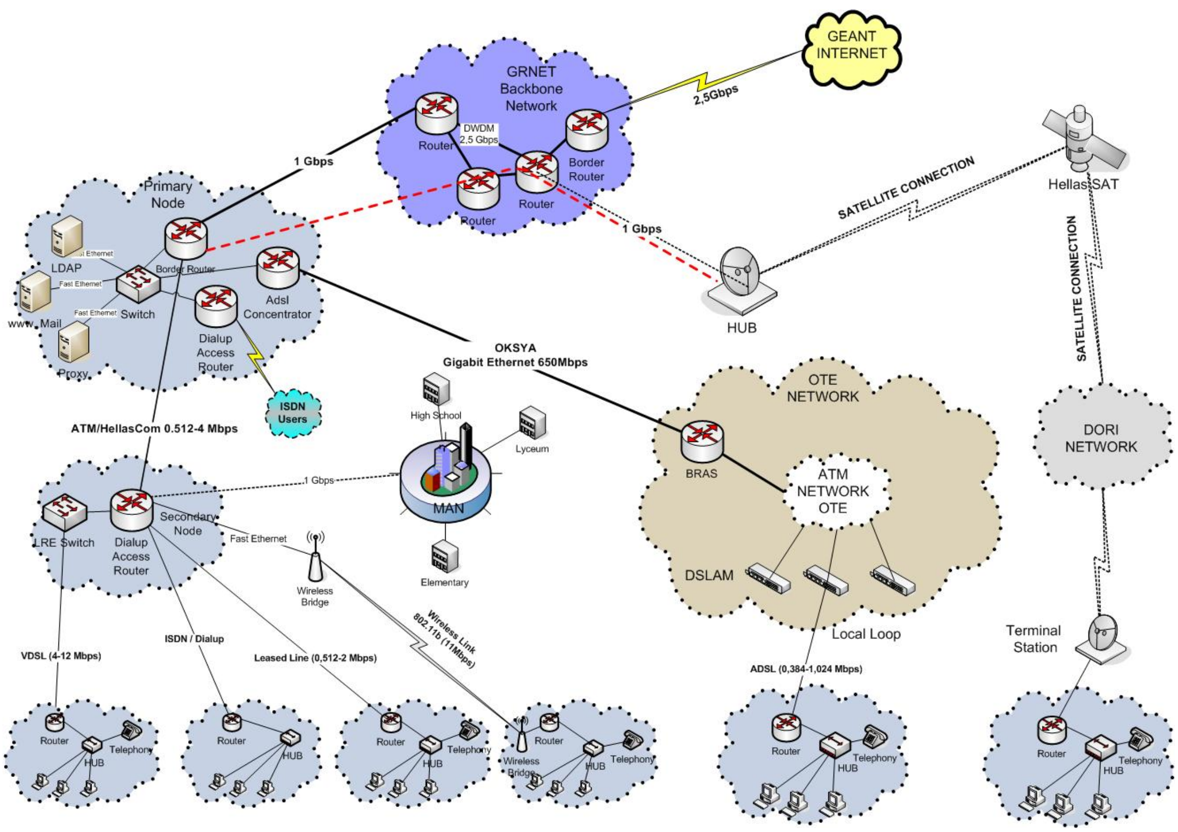


Figure 4: Access Network

3. Drivers for migration to IPv6

3.1. Shortage of IPv4 addresses

The GSN interconnects thousand of end sites in Greece, as mentioned in previous sections. In each end site few tens of networking devices are connected. For example, a typical school has at least a router (gateway), an application server and 10 or more PCs for the pupil-labs or the administration personnel. Due to the shortage of IPv4 addresses, end sites are delegated few public IPv4 addresses, usually one for the router and one for the application server. The rest of the networking systems are using private address space.

The deployment of IPv6 in GSN allows the allocation of adequate address block to each end site. Each system connected to the network will eventually acquire a public IPv6 address, in addition to a private IPv4 address. The addition of more systems with public IPv6 addresses to the network will be practically unlimited. The addition of more systems with IPv4 private addresses is also possible but the complexity and the operational cost for new services will significant be increased, as discussed in the following sections. Nowadays initiatives, such as the provision of a laptop for each pupil in the class, prerequisite an IPv6 ready infrastructure.

The allocation of public IPv6 addresses in each networking system is not per se a significant improvement for the community that uses the GSN. The end users will not notice any performance or other improvement while accessing "old-fashion" services, e.g. web browsing. As IETF RFCs proposes, the end systems will prefer to use the IPv6 addresses than the IPv4 addresses, whenever possible. Obsolete services will continue to be accessed via IPv4, especially when the *server* is not IPv6-capable or there is no IPv6 path between the *client* and the *server*.

3.2. Development of new applications

The implications of the NAT gateways –or any other middle-box– introduced in the GSN, are many. With middle-boxes, it is difficult to provide end-to-end connectivity for many applications. Hosts behind the NAT gateway can initiate new connections towards the Internet but host cannot receive incoming connection requests. There is a variety of solutions at the IP layer to mitigate the negative impact and address the technical issues raised, e.g. configure the middle-box to forward incoming requests to a particular port –or list of ports– towards a specific host behind the NAT gateway. Such solutions increase the complexity of the network – consequently, operational costs are also increased–, reduce the availability of services –as it is more difficult to deploy and troubleshoot– and they impose technical limitations, e.g. only one host behind the NAT can receive incoming requests from a particular port. Alternatively, the lack of end-to-end connectivity can be handled at the application layer requiring applications to establish connections to specific servers prior be able to receive incoming requests, e.g. as VoIP (skype, Gtalk) clients does. This approach, even if it is successful, significantly increases the cost of development of the applications. In addition, it requires special purpose servers to be operational in order hosts behind middle-boxes to be able to communicate to each other. This requirement leads to reduced availability of services but also allows a Network/Service Provider to easily "control" access to specific services by blocking networking access to special purpose servers.

In the past, the majority of applications followed the client-server communication model, e.g. a user accessed a service using a thin client such an Internet browser. The useful content was concentrated in a small number of servers, which the rest of the host could access over the network. Today, a variety of new applications, such as Voice over IP and peer-to-peer file sharing, create new challenges to the network. Each host can now be a potential producer or consumer of content, which makes impossible to predict the characteristics of established connections in the network.

The GSN has planed –provided that funding is granted– the deployment of new advanced services to its users. A –non complete– list of new applications to be developed in GSN is the following:

- Sharing multi-media content via peer-to-peer applications
- Blogs, personalised web sites, discussion forums, etc
- Virtual collaboration environment based on web technologies
- VoIP (mainly for administration personnel)
- Digital educational TV - Multicasting

The deployment of IPv6 and the provisioning of public addresses to all networking devices will enable the network to support the new services.

3.1. Reduce Operational Costs

Enabling IPv6 protocols to the GSN imposes some new operational costs, mainly due to the effort that NOC personnel have to put on learning the peculiarities IPv6 protocols. The network engineers, first of all, have to add IPv6-related configuration to all routers and address IPv6-related technical cases due to improper implementation of routers software. As the basic networking principles remain the same for IPv4 and IPv6 (routing) protocols, the overhead for the network engineers is rather marginal to built-up the new configuration and troubleshoot any problems. In addition, the quality of routers software for basic networking IPv6 interconnection services has matured the last few years and, consequently, does not have major flaws. The system administrators, secondly, do not have significant problems while enabling IPv6 services at their systems. The vast majority of operating systems natively support IPv6 protocols and most of the applications –especially the open-source software used in GSN– support IPv6 as a standard feature. The administrators have, however, to search their system, for obsolete software, especially when the IP address is processed at the application layer. On the contrary, the security engineers have to put significant effort to protect the network and systems form IPv6-based attacks. Even if many threats experienced in the IPv4-only networks have been addresses during the design phase of IPv6 protocols, new threats for the network and the services may emerge due to improper protocol design, inadequate implementations or human miss-configurations.

Even if enabling IPv6 protocols to the GSN imposes today some extra operational costs, it will eventually –by the time PC labs are fully interconnected via IPv6– reduce the total operational costs. The large address space and some unique features of IPv6 significantly simplify the operation of the large networking and system infrastructure of the GSN. In what follows, some examples of how this can be achieved are presented:

- Stateless/stateful auto-configuration simplifies the deployment of large amount of PCs in the labs as there is no need to allocate human resources to set basic configuration. A hardware upgrade of 1000 school labs, for example, requires setting up tens of thousands of PCs. Today, the local administrator in each school has to manually set the basic configuration, e.g. IP address of the gateway and DNS server, using the instructions of the central NOC.

- Provided that all PCs acquire public IPv6 address, the software upgrade process can be handled centrally using automating tools. Today, technical staff has to visit each school in order to do the software upgrades, whenever necessary. The current process, apart from being costly, takes quite a lot of time to be completed. In some cases, long delays may affect the whole infrastructure, especially when security patches have to be quickly deployed.
- Stateless auto-configuration also simplifies the logistic process in delivering edge routers in the network. Nowadays, when a router has to be replaced –either due to a functional problem or during hardware-upgrade cycles–, another router has to be configured on site. Using IPv6 auto-configuration techniques, the new routers can have a basic configuration, automatically be connected to the network via IPv6 and, then, be configured centrally by the NOC. Consequently, the necessity for technical personnel on site is significant reduced.
- Administration of routing policies is simplified as address fragmentations in no more an issue in IPv6. This makes routing configuration less complex and less vulnerable to human miss-configuration.
- Effort for administrating NAT gateways is reduced and service provision is in school labs is simplified.

In the future, the GSN might also take advantage of extensions IPv6 protocols that improve the autonomicity of networking systems, e.g. the ability of systems to self-organise based on the environment they are attached to. These improvements are beyond the scope of this document thus are not further discussed.

3.2. Security Management

In each GSN end site, a single security policy is applied to all the hosts behind the NAT gateway, especially when the policies are applied centrally. For example, all the HTTP traffic towards the Internet is filtered by a central proxy server at the GSN interconnection PoP. Consequently, the security policies are the same for the PCs at the school labs as well the hosts at the administration units.

The large available IPv6 address space allows the administrators to assign public addresses to hosts according to the policy to be applied. This allows hosts to be distinguished based on the LAN they are connected to. The PC-labs, therefore, can be easily protected from inappropriate web sites and viruses while the hosts in administrative units may only be protected from viruses.

3.3. Improve Educational Process

A main objective of the GSN is the improvement of the educational process. The deployment of advanced peer-to-peer and virtual collaborative-environment applications allows students to easily cooperate with each over the Internet, overcoming location and time limitations. It is critical that students get familiar with advance technologies and develop as many capabilities as possible on how to process huge amount of available information/data and take advantage of diverse services.

The deployment of IPv6 services is also envisaged to stimulate innovation; an IPv6-enabled infrastructure within the Greek schools provides students with an environment in which they can use the new protocols, get familiar with it, and experiments with advanced applications supported. As IPv6 exhibits new features –such as enhanced security, multicast or mobility-, it allows the students to address community problems using new technologies. In addition to this, a portion of today students will eventually become the future engineers that will further extend the networking technologies.

4. Deployments Phases

Deployment of IPv6 services in the GSN is being realised in four phases lasting more than 5 years, in total. As the GSN is a large infrastructure -in terms of number of end-sites and number of network nodes-, the deployment had to be realised in accordance to the available funding schemas, governmental programmes and bureaucratic procedures. This required proper planning by the GSN administration personnel in order to avoid long delays and unnecessary expenses. In the following paragraphs we describe how IPv6 deployment took place the last few years starting from early trials until large scale deployments of access routers.

4.1. Phase 1: Design studies & Preparation

This phase included the IPv6 address acquisition from the local registry and the preparatory testing of IPv6 protocols in an xDSL environment. It also included a partial upgrade of the networking infrastructure in order network engineers to get familiar with IPv6 routing protocols and security mechanisms.

This phase lasted approximately 2 years, from 2004 until 2005.

4.1.1. Acquire Address Space

The GSN has not officially entitled as an Internet Service Provider (ISP), even if interconnects thousands of end sites geographically distributed around Greece. Consequently, the GSN could not apply RIPE for a /32 address space without becoming an ISP.

GRNET, the Local Internet Registry (LIR) for Greek universities and research institutions, allocated to GSN a /47 and /48 IPv6 address prefix from the sTLA `2001:648::/32`. This address block (2001:648:2300::/47, 2001:648:2302::/48), even if it is adequate for the middle-term needs of the GSN, it may need to be extended in the future, especially if each student is allocated a group of /64 prefixes (for supporting dial-in services)[5].

4.1.2. IPv6 Trials in xDLS environment

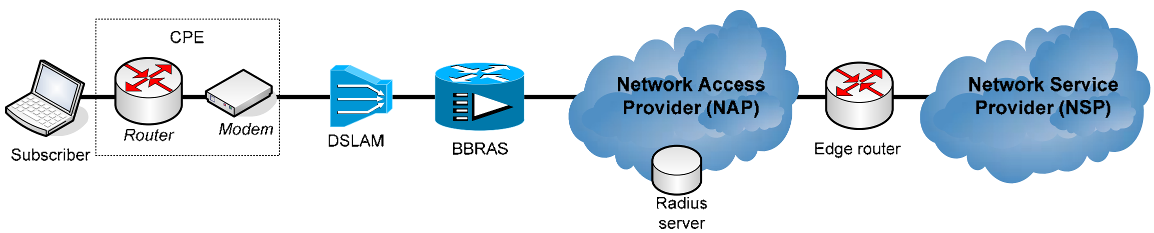
The trials on IPv6 technology in xDSL environment started back in 2004. At that point of time, the vast majority of the school networks were connected via PSTN/ISDN lines, allowing maximum interconnection speed of 128Kbps per school. The GSN Technical Committee (TC)

[5] According to current RIPE-421 policy document, a LIR can request an address block larger than /32 provided that adequate justification is given. Therefore, GRNET may request address space larger than currently allocated /32 and then allocate an -up to- /32 address block to GSN.

concluded that xDSL would become the prevailing broadband technology in Greece and IPv6 technology was chosen as the suitable protocol to be used at the new infrastructure.

4.1.2.1 Interconnection Scenario

A typical xDSL environment, as shown in the following figure, is composed of the following entities; the *Subscriber*, the *Network Access Provider (NAP)* and the *Network Service Provider (NSP)*. The Subscriber installs in his/her premises a *Customer Premises Equipment (CPE),* which is a small xDSL router or modem. It is usually controlled by the *Subscriber* but it could also be the responsibility of the *NSP*. The *NAP* is responsible for the management of the copper local-loop infrastructure, the operation of *DSL Access Multiplexer (DSLAM)* and the operation of the *Broad Band Remote Access Concentrator (BBRAS)*. The *NSP* is responsible for providing interconnection with the Internet and often offers other added-value services. The NAP network in the xDSL environment is usually based on the ATM technology. The link layer of the xDSL subscriber's connections is ATM and traffic is encapsulated into ATM cells. The *DSLAM* performs the (de)modulation of the customer signal and aggregates multiple customers' traffic over an ATM link. The *BBRAS* terminates the Subscribers' ATM connections and forwards the subscribers' traffic to the edge router of the *NSP* via high capacity links.

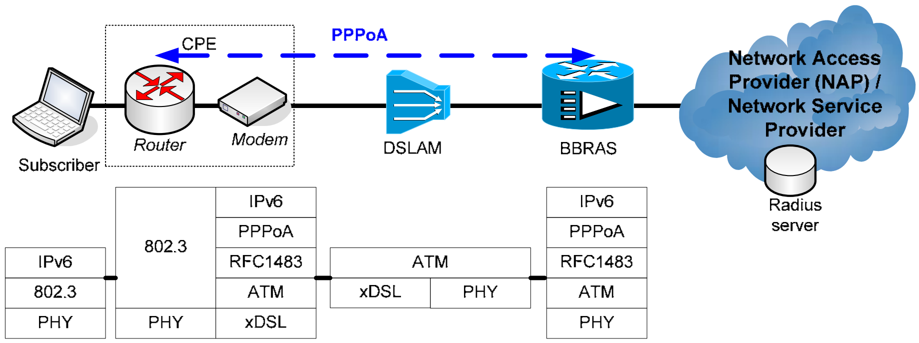


The GSN Network Operation Centre (NOC) is responsible for the administration of the subscriber edge routers (CPE) in each school as well the local school server. The administration of the school PCs is delegated to the local personnel in each school. The GSN has also the role of the NSP and, thus, the NOC is responsible for the operation of the core/distribution network as well the core application servers. The local PTT (OTE) has the role of the NAP over its national wide (copper-based access) network

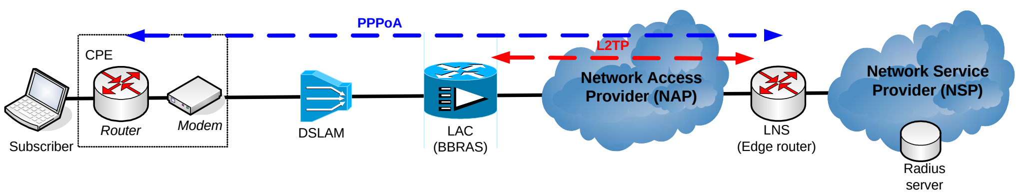
The deployment of IPv6 interconnections services over xDSL circuits can be realised by enabling different technologies, such as:

- Ethernet bridging over ATM
- PPP over AAL5 (PPPoA)
- PPP over Ethernet (PPPoE)

In GSN, the PPPoA [RFC2364] is used for the vast majority of the interconnected schools. The CPE supports IPv6/4 packet forwarding and interconnects multiple systems in the schools local network. A single PPPoA session is established over a ATM PVC allowing the CPE router to establish two PPP sessions; one for IPv6 and one for IPv4 traffic. Addresses can be assigned automatically over the PPP session using attributes stored in a centralised radius server. Also, the CPE may be authenticated using one of the multiple protocols, such as PAP, CHAP, MS-CHAP, EAP, etc.



As the NAP (OTE) and the NSP (GSN) are different, the PPP sessions do not terminate at the BBRAS but at the edge router, as shown in the next figure. The BBRAS and the edge router are called *L2TP Access Concentrator (LAC)* and *L2TP Network Server (LNS)*, respectively. As before, two PPP sessions are established from the CPE router, which terminate at the LNS. Address assignment and authentications methods are performed in the same way as previously but now the radius server is managed by the NSP. This model is applied in GSN as it does not mandate IPv6 support at the BBRAS, which is operated by the NAP.



4.1.3. Upgrade Core network and enable *IPv6 routing*

The GSN core and distribution networks had to support both IPv4 and IPv6 protocols (dual stack).

MP-BGP was selected for exchanging IPv6 routing prefixes among GSN and the GRNET border routers. Routers maintain separate routing tables for IPv4 and IPv6 traffic and, thus, no impact at the IPv4 interconnection services was noticed while enabling IPv6. OSPFv3 is selected as the interior gateway protocol for distributing the IPv6 addresses of the backbone links. The reason for selecting OSPFv3 instead of IS-IS is due to increased granularity and functionality of redistribution and route injection capabilities of OSPv3, and much wider availability of OSPFv3 on smaller routers. OSPFv2 was used for exchanging IPv4 connectivity information, which allowed gradual deployment of OSPFv3 (IPv6) without affecting IPv4 connectivity.

It should be noted that the hardware of the core routers in the main GSN PoPs had to be upgraded in order to support IPv6 protocols and services. This had been planned quite a long time before transition to IPv6 was attempted in the core. Therefore, by the end of the 2005, the majority of the core routers could support IPv6 protocols, i.e. had adequate CPU power and memory. On the contrary, the distribution (ISDN dial-in) routers were never planned to be upgraded as the ISDN access technology was inadequate to fulfil future needs of the GSN.

4.1.4. Upgrade basic networking services

As IPv6 addresses are 128-bit long, they are much harder to remember than IPv4 counterparts. Therefore, *Domain Name Service (DNS)* is much more useful in an IPv6 environment than in IPv4 environments. Enabling IPv6 functionality in DNS has two aspects; to allow the exchange of DNS information and to transport DNS queries over IPv6. In GSN, BIND version 9.3.1 was (initially) used for adding AAAA records to forward zone files and PTR records to reverse zone *ip6.arpa* files. Transport over IPv6 was also activated for the exchange of DNS information. It should be noted that, prior a new AAAA entry was added in the DNS forward zone files for a specific server, all the hosted services were upgraded to support IPv6. This prevented delays during end-user requests or even breaks in access. For a limited period of time, forward zone A and AAAA entries were different.

The electronic mailing service, initially based on the Qmail version 1.03, was upgraded using an available patch. The SMTP daemon was able to handle both IPv4 and IPv6 connections. In addition, IMAP and POP3 access over IPv6 was granted using the courier *imap* server. After that, the IPv6 enabled clients, such as Mozilla mail client, were able to sent mails over IPv6, as shown in Figure 5[6].

```
Received: (qmail 6353 invoked by uid 207); 27 May 2005 10:17:23 -0000
Received: …
Received: from unknown (HELO sch.gr) (2001:0648:0000:a351:0203:baff:fe45:129d)
  by 2001:0648:0000:a301:0a00:20ff:feb5:5652 with SMTP; 27 May 2005 10:16:36 -0000
Message-ID: <4296F385.6090408@sch.gr>
Date: Fri, 27 May 2005 13:16:37 +0300
From: ipv6 <ipv6@sch.gr>
User-Agent: Mozilla/5.0 (X11; U; SunOS sun4u; en-US; rv:1.4) Gecko/20040414
X-Accept-Language: en-us, en
MIME-Version: 1.0
To:  ipv6@sch.gr
…
```

Figure 5: Delivery of electronic messages over IPv6-enable SMTP server.

The GSN Web portal offers multiple services and informative material. The software platform used for the implementation of the portal is based on the Jakarta Project. The Apache HTTP daemon is used combined with Jboss application servers, which handle incoming requests (Figure 6).

[6] Email services over IPv6 were provided only to a limited number of users.

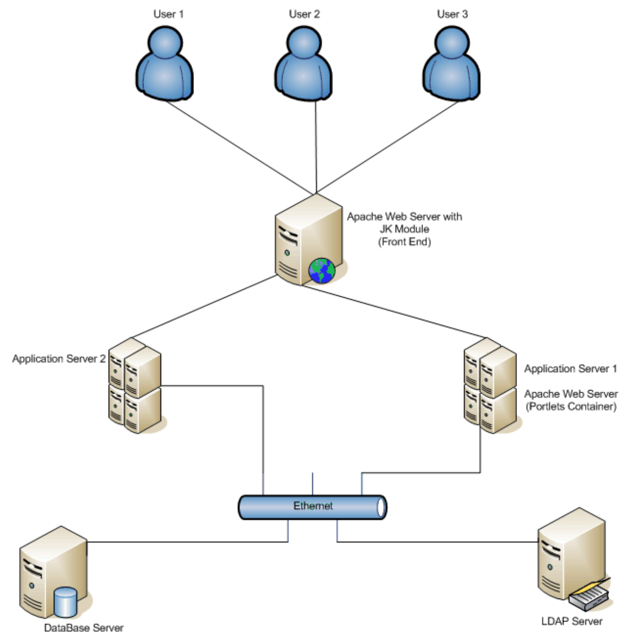


Figure 6: Architecture of the web portal

The GSN used the Sun One i-planet directory server version 5.2 that supported IPv6. The directory services were the central back-end attribute repository for every user and service associated with him/her. Therefore, it was a very crucial service as it stored all the authentication and authorisation information for the end users.

GSN supported transparent content filtering to all http port 80 requests originating from schools. This is accomplished using the squid web proxy cache using a specific –at that point of time- patch. It should be noted that IPv6 support for squid web proxy is now provided in the squid3 branch of the squid project (http://www.squid-cache.org/).

4.1.5. Specify procurement specifications

The procurement process of GSN is complex and time consuming due to the large number and the geographical distribution of end sites. Public procurement legislation also imposes bureaucratic obstacles while a large amount of national funding is necessary for replacing obsolete –in terms of technology or performance- edge routers.

Even if at the end of 2005 the PSTN/ISDN was the prevailing access technology of the school networks, the procurement technical specifications for edge routers included:

- Support of IPv6 switching, routing and security functionality
- Support of logical (virtual) LANs
- Adequate switching performance and memory

The necessity for the first set of specifications is obvious. The edge routers had to be able to switch IPv6 packets, support routing protocols and implement (basic) access lists. The second requirement was necessary as the IPv6 address assignment per school could now allow the provision of public IPv6 addresses to more than one internal networks. This allowed the separation of school-lab networks from other purpose networks. Finally, the increased performance of the edge routers was also considered critical as the interconnection circuits would gradually increase from 56kbps (PSTN) to couple Mbps (xDSL). Increased memory capabilities were necessary as software images supporting IPv6 functionality were larger in size compared to IPv4 only images.

4.2. Phase 2: Pilot - Limited size network

This phase included limited size trials on access and core network. The NOC personnel acquired operational experience and defined detailed specifications for the hardware and software upgrades.

This phase lasted from 2006 until 2007.

4.2.1. Addressing schema

According to RIPE-421 policy document, there is no specific policy for an organisation (LIR) to allocate address space to subordinate ISPs. Each LIR organisation may develop its own policy for subordinate ISPs to encourage optimum utilisation of the total address block allocated to the LIR. As noted previously, the GSN is not entitled as ISP but it is considered a special case of GRNET end-user.

Each individual school laboratory could be considered as a Small Office and Home Office (SOHO), usually assigned a /48 or /56 address space. In special cases, aka only one subnet is anticipated, the end site may be assigned the minimum /64 address space. The assignment of a /56 address space, aka 256 LAN per school, was considered excessive for the today needs of a typical school network. Therefore, only a /61 address space, aka 8 LAN per school, is initially assigned.

GRNET LIR assigned the 2001:648:2300::/47 and 2001:648:2302::/48 address space for the addressing needs of GSN. The GSN has collapsed its IPv6 peering with GRNET in two (2) major points of presence in Greece (Athens and Thessaloniki). The assigned address space is divided in smaller address blocks, as follows:

Prefix	Description	Router	No of available /61 Subnets
2001:648:2300::/48	Access Network	Athens	8.192
2001:648:2301::/48	Access Network	Thessaloniki	8.192
2001:648:2302::/49	RESERVED BLOCK A	Athens	4.096
2001:648:2302:8000::/50	RESERVED BLOCK B	Thessaloniki	2.048
2001:648:2302:C000::/51	RESERVED BLOCK B	Thessaloniki	1.024
2001:648:2302:E000::/52	RESERVED BLOCK B	Thessaloniki	512
2001:648:2302:F000::/53	RESERVED BLOCK B	Thessaloniki	256
2001:648:2302:F800::/54	RESERVED BLOCK B	Thessaloniki	128
2001:648:2302:FC00::/55	Backbone Network	Athens	64
2001:648:2302:FE00::/55	Backbone Network	Thessaloniki	64

It should be noted that the addressing schema undergo multiple revisions in the last years. In the future, the addressing schema will need to be revised again because a larger address space might be allocated to GSN (ref to previous sections).

4.2.1. Limited size trials

The GSN limited size trials allowed the deployment of IPv6 interconnection service to a limited number of schools, initially around 50 in one area in Greece. The main objective of the limited size trials was to acquire operational experience by addressing operational challenges in the production network and verifying that the supporting infrastructure -management tools, radius database, etc- was ready to support IPv6 services. The small size trials allowed also improving the specifications for the long-term hardware (and software) procurements.

Trials allowed the verification of multiple CPE configuration templates based on different interconnection models. Assessing the -additional to IPv4- operational cost of the IPv6 infrastructure was also important. Auto-configuration techniques were tested such as dynamic address assignment to internal school LANs using DHCP prefix delegation under the support of a radius database[7].

The trials were extended to more than 500 schools in areas all over Greece. The IPv6 interconnection service was terminated at CPE for the vast majority of the cases. The PC labs still lacked IPv6-enabled OS while the administration of the labs was delegated to the technical personnel in each school[8].

4.2.1.1 CPE configuration

As discussed in previous sections, a typical GSN access router supports a local area network and terminates an xDSL access circuit. An IPv6 address may be automatically assigned to the xDSL WAN interface and each PC inside a school lab by using stateless auto-configuration and DHCP prefix delegation (DHCP-PD)[9].

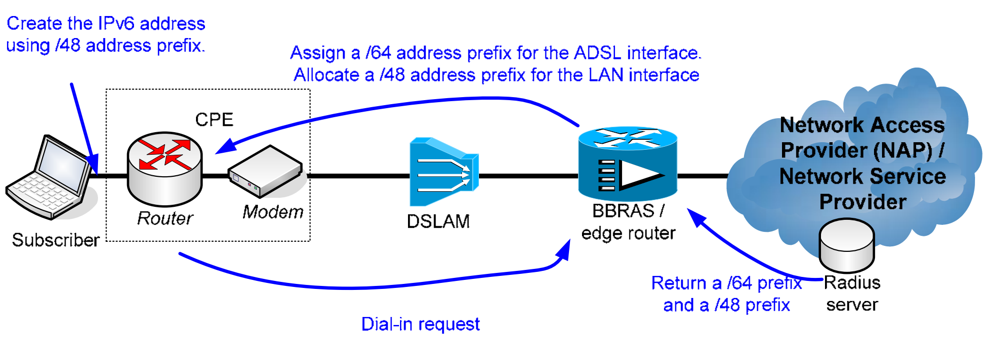


Figure 7: Address allocation procedure using DHCP-PD

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[7] Appendix includes an IPv6 configuration template for a typical CPE router.
[8] Until 2006, the administration of the school labs was responsibility of the GSN. This allowed better control over the provision of new services to the labs at the expense of increased complexity and cost.
[9] The WAN interface and the LAN interface of a CPE may be manually configured, especially when the CPE lacks DHCP-PD functionality.

Address assignment is performed in two steps, as shown in Figure 7. The router requests an address for the xDSL interface by presenting statically configured credentials, i.e. a username and password. In the next step, the router requests for a prefix to be assigned for the local network by exploiting DHCP-PD. When the address assignment is completed, the LNS router installs automatically a static route pointing to the schools xDSL access interface. The above IPv6 prefix assignment method allows permanent IPv6 address prefixes to be assigned to school edge routers and local PC-based LANs.

Remote access of school routers is managed exclusively by radius protocol. The radius server used in GSN is based on the open-source free-radius server. This radius server does not support any data exchange over IPv6 but only over IPv4. However, the software supports IPv6 aware attributes, such as *ipv6 prefix*, *ipv6 route*, *ipv6 acl* as vendor specific attributes.

Every router is represented as a radius user with the necessary network information. Dialup admin (http://sourceforge.net/projects/dialup-admin/) has been extended to support new attributes necessary for stateless auto configuration, i.e. Framed-id and DHCP-PD route prefix. An example of user attributes stored in the radius server is shown in Figure 8.

```
"user1"
Auth-Type = Local, Password = "foo"
User-Service-Type = Framed-User,
Framed-Protocol = PPP,
cisco-avpair = ipv6:prefix#1=2001:648:4567:1234::/64"

"user1-dhcpv6"
Auth-Type = Local, Password = "foo"
User-Service-Type = Framed-User,
Framed-Protocol = PPP,
cisco-avpair = "ipv6:prefix#1=2001:db8:aaaa::/48"
```

Figure 8: Radius configuration

4.3. Phase 3: IPv6 & Broadband access

This deployment phase includes major upgrades in the core and access infrastructure in order to support of IPv6 interconnection services in a large portion of GSN. It also includes studies on how to enhance management and security of security

This phase started in 2007 and will be completed by the end of 2008.

4.3.1. Deployment Strategy for Core Network

The core network is the first part of the GSN infrastructure fully upgraded to support IPv6. Gradual hardware and software upgrades of the core routers made possible to provide IPv6 interconnection services among major PoP. Internal routing based on OSPFv3 was fully activated and IPv6 BGP peering sessions established with GRNET, operating as an upstream provider. Apart from this, operational procedures were adapted to address troubleshooting of IPv6 protocols and technical personnel underwent training of the new protocols.

4.3.2. Deployment Strategy for Access Network

When the GSN was designed, the end-sites (schools) were connected with distribution nodes via PSTN/ISDN lines. This allowed schools to have narrowband interconnection to the Internet, aka could exchange electronic mails and browse web sites. Even today, a large percentage of schools are still connected with ISDN circuits, especially in places where the broadband circuits is difficult to be provided, e.g. in isolated villages. GSN Technical Committee decided to avoid deploying IPv6 services to the distribution nodes that aggregate dialup connections from (obsolete) ISDN access routers. This would require hardware upgrades, e.g. memory and CPUs, in order to support IPv6 protocols. However, the provision IPv6 services over narrowband circuits would not improve the level of service to the community.

GSN decided to shift interconnection model from narrowband (PSTN/ISDN) circuits to broadband (xDSL, Wireless, Satelite, WiMAX, Metro Etherent) circuits. The GSN revised the hardware and functional specifications for new networking equipment. IPv6 specifications were extended and become compulsory for networking suppliers for forthcoming procurement tenders. This procurement policy allowed more than 50% of the edge routers to be IPv6-ready by first semester of 2008 without any explicit cost.

4.3.3. Deployment Strategy for Servers

Even if the IPv6 services had been successfully tested in the lab or in pilot trials, the deployment of production-level services imposes different challenges. The most important challenge is to avoid degradation of already provided services over IPv4.

The GSN initially upgraded all the core servers in order to become dual stack. This required software upgrades and, in few cases, hardware upgrades (in order to support latest versions of software with increased requirements).

The commission of IPv6 services in the network was done in phases, each of which a different group of services was supported. At the end, the following services became available:

- Email (SMTP, IMAP, POP3)
- Web hosting
- GSN Web portal (www.sch.gr)
- Web proxy / web filtering
- AAA (Radius software and attributes)
- Instant Messaging
- Directory service (LDAP)
- DNS Service
- Dual stack data-centres

In the past, the GSN was responsible for the administration of the PC labs in each end site. Today, the administration of these systems is delegated to local personnel. The lack of central control (and possible coordination) imposes extra challenges in the deployment of new software or services, especially when the PCs are connected behind NAT gateways. In order to address this, the GSN initiated pilot tests targeting to minimise the management overhead using remote administration tools over IPv6. A limited number of schools already have commercial remote management software over IPv4 but also open source remote management tools are under evaluation over IPv6.

4.4. Phase 4: Advanced Applications

This GSN upgrade phase focuses on "services". It is planned to start in mid 2009 and be completed by the end of 2011. This phase is realised in the context of the Greek programme National Strategic Reference Framework, relevant to the EU's funding programmes that apply for the 2007-2013 budgetary period.

This phase will include large-scale PC-lab upgrades with the commissioning of thousands IPv6-ready PCs at schools. Today, PC labs are based on (obsolete) operating systems, such as Microsoft Windows 2000 without any official support of IPv6. The number of Linux-based – and, thus, IPv6-ready– PC labs is currently small. The hardware/software upgrade of GSN PCs is a great challenge to be address during this phase as the number of under deployment systems exceeds a hundred of thousands while the end sites exceeds ~15 thousands. It should be noted that IPv6 deployment of PC labs has been delayed in order to be combined with the lifecycle of the hardware/software. This approach minimises the total cost for the IPv6 upgrades.

New applications and services -such as peer-to-peer content sharing software and collaborative environment applications- are to be developed and integrated to the educational process. The number of nodes attached to the GSN is envisaged that will sharply be increased. Laptops or PDAs per student will be connected using wireless access technologies. In addition, the number of VoIP terminals (using public IPv6 addresses) will also increased making possible to support all the need of the administration units. Efficient building management (using sensors) and surveillance systems will also be supported by the networking infrastructure.

The GSN upgrade plan is still not officially included in the National Strategic Reference Framework. Therefore, at this point of time it is unknown which and at which extend the GSN upgrade plans will be granted.

5. Experiences

The deployment of IPv6 in the GSN proved to be a positive and valuable experience. This deployment is often referenced as a standard case study for deploying IPv6 in educational environments. Within Greece, the project stimulated other IPv6 efforts that involved public and private sectors.

5.1. Maturity of Technology

IPv6 technology proved to be mature in the GSN projects. IPv6 services were deployed in the core and distribution networks without degrading the already deployed production IPv4 services.

In most cases, the increase of the operational costs after enabling IPv6 services was marginal.

5.2. Migration Costs

The migration costs to support IPv6 services was minimised as the IPv6 deployment process was correlated with the equipment upgrade cycles. For the GSN, where the number of end sites is multiple thousands, the upgrade cycles of edge routers lasts for couple of years. The IPv6-related technical specifications were added in the procurements tenders couple of years prior the large-scale IPv6 deployment is started.

Large amount of effort was saved by postponing the IPv6 deployment process until obsolete equipment was replaced. For example, the ISDN dial-in routers are not planned to be upgraded but will be removed by the time all the end-sited become connected via broadband connections. This approach reduces the cost for providing and maintaining workaround solutions and saves resources for other activities.

5.3. Risks

The GSN is a large infrastructure composed by thousands of routers, servers and PC labs. Consequently, the hardware and software upgrade as well the deployment and operational costs are large. In addition, the upgrade cycles may last for years, especially if the number of upgraded systems is distributed at the end sites. Under this prism, it is crucial to deploy IPv6 services taking into consideration of long-term funding programmes and upgrade cycles planed. If not, the cost of deploying IPv6 services may be sharply increased or the overall period to deploy a service may be extended to years. In addition,

As the GSN infrastructure is extended over thousands of sites, the administration of the infrastructure is performed centrally by the NOC. If a service is not designed or commissioned correctly, it may create a security breach, which cannot be easily identified from the on-site administration personnel. As IPv6 is a new technology, the level of support expected from the on-site personnel is considered minimal. Therefore, the commissioning of new services has to be realised in carefully designed steps and complementary training is necessary for the on-site personnel.

6. Conclusions

The deployment of IPv6 technology in the Greek School Network (GSN) is a long-term process that started almost 5 years ago. At this point of time, most of the networking infrastructure is IPv6-ready and efforts are concentrated to the upgrades of the end-systems (PC labs) and the development of new applications.

The deployment of IPv6 services, e.g. IPv6 interconnection services, was smooth and did not cause any degradation to IPv4 services. This reveals that the IPv6 technology is mature enough for production-level networks, such as the GSN.

7. Appendix: CPE configuration example

The following template is a typical example of CPE configuration for Cisco 876, which is a CPE extensively used in the GSN. The configuration aims to minimise the management overhead of the CPE and, thus, takes advantage of IPv6 protocol features such as DHCP-PD. The final configuration per school is automatically generated using data stored in the central configuration database of GSN.

```
no service pad
service timestamps debug datetime localtime
service timestamps log datetime localtime
service password-encryption
!
hostname $SCH_ROUTER_DNS
!
boot-start-marker
boot-end-marker
!
logging buffered 16384 debugging
enable secret 5 xxx
!

username netmgr privilege 15 password 7 xxxx

clock timezone EET 2
clock summer-time EET recurring last Sun Mar 2:00 last Sun Oct 3:00
no aaa new-model
ip subnet-zero
ip cef
!
!
no ip dhcp conflict logging
ip dhcp excluded-address $SCH_PRIV $SCH_PRIV_PLUS127
!
ip dhcp pool lan
network $SCH_PRIV 255.255.255.0
domain-name $SCH_DOMAIN
default-router $SCH_PRIV_PLUS1
netbios-node-type b-node
dns-server $SCH_PRIV_PLUS_TEN 194.63.239.164 194.63.237.4 194.63.238.4
lease 30
!
!
ip domain name $SCH_DOMAIN
ip name-server x.x.x.x
…

ipv6 unicast-routing
ip multicast-routing

isdn switch-type basic-net3
!
```

```
!
class-map match-all voip
description Match traffic from VoIP device IP and is marked with DSCP=46
…
!
!
policy-map schqos_out
…

!
!
interface Loopback0
description Router-id
ip address $SCH_LOOPBACK 255.255.255.255
!
interface BRI0
description WAN_ISDN_BRI_Interface 128 kbps
no ip address
no ip redirects
ip route-cache flow
carrier-delay 1
dialer pool-member 1
dialer idle-timeout 180
isdn switch-type basic-net3
isdn point-to-point-setup
no fair-queue
no cdp enable
!
interface ATM0
no shut
description DSL - WAN
mtu 1492
bandwidth 256
no ip address
no ip redirects
no ip unreachables
no ip proxy-arp
ip nat outside
ip virtual-reassembly
backup interface BRI0
ip route-cache flow
no ip mroute-cache
logging event subif-link-status
no atm ilmi-keepalive
pvc 8/35
vbr-nrt 256 256
encapsulation aal5mux ppp dialer
dialer pool-member 1
max-reserved-bandwidth 95
service-policy out schqos_out
!
dsl operating-mode auto
!
…

!
interface Vlan1
description School_LAN 10 Mbps
```

```
ip address $SCH_PRIV_PLUS1 255.255.255.0
ip access-group 110 in
no ip unreachables
no ip proxy-arp
ip pim sparse-dense-mode
ip nat inside
ip virtual-reassembly
service-policy input schqos_in
ip route-cache flow
ip tcp adjust-mss 1452
ip igmp helper-address udl Dialer1
ipv6 address schpfx ::/64 eui-64
ipv6 enable
ipv6 traffic-filter LAN6 in
hold-queue 100 out
!
interface Dialer1
description Connection to Edunet over aDSL
ip unnumbered Loopback0
ip access-group only_schoolips out
ip mtu 1492
ip pim sparse-dense-mode
ip nat outside
ip virtual-reassembly
encapsulation ppp
ip igmp unidirectional-link
dialer pool 1
dialer-group 1
ipv6 address autoconfig default
ipv6 enable
ipv6 mtu 1480
ipv6 nd ra-interval 180
ipv6 nd ra-lifetime 3600
ipv6 dhcp client pd schpfx
fair-queue
no cdp enable
ppp authentication chap callin
ppp chap hostname $SCH_ROUTER_DNS@sch.gr
ppp chap password 7 xxx
ppp pap refuse
!
ip classless
ip route 0.0.0.0 0.0.0.0 Dialer1
!
!
…
ip nat pool reg_ips $SCH_NATSPACE_PLUS2 $SCH_NATSPACE_PLUS2 netmask x.x.x.x
…
!
ip access-list extended only_schoolips
permit tcp $SCH_NATSPACE x.x.x.x x.x.x.x x.x.x.x eq xxx
…
!
access-list xxx deny ip $SCH_PRIV x.x.x.x any dialer-list 1 protocol ip
permit
```

```
…
snmp-server community xxx RO
snmp-server enable traps tty
!
route-map natmap permit 10
match ip address 102
!
!
ipv6 access-list LAN6
deny xxx any any eq xxx
…
!
control-plane
!
banner motd ^CEduNet Version ADSL-20080331, Cisco 876 (P105)^C
!
…
!
scheduler max-task-time 5000
scheduler interval 500
ntp server 194.63.239.238
end
```