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Layer 2 Quality of Service Architectures

Christos Bouras[1,2], Vaggelis Kapoulas[1], Vassilis Papapanagiotou[1,2],
Leonidas Poulopoulos[2,3], Dimitris Primpas[1,2] and Kostas Stamos[1,2]
[1]Research Academic Computer Technology Institute, Greece
[2]Computer Engineering and Informatics Dept., University of Patras, Greece
[3]Greek Research and Academic Network - GRNET, Greece

1. Introduction

Quality of Service (QoS) provisioning has become indispensable in today's networks. Most existing QoS solutions are deployed in Layer 3 (network layer). In order to provide end-to-end QoS guarantees in these networks, the need for Layer 2 QoS deployment as well as the cooperation between any existing Layer 3 QoS deployment must be studied. QoS provisioning in Layer 2 is very important to networks that are primarily based on Layer 2 infrastructure as it is the only way to provide QoS on the network. Furthermore, networks based on both Layer 2 and Layer 3 network devices could benefit from a more integrated approach in end-to-end QoS provisioning that includes both Layer 2 and Layer 3.

In today's broadband networks, congestion does not necessarily occur at the edge of the network (the link interconnecting the subscriber to the network core): congestion is equally likely to occur at the edge and in the core of the network. A common congestion cause of in broadband networks is the capacity mismatch in different parts of the network core. This calls for protection measures at the network perimeter and unified or interoperable QoS schema across all network (both layer 2 and layer 3).

Moreover, Layer 2 QoS is lightweight, easily implemented and independent of Layer 3. Because of its independency, it can also be applied to non-IP networks where any QoS provisioning was impossible or very difficult. In this chapter, we examine the cooperation between Layer 2 and Layer 3 QoS in IP networks. When discussing Layer 2 devices and procedures in this chapter, we are specifically referring to Ethernet technology switches, which have become the dominating Layer 2 technology during the past years and have largely substituted older technologies at the same layer, such as ATM and Frame Relay.

Layer 2 Ethernet switches rely on 802.1p standard to provide QoS. The standard 802.1p is part of the IEEE 802.1Q (IEEE, 2005) which defines the architecture of virtual bridged LANs (VLANs). This architecture uses tagged frames inserted in Ethernet frames after the source address field. One of the tag fields, the Tag Control Information, is used by 802.1p in order to differentiate between the classes of service. More specifically, the 3 most significant bits of the Tag Control Information field known as Priority Code Point (PCP) are used to define frame priority. Taking advantage of PCP, QoS in Layer 2 can be applied.

Layer 2 QoS experiments with Ethernet switches have been conducted and described in (Ubik & Vojtech, 2003). In (Ubik & Vojtech, 2003) 4 Layer 2 QoS experiments are conducted

and effects on link throughput and packet loss are shown. Other researchers such as (Liotopoulos & Guizani, 2002) have dealt with Layer 2 QoS in ATM networks. An interesting application of L2 Ethernet QoS has been studied in the field of avionics networks with the demand for low latency and jitter in (Wernicke, 2006) and (Jacobs et al., 2004), while 802.1p has been studied as an approach for the improvement of traffic performance originating from collaborative systems applications in (Perez et al., 2006).

In the next sections of this chapter, we discuss the issue of Layer 2 QoS deployment, and in particular we present in detail:

- The cooperation of Layer 2 QoS with possibly pre-existing Layer 3 QoS architectures in MAN broadband networks.
- The architecture for Layer 2 QoS deployments, with analysis of the authors' experience at GRNET as a case study.
- The status of Layer 2 QoS support in various vendors' equipment according to our experience.

2. Integration of Layer 2 and Layer 3 architectures

Quality of Service support was initially enabled on routing devices using the available fields in the IP header. Therefore, a comprehensive architecture has to take this into account and be able to accommodate the addition of more devices, which do not route packets, in the overall QoS architecture. For example, Layer 2 Ethernet switches rely on 802.1p standard to provide QoS. An example of a network where the need for integrated Layer 2 and Layer 3 QoS provisioning has been investigated is the Greek Research Network (GRNET, 2009a), which is described in detail in the next section of this chapter.

In general, the integration of Layer 2 and Layer 3 QoS architectures can take several forms, depending on the purpose for which the switching and/or routing devices are used (access, core), their functionality (since several devices have capabilities that tend to blur the L2/L3 distinction, for example switches that can inspect the IP header), the policies of the network domain and other factors. A basic distinction of the most common choices is provided below:

- Layer 2 devices at the edge (access) of the network and routing devices (possibly using MPLS) in the core: A very common case, this scenario is studied in detail in the next sections of this chapter, as it largely describes the structure of GRNET.
- A combination of Layer 2 and Layer 3 across the network, with switching devices comprising L2 MANs: Sometimes it is convenient to build "islands" where traffic is simply switched and not routed. This approach is usually accompanied with extensive VLAN usage for traffic management purposes. Part of the GRNET network has been built with this philosophy, and its practical implications are described in the relative section of the chapter.
- Switched-based network, with Layer 3 devices at the periphery: A growing tendency in high speed modern networks has been towards connectivity at lower layers, bypassing expensive routing functions. In this case, L2 QoS takes center stage in the planning of a QoS architecture.

In all cases, a proper QoS architecture has to include the basic steps of classification, policing, marking and scheduling. The design of the network and the specific mix of devices

and requirements will determine whether both Layer 2 and Layer 3 devices perform all of these functions, or whether these functions are distributed.

A network that serves several clients at its periphery will generally have to consider the traffic sources untrustworthy, in terms of proper packet classification and marking. Therefore, the edge devices of the network will have to take up this role. Classification typically requires packet inspection and is therefore more suited for higher-layer devices, although several switching devices do support some form of inspection of encapsulated higher layer headers. If that is not the case, then traffic might have to be classified when it first traverses suitable equipment. This means that incoming traffic might not be subjected to prioritized treatment immediately upon arriving at the borders of the network.

3. Layer 2 QoS case studies

GRNET is the Greek National Research and Education Network (NREN) (GRNET, 2009a). GRNET is a mixed IP- and Ethernet-based network, operating at Gigabit speeds. Together with the high-speed LANs of its subscribers (universities and research institutes) and the European academic and research backbone, GEANT, GRNET forms a set of hierarchically-federated networks.

However, because part of its backbone consists of switch based MANs, this architecture had to be extended in order to encompass Layer 2 (Ethernet) devices, which should appropriately implement QoS policies and QoS signaling/metering as well.

The GRNET backbone consists of network nodes in 8 major Greek cities, namely, Athens (2 PoPs), Thessaloniki, Patras, Ioannina, Xanthi, Heraklion, Larisa and Syros as shown in Fig. 1, a screenshot from the GRNET's GoogleMaps Topology Visualization (GRNET, 2009b).

The WAN network is built on DWDM links with 2.5Gbps capacity (STM-16 lambdas). The access interfaces of the routers are using Gigabit Ethernet technology and connect the 130 subscribers of GRNET which consist of universities, technological educational institutes, research institutes, two content providers (the Greek National Television and the Greek Parliament) and the school network. During the last few months the major Greek Universities upgraded their connection speed to GRNET from 1-Gbps to 10-Gbps. In addition to the WAN, GRNET also has 2 distinct MAN networks. The Athens MAN is router-based (Fig. 2), whereas the Crete MAN is switch-based (Fig. 3), with a router in the main aggregation site (Heraklio).

The Greek Research and Academic Network (GRNET, 2009a) has deployed for several years a Layer 3 QoS service based upon the features provided by the MPLS technology deployed in the core of the GRNET network, and DiffServ architecture. This architecture allows the support of multiple classes of service. The focus is on three separate classes of service, namely IP Premium for absolute performance guarantees, best effort for the usual treatment of traffic packets and Less than Best Effort (LBE) for non-critical traffic that can be dropped first in case of congestion. IP Premium service is a circuit-like subscriber-to-subscriber service, where both subscriber end-networks and the necessary bandwidth allocation are known at request time. IP Premium service is provided using a provisioning tool called ANStool (Varvitsiotis et al., 2005; GRNET, 2009c). LBE is provided unprovisioned, which means that each subscriber decides on its own and uses this service simply by marking the packets appropriately. In order to provide the QoS service, the Layer 3 network equipment (routers) has to perform traffic marking, classification, policing and shaping. Per-flow

functions are performed at the edge routers of GRNET network, while core routers only perform per-traffic class functions, based on the MPLS Exp field.

Fig. 1. GRNET's Layer 3 Country Network Topology

The above service design has several implications for traffic between two GRNET clients (such as institutions, universities or other research organizations). It means that traffic coming out of GRNET network ("output" for GRNET edge routers) has been subjected to the specified QoS mechanisms. However, traffic coming into the GRNET network ("input" for GRNET edge routers) receives no treatment up to the point of reaching the edge Layer 3 device (router) of the GRNET network.
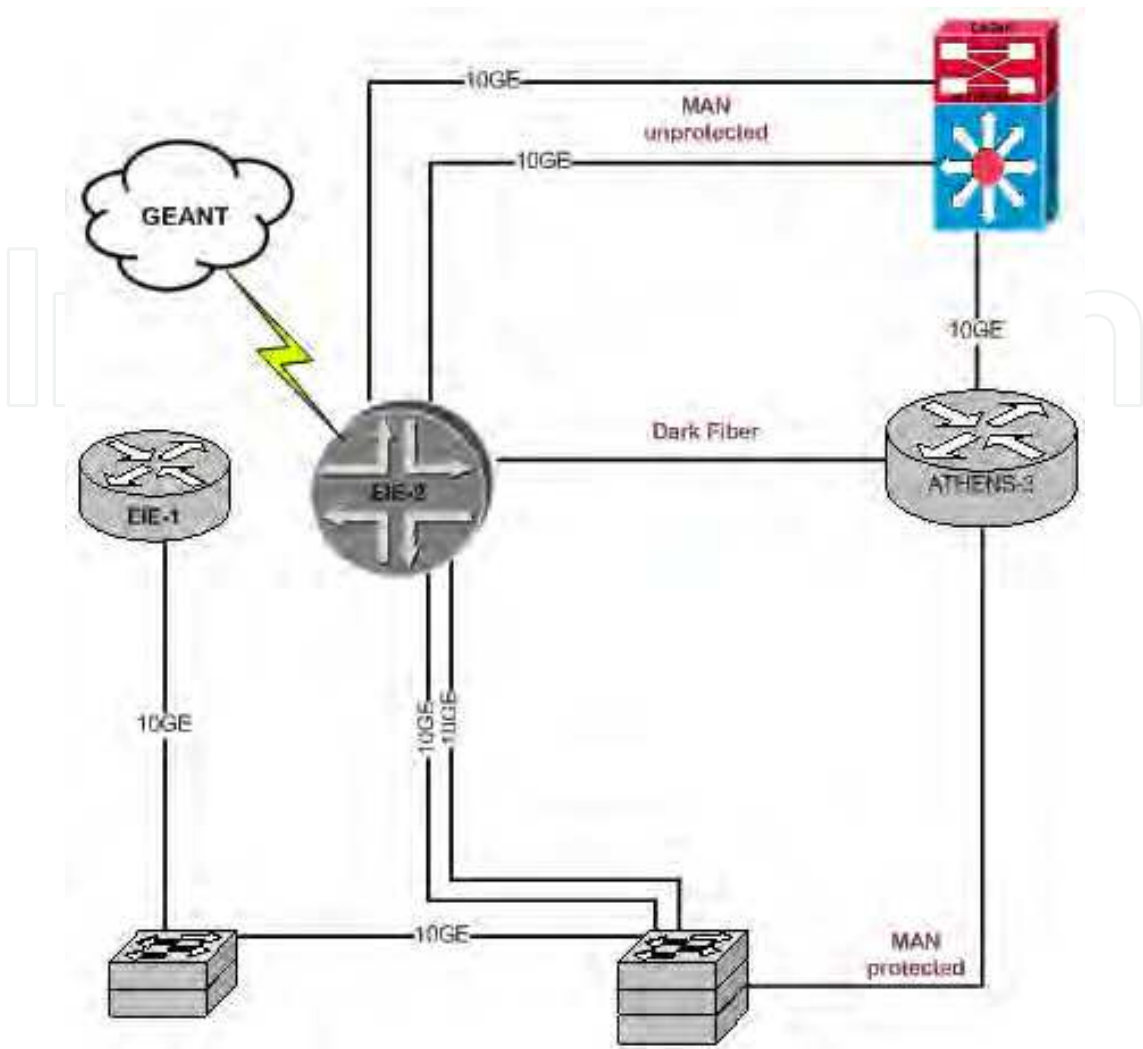
Fig. 2. Athens' MAN

In the most common case (except Crete's MAN), traffic between the GRNET client and the GRNET edge router will go through one or more Layer 2 devices (Ethernet switches). For the simple case where only one Layer2 device is located between GRNET and the subscriber, we use scripting to query the speed and bandwidth settings at each L-2 border interface. We then reflect the speed setting of the border interface into a traffic shaping queue for the respective VLAN at the L-3 border. Using this technique, we make sure that the congestion points occur only at the L-3 border.

With the advent of hybrid networks and the tendency to carry high speed network traffic at the lowest layer possible (in order to avoid handling it with costly Layer 3 equipment), this part of current and future network is bound to expand. Whether this Layer 2 part of the network forms multiple paths between the connected Layer 3 devices (in which case the need for spanning tree algorithms arises in the common Ethernet case) determines in large part the complexity of the Layer 2 QoS solution that will have to be adopted.

Therefore, in designing and implementing the service described in this chapter, we took into account the current need for controlling traffic behavior at the edge of the GRNET network (where it slips from current Layer 3 QoS model) and we also considered the increasing importance of that part of the network to the overall network architecture in the future.
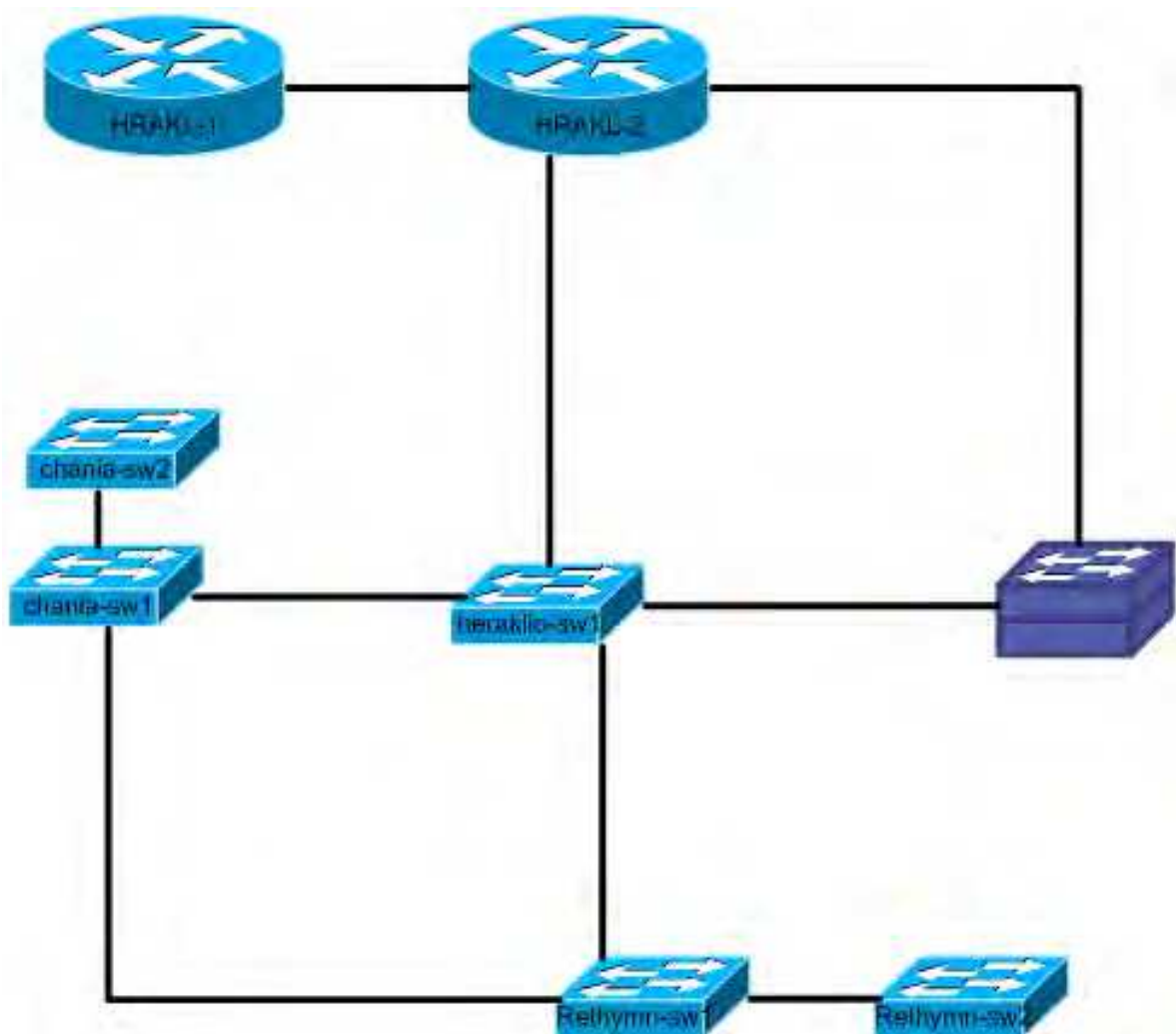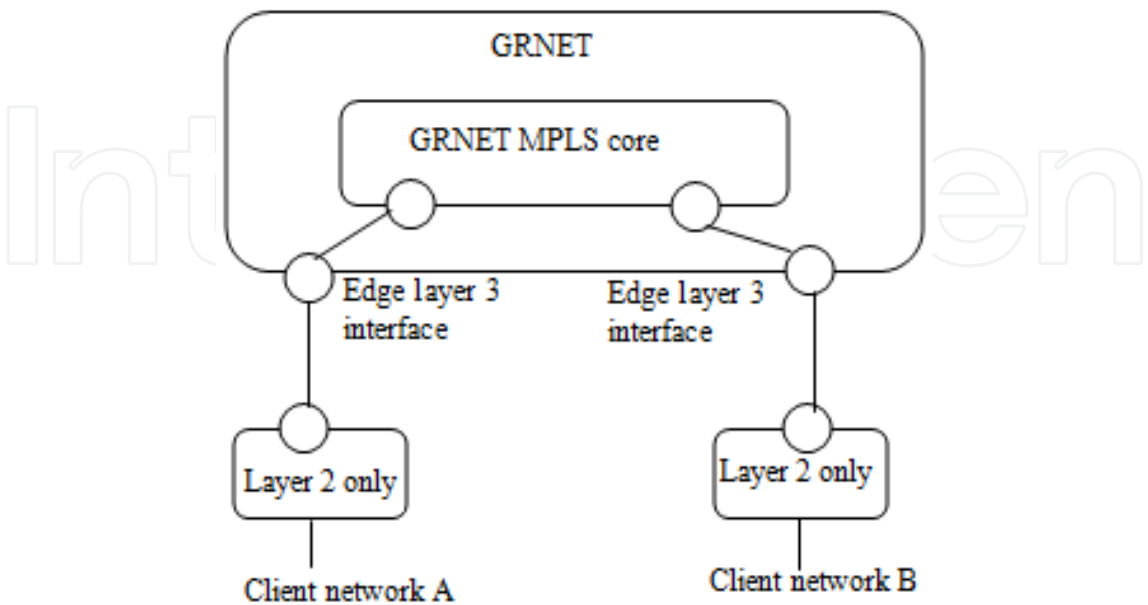
Fig. 3. L2 Crete's MAN

Fig. 4. Schematic of GRNET core/edge/L2-only edge network parts

3.1 Implementation Issues

IEEE 802.1Q (also known as VLAN tagging) defines a 3-bit field called Class of Service (CoS), which can be used in order to differentiate traffic. Table 1 shows the 8 possible values of the CoS field and their original purpose.

CoS	Acronym	Purpose
0	BE	Best effort
1	BK	Background
2	-	Spare
3	EE	Excellent Effort
4	CL	Controlled Load
5	VI	"Video" < 100 ms latency and jitter
6	VO	"Voice" < 10 ms latency and jitter
7	NC	Network control

Table 1. CoS field values

For the purposes of our deployment, we have adopted the usage of CoS value 5 for marking premium traffic (which requires quality of service), CoS 0 for best-effort traffic and CoS 1 for less than best effort traffic. Traffic is marked as less than best effort when it is of minor importance, and is allowed to occupy at most 1% of the total bandwidth. The usage of CoS value 5, indicates that the default DSCP-to-CoS mapping scheme is followed, bearing in mind that in GRNET IP Premium is marked with DSCP 46 as denoted in (Varvitsiotis et al., 2005).

In the case of the GRNET (GRNET, 2009a) network, end to end traffic between client network interconnected through GRNET will traverse a combination of Layer 2 (switches) and Layer 3 devices (routers). To this end, the policies of the edge routers of the GRNET network must be adapted so that ethernet frames belonging to premium traffic are marked with CoS 5 at the output. Additionally, the port of the subscriber's switch which is connected on the edge router has to be configured in order to trust the values of CoS of the received traffic streams. Because CoS is part of the standard 802.1Q (IEEE, 2005), the port on which the edge router is connected must be in trunk mode. When a port is in trunk mode it uses the tagged frames of 802.1Q (IEEE, 2005) to communicate, which contain CoS and other information about virtual bridged local area networks (VLANs).
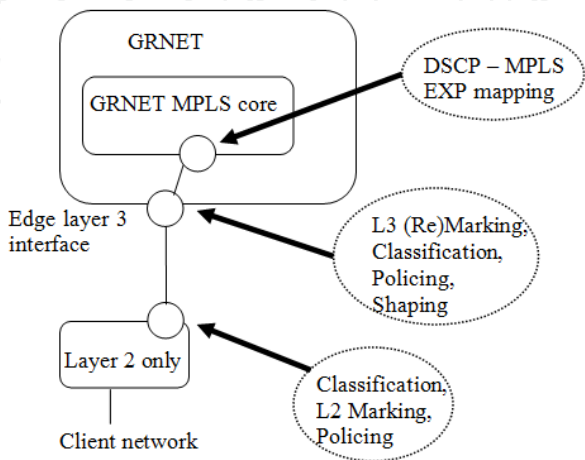

Fig. 5. Schematic of L3 and L2 QoS actions

The procedure of deploying Layer 2 Quality of Service is quite similar to the one of Layer 3 QoS. Classification procedure is applied in incoming packets along with policing functions. Next, if traffic is in profile it is marked accordingly, else the packet is marked down or dropped. Next, the packets enter the switch's queues according to their markings.

Queue management and scheduling are the most important issues in configuring Layer 2 Quality of Service. L2 Ethernet switches support a number of ingress and egress queues (switches in our testbed support 2 ingress queues and 4 egress queues). Scheduling in our equipment (Cisco Systems devices) is performed using the Shaped Round Robin (SRR) algorithm. The ingress queues can only be shared whereas the egress queues can also be shaped. When queues are shared their bandwidth is guaranteed to configured weights but is not limited to it. When a queue is empty, the other queues in shared mode share its unused bandwidth. When a queue is shaped it is guaranteed a percentage of bandwidth but it is rate limited to that amount. By default, from the ingress queues the second one is used to handle high priority traffic, and from the egress queues the first one is the high priority queue and it cannot be changed. Additionally, the high priority egress queue is by default shaped to occupy 1/25 of total bandwidth, and when a queue is shaped any sharing settings are overridden. When the expedited output queue is enabled (as in our experiments, using the command priority queue-out), the expedited queue is serviced first until it is empty and then the other queues are serviced in a round-robin manner. More information can be found in (Cisco, 2009). In the GRNET network the edge routers shape the traffic on the output, so there is no need to shape the queues on the switches, however in our experiments, we use policies to limit the bandwidth when needed. Additionally, in the GRNET network the switch trusts the CoS of the packets coming from a GRNET edge router. By contrast, in our experiments traffic was classified by the switch and the DSCP field (46 for premium traffic, 0 for best-effort) was set, as in testing equipment policies that set CoS are not supported.

In order to verify the proper configuration and operation of the Layer 2 QoS service, extensive experimentation was performed in both laboratory and production environments (Bouras et al., 2008). The conducted experiments acknowledged and proved that the activation of L2 QoS does benefit the overall result that was previously produced by only L3 QoS in GRNET's network.

An additional step is the enhancement of the GRNET QoS provisioning tool (GRNET, 2009c) with the necessary functionality and features in order to manage the L2 QoS service as well. In this direction, a module was developed and integrated into GRNET's QoS provisioning tool. This service is unprovisioned and does not require any type of interaction of GRNET's customers with the Layer 2 module. Of course, for the proper operation of the end-to-end QoS provisioning, GRNET's clients must submit a Layer 3 request in the first place.

The Layer 2 module of the QoS provisioning tool provides the network administrator with the appropriate vendor-specific configuration, which in turn is applied to the network switches. A view of the switches' list is presented in Fig. 6.

When a switch is selected, the administrator must activate QoS at the switch by selecting "Standard CPE QoS configuration" as shown in Fig. 7, an option that provides the appropriate configuration. Finally, the requested interfaces are selected. Once the Layer 3 configuration is applied to router and the Layer 2 configuration is applied to the switch, the customer is given end-to-end QoS.

ihu-asw.grnet.gr	Extreme	Extreme 450
iibeaa-asw.grnet.gr	Extreme	Extreme 450
ilsp-asw.grnet.gr	Extreme	Extreme 450
ionio-asw.grnet.gr	Cisco	catalyst37xxStack
iptil-asw.grnet.gr	Cisco	catalyst37xxStack
kape-asw.grnet.gr	Extreme	Extreme 450
maich-asw.grnet.gr	Cisco	catalyst3512XL
noa-asw.grnet.gr	Cisco	catalyst37xxStack
ntua-asw.grnet.gr	Extreme	Extreme 450
oipp-asw.grnet.gr	Extreme	Extreme 450
panteion-asw.grnet.gr	Cisco	catalyst3512XL
pasteur-asw.grnet.gr	Extreme	Extreme 450
selete-asw.grnet.gr	Extreme	Extreme 450
teiath-asw.grnet.gr	Cisco	catalyst297024TS

Fig. 6. View of network switches

L2 QoS configuration

Standard CPE QoS Configuration

teilar-asw.grnet.gr

Uplink interface(s)

GigabitEthernet0/25 - *** Uplink to grnet ***

Access interfaces

GigabitEthernet0/24 - *** tei-lar ***

Fig. 7. Switch QoS configuration options

The interoperability between Layer 3 QoS and Layer 2 QoS takes actual place at the border router and in particular, at the interface which is connected to the Layer 2 device. As the majority of GRNET's switches are multilayer (mls), meaning that it is possible to classify based either on DSCP or CoS, there are two options concerning the marking of packets or frames performed by the border router at the egress:

- CoS marking: For each packet with a given DSCP value, mark the frame with the corresponding CoS value as indicated in Table 2.
- DSCP marking: For each packet with a given DSCP value keep this value intact.

Regarding the switch, at the ingres of its interfaces, the DSCP and CoS values of the packets and frames received respectively are trusted as marked by the router. At this point it should be mentioned that the majority of vendors, by default, disable the trusting of DSCP and CoS values at the ingress interfaces of Layer 2 devices. In order to achieve integration between Layer 3 and Layer 2 for QoS, trusting of DSCP and/or CoS values should be enabled. Thus internal DSCP-to-CoS mapping at the switch is avoided. However, this should be performed in combination to very strict policies so as to avoid abuse of the QoS service.

GRNET's switches provides the flexibility to classify incoming traffic based either on DSCP or CoS. CoS classification is preferred as it can provide backwards compatibility with some no-mls capable switches.

DSCP	CoS	Description
46,47,40	5	IP Premium
0	0	Best Effort
8	1	Less than Best Effort

Table 2. DSCP-to-CoS mapping

3.2 Multiple L2 paths in Crete's MAN

An exception to the more common structure of the GRNET network described above is the part of the GRNET network at the island of Crete, which forms the Crete's MAN. It consists exclusively of L2 Ethernet switches which are aggregated to the only L3 device, a router at the city of Heraklio connected to the rest of GRNET (Fig. 3). Some of the L2 interfaces are therefore considered part of the GRNET core network (the ones which form the MAN itself), while the rest connect to client networks, similarly to the common case discussed in previous sections. Therefore, for the latter case, the existing L2 approach can be still utilized. The core L2 devices form a ring consisting of 3 Ethernet switches (Cisco 3750), with several client networks connected on each one of them. Traffic between the client networks in Crete and towards the rest of the GRNET network is carried in VLANs in order to form isolated VPNs. A related limitation of the current Cisco L2 equipment is that it does not support QoS classification of traffic on VLAN ports, but only on physical ports.

Each VLAN has its own spanning tree which directs the traffic accordingly, and which can be quickly adjusted using Rapid Spanning Tree Protocol (RSTP) for link failure recovery and load balancing. In the case of a link failure, VLAN traffic using the failed link will be redirected due to the corresponding spanning tree protocol switching a blocking link's state to forwarding. This means that assuming the worst case scenario, a core L2 link will have to be able to carry the whole of the traffic traversing the core of Crete's L2 MAN. Under such an assumption, the worst-case dimensioning algorithm will have to allow premium traffic reservations up to the specified allocated percentage for the whole of the L2 MAN

(conversely this can be expressed as the requirement that the allocated percentage should be calculated by adding all allowed traffic reservations through the MAN). The premium allocated percentage can follow the guidelines set by L3 allocations for L3 links of similar bandwidth. The symmetry of Crete' MAN regarding link capacity simplifies this calculation. The worst case assumption has also been the selected approach for premium reservations at the L3 part of the network, and is therefore a natural extension for this case.

4. Status of Layer 2 QoS support

Many vendors have presented Layer 2 devices (switches) with increased capabilities, which are able to inspect Ethernet frames and support CoS or DSCP based differentiation. In this chapter we discuss the approaches chosen by each of the main switching equipment vendors where we have enabled Layer 2 QoS capabilities.

Cisco is possibly the most important vendor of network equipment and, as discussed above, GRNET has traditionally based its network infrastructure largely on Cisco equipment and in particular Cisco Catalyst switches. L2 QoS has been extensively tested on Catalyst 2970 and Catalyst 3750 series that comprise a large part of GRNET's access network and some parts of its core MAN networks as described above (Bouras et al., 2008).

GRNET includes many switches from Extreme Networks, and namely SummitX450 and SummitX350 type switches, which also support L2 QoS (Extreme Networks, 2008). In particular, Policy-based Quality of Service (QoS) is implemented in ExtremeXOS, the operating system used by Extreme Networks switches, and it allows the user to specify different service levels for traffic traversing the switch. The hardware implementation varies depending on the platform, for example some Extreme Networks BlackDiamond series switches contain separate hardware queues on every physical port, while other switches such as the Summit series contain two default queues and several more configurable queues on a switch-wide level. When two or more queues are contending for transmission on the same physical port, the switch makes sure to prioritize usage of the port with regard to the respective queue management parameters. Extreme Networks consider Layer 2 QoS to be applicable in a number of traffic requirements, and provide specific guidelines for applications such as voice, video, critical databases, web browsing and file server applications. Configuration is based on the concept of QoS profiles, which encompass a list of parameters (depending on the specific hardware implementation, this list generally varies between different families of products), such as the maximum amount of packet buffer memory available and the relative weight assigned, or the maximum bandwidth that can be transmitted, the minimum bandwidth reserved and the level of priority.

L2 QoS support by Extreme Networks switches has been extensively tested by GRNET in both laboratory and production environments. The GRNET network is in a position to successfully integrate Extreme Networks switches in a production network comprised of devices from multiple vendors and has verified their interoperability.

Moreover, during the last few months there have been conducted a series of tests concerning the interoperability between Layer 2 and Layer 3 devices. The majority of GRNET's Layer 3 devices is CISCO GSR (12xxx) Series Routers (IOS), while there has been a Juniper T1600 (JunOS 9.4) in production for the last 6 months. Juniper seemed to be much more flexible and granular than Cisco concerning QoS provisioning and setup (Juniper Networks, 2009).

There have been tests with all the combination of equipment showing that GRNET is capable of providing end-to-end QoS regardless of vendor.

5. Conclusions

In this chapter we have provided a wide overview of the existing solutions and deployments for QoS provisioning at Layer 2, with an emphasis on Ethernet-based deployments, which is the dominant Layer 2 technology. We have discussed the integration of existing Layer 3 QoS deployments with the introduction of Layer 2 devices (switches) with relevant capabilities, the implementation issues from a case study implemented in Greece at the GRNET network, and we have presented the current status of Layer 2 QoS support for various equipment vendors.

Our future work includes extensive interoperability testing, including Layer 2 QoS solutions by Cisco, Extreme Networks, Juniper Networks and more vendors such as Nortel. Such interoperability testing has to include all combinations of vendor equipment and Layer 2 – Layer 3 interactions. Furthermore, large scale testing and results from production availability of the services are going to be conducted and analyzed for further service refinement.

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Trends in Telecommunications Technologies

Edited by Christos J Bouras

The main focus of the book is the advances in telecommunications modeling, policy, and technology. In particular, several chapters of the book deal with low-level network layers and present issues in optical communication technology and optical networks, including the deployment of optical hardware devices and the design of optical network architecture. Wireless networking is also covered, with a focus on WiFi and WiMAX technologies. The book also contains chapters that deal with transport issues, and namely protocols and policies for efficient and guaranteed transmission characteristics while transferring demanding data applications such as video. Finally, the book includes chapters that focus on the delivery of applications through common telecommunication channels such as the earth atmosphere. This book is useful for researchers working in the telecommunications field, in order to read a compact gathering of some of the latest efforts in related areas. It is also useful for educators that wish to get an up-to-date glimpse of telecommunications research and present it in an easily understandable and concise way. It is finally suitable for the engineers and other interested people that would benefit from an overview of ideas, experiments, algorithms and techniques that are presented throughout the book.

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