Dynamic End-to-End QoS Provisioning and Service Composition over Heterogeneous Networks

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Abstract

This paper presents an approach that aims to provide Quality of Services (QoS) over heterogeneous Internet domains. The goal is to install and to manage QoS inside each domain and to ensure it on the end to end data path. QoS is a key requirement representing a significant infrastructure upgrade for future networks. Our proposal relies on the multi-service, multi-technology model based on Bandwidth Broker, entity in charge of controlling a given domain. It introduces a concept able to provide QoS in a set of domains using an inter domain signaling protocol as well as dynamic provisioning schemes that optimize resource usage. The approach is independent of the intra-domain routing protocol. Moreover it is independent of the underlying technology and imposes minimal constraints leaving a maximum degree of freedom for users and domains providers to implement specific internal solutions. The efficiency of the solution is shown through extensive simulations.

Keywords: *QoS, CAC algorithm, adaptive provisioning, resource optimization*

1. Introduction

The progress of new technologies during past years contributed to a development of new types of various applications. These applications, simultaneously multimedia and/or multi users, cover a large spectrum such as IP telephony, video on demand, streaming, tele-engineering, interactive games, peer to peer. Such applications need a special handling for their packets in order to work properly, thus they require new services other than those supported by the actual Internet. At the same time, current (and future) networks are deeply heterogeneous: from IP wired networks, to WI-FI, satellite, and UMTS. Moreover, each domain (that we assimilate later on to Autonomous System - AS) has independent policies in terms of services, security, admission control etc. As a result, the problem of end to end QoS must be addressed. QoS is targeted to support new applications and mechanisms. Therefore, QoS allows the deployment of richer services, potentially chargeable per user, thus it is a source of revenue, both for operators and for service providers. This analysis leads us to answer the next challenge: how to offer and control in the network the QoS required by applications (especially multimedia and real-time ones), taking into account the strong heterogeneity of the multi domain context Internet.

The convergence of services over the same IP infrastructure and the growth of the number of users lead the Internet community to research on standards and prototypes in order to implement these new technologies.

Actually, all packets receive the same treatment in network devices, without any differentiation. The need to offer new services demands a reconsideration of actual Internet packet treatment:

- new functionalities are needed in network devices (routers) in order to support service differentiation;
- new provisioning, resource management and admission control mechanisms are required on the data path;
- communication and cooperation between network equipments are required; these exchanges represent the signaling necessary to install and manage the quality of service on the data path.

In the following of this section, extending the work presented in [1], we present several proposals that aimed to deal with the QoS at different level on Internet architecture over IP networks.

1.1. Previous work

First IntServ [2]-[4] and then DiffServ [5]-[7] were proposed by the Internet Engineering Task Force (IETF - www.ietf.org) working groups to add QoS to best-effort Internet. Note that several contributions proposed a combined inter functioning architecture taking into account the advantages of each IntServ and DiffServ [8].

IntServ and Diffserv models have been used as a basis for several American and European projects such as QBone (http://qbone.internet2.edu) in USA or AQUILA (http://www-st.inf.tu-dresden.de/aquila), TEQUILA (www.ist-tequila.org), CADENUS (http://wwwcadenus.fokus.fraunhofer.de), MESCAL (www.mescal.org) and more recently EUQOS (www.euqos.eu) in Europe.

None of the above proposals answer to the QoS problem completely. The difficulty comes, on the one hand, from the variety of requirements of applications, and on the other hand, from the Internet structure, nowadays heterogeneous at several levels. By definition multi technology, Internet is now multi domain, each domain (AS) managing independently its resources and its services. Several issues need to be taken into account in this context:

- *provisioning*: the goal of service provisioning is to properly dimension of network resources accordingly to signed contracts (SLA) with different clients (individuals, companies, other providers);
- *admission control*: it aims to accept new traffic in the network without harming previous flows. Controlling the amount of traffic allows avoiding congestions and performance deterioration in the network;
- *signaling*: in a multi-domain Internet, it is imperative to install and manage QoS in each domain. Therefore a signaling across all domains on the data-path is needed.

The contributions which are described in this paper have been mainly performed within the EuQoS project [9], whose main goal was to develop a new QoS architecture over a multi-domain heterogeneous Internet. The key objective of EuQoS was to research, integrate, test and demonstrate end-to-end QoS technologies to support the infrastructure upgrade for advanced QoS-aware applications over multiple, heterogeneous network domains. The EuQoS system has been deployed on a Pan European test bed for the purposes of trial and validation.

More precisely, our contributions aim to offer QoS guarantees by coupling provisioning and admission control in a single signaling protocol. We propose an evolving architecture that decouples the service and the control plane that minimizes constraints for network administrators. We also propose a dynamic user centric provisioning, which allows optimizing the use of the most costly resources still satisfying the QoS demand.

The rest of the paper is organized as follows: the QoS architecture on which our proposition is built as well as related work are presented in Section 2. Section 3 details our dynamic end to end provisioning approach. Section 4 introduces the specifications of the signaling protocol that supports the process. These proposals are evaluated in Section 5 which also addresses scalability issues. Finally, conclusion and future work are given in Section 6.

2. QoS Architecture

2.1. General Considerations

Guaranteeing quality of service requires mastering the vastly distributed and dynamic nature of Internet and defining a new architecture and a set of new mechanisms. Our proposal is based on the following fundamental high level design rules:

- such a complex system cannot be provided without a high level design, i.e. without conceiving the architecture globally and without a strong coherence between all its sub-systems;
- given the geographical distribution and the high heterogeneity of Internet, proposals based on a set of identical solutions for each sub-system cannot work, as it will not possible to efficiently handle all possible underlying (different) technologies;
- as the involved sub-systems can range from simple to very complex, the proposed approach must allow a possible recursive handling of the different networks and technologies;
- starting from the global architecture, only key interfaces or APIs have to be defined, to leave as much freedom as possible to designers and users.

2.2. Definitions

1. *QoS-Domains* (or QoS-AS) is a domain that offers QoS guarantees for the transversal traffic.

2. *Over-provisioned QoS-Domain*. A QoS-domain D is over-provisioned if it is able to transfer any entering communication, via an ingress border router, to another domain by an egress border router, introducing

a modification of its properties that is under a well defined and accepted threshold. Naturally, the domain owns enough resources to satisfy all the incoming requests.

3. *Controlled QoS-Domain*. A QoS-domain is controlled if it is not Over-provisioned although it contains a control function allowing selecting a subset of the entering communications, for which it ensures the modification of their properties to be under a given threshold.

Therefore, a QoS-domain is a domain that is either controlled (C-AS) or over-provisioned (O-AS). In order to guarantee end to end QoS, all domains on the data path must be QoS Domains (either over provisioned or controlled). The sequence of domains followed by data is given by the Border Gateway Protocol (BGP), the "de-facto" inter-domain routing protocol in Internet.

2.3. Bandwidth Broker

The RFC 2638 [10] defines the Bandwidth Broker in the framework of DiffServ as the entity that has the knowledge of a domain's policies and resource availability, and allocates bandwidth with respect of these policies. In order to have a successful end to end reservation across several domains, the Bandwidth Broker managing a domain must communicate with its adjacent peers, which allows configuring the end to end path. This procedure also requires a particular agreement between involved peer domains.

Several concepts of Bandwidth Broker are present in current literature. According to the way they distribute the activity in term of processing, they may be classified as centralized, distributed or hybrid. We adopt the centralized approach in our study. Nevertheless we leave open the possibility to a further evolution of the architecture.

The Bandwidth Broker efficiency depends on the interoperability between all of its subcomponents. Bandwidth Broker functions are distributed both horizontally (among the different QoS domains) and vertically among different layers. Our Bandwidth Broker instantiation functionalities are summarized as follows:

- it acquires topology and routing information;
- it controls end to end network technology independent QoS;
- it implements the suitable signaling in order to support the QoS in all domains on the end to end data path;
- it performs the inter-domain admission control (distributed among all Bandwidth Broker) and local admission control based on resource availability or policies;
- it sets up path and ensures that the requirements will be met by the network when a request is accepted.

2.4. Underlying Network Representation

As stated previously, our proposal aims guaranteeing end to end QoS for communications that cross several heterogeneous domains. We present an approach that attempts to address the provisioning, admission control and signaling problems.

First of all we separate the service plane (set of devices offering application functionalities) from the control plane (equipments in charge of establishment and management of communications) and the inter-domain signaling from the intra-domain one. In this way, the domain administrators can implement any particular solution inside their own domain. Moreover, the reservation system can be triggered independently by an application, proxy, gateway or any other trusted entity and the associated network QoS management is independent from any application layer negotiation (for instance SIP, H323 or other proprietary solution).

Our QoS mechanism relies on the characterization of performances inside a domain between each couple of border routers. For such characterization model, please refer to our previous work [11]. As a result, we consider a high level representation of the physical network (devices and interconnections). This representation is independent from the underlying technology and it is stored in a database handled by the Bandwidth Broker. We reduce the topology of the domain to its border routers and the performances between them. The management of each domain is addressed in a hierarchical manner by using the concept of Bandwidth Broker (presented paragraph 2.3). The goal of our approach is to eliminate from the network topology the internal equipments keeping only the border routers (see Fig. 1).

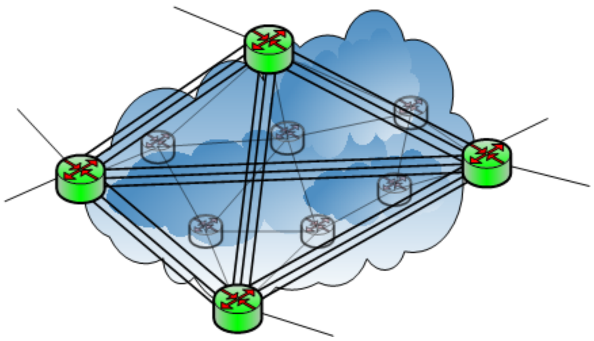

Fig. 1: Topology Representation

For instance, considering the bandwidth available between a couple of border routers, we do not store all values from intermediate routers in the database, but a unique value that is the result of composition of all intermediate values (the minimum bandwidth available from each link). Interested readers may refer to [12] for an optimized algorithm to perform such mapping.

2.5. Admission Control

Resource provisioning is not enough in order to guarantee at any moment the resource availability on the data path. Consequently, the solution is to set up an admission control applied to all new QoS requests. Therefore, admission control is one of the major tasks that a Bandwidth Broker has to perform, in order to decide if a new request is accepted or not. Admission control modules could have various and sophisticated algorithms using several metrics as peak bit rate, latency, network occupation etc.

There are two possible approaches to perform admission control: measure-based and reservation-based. The first one assumes a periodical estimation of resource load and consumption by the new requests. A new flow is accepted if its load does not produce a congestion risk level. The second approach (that we follow in our proposal) assumes a reservation (by flow, class or aggregate) in some devices. A new request is accepted if the resources are available taking into account prior reservations. In order to pass on the requests to next involved devices, a signaling protocol is required.

In our proposal, the second approach is adopted. We divide the admission control process in two steps:

- Step 1: based on the knowledge from the database and from routing information (network topology, resource availability); a high level admission control is performed using the mapping mechanism described in 2.4. We call this processing “pre reservation”. We prompt that the result of the database is reliable and coherent with the physical resource availability.
- Step 2: after having the confirmation of all following domains (using the signaling protocol that propagates the request to the next peer Bandwidth Broker), the pre-reservation is ratified. This procedure ends with the configuration of devices (routers) by the means of protocols such as COPS, SNMP, etc.

Considering the reservation activation, there are two types of request, taking into account the period for which the resources are desired:

- immediate requests: the resource reservation is effective right after the request result;
- advance requests: the reserved resources are to be used in the future, and do not need immediate installation. The classical example of application that uses this type of reservation is the current pre-established audio or video conference.

Our work is mainly centred on the first design, considering a system delivering QoS on demand with instant result. Nevertheless, the signalling protocol that we propose is not affected by one of these approaches. It can be equally used in both cases by introducing advance request functionality in the BB.

2.6. Service Provisioning

To guaranty an end-to-end QoS in the Internet, it is necessary to take into account the heterogeneity of the IP services provided by the domains involved in the data path, by *choosing a concatenation of services* matching the client’s QoS requirements. This choice is part of the *service provisioning* problem, which we address in this paper.

Two points of view are considered to deal with the end to end provisioning:

- in the first one, the problem is approached from a static point of view, where providers offer their clients with end-to-end services having pre-defined static performances; the goal is to establish a compromise between the global capacity of the domain and its external links, and the number of potential clients;
- the second point of view relies on the “on-demand” mechanism using a signaling that dynamically checks and select the end-to-end service matching the QoS requirements; the goal is to invoke the service that best suits the QoS requirements.

In the first case, the user invokes the service that has been defined to be *a priori* adapted to its application. In the second case, the invocation is done only after the adequacy of the concatenated service classes has been verified. Our work follows the second point of view and proposes a characterization of the end-to-end performances, which allows performing a concatenation choice guided by a quantitative expression of the QoS requirements.

So as for the reader to have a more detailed view of the different service provisioning approaches, the next section (2.7) is devoted to the corresponding state of the art. Our contribution to service provisioning is then detailed in section 3.

2.7. State of the art of provisioning

Several solutions have been proposed to tackle the service provisioning problem. They are detailed hereafter.

Following the static point of view:

- reference [13] proposes a solution based on the establishment of end-to-end pipes for which bandwidth reservation has been performed. Those pipes only concern the provider's domain and are only established for a few predefined services, supported by all domains. The concatenation choice consists in the choosing of a pipe compatible with the request. The main drawback of the proposed solution comes from the strong homogeneity of the provided services; moreover, the automation of the pipe set up is an open issue, which is necessary to make the approach dynamic;
- the MESCAL approach [14] proposes a solution for inter provider provisioning that quantifies the performances of services before the invocation step. The concatenation choice is based on the extended QoS class concept (e-QC), which is recursively defined as the concatenation of a local class (l-QC) and a e-QC of an adjacent domain. Prior to the subscription requests, the concatenations of the l-QC with the e-QC of the adjacent domains are evaluated; then, one of those satisfying the SLS is retained [15].

Following the dynamic point of view:

- [16] proposes mechanisms allowing the providers to exchange QoS parameters for the supported services in order to provide information on the available QoS before the SLS.
- in [17], the author's proposition is based on service vectors allowing the choice of different successive services retrieved using PROBE RSVP messages on each router, in order to obtain a concatenation matching the targeted requirements. However, the multi domain context is not explicitly considered.

Our proposed provisioning method is also of dynamic nature. However, it defers from [16] by the fact that the concatenation choice is performed at the time of the QoS request (and not at the subscription step). Moreover, we propose a model of service characterization which: (1) allows the request to take the usual forms of the QoS request into account, and (2) is applicable at the scale of one or more domains (typically those involved in the data path). Our proposal follows a similar approach to [17], but in a multi domain context. The dynamic end-to-end provisioning relies on a signaling protocol coupled with an optimized algorithm to choose the best concatenation of classes of services that fulfils QoS requirements and respects a set of predefined preferences.

The reminder of the paper is structured as follows. Section 3 presents the end-to-end service characterization. We first illustrate the interest of the proposed model. Next, we explain the composition and the compliance with a multi domain context. In Section 4, we discuss the signaling solution adapted to dynamic end-to-end provisioning. Finally, Section 5 presents a set of simulation results followed by the conclusion and future work.

3. End-to-End Dynamic Provisioning

3.1. Service Characterization

The usual performance characterization of a domain (from an entry point to an exit point) is often given in terms of maximal transit delay and/or jitter. The drawback of this model is that it conducts to non optimal characterization when considering the end-to-end service provided by several domains.

In previous work [18], based on ns-2 simulations and real measurements, we propose to characterize the performances between two edge routers by the *cumulative distribution function (CDF) of the transit delay*. Considering X, the transit delay of each packet between two edge routers as a random variable, the CDF F_X is defined by $F_X(t) = P(X < t)$, where P defines, for a packet, the probability that its transit delay is lower than t.

Such a characterization is interesting for different kinds of application requirements. For instance, if the required QoS is expressed in terms of:

– partial reliability τ_r (e.g. for a video stream without strong constraint on the delay), then it is satisfied if $\tau_r \leq \lim F(t \rightarrow \infty)$;

- partial reliability τd and constraints on the maximal transit delay b (e.g. for distributed games), then it is satisfied if $\tau d < F(b)$;
- bounded jitter g and constraint on the average transit delay dm (e.g. for interactive audio), then it is satisfied if $g \geq k.\sigma$ and $dm \leq \overline{x}$, where $\overline{x}$ and σ respectively define the mean value and the standard deviation of the transit delay (k defining a constant function of the probability law of the delay).

3.2. Multi Domain Composition

In a multi domains context, there is a need for characterization of the performances resulting from the concatenation of several service classes along a data path involving several domains (Fig. 2).

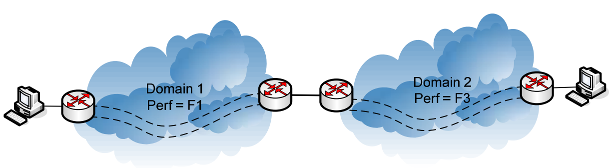

Fig. 2: Multi Domain Case

In the case of two consecutive domains D_1 and D_2, let X_1 and X_2 be the transit delays of a same packet crossing each of the domains, and let $F_1(t)$ and $F_2(t)$ be the corresponding CDF. One can assume that the transit delays observed in each domain are independent in probability. Thus, the CDF $F_{1,2}(t)$ of the end-to-end transit delay $X_{1,2} = X_1 + X_2$, is given by:

$$F_{1,2}(t) = \frac{d}{dt}\left(F_1(t) * F_2(t)\right)$$

where * indicates the convolution product. The generalization for n domains is obtained using the associative property of the concatenation resulting in:

$$F_{1,n}(t) = \frac{d}{dt}\left(F_n(t) * F_{1,n-1}(t)\right)$$

This result makes it possible to consider that an application can determine the concatenation(s) of classes which meet its QoS requirements once having the knowledge of performances for all services in domains on the data path.

3.3. Formalization

3.3.1. Hypothesis

Our proposal relies on the following assumptions:

- Inside each domain, there are one or more Classes of Service (CoS) supported by the providers;
- An entity in each domain has the knowledge at each moment of resource availability for each CoS between all couples of ingress-egress point (routers) in the domain.

For each CoS i in the domain D, we associate:

- An amount Bw_{iD} of available bandwidth;
- A cost C_{iD} for a client to use it;
- A QoS function $Fqos_{iD}$ which represents the resource characterization between each couple of ingress-egress point in the domain. In our work we considered for now the characterization described in section 3.1 assimilating to the CDF, but other function may be used as well.

3.3.2. Multi domain service composition

We propose an evolutionary approach that: (1) first evaluates the end-to-end performances on the data path and resulting from all possible concatenation and (2) choose and invokes the most adequate one with regard to a set of preferences and that fulfils application's QoS requirements at the same time. The preferences can be chosen from various criteria, grouped into two main categories:

- User-oriented (lower cost) or
- Provider oriented (income maximization, resources utilization).

Let us remark that a combination of several preferences can be also considered. Nevertheless, in this paper we illustrate our proposal with an approach that minimizes the cost by choosing the less expensive concatenation from all possible alternatives.

Based on the client QoS request (in terms of bandwidth and parameters presented in section 3.1), the conditions to be fulfilled by the chosen concatenation of CoS are:

$$1) \rightarrow Bandwidth \leq Min(Bw_i)$$

$$2) \rightarrow F_{target} > \left(Fqos_{1D} \circ Fqos_{2D} \circ .. \circ Fqos_{ND}\right)$$

where "o" represents a general function composition. In our instantiation, the target function is represented by the convolution product as explained in section 3.2. This means that on the data path there is enough bandwidth for the service and additionally, the application QoS requirements are satisfied.

Let suppose N QoS domains and at most M CoS in each domain. The goal of our selection mechanism is to choose a vector $\left[CoS_{D1},..,CoS_{DN}\right]$ (one CoS in each domain on the data path) under conditions 1) and 2) such that $\underset{D}{Max}\, QoS(D)$). In other words, the mechanism is able to find a concatenation of CoS in each domain that fulfils application requirements (1 and 2) and that maximize a *QoS* function with respect to imposed preferences. An example is illustrated in Fig. 3. In our study, the *QoS* function that minimizes the cost is:

$$QoS(D) = \sum_{i=1}^{N} \underset{j=1}{\overset{M}{Min}}\left(C_{ij}\right)$$

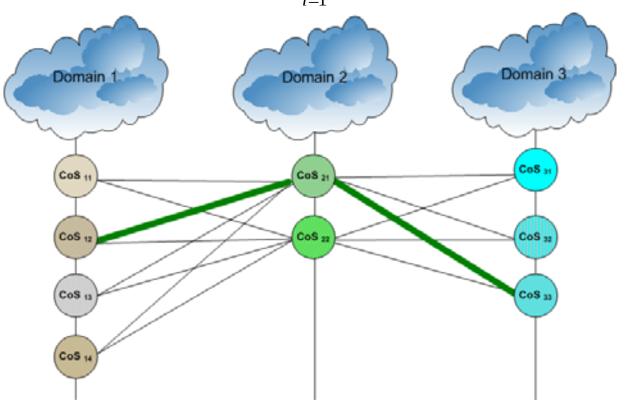

Fig. 3: Class of Service Selection

4. Signaling Protocol

As presented in Section 2, several models of QoS management have been proposed for multi domain Internet. The convergence point of these proposals is the necessity to set up a signaling in order to interoperate between different network equipments. Several contributions dealing with the signaling issue have been considered, mainly at the IETF (especially Next Step In Signaling NSIS work group). Two perspectives are present in the literature:

- path-coupled signaling (also called "on-path") that extends the IntServ/RSVP view. The entities involved in signaling process are mandatory on the data path;
- path-decoupled signaling (or "off-path"). The signaling entities cannot be all located on the data path, but they are aware it.

In our work we adopt a path decoupled approach in a hierarchical way using the Bandwidth Brokers (BB) concept [9] for the intra domain management. Moreover, we assume the knowledge by each BB of the IP services for all couples of its border routers. Therefore the BBs are the main admission control and signaling equipments of the domain. Considering the hierarchical management of a domain, we consider the off-path solution in order to impose arrival of signaling messages to the Bandwidth Broker.

The concatenation of the domains and the related admission control are performed dynamically after a QoS request expressed in terms of parameters such as a maximal transit delay, a maximal loss rate, etc.

The concatenation choice is resolved in three steps:

- first, the classes of service (and their performances expressed by means of the CDF of the transit delay) available on each domain of the data path(s) are discovered;
- second, the end-to-end performance model is evaluated for all the service classes available on the data path; this evaluation is performed by means of convolution;
- third, the choice of the adequate service satisfying the QoS request and given preferences is performed. This algorithm is implemented at the client's level (or proxy).

The signaling protocol will then be handled by:

- the sender and receiver hosts or dedicated equipments such as proxies.,
- the Bandwidth Broker of each domain.

Our protocol relies on BGP (Border Gateway Protocol), the inter AS routing protocol used in the Internet. The sequence of domains and the two data and signaling paths are illustrated in Fig. 4. Our solution decouples then the inter-domain signaling from the intra domain one. In all domains, decisions are local, and so any routing protocol can be defined within one domain. The purpose of this approach is to give a maximum degree of freedom to providers to implement the most suitable solution inside their domain. Consequently, the end-to-end inter-domain path is given by BGP tables and internal path (i.e. within each AS) can be freely selected by the AS providers, depending on local constraints.

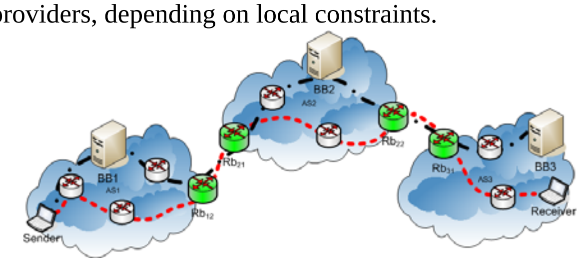

Fig. 4: BGP Data Path and Signaling Path

The performance of the end-to-end path and later the corresponding admission algorithm requires checking availability of the needed resources along the data path. This has to be done by some dedicated equipment, the Bandwidth Broker. The following Fig. 5 illustrates the case of a QoS request which transverse three domains. Following [19], the selection of the service matching the QoS requirements is based on:

- the discovery of the available services on the data path (request/response PDU exchanges),
- the characterization of the end-to-end services resultant from the composition of the available services classes, and then the selection of the cheapest service matching the QoS requirements,
- the reservation and the refreshing of the selected service class.

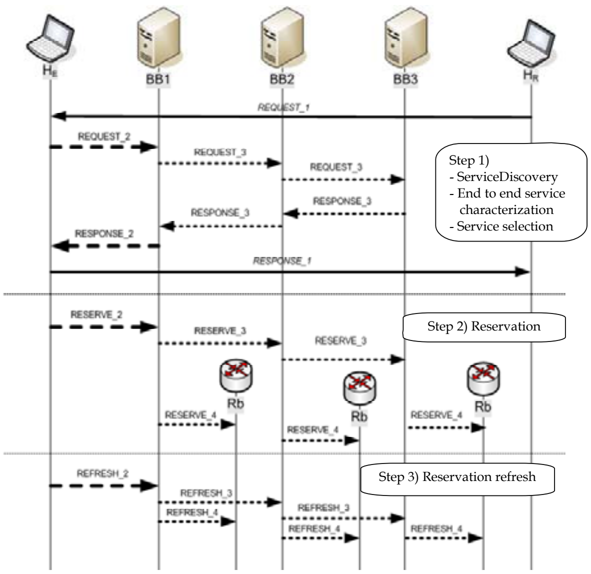

Fig. 5: PDU exchange

5. Simulation Results

In this section, the simulation results obtained for both the signaling protocol and the dynamic provisioning algorithm presented previously are presented. In both studies, issues regarding the scalability of the approaches are identified and discussed.

5.1. Evaluation of the architecture and signaling protocol

5.1.1. Performance tests

The performance tests performed on our signaling protocols were conducted on a platform composed by:

- power edge 750 computers with Intel Pentium 4 processor at 3 GHz and 1 GB RAM memory; (running Linux Debian or Fedora with 2.);
- two Cisco switches c2960.

In order to test and validate our implementation, we developed multithread tools that simulate the high level behavior of an application and trigger the QoS system. The java virtual machine used was 1.5.0_11 and the database server was MySQL 5.0.18. Using the testbed described above, we emulated the multi-domain context presented in figure 4.

We first measured the processing time on all Bandwidth Brokers, the results being comparable for all of them. We stressed the system by launching simulation of 5, 10, 50, till 200 requests per second. Fig. 6 illustrates the answer time for each of the above scenarios. Note that time consists of request parsing, several access to the database, state management and also an emulation of device configuration. Let us observe the increase response time when the number of requests became greater than 150 per seconds. This can be explained by the different time spent in the queues while waiting for processing. Tuning the implementation prototype to take into account this limitation is one of the prospects of this work.

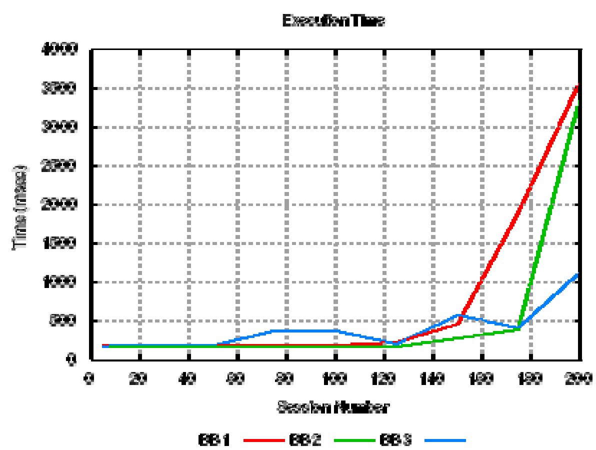

Fig. 6: Processing time

In a second time, we measured the round trip time between the client request and the response arrival (Fig. 7). We suppose a communication crossing three domains and this time includes: the processing time in each Bandwidth Broker, the time to exchange signaling messages (RESERVE and RESPONSE) and the update of configuration in each domain.

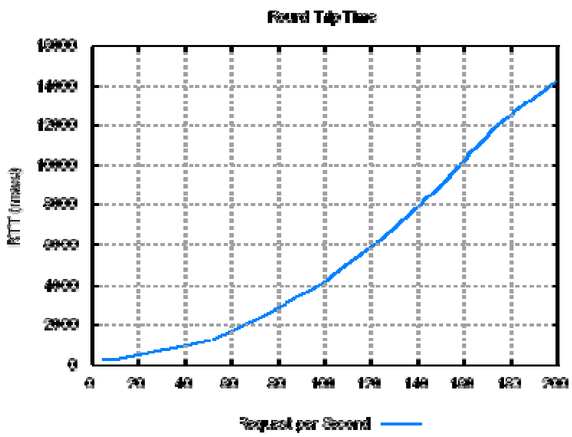

Fig. 7: RTT for three domains

Let us remark that the response time is increasing with the number of requests. The mean RTT remains under 4 seconds for less than 100 requests per second and under 8 seconds between 100 and 150 requests per second. We also observe an increase of this time after 150 requests per second, with a mean around 12 seconds for 200 requests per second. However, the processing and request handling in each domain of our protocol conducts to satisfactory values of the RTT for reasonable number of requests per second.

Next Fig. 8 and 9 describe the usage of CPU and memory, measured during the same simulation on the second BB. During the processing of all 200 flows, a separate process investigates each second the resource utilization of the computer where the Bandwidth Broker is located.

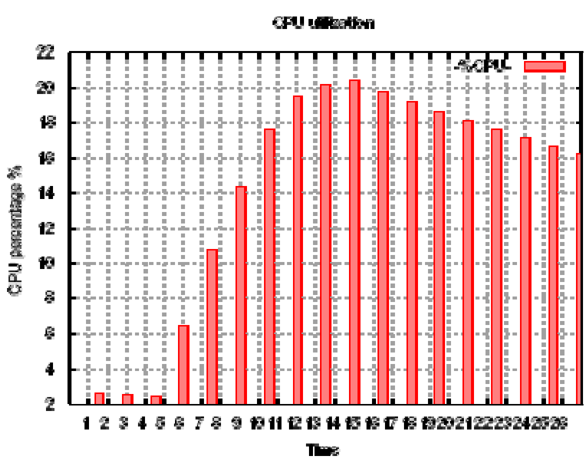

Fig. 8: CPU utilization

It is worth mentioning that for this specific test we used the results obtained by the Linux based tools (top, htop, ps). Therefore, the CPU utilization represents the CPU time used divided by the time the process has been running (CPU time / real time ratio) expressed as a percentage. We can observe the increase during the processing off requests, the values being satisfactory even if we didn't use very powerful equipments (such as the operator owns).

Let us note the augmentation of memory (the physical resident size that a task uses expressed in Kilo Bytes) due to possibly creation of new threads to process new requests. It is worth to observe that after handling all requests, the CPU percentage is decreasing while the memory remains at its last stable level. This is caused by the implementation collaborated with the memory allocation/free algorithm of the virtual machine. When all the threads in the handling pool are started the memory will not increase, having a stable value.

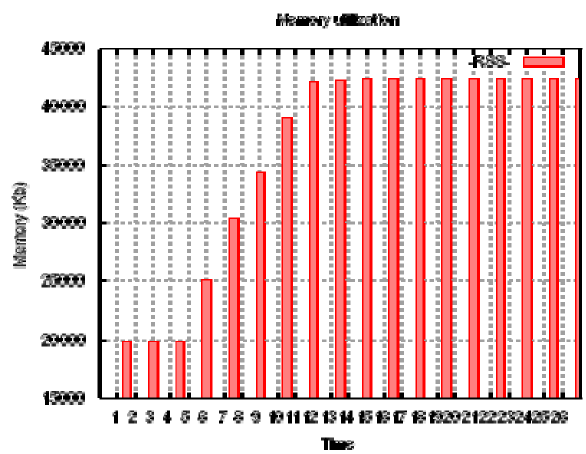

Fig. 9: Memory Utilization

5.1.2. Conclusions

The previous results show that the memory and CPU consumption of BBs remain in reasonable values. The RTT and the processing time are also acceptable in the vision of a session establishment in a multi-domain context, matching ITU requirements [20]. Moreover, the network overhead introduced by our signaling protocol is limited (in the current implementation 64 bytes to request reservation for a flow and 68 bytes for the response).

In the general case, QoS seems to be difficult to deploy. Nevertheless, the users requesting QoS will be much less numerous than the number of best-effort users. It will start with a reasonable number of users and domains, and extend them when the number of QoS requests will grow. Moreover, when the number of requests becomes important, the tasks of the

Bandwidth Broker can be distributed.

5.2. Performance of the dynamic provisioning algorithm

This section is focused on the performance results related to the dynamic end-to-end provisioning scheme which has benne proposed in section 3. Let us recall that we consider an algorithm aimed at choosing the "best" (here the less expensive) CoS concatenation along the data path, using the mechanism described in section 3.2. Details for the composition using cumulative distribution function can be found in [11].

Our simulation is based on a Java implementation of the proposed model. We use a multi domain model similar to the one presented in Fig. 4 considering four domains (identified from 0 to 3). For simplicity, we consider three CoS in each domain, having the same QoS characteristics. We name these classes CoS_1, CoS_2 and CoS_3, and we assume that the quality associated with these classes is such that: $QoS(CoS_3) > QoS(CoS_2) > QoS(CoS_1)$. Consequently, the price to use one of these classes follows the same relation. The bandwidth amount allocated in each domain for each class of service is 60% for CoS_1, 20% for CoS_2 and 20% for CoS_3.

The simulation time is set to take into account one day with collection of results each second using 300000 clients equally spread in each domain. The communication duration of each client follows the Poisson law and the reservation invocation time is uniformly distributed throughout the simulation duration. Each client performs one QoS request through several randomly chosen domains (the destination domain being always identified by a grater number). We compare our model with the general most used one that statically associates a well defined CoS to a given type of application (same in each domain). In this basic approach, the user attempts to reserve the same related CoS in all domains on the data path.

We remind that in our approach, the QoS request does not precise a specific CoS, but only parameters. Retrieving all available CoS on the data path and based on the application requirements and given preferences, a concatenation of CoS (which can be different on each domain) is chosen and resources are reserved afterwards.

We consider three types of application, each one having specific well defined QoS characteristics (i.e. video streaming, telephony, etc). The need in QoS for these applications follows a similar relation as for the CoS: $N(Type_3) > N(Type_2) > N(Type_1)$. A client uses one of the application types following a probability law: 0.6 for $Type_1$, 0.2 for $Type_2$ and 0.2 for $Type_3$.

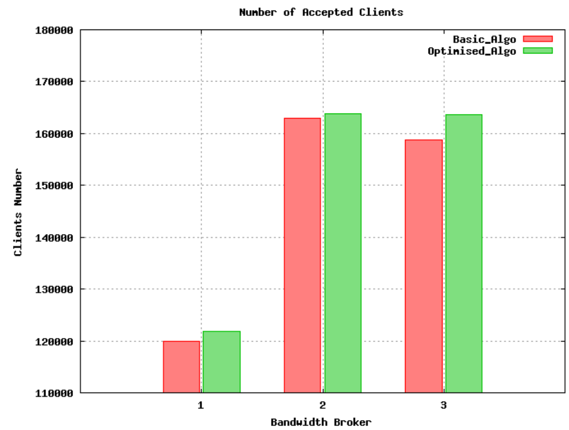

Fig. 9: Number of Accepted Clients

First of all, we analyze the number of clients accepted in each domain. Fig. 9 illustrates the number of accepted clients and Fig. 10 the total number of clients that made a QoS request to a BB (per domain).

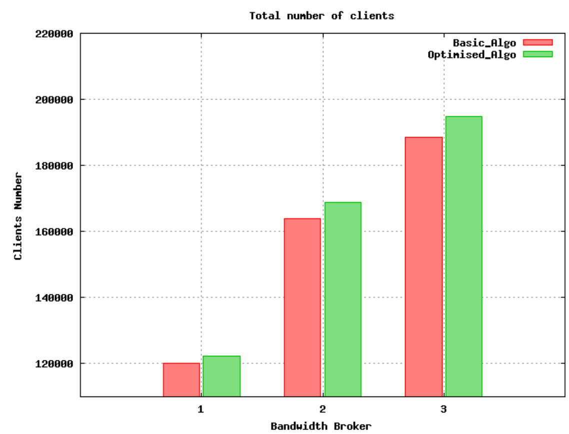

Fig. 10: Total Number of Clients

We can observe that with our model, the number of accepted clients is greater on each domain compared with the classical algorithm. Furthermore, the total number of clients is superior in our approach, meaning that more QoS request can be satisfied. The fact that a greater number of client requests are processed with our algorithm results from the behavior of our signaling approach: if the resources are not available, the request is not propagated forward. Compared with the basic general approach, our methodology gathers information for all available CoS and do not reduce the solution to only one CoS. This flexibility allows a greater number of requests to be satisfied.

These results are also confirmed by the Fig. 11

which represents the bandwidth occupation on the second Bandwidth Broker (on the other BB the results are similar; we choose to illustrate the second one as a greater number of requests are processed). We can remark that using our algorithm, we obtain a better occupation of the bandwidth which is predisposed to increase the profits for providers.

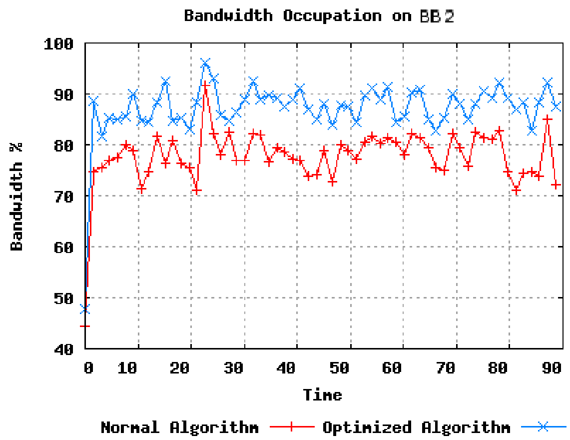

Fig. 11: Total Bandwidth Occupation

We also analyzed the bandwidth occupation for each CoS. We illustrate the CoS_1 as it is the most used in these simulations (see Fig. 12).

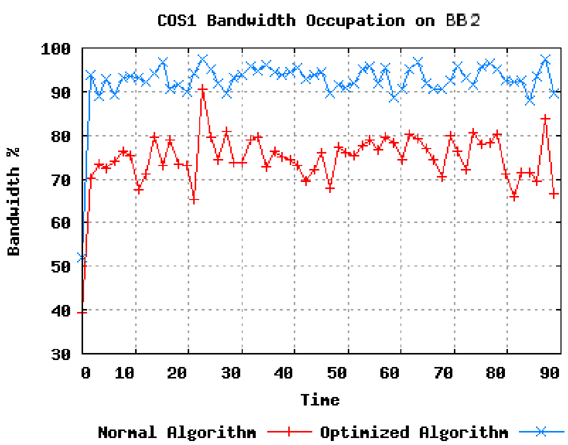

Fig. 12: CoS 1 Bandwidth Occupation

Let us remark that we also performed simulations using different distributions of application types with the same three CoS. Results are comparable, the bandwidth occupation being greater with our algorithm, however with increasing differences if the proportion of CoS_2 and CoS_3 are greater.

Based on these results, we conclude that not only the degree of satisfaction of clients is improved, but also that providers can take advantage of this approach. Having a larger number of clients and a better bandwidth occupation implies more incomes and also an optimization of resources.

6. Conclusion

This paper addresses the problem of providing a guaranteed end to end QoS over multiple Internet domains. More precisely, we proposed a solution of QoS domain architecture managed in a hierarchical manner by a Bandwidth Broker. In addition we presented solutions for both inter-domain signaling and optimized QoS management to perform admission control. With respect to other similar contributions, our proposal is independent of the underlying network technology and minimizes the constraints introduced to the global architecture. In addition to the implementation of several modules, we presented a first round of tests that aims at validating our solution.

The main perspectives of this work are:

- to conduct further investigation on performance and scalability;
- to take into account the heterogeneity of the Internet with non QoS domains and to consider several different domains with different technologies.
- to introduce other criteria for our selection algorithm (possible provider preferences. In this paper we used minimization of cost as criteria).
- to extend our solution in order to integrate the evolution of the NSIS protocol suite.

7. Acknowledgment

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8. References

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