A QoS architecture with adaptive resource control: The AQUILA approach

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Abstract
The Information Society Technologies (IST) project AQUILA[1] aims to develop a flexible, extendable and scalable Quality of Service architecture for the existing Internet.
The core network will be an enhanced DiffServ network providing several dynamically manageable traffic classes with specific QoS parameters, per hop behaviors, and other "guidelines" that realize different traffic handling for different network services to be requested.
In order to provide QoS support for end-users, the overall approach is based on real Internet scenarios, where several hosts are connected via access nets to a core network. The latter consists of several Internet Service Provider domains connected by border routers. On the other hand, the access networks are connected to their domains by edge routers.
A new layer will be developed on top of this physical architecture, the Resource Control Layer. The task of this layer is to control the underlying network in order to provide QoS features to the customers of the network.
Resource Control Agent, Admission Control Agent and End-user Application Toolkit (EAT) components are not physical devices but logical components that may be placed anywhere within the network.
Further components of the architecture are legacy as well as new QoS-aware applications running on the hosts. Both types will use the EAT middleware to benefit from the QoS capabilities of the AQUILA approach.

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[1] AQUILA (Adaptive Resource Control for QoS using an IP-based Layered Architecture) is a European research project partially funded by the IST Programme under IST-1999-10077

1 Introduction

This paper describes briefly the general AQUILA network architecture focussing on the Resource Control Layer. It is meant as introduction to some other papers of the ComCon8 Conference, which present in more detail special topics of the AQUILA project. More information can also be found in the project home page [AQUILA].

2 Project Objectives

In order to satisfy the huge commercial demand for Quality of Service (QoS) solutions over IP networks, the project AQUILA defines, evaluates, and implements an enhanced architecture for Quality of Service. Existing approaches for QoS provisioning in the Internet e.g. Differentiated Services (DiffServ), Integrated Services (IntServ) and label switching technologies (e.g. MPLS) are used as basis for the specification of this architecture and will be significantly enhanced and exploited.
The achieved technical solutions will be verified by testbed experiments and by trials involving end-users. The trials will include QoS demanding on-line services, e.g. multimedia services. The straight exploitation of the results will be achieved by the development of business models and business plans.
The key objectives of the project are:

1. To enable dynamic end to end QoS provisioning in IP networks for QoS sensitive applications e.g. Internet telephony, premium web surfing and video streaming. Static resource assignments will be considered as well as dynamic resource control. The latter can take into account the actual load situations in the IP network and can adapt the network to dynamic load changes.
2. To continuously analyze market situations and technological trends for QoS solutions and to exploit the results of the project creating applicable business plans based on the user and service provider requirements.
3. To design a QoS architecture including an extra layer for resource control for scalable QoS control and to facilitate migration from existing networks. The Differentiated Services architecture for IP networks will be enhanced introducing dynamic resource and ad-mission control. The main features of this architecture are as follows:
   - The architecture will be usable by any relevant kind of IP application; i.e. to provide several options for the establishment of QoS requests by user applications, e.g. via CORBA, RSVP or HTTP.
   - The architecture will be cost-effective, scalable and backward compatible for the provisioning of QoS in IP networks covering both the inter- and intra-domain QoS.
   - The architecture will consider the requirements for QoS accounting.
   - The architecture will be kept open and flexible so that the project can incorporate new concepts and knowledge from other research projects (in particular the European Quantum project, the Internet-2 and the Qbone initiative) and from standards bodies (e.g. IETF, OMG).
4. To implement prototypes of the QoS architecture as well as QoS based end-user services and tools in order to validate the technical approach of the solution design. This includes:
   - To develop a novel resource control layer extending Bandwidth Broker functionality.
   - To provide an End-user Application Toolkit (EAToolkit) in order to support the establishment of QoS by end-users and applications.
   - To create tools for QoS provisioning, monitoring and management in order to facilitate operators to control QoS IP networks.

  - To develop a distributed measurement infrastructure for end-to-end QoS parameters. The results are a basis for optimization of protocol parameters and QoS network management.
5. To validate the QoS architecture in a field trial involving a commercial online service. To prove the concepts for larger scale networks, higher network load and different kinds of end-user services within a distributed testlab and by simulations. To examine the commercial acceptance of the offered QoS, for both business and residential users.
6. To enable migration to QoS-enabled networks including deployment aspects. The project will support incremental transition from best effort to differentiated QoS. The change will involve both the technology and the offered services. The project will evaluate different deployment scenarios and define a migration strategy for the operators and service/content providers.
7. To contribute to standardization bodies like IETF, ITU, ETSI, OMG etc. This includes regular attendance of key personnel at the standardization meetings and active contributions.

In order to achieve these objectives, the AQUILA project joins the strengths of a consortium of partners covering all the appropriate competence areas: multimedia content and services providers, network operators and Internet service providers, network technology manufacturers for routers, remote access servers and access technology, and research institutes with experiences in router technology, IP test and measurement tools, network simulation and soft-ware technology. This comprehensive combination enables the AQUILA consortium to de-sign, implement and practically demonstrate novel prototypes for future end-to-end IP-Quality of Service solutions to technological, service provision, operational and economical aspects.

3 Project Consortium

The AQUILA consortium consists of 12 partners from 6 European countries, including a manufacturer, five Internet Service Providers and Network Operators, five universities and research institutes and a Web application provider.
The list of project partners is as follows:
Siemens, Germany, coordinating partner; National Technical University of Athens, Greece; Bertelsmann mediaSystems, Germany; Elisa Communications, Finland; Dresden University of Technology, Germany; CoRiTeL, Italy; Salzburg Research, Austria; Q-Systems, Greece; T-Nova Deutsche Telekom, Germany; Telekom Austria, Austria; Polish Telecom, Poland and Warsaw University of Technology, Poland.

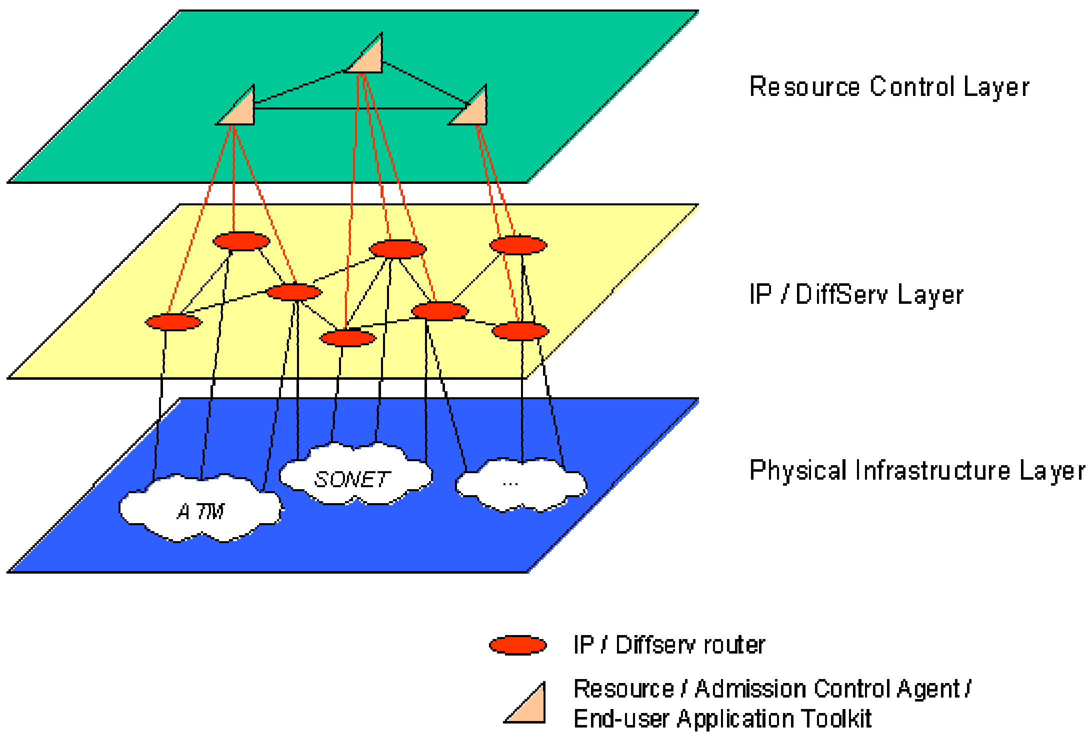
4 General Approach

The general AQUILA network architecture is based on the DiffServ network concept. The objective of the project is to provide dynamic control to QoS based traffic. To do so, a new layer for controlling the network resources is added above the DiffServ network. This Resource Control Layer (RCL) maintains the distribution of network resources between different network entities, especially the network access points. So it can be assured that the underlying IP network can provide the assumed Quality of Service for the specific network services.

The technical approach taken by the project integrates all relevant aspects for future integrated services networks based on the Internet. Therefore it covers economical aspects, technological concepts, aspects of network planning and analysis, aspects of network service creation and administration as well as aspects of end-user service provision. For all these aspects, the project applies a common philosophy of taking the best available concepts and technologies, integrating them into a holistic view of future telecommunication services and providing tools for migration from the current to the future situation. In terms of networking technology, the project assumes the to the future situation. In terms of networking technology, the project assumes the DiffServ architecture as the most promising starting point for its work.

On top of this technology, a hierarchically structured Resource Control Layer is built, which applies admission control and resource management to the network. Dynamic adaptation of resource allocation to user requests enables the overall architecture to scale to very large networks.

For end-user applications, the project attempts to make its infrastructure available to a large class of already existing applications based on Internet technology. So the project will not attempt to develop end-user applications "from the scratch", but will instead develop a toolkit, which can be used to make existing applications aware of the QoS capabilities of the underlying network. The usability of the toolkit for migration and adaptation of applications will be demonstrated by developing applications to be used in the trial phases.



5 Resource Control Layer

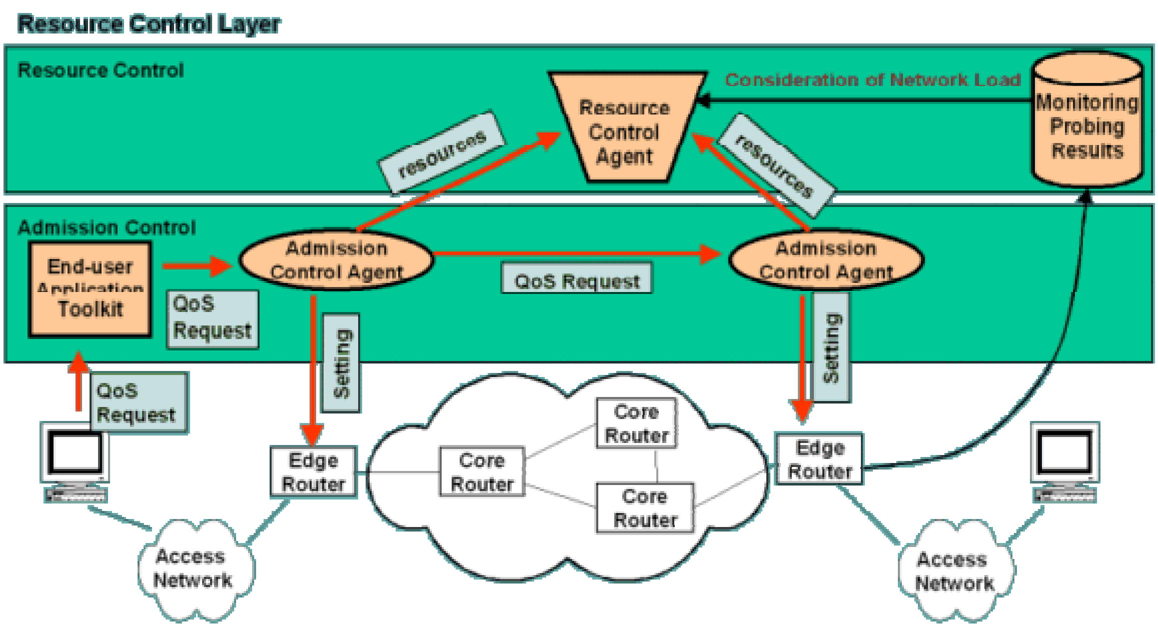
The RCL is responsible for the management of QoS resources inside the AQUILA network. This can be split in three main tasks, which are assigned to different logical entities:

- **End-user Application Toolkit (EAT)**
  A graphical user interface is offered to the end-user directly or to the applications run by the user. Using this, any application can request certain resources from the network to run with a specified QoS. The EAT is the interface to the AQUILA QoS infrastructure.

- **Admission Control Agent (ACA)**
  Performs policy and admission control at the network edges. Each edge router or border router is controlled by an ACA. Each ACA gets a certain amount of resources by the RCA enabling the ACA to perform admission control autonomously. The ACAs receive requests for new IP flows with specific QoS requirements. Their task is to authorize the requests and to check, if the network is able to support the new flow. For this task, they closely interact with the second main entity, the so-called Resource Control Agents.

- **Resource Control Agent (RCA)**
  Monitors and controls the available resources in the network. It is the ultimate authority for the resource handling in the AQUILA network. Based on the prior history of resource usage and actual requests, the RCAs distribute resource shares to the Admission Control Agents.

End-users access the Resource Control Layer by using the End-user Application Toolkit. The EAT does not constitute a new signaling protocol for IP networks. Instead, it can be described as a QoS middleware that brings the functionality of the Resource Control Agents Network into the end-user terminals and servers. The internal signaling protocol used between user terminals and the main network can be based on existing schemes (e.g. RSVP) or even on CORBA or DCOM interfaces depending on application needs. In any case, the Edge Device (ED) analyses the user request and executes the user policy control and the local admission control operations in order to determine whether the specific user has the administrative rights and whether there are enough internal resources for the handling of the particular request. However, end-to-end guarantees can be provided only if the level of available resources of all intermediate routers until the final destination is known. Therefore, the ED uses its interface with the Resource Control Agents Network for performing the network admission control operation.
The following figure illustrates a schematic QoS scenario of the project. End-users as well as content providers are connected via EDs, which control the access to the core network.



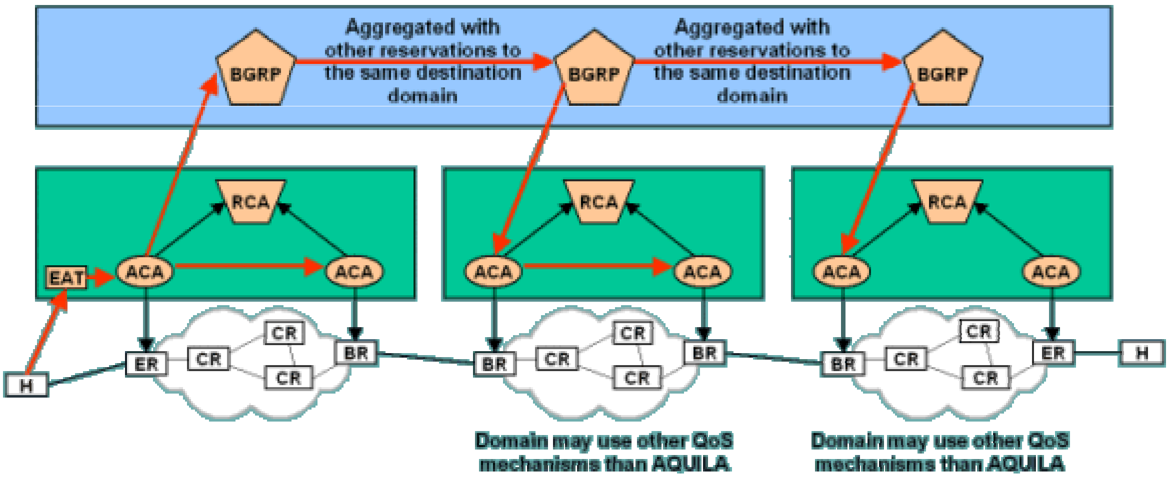
6 Reservation request scenario

To give an idea, how the single entities' are working together for establishing a QoS connection, in the following an example is given. It demonstrates a successful reservation request, initiated by the calling party.

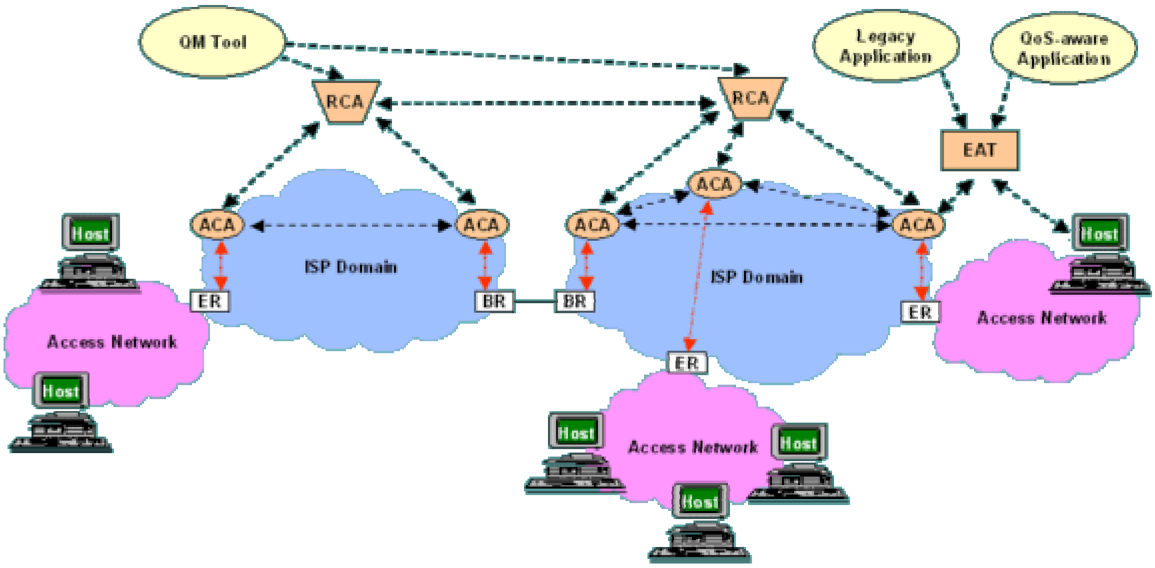
- A user, who wants to set up a call, uses the means of EAT to set up a reservation request first. The request is received by the corresponding "requester" ACA. Usually, the request specifies at least the source and destination hosts, and the information about which class of service shall be used. Based on this information, the requester ACA maps the offered network service to so-called Traffic Classes, performs the policy control and resolves the involved sender and receiver ACAs (the receiver and sender ACA can be the same machine !). Then, the requester ACA sends a reservation request to the sender ACA (which is located at the ingress of the network) as well as to the receiver ACA.
- The main task of the sender ACA is to make a flow based admission control decision on the ingress side. The specific operations required for such a decision depend on the algorithm used, and depend on the resource configuration controlled by the RCA. If there are sufficient resources available, the sender ACA configures the appropriate edge device accordingly.
- The previous step is repeated for the receiver ACA that has to make the same operations at the egress side.
- After the reservation of the resources, the sender may start sending data traffic to the receiver with the desired QoS. The QoS reservation will be kept until a disconnect message is sent out by any of the involved parties.

7 Multi Domain Aspect

While the previous figure depicts the Resource Control Layer for a single domain, additional mechanisms are necessary to extend this architecture over multiple domains. The project is developing such mechanisms, based on the BGRP proposal, and extends the architecture by an additional inter-domain layer.



AQUILA is designed to fit in real Internet scenarios, where several Internet Service Providers (ISP) are connected via border routers (BR), and different access networks are connected via edge routers (ER). Extending the more schematic view above, the following figure depicts the seamless integration of the AQUILA architecture into these structures.

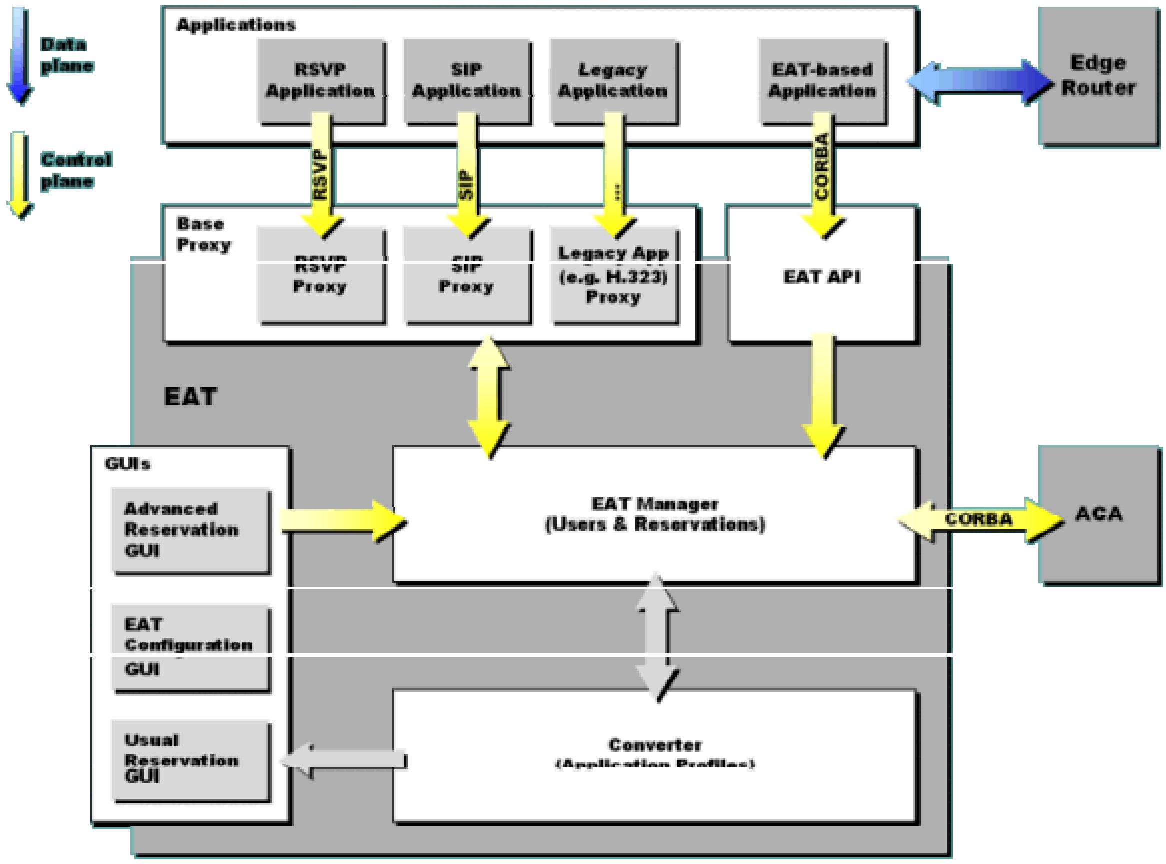


8 End-user Application Toolkit

The End-user Application Toolkit (EAT) is a distributed middleware architecture that aims to provide users and applications with access to the QoS facilities of the AQUILA architecture. The EAT specifies the QoS interfaces, both human and programmatic, that users and applications may use in order to get QoS support from the network. Therefore, its main purpose is to bridge the gap between applications/users and the network, playing the role of a QoS portal.

The EAT aims to support a variety of application genres and needs. However, it focuses on legacy applications: non QoS-aware applications that cannot be modified to leverage the AQUILA QoS functionality. Specific mechanisms are being developed in order to QoS-enable such applications:

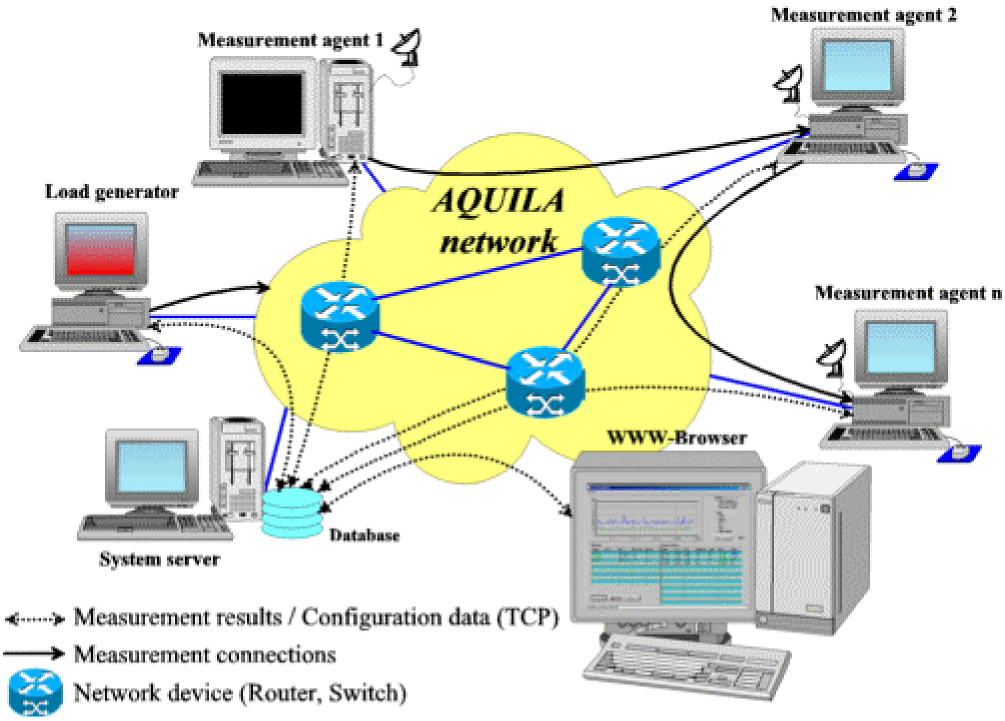
- Application profiles capture the QoS needs of individual service components (audio, video, data) of applications both in terms of network-level as well as of application-level parameters.
- Protocol translators or Proxies intervene in the operation of standard connection establishment protocols (SIP, H.323) in an effort to extract QoS-relevant information from the protocol messages (dynamically negotiated IP port numbers, information on audio and video codecs etc.). Such information is used in reservation requests to the network.
- A generic reservation request mechanism is specified and implemented in CORBA. However, other QoS signaling protocols (especially RSVP) are also supported by the AQUILA architecture: specific translators terminate QoS signaling originating from hosts and map it to an appropriate AQUILA service class inside the core network.
- A web-based approach is adopted for the presentation of the above information to the end-user. Java Server pages are dynamically created from application profiles and present users with all the available reservation options for a particular application. Therefore, only a web browser is needed for the operation of the EAT and no software installation on end-hosts is necessary.



The End-user Application Toolkit is also oriented towards the support of new QoS applications. To this end, a QoS API is specified in Java that will expose the EAT components for use by other applications. Since most application developers are not QoS experts, they are expected to benefit from the use of a QoS API, as they will be able to leverage the EAT QoS functionality.

9 Distributed QoS Measurement

Within AQUILA active and passive measurements are performed. Passive measurement (or "monitoring") is a method, where no additional measurement packets are created, active measurement ("probing") uses test packets for measuring the QoS parameters. The results of these measurements can be used by the RCL for a distribution of resources. Additionally load generators are used to measure the end-2-end-QoS at the application level (simulation of applications) to validate the QoS targets for each network service. Distributed agents along the network are installed for the test execution, which can be equipped with GPS-clocks for synchronization to enable one-way delay measurements. A measurement database for storing the measurement scenarios and the results is created. The user can interact with the measurement system through a WWW-Browser.



10 First trial results

For practical verification of the AQUILA architecture concept, three testbeds were established at Warsaw (TPS), Vienna (TAA) and Helsinki (ELI). These testbeds differ in network configurations, mainly in the number of routers and the focus of test scenarios. Appropriate software developed inside the AQUILA project was integrated in testbeds. In particular, EAToolkit, RCA, ACA and measurement tools were integrated with router configurations.
The trial experiments are mainly focused on the evaluation of previously defined network services providing QoS: Premium CBR (PCBR), Premium VBR (PVBR), Premium Multimedia (PMM) and Premium Mission Critical (PMC).
The following objectives were defined:

- In the Warsaw testbed two network services, PCBR and PMM, are to be tested. A mixture of network services is also to be tested in order to check ability of assumed AQUILA architecture for providing service differentiation. Additionally, the correctness of admission control as well as resource pool algorithms is to be verified. The experiments are provided under artificially generated traffic and real Internet applications.
- In the Vienna testbed two network services, PVBR and PMC, are to be tested.
- In the Helsinki testbed measurements of the performance of the RCL are to be tested.

On the basis on the analysis of the results obtained during the first trial, the main conclusions and hints for the next stage of the AQUILA project are the following:

Regarding network services:

- Implementation of each network service is in accordance with the assumed specification;
- Efficiency of AC algorithms agree with the assumptions;

- Tuning the appropriate values of traffic descriptors for real applications is sometimes very difficult to do. For instance, in the case of the NetMeeting application it can be done only experimentally; therefore, there is the suggestion to simplify traffic descriptors;
- It was proved that mixing streaming and elastic traffic inside one network service should be avoided;
- PCBR and PVBR network services, dedicated for serving streaming traffic, guarantee the assumed target QoS requirements (like packet delay characteristics, packet loss ratio);
- PCBR network service is well suited for applications generating constant bit rate traffic, like WinSIP;
- PVBR network service is well suited for applications generating variable bit rate traffic, like NetMeeting,
- PMM and PMC network services, dedicated for serving elastic traffic, guarantee the target throughput requirements, while fail in guaranteeing target packet loss rate; this requires redesign of particular mechanisms associated with these services;
- The capacity allocated to the PMM or PMC service is fairly shared among all accepted TCP-controlled flows (in the case of PMM service the throughput is proportional to the declared SR value while in the case of PMC to the calculated equivalent bandwidth);
- PMM service is well suited for serving traffic produced by greedy TCP-controlled sources (like FTP) and adaptive streaming video (like Real-Player) while PMC service is better suited for serving traffic produced by non-greedy TCP sources;

Regarding RCL layer:

- Resource pool mechanism works correctly for TCL1, TCL3 and TCL 4, but should be redesigned for TCL2, the trial will continue;
- In the initialization phase, most of the signaling is produced by the connection between the RCA and database; the second largest part of signaling is produced by ACAs (for configuration of edge devices);
- During reservation set-up the largest contribution to signaling traffic is produced by ACA logging; the second largest contribution to signaling came from the ACA; the third largest contribution to signaling was the database communication;
- The set-up and release times were reasonable for production use. Times for making and releasing the reservation were the same, about two seconds each;
- The most critical point of failure is the database; the second critical point is the RCA.

More details about the results of the AQUILA First Trial can be found in [D3201] and in [MR].
In the Second Trial the project will focus on the multi-domain aspect and the involvement of real users.

11 References and acknowledgement

[AQUILA] AQUILA home page: http://www-st.inf.tu-dresden.de/aquila/, Dresden, July 2001.

[D3201] Z. Kopertowski et al.: First Trial Report, Project deliverable IST-1999-10077-WP3.2-TPS-3201-PU-R/b0, Warsaw, July 2001.

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