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| **Abstract:** | This deliverable D005 is the Final Project Report of the AQUILA project. It gives a brief overview on the project, lists the main achievements, the deliverables and the results. It also provides a self-assessment. |
| **Keyword List:** | AQUILA, IST, QoS, Internet, Resource Control |

# Executive Summary

In this deliverable we give a brief overview on the project, the consortium and it objectives from the very beginning.

A list of the main achievements in the project is then followed by a chapter on the methodologies used during the projects runtime and a comparison how developments in state-of –the-art influenced the project.

More detailed follows a report on the results and achievements, which can be summarised as:

- The integration of research and educational facilities with industrial partners
- Support of any relevant kind of IP applications by the End-user Application Toolkit:
  - new QoS-aware applications and services are supported by providing an Application Programming Interface (API)
  - The users of existing, QoS-unaware legacy applications are supported by providing Graphical User Interfaces (GUIs)
  - Some special applications based on dynamic signalling protocols are supported by providing transparent Proxies (Protocol Gateways)
  - Also automatic tests and measurements by the project itself are supported by providing a script interface.
  - The application profiles methodology provides a generic mechanism to specify QoS characteristics on different levels and for different protocols.
- Integration of the system modules at the trial sites in Helsinki, Vienna and Warsaw.
- Practical verification of the developed solution as one of the main objectives of the project. During two phases of trials, the AQUILA approach was proven taking into account different objectives for its evaluation. Particularly, for the AQUILA solution the following results were achieved:
  - Network services (inter- and intra-domain) PCBR, PVBR, PMM, PMC services meet QoS requirements specified for each service.
  - For secondary access link the results show that some QoS targets were not quite reached, but sufficient differences between traffic classes were noticed
  - The user trial confirms the expectations that VoIP needs a prioritised service in IP network. PCBR service supports VoIP sufficiently.
  - For intra- and inter-domain RCL performance the results are very promising.

  - For the Resource Pool Mechanism the trial shows the stability of the algorithm.
  - AQUILA measurement tools were useful and necessary components for the trials in addition to other existing measurement equipment.

- Differences and common points of the Western European and Central & Eastern European network markets in particular were acquired. On the basis of the gained information, general value chains were generated and the exploitation plans of each project partner were updated.

After a list of all deliverables and publications we report on the project's co-operation with the projects CADENUS and TEQUILA in the Premium IP Cluster, several activities with contributions to standardisation (IETF) and the co-operation with the GÉANT network during the 2nd integration and trial phase.

The next chapter compares comments and recommendations given by the reviewers during five project reviews with the consortium's response. In addition we compare the project achievements with the initial objectives.

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# 1 Project Overview

## 1.1 Consortium

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 software technology.

### *1.1.1 Siemens AG*

**Siemens** has accepted the role of the co-ordinating partner for the AQUILA project proposal. Therefore, Siemens is responsible for WP 0 (Project Management) and provides the project manager.

Siemens has great expertise in the area of public switched networks and a broad spectrum of products in that field. Furthermore Siemens provided substantial competence in the areas of IP networks and IP solutions and is a main supplier of IP products. Siemens contributed to most of the workpackages, particularly to the overall requirements and architecture definition of the project. Traffic engineering complements these. In the implementation work, Siemens concentrated on the resource control layer including the development of a QoS Manager and the development and adaptation of edge devices. Siemens took workpackage leadership for the specification and resource control implementation workpackages. Moreover, Siemens provided support for the integration phase and for the trials and exploitation.

### *1.1.2 National Technical University of Athens*

NTUA was involved in the part of the project dealing with the specification of the system architecture as well as in the performance analysis studies of the system alternative. The major contribution of NTUA was in the design and implementation of the prototypes (Resource Control Agent, End-User Application Toolkit and QoS Management Tool etc) needed for the realisation of the project's goals. In addition, NTUA took the leadership of the integration workpackage. Based on the already acquired expertise in the area of integration in combination with the valuable experience gained from the 1st trial integration, the final trial integration was a great success.

### *1.1.3 arvato systems GmbH*

arvato systems played the role of the system user, the business customer and Internet service/content provider. As a major industrial partner arvato conducted all market analyses related activities, investigated business alternatives, provided content and Internet services as well as the projects exploitation activities.

### 1.1.4 Elisa Communications

The main role of Elisa was to bring operator and service provider viewpoint into the project. The focus areas of Elisa were to set requirements for QoS management platform, to develop QoS-aware measurement tools and to perform the trials. These requirements and development were based on real commercial needs that are already visible in the Finnish IP-provider market, and are thus concrete and beneficial for the AQUILA consortium. Elisa provided facilities for laboratory and field trials in Helsinki. Performing router, signalling and network service measurements as well as reporting the test results was Elisa's main contribution.

### 1.1.5 Technische Universität Dresden

Dresden University of Technology concentrated its effort on a few topics. First task was to support the project in creating and specifying an adequate and flexible design for the distributed RCA architecture.

TUD also took the leadership of workpackage 2.2 and led firstly the development of the end-user application toolkit (EAToolkit) for adapting user applications to benefit from QoS capabilities in the network, and secondly the development of a generic methodology to support legacy applications without the need to modify them.

### 1.1.6 CoRiTeL – Consorzio di Ricerca Sulle Telecomunicación

CoRiTeL took the leadership of WP 1.3, providing its expertise in the area of Traffic Control and Traffic Engineering. CoRiTeL contributed the traffic handling aspects into the architectural specification.

### 1.1.7 Salzburg Research Forschungsgesellschaft mbH

Salzburg Research developed an active measurement tool for precise measurement of IP end-to-end QoS by emulation of different kinds of applications and led the workpackage "Distributed QoS Measurement".

Additionally, Salzburg Research contributed to the WP dealing with traffic engineering, where they brought in their knowledge especially in packet level handling mechanisms, TCP congestion control and network simulation.

Furthermore, Salzburg Research actively participated in the trials by setting up a measurement end-point and a Mediazine client in their premises connected to the AQUILA testbed. They also supported the trials by developing test scenarios and evaluating measurement results.

### 1.1.8 Q-Systems Association

Q-Systems took a set of its existing commercial applications and made the required modifications so that they can use the EAToolkit. Q-Systems undertook the adaptation of other Web applications in QoS awareness, and contributed in the development of EAToolkit.

### 1.1.9 T-Systems NOVA GmbH

T-Systems NOVA lead WP "Requirement Analysis" and contributed to the specifications. The implementation activities covered the field of accounting and measurement of end-to-end QoS parameters as well as integration of synchronisation mechanisms. The third focus was the preparation and participation in the trials.

### 1.1.10 Telekom Austria AG

Telekom Austria worked in the field of specification (Requirement Analysis) and lead WP 3.2 (Trials and Measurements) activities during the first phase.

TA participated in the elaboration of the workplan for the trials and in testing the Resource Control Agent in both phases of the project, under different, as realistic as possible conditions. TA contributed to the Requirement Analysis with a focus on ongoing standardisation aspects influencing the project activities. Further TA participated in the evaluation process of the project results.

### 1.1.11 Telekomunikacja Polska S.A.

Polish Telecom focused on requirements identification for the QoS IP network from the provider's point of view, software world wide market trends analysis, the implementation of a pilot network together with QoS management and measurements in the backbone in the AQUILA trials as well as Central & Eastern Europe market analysis for IP services and exploitation of project results. TP lead WP 3.2 from the first trial until the end of the project.

### 1.1.12 Politechnika Warszawska

Warsaw University of Technology was involved in four workpackages: WP 1.2 (System Specification), WP 1.3 (Traffic Engineering), WP 3.1 (Trial Integration) and WP 3.2 (Trials and Measurements). Main contributions were to WP 1.2: specification of control loops, to WP 1.3: specification of network services (traffic descriptors, developing of admission control rules, guidelines for trials), to WP 3.1: system integration in Warsaw testbed (including) router trial performing, to WP 3.2: specification of trials corresponding to network services, trial performing.

## 1.2 Main achievements

- The project designed an architecture for a distributed resource and admission control infrastructure to enable edge-to-edge QoS oven a DiffServ network. The architecture comprises the following components:
  - A Resource Control Agent (RCA), which manages a hierarchical view of available resources in the network. The hierarchical structure enables distributed operation of this core component.

- Admission Control Agents (ACA), which can autonomously make admission control decisions according to the resource limits provided by the RCA. The ACA also establishes the necessary rules in the associated router to enable the QoS flow and to retrieve usage data.
- End-user Application Toolkit (EAT), which provides versatile mechanisms to access the AQUILA QoS architecture. Newly developed applications as well as legacy applications can use the EAT to request network resources.
- Inter-domain QoS is provided through an additional layer on top of the basic QoS domain architecture. BGRP agents are used to signal resource request over domain boundaries, taking into account the established SLAs between neighbouring domains. Appropriate aggregation mechanisms are used to provide a Internet-wide scalable architecture.

- The project considered the full range of traffic handling mechanisms that are needed to support the designed end-to-end dynamic QoS architecture:
  - Provisioning mechanisms for long term assignment of resources operating at the time scale of days to weeks
  - Resource Pools mechanisms for short term resource redistribution between RCA and ACA, operating at the time scale of tens of minutes to hours.
  - Admission Control mechanisms dealing with acceptance of new flows, operating at the time scale of seconds to minutes.
  - Traffic Control mechanisms related to the handling of IP packets in the routers, operating at (sub)milliseconds time scale.

The detailed specification of all mechanism in a consistent framework was given (as needed for the implementation and the demonstration). Theoretical analysis has complemented and where possible guided the specification work.

- The project implemented the above-mentioned architecture using the JAVA platform.

Finally it can be stated, that the approach, methodologies and technologies used have been well suited for the distributed development within an international project:

- Segmentation of the overall system into well-defined subsystems using object oriented analysis.
- Early specification of interfaces using a formal interface definition language (IDL)
- Common base technologies for application start-up, tracing and configuration.

- The project successfully developed and tested several mechanisms to provide AQUILA QoS support to different kinds of applications. The one responsible middleware that offers all these interface is the EAT which acts as the only QoS portal to the AQUILA's RCL controlled network. The application interfaces are:
  - Application Programming Interface (API) for QoS-aware applications

  - Graphical User Interface (GUI) for manual reservations in different modes for legacy applications that are not QoS-aware
  - Application Profiles to store QoS characteristics of legacy applications and to allow QoS mapping from a technical to a user-friendly level
  - Application Level Proxies to support some special application signalling protocols

- Design and implementation of a distributed measurement architecture with the following main features
  - Combination of active and passive measurement technologies
  - Centralised measurement control via a web-based graphical user interface
  - Remote controlled measurements by distributed agents
  - Performant load generators highly parameterisable for emulation of applications
  - High-precision one-way measurements by usage of GPS equipment
  - Reservation signalling to the AQUILA QoS architecture
  - Implementation of standardised parameters (IETF IPPM)
  - Measurement database storing measurement results correlated to test scenarios.
- The project successfully integrated the proposed system architecture in the three trial sites (Warsaw, Vienna, Helsinki). The key characteristics and factors that enabled the successful completion of the integration procedure included:
  - Well defined integration workplan
  - Stepwise integration procedure, starting from stand-alone integration for each module to the overall system integration.
  - Excelent teamwork and cooperation between the partners
  - Well defined test scenarios that ensured the required functionality provided by the system components
- In the project the testing environment and methods were developed and measurement results were obtained for the following trial scenarios:
  - evaluation of network services (single domain, inter-domain and for secondary access links),
  - users trial for different applications (voice, video and audio streaming, interactive games),
  - RCL performance (inter- and intra-domain),
  - evaluation of resource pool mechanism.

# 2 Project Objectives

In order to satisfy the huge commercial demand for Quality of Service (QoS) solutions over IP networks, the project AQUILA defined, evaluated, and implemented 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) were used as basis for the specification of this architecture and significantly enhanced and exploited.

The achieved technical solutions have been verified by testbed experiments and by trials involving end-users. The trials included QoS demanding on-line services, e.g. multimedia services. The straight exploitation of the results was achieved by the development of business plans.

**The key objectives of the project were:**

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 were 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 analyse ***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 has been enhanced introducing dynamic resource and admission control. The main features of this architecture are as follows:

   - The architecture is 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 is cost-effective, scalable and backward compatible for the provisioning of QoS in IP networks covering both the inter- and intra-domain QoS.

   - The architecture considers the requirements for QoS accounting.

   - The architecture keeps 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 included:

   - 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 were a basis for optimisation 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 supported incremental transition from best effort to differentiated QoS. The change involved both the technology and the offered services. The project evaluated different deployment scenarios and defined a migration strategy for the operators and service/content providers.

7. To ***contribute to standardisation*** bodies like IETF, ITU, ETSI, OMG etc. This included regular attendance of key personnel at the standardisation meetings and active contributions.

In order to achieve these objectives, the AQUILA project joined 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 software technology. This comprehensive combination enabled the AQUILA consortium to design, 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 Methodologies

One of the most challenging aspects of the project was the high speed of technological development in the area addressed by the project. It is very difficult - if not impossible - to define detailed objectives and technical approach for such a project in advance for a period of three years. Therefore, this project defined a project structure, which was able to adapt the project to the rapid changes in its scientific and market environment.

In the discipline of software engineering, approaches for dealing with projects of high-risk have been investigated already for some time. One of the most famous results is the so-called "spiral model" of system development (Barry Boehm 1988). Figure 1 shows a simplified version of this model. The basic idea is that the move from requirements to final product does not only go through several phases (as the basic "waterfall model" assumes) but that progress takes place in circles where some activities are repeated several times, but applied to more detailed intermediate products. In particular, the assessment of risk and the evaluation of alternatives should be part of any pass of the circle. Moreover, it is recommended to develop some kind of prototype at the end of each circle, even in the early phases of the project.

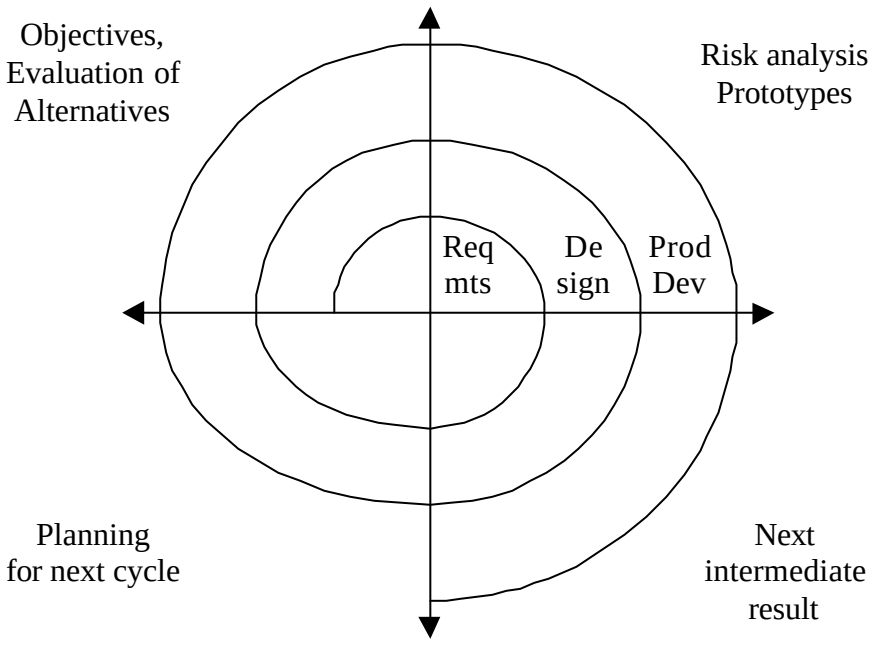



***Figure 1: Spiral Model of Development***

This basic idea was adapted to the project structure for this proposal as follows:

- There was a workpackage (WP 1.1) for the whole project lifetime, which watched the current technological trends and evaluated alternatives to achieve the project objectives.

- There were six pre-planned cycles of development, leading to a first trial (in three iterations through requirement analysis, design and development) and to a second trial (in the same three kinds of iterations). Compared to Figure 1 above, the project added three more cycles.
- In each development cycle, it was possible that some technological decisions of the project were changed. This was trivially true for the two iterations that explicitly dealt with requirement analysis. But also during other project phases (design, product development), changes of direction were possible. Such changes were initiated by the ongoing trend watch workpackage, but of course were carefully evaluated against the potential risks (i.e. risk of not using adequate technology vs. risk of delay or risk of reduced functionality).

In more detail, the following methodologies have been used:

- Regarding AQUILA resource control components:
  - Clear package separation and interface definitions using CORBA IDL,
  - common JAVA development platform,
  - common source code repository,
  - centralised LDAP database for all configuration data,
  - XML-based configuration data description and automatic code generation for access to this data.
- Regarding traffic handling specification and studies
  - Simulation using both public domain (NS) and commercial tools (OPNET)
  - Analytical modeling
- Regarding application support & interfaces:
  - distributed QoS middleware architecture with different application interfaces,
  - platform and programming language independent, remote (CORBA) QoS API,
  - extensible proxy framework for independent automatic and half-automatic protocol gateways,
  - web-based graphical user interfaces (AQUILA portal),
  - automatically generated regular reservation pages for different applications,
  - flexible, extensible application profiles in XML to support legacy applications.
- Regarding distributed measurement architecture:
  - active measurements with application-like load generators for evaluation and validation of the QoS architecture

  - active network probing for measurement of path performance characteristics
  - passive measurements by router monitoring for detection of bottleneck links.

- Regarding the integration of the system components:
  - Definition of a step-wise integration methodology starting with standalone verifications, moving to island integration and finally obtaining global interconnection
  - Establishment of a software library (including the code and the configuration data) to ensure the integrity and the consistency of all the modules installed in the trial sites
  - Definition of test cases that were carried out during the integration meetings in order to validate the required functionality.
- Regarding methodologies for trial scenarios:
  - trial objectives, testbed configuration, partners co-operation,
  - measurement methods for different QoS and network parameters,
  - result assessment and analysis methods.
- Regarding project management:
  - Intensive use of e-mail for discussion, information dissemination etc.; establishment of e-mail exploders for workpackages and special topics
  - Establishment of a project document archive with restricted access for consortium members only; upload area for software development (sources, modules etc.) and trials
  - Handling of unique document numbers via a special reference number server
  - Maintenance of the project's Internet home pages including a download area for all public documents.

# 4 Project Results and Achievements

The project team based its work on the specification of the AQUILA architecture on the technical state of the art. DiffServ in the core network and the bandwidth broker concept have been the starting point for the definition of this architecture. The basic requirement for scalability resulted in a highly distributed and modular architecture. Practical deployment of the architecture requires, that the AQUILA resource control layer can interact with off-the-shelf router products. Interworking with several types and software versions of Cisco routers as well as Unisphere/Juniper routers has been demonstrated.

During the process of definition of the architecture, also the practical implications for implementation have been taken into consideration. Modular building blocks have been designed, which have clear and narrow interfaces and can operate autonomously, as far as possible. This has advantages for implementation, scalability and robustness.

Intra-domain and inter-domain resource control are seen as two separate layers. This enables the deployment of inter-domain QoS in a scenario, where not all domains implement the AQUILA style of resource control.

An important achievement was the specification of the whole set of traffic handling mechanisms for dynamic IP QoS in a consistent framework. The relationships between packet level Traffic Control, flow level Admission Control and resource control at aggregate level have been considered, so that all these mechanism are exploited in the AQUILA architecture. From the theoretical point several interesting results about the Traffic Handling mechanism in dynamic Diffserv-based IP QoS networks were obtained. Some of the topics that have been addressed are: Declaration and Measurement Based Admission Control, Inter-domain resource management, Distributed Admission Control, WRED mechanisms for TCP traffic, rate assurance for TCP flows and so on.

While technological leadership was one of the driving forces of the project, the end-users needs have not been neglected. Network service definitions cover the full range of Internet applications available today and in the near future.

- The integration of research and educational facilities with industrial partners in IST projects improves personal contact of students and potential employer.
- The project fulfilled one of its main objectives, which is the support of any relevant kind of IP application. In the following, the different aspects of this support are mentioned as well as their implications on the application developers & users:
    - The developers of new QoS-aware applications and services are supported by providing an **Application Programming Interface (API)** on the top of the **End-user Application Toolkit (EAT)**, which is a QoS middleware between applications and the (AQUILA) network. The EAT and its API is implemented in Java and provides its interfaces via CORBA in order to remotely support a wide range of applications. The by the project

adapted Complex Internet Service **Mediazine** shows how to access the API in order to provide QoS to its embedded basic applications such as NetMeeting and RealPlayer.

- The users of existing, QoS-unaware legacy applications are supported by providing **Graphical User Interfaces (GUIs)** for manual QoS requests in different usage modes. These GUIs together form the web-based **AQUILA QoS Portal**. Since the most users might be not familiar with AQUILA, the flexible approach of predefined **Application Profiles** is used to allow a mapping between user's QoS understanding and the technical details of AQUILA QoS reservation requests. Moreover, theses application profiles are also used by Mediazine for its embedded legacy applications without any need to recompile them.

- Some special applications based on dynamic signalling protocols are supported by providing transparent **Proxies (Protocol Gateways)** which collect important information directly from application's traffic in order to use them for reservation requests. Two different kinds of proxies were developed and tested: one half-automatic proxy for applications that rely on the H.323 signalling protocol (such as NetMeeting), and one full-automatic proxy for SIP-based applications (such as VoIP).

- Also automatic tests and measurements by the project itself are supported by providing a script interface for the batch processing of QoS requests. Similar to the GUIs, this script interface acts as a client of the EAT's API.

- Despite of the fact that all these interfaces are developed for AQUILA, they can be adapted and reused for other underlying QoS architectures. The application profiles methodology, for example, provides a generic mechanism to specify QoS characteristics on different levels and for different protocols.

- Another great challenge for the project consortium was the integration of the system modules at the trial sites. The key objectives of the integration workpackage (3.1) included:
  - elaboration of a two-phase integration workplan and definition of the interoperability tests
  - continuous check of availability of all software and hardware components, identification and monitoring of the critical integration paths
  - stepwise integration and test of all software and hardware modules

  During the project lifetime two integration meetings were held following the two-phase trial workplan. Both meetings have been concluded with great success enabling the trials to be carried out in time. The integration workplan followed a stepwise approach:

- Standalone integration: the functionality of individual modules was tested. In some cases this was achieved with the use of dummy modules. With the term "dummy", we refer to modules that only implement the interface to the module under test and not the complete functionality.

- Overall software integration: the functionality of the various layers (Resource Control Layer, Inter-domain Layer, management layer) was tested. End-to-end reservations were accomplished, without using any network infrastructure (e.g. routers).

- Overall system integration: Routers were incorporated to the already tested software layers and end-to-end reservation tests were conducted, using applications or traffic generators.

  The first trial served as a proof of concept of the system architecture and from the integration point of view provided valuable experience that was employed for the next steps towards the final trial integration

  The second trial required the setup of three trial sites, Vienna, Warsaw and Helsinki One of the main challenges of the second trial, from the integration point of view, was the interconnection of the trial sites (namely Vienna and Warsaw). Towards this end, the assistance of the operators of the European research network (GEANT) has been requested. The response was imminent and thanks to a fruitful cooperation the interconnecting link was up on time. It must be noted at this point that all the integration tests were performed successfully.

- One of the main objectives of the project was the practical verification of the developed solution. During two phases of trials, the AQUILA approach was proven taking into account different objectives for its evaluation. Particularly, for the AQUILA solution the following results were achieved:

  - For network services approach evaluation (inter- and intra-domain), PCBR, PVBR, PMM, PMC services meet QoS requirements specified for each service. The measured delay and packet loss ratio does not exceed predefined values.

  - For secondary access link in the case of network services the results show that some QoS targets were not quite reached but sufficient differences between traffic classes were noticed. So, the proposed approach can work properly in access networks.

  - The user trial confirms the expectations that VoIP needs a prioritised service in IP network. PCBR service in AQUILA network supports VoIP in sufficient way. For real-time services, like videoconference and video streaming, one can conclude that such applications can be effectively supported by the PVBR service. For video streaming application, like those provided by the Mediazine server, it was observed that the PMM service in AQUILA network supports non-real-time streaming services in appropriate way.

  - It was shown, that different services, providing appropriate QoS to different applications, can co-exist in the AQUILA network.

  - For intra-domain RCL performance the results show the following:

    - the processing delay of signalling messages is not dependent on AC scheme,

    - the increasing number of existing reservations does not increase the reservation set-up time,

    - processing delay of initial request operation is much longer than for subsequent requests (4, 5 seconds for initial and 1,1 seconds for subsequent),

  - processing delay of release operation is much shorter than request operation,
  - router contribution to total delay changes with different operations, and is about 70% of total delay for subsequent requests and 20% for initial requests

- For inter-domain RCL performance the results show the following:
  - router configuration and BGRP agent makes up a relatively large contribution to total reservation set-up times,
  - the increasing number of existing reservations does not increase the reservation set-up time,
  - processing delay of initial request operation is much longer than for subsequent requests (25,8 seconds for initial and 1,45 seconds for subsequent),
  - joining an existing sink-tree decreases the reservation set-up time.
- For the Resource Pool mechanism developed in the AQUILA project the objective was to verify whether the requests are accepted or rejected, depending on the RP algorithm and on the configured AC limits. The trial shows that the stability of the algorithm was achieved and it works properly in the case of resource requests made by one host.
- For the evaluation and validation of the QoS architecture the application-like load generator with end-to-end QoS measurement was developed to evaluate the end-to-end performance of the network and to validate, whether the network provides the requested QoS parameters. The parameters were one-way delay, jitter, throughput and packet loss. Different load models were used according to the different network services.
- The main enhancements of the measurement tools for the second trial were the support of collecting router monitoring data and the provision of enhanced traffic generators. Furthermore the feedback on the design and implementation of the measurement tools coming from the first trial has been taken into account for the enhancements for the second trial.
- AQUILA measurement tools were useful and necessary components for the trials in addition to other existing measurement equipment. Due to their flexibility they were extensively applied for a wide range of trial scenarios.

- Key objectives of WP 3.3 “Exploitation and business plans” were to analyse the market situation for QoS solutions and to exploit the results of the project creating applicable business plans based on the user and service provider requirements. Therefore an end user online survey was implemented and decision-makers from potential AQUILA business customers were interviewed. First general conditions for the creation of exploitation and business plans were specified by means of the statistical analyses of the gained data and the valuation of possible field of business and companies and their needs for QoS supported solutions and technologies.

Differences and common points of the Western European and Central & Eastern European network markets in particular were acquired. The results are available in detail within deliverable D3301.

On the basis of the gained information, general value chains were generated and the exploitation plans of each project partner were updated. The partners were divided into four groups: researchers, suppliers, network operators and service providers. The possibilities for exploitation of the AQUILA results were dealt with in detail in a second cycle. Due to the poor global market situation for IT companies, no meaningful and usable business ratios for the elaboration of concrete business plans could be ascertained. As an alternative a detailed description of the current market situation for QoS solutions as well as first basic ideas and approaches for possible business plans is available within deliverable D3302.

# 5 Deliverables and References

The project produced a set of *management* and *technical* deliverables. This chapter contains a table as well as a list of brief descriptions of all deliverables. They are ordered by due date of the deliverables according to the Technical Annex.

All deliverables with the security level "Public" are available on the project's home page at http://www.ist-aquila.org/, and can also be download directly from this document, chapter 5.2.

All deliverables were submitted in time or even before the contractual due date or with little delay as agreed by the Project Officer of the European Commission.

## 5.1 Deliverables Table

| Del. No. | Revision | Title | Type[1] | Classification[2] | Due Date | Issue Date |
|---|---|---|---|---|---|---|
| D001 | b0 | Relations to other IST projects and external organisations | R | Pub. | 31.03.2000 | 23.03.2000 |
| D1101 | b0 | Analysis and requirements report | R | Pub. | 31.03.2000 | 30.03.2000 |
| D002 | b0 | Project Presentation | R | Pub. | 30.04.2000 | 30.04.2000 |
| D1201 | b0 | System architecture and specification for the first trial | O | Pub. | 30.06.2000 | 30.06.2000 |
| D1301 | b0 | Specification of traffic handling for the first trial | O | Pub. | 30.06.2000 | 21.07.2000 |
| D003 | b0 | Dissemination and Use Plan | R | Rest. | 30.06.2000 | 30.06.2000 |
| D2101 | b0 | Design and functional specification of the Resource Control Agent for the first trial | O | Rest. | 30.09.2000 | 29.09.2000 |
| D2201 | b0 | Specification of End-user Application Toolkit | O | Rest. | 30.09.2000 | 29.09.2000 |
| D2301 | b0 | Report on the development of measurement utilities for the first trial | R | Pub. | 30.09.2000 | 29.09.2000 |
| D2102 | b0 | Report on implementation of the Resource Control Agent for the first trial | R | Rest. | 31.03.2001 | 29.03.2001 |
| D2202 | b0 | Description of user applications for the first trial | O | Pub. | 31.03.2001 | 29.03.2001 |
| D3101 | b0 | First Trial Integration Report | R | Pub. | 31.03.2001 | 29.03.2001 |
| D1202 | b0 | System architecture and specification for the second trial | O | Rest. | 30.06.2001 | 28.09.2001 |

| | | | | | | |
|---|---|---|---|---|---|---|
| D1302 | b0 | Specification of traffic handling for the second trial | O | Rest. | 30.06.2001 | 28.09.2001 |
| D3201 | b0 | First Trial Report | R | Pub. | 30.06.2001 | 13.07.2001 |
| D2103 | b0 | Design and functional specification of the Resource Control Agent for the second trial | O | Rest. | 31.12.2001 | 21.12.2001 |
| D2203 | b0 | User Guide for End-user Application Toolkit | R | Pub. | 31.12.2001 | 21.12.2001 |
| D2303 | b0 | Report on the development of measurement utilities for the second trial | R | Pub. | 31.12.2001 | 21.12.2001 |
| D3301 | b0 | Exploitation Plan | O | Rest. | 31.12.2001 | 21.12.2001 |
| D1202 | b1 | System architecture and specification for the second trial | O | Pub. | | 31.12.2001 |
| D1302 | b1 | Specification of traffic handling for the second trial | O | Pub. | | 31.12.2001 |
| D1203 | b0 | Final system specification | O | Pub. | 31.03.2002 | 26.04.2002 |
| D2104 | b0 | Report on implementation of the resource control agent for the second trial | R | Rest. | 30.06.2002 | 28.06.2002 |
| D2204 | b0 | Description of user applications for the second trial | O | Pub. | 30.06.2002 | 28.06.2002 |
| D3102 | b0 | Second trial integration report | R | Pub. | 31.10.2002 | 30.10.2002 |
| D2104 | b1 | Report on implementation of the resource control agent for the second trial | R | Pub. | | 12.12.2002 |
| D3202 | b0 | Second Trial Report | R | Pub. | 31.12.2002 | 27.02.2003 |
| D004/ D3302 | b0 | Dissemination and Use Plan Update | R | Rest. | 31.12.2002 | 20.12.2002 |
| D1203 | b1 | Final system specification | O | Pub. | | 26.02.2003 |
| D2203 | b1 | User Guide for End-user Application Toolkit | R | Pub. | | 26.02.2003 |
| D004/ D3302 | b1 | Dissemination and Use Plan Update | R | Rest. | | 26.02.2003 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **D2303** | **b1** | **Report on the development of measurement utilities for the second trial** | **R** | **Pub.** | | **09.03.2003** |
| **D1302** | **b2** | **Specification of traffic handling for the second trial** | **O** | **Pub.** | | **31.03.2003** |
| **D1303** | **b0** | **Traffic Handling Studies** | **R** | **Pub.** | | **31.03.2003** |
| **D005** | **b0** | **Final Project Report** | **R** | **Pub.** | **31.12.2002** | **31.03.2003** |

[1] *R: Report; O: Other – Specify in footnote (**here: Specification**)*

[2] *Rest.: Restricted circulation list and Commission SO + reviewers only; Pub.: Public document*

## 5.2 Summaries of Deliverables

### *5.2.1 D001*

Deliverable N°: D001 (IST-1999-10077-WP0-SAG-001-PU-R/b0)

Title: Relations to other IST projects and external organisations

At the beginning of the new IST Programme work item: "Next Generation Networks (NGN)", it is necessary to ensure that the Commission and all the projects working on this topic are familiar with the scope and objectives of the other projects, in order to exploit areas of synergy and to avoid overlap. After a short Introduction to this document, chapter 4 performs precisely this task, by presenting a short description of each selected project addressing Action Line IV.2.3.
All projects working in the area of Next Generation Networks and the related Action Lines covered by Unit INFSO E1, as well as projects from other Units, which have interests in Next Generation Networking, and in particular relevant testbeds, and relevant third parties have been invited by the CEC to participate in related concertation actions.
It is important to note that, although all projects address the same Action Line, this document highlights the fact that the topic of "Internet Infrastructure" is many-faceted.
When also other aspects such as standardisation (including the work in IETF, Internet2 and ETSI), management, charging and trialling of new protocols are included, it can quickly be appreciated that there is room for all the projects mentioned in chapter 4, without a danger of serious overlap.

### *5.2.2 D1101*

Deliverable N°: D1101 (IST-1999-10077-WP1.1-DTA-1101-PU-R/b0)

Title: Analysis and Requirements Report

The aim of the AQUILA project is to create, implement and evaluate a scalable enhanced end-to-end Quality of Service architecture for IP networks. During the ongoing project, the AQUILA project partners will observe the Internet2 initiative as well as IETF and other related activities not only to be as open as possible to new developments, but also to actively contribute.

This deliverable collects an overview and identifies Quality of Service sensitive products as well as implementations which could be the base for the project at an early stage. First recommendations for the project are given.

Both provider and user requirements will be summarised in order to be in the position to establish a customer friendly environment that is manageable and scalable as well. To meet the actual user requirements, questionnaires were designed for both end users and business customers. The subjectively felt insufficiencies of the current internet were addressed as well as the preferred services and the access methods used.

### 5.2.3 D002

Deliverable N°: D002 (IST-1999-10077-WP0-SAG-002-PU-R/b0)

Title: Project Presentation

This deliverable includes an overall description of the AQUILA project. It gives an overview on the objectives and the technical background. The document also contains the project's technical approach and a description of the various workpackages.

Additional information can be found at the project's home page at: http://www.ist-aquila.org/

### 5.2.4 D1201

Deliverable N°: D1201 (IST-1999-10077-WP1.2-SAG-1201-PU-O/b0)

Title: System architecture and specification for first trial

This deliverable details the system architecture used for the prototypes in the first trial. The focus is on a single-ISP scenario. The architecture specifies the function split and the black-box behaviour of the components developed in WP 2.1. The deliverable is used for internal and external communication of the system architecture.

### 5.2.5 D1301

Deliverable N°: D1301 (IST-1999-10077-WP1.3-COR-1301-PU-O/b0)

Title: Specification of traffic handling for the first trial

This deliverable specifies the traffic handling mechanisms for the first trial. The traffic handling mechanisms are defined in the AQUILA project at three different levels: traffic control, admission control and initial provisioning. The traffic control mechanisms are referred to the packet level control in the IP routers (i.e., scheduling and policing). The admission control mechanisms are referred to the dynamic flow level admission control performed by the AQUILA resource control layer. The initial provisioning mechanisms are referred to the "off-line" configuration of the traffic control and admission control mechanisms.

### 5.2.6 D003

Deliverable N°: D003 (IST-1999-10077-WP0-SAG-003-RE-R/b0)

Title: Dissemination and Use Plan

In this deliverable, the use plans of the industrial partners and some preliminary ideas for the dissemination plan of the research partners are put together.

While industrial partners (like equipment providers, network operators, Internet service providers) focus on the demands of next generation Internet and its need for development of adequate products, the research partners describe their view of potential publications in the research community and the enhancement of educational activities by the knowledge gained during the project.

Moreover, in addition to these somehow individual plans, the project plans to actively contribute to and participate in related horizontal or concertation activities together with other IST projects in the Next Generation Networks cluster.

### 5.2.7 D2101

Deliverable N°: D2101 (IST-1999-10077-WP2.1-SAG-2101-RE-O/b0)

Title: Design and functional specification of the Re-source Control Agent for the first trial

This deliverable describes the functions and the design of major parts of the AQUILA resource control layer. It is based on the system architecture specified in D1201. It covers all the components described there, except for the end-user application toolkit (EAT), described in D2201. As D1201 is already considerably detailed with respect to the functional descriptions and partly even contains coarse design descriptions, this document uses references to D1201 wherever reasonable in order to avoid redundancy.

### 5.2.8 D2201

Deliverable N°: D2201 (IST-1999-10077-WP2.2-TUD-2201-RE-O/b0)

Title: Specification of End-user Application Toolkit

This deliverable specifies the general functionality of the End-user Application Toolkit (EAT). It describes how applications will be supported to benefit from the QoS capabilities of the AQUILA approach.

On the one hand, this deliverable contains, on an overall level, the specification of the EAT for the whole project. On the other hand, it focuses on the single components that are going to be realised for the first trial. This will be done in more detail than the overall description, i.e. the concerning chapters contain design models and specifications.

The reason is that workpackage 2.2 aims at the preparation of a skeleton toolkit for the first trial. Several important components will be realised in order to support at least legacy applications.

### 5.2.9 D2301

Deliverable N°: D2301 (IST-1999-10077-WP2.3-SPU-2301-PU-R/b0)

Title: Report on the development of measurement utilities for the first trial

This deliverable describes the status of the development process of the measurement utilities for its usage in the first trial. Until D2301 the development concentrates on the basic implementation with a measurement information database and simple traffic generators simulating different types of application oriented synthetic load. Part of this deliverable will be a guideline for integration of the measurement utilities into the first trial. Hence, target audience for this deliverable are the members of WP3.1 and WP3.2.

### 5.2.10 D2102

Deliverable N°: D2102 (IST-1999-10077-WP2.1-SAG-2102-RE-R/b0)

Title: Report on implementation of the Resource Control Agent for the first trial

This deliverable reports on the implementation of major parts of the AQUILA resource control layer. It is based on the design and functional specification [D2101]. D2102 was produced by updating D2101, so that it now describes the status of the resource control layer components as used for the first trial.

### 5.2.11 D2202

Deliverable N°: D2202 (IST-1999-10077-WP2.2-TUD-2202-PU-O/b0)

Title: Description of user applications for the first trial

This deliverable describes the application functionality offered to the end-users of the first trial. Existing multimedia offers and applications will be the focus of the first trial. Therefore, the deliverable concentrates on so-called legacy applications and how to support them.

Although a full integration with the End-user Application Toolkit (EAT) is not yet expected for the first trial but for the second one, the applications mentioned in this deliverable will benefit from a skeleton EAT which is already specified in [D2201]. In detail, the deliverable describes how applications will be integrated in the AQUILA approach for the first trial.

### 5.2.12 D3101

Deliverable N°: D3101 (IST-1999-10077-WP3.1-NTU-3101-PU-R/b0)

Title: First Trial Integration Report

The present document is the first major deliverable provided by WP 3.1 of the AQUILA project. It describes in detail the procedures that took place for the verification of the correct operation of the AQUILA Resource Control Layer and Measurement Tools. It also contains instructions for the installation of the working prototypes in other trial sites as well as instructions for their use during the trials. Finally, the results of the integration are presented.

### 5.2.13 D1202

Deliverable N°: D1202 (IST-1999-10077-WP1.2-SAG-1202-RE-O/b0)

Title: System architecture and specification for the second trial

This deliverable describes the system architecture used for the prototypes in the second trial. Additionally, studies on related topics, which are not going to be implemented, are included in this document. The base for this specification is D1201. For the second trial, a couple of extensions are specified.

### 5.2.14 D1302

Deliverable N°: D1302 (IST-1999-10077-WP1.3-COR-1302-RE-O/b0)

Title: Specification of traffic handling for the second trial

This deliverable provides the specification of traffic handling for the second trial. Three main objectives are covered:

- to fix the shortcomings in first trial specification, taking into account the valuable experience of the implementation work and especially of the trials
- to enhance the first trial specification with new outstanding features:
  - Measurement Based Admission Control
  - Control loops from Measurement into Provisioning and Resource Pool
  - Inter-domain Resource Reservation
- to provide a critical analysis and to review some aspects of first trial specifications:
  - Choice of network services and traffic classes
  - Scheduling and queue management mechanisms

### 5.2.15 D3201

Deliverable N°: D3201 (IST-1999-10077-WP3.2-TPS-3201-PU-R/b0)

Title: First Trial Report

This deliverable reports and summarises the experimental results obtained during the first trial. The primary objective of these experiments was to verify the AQUILA architecture for providing QoS in the IP network (described in previous deliverables D1201 and D1301). In particular, the reported results cover the following areas: evaluation of network services, experiments with legacy applications supported by defined network services, validation of admission control algorithms, validation of resource management functions (e.g. resource pool mechanisms) and performance evaluation of the signalling system.

### 5.2.16 D2103

Deliverable N°: D2103 (IST-1999-10077-WP2.1-SAG-2103-RE-O/b0)

Title: Design and functional specification of the Resource Control Agent for the second trial

Taking into account the experiences from the first trial implementation, this deliverable specifies the design of the resource control and inter-domain layer as well as management and utility components. It reuses elements from the first trial implementation wherever possible. Addition of functions, better structuring and unification however cause redesign of some parts of the architecture.

### 5.2.17 D2203

Deliverable N°: D2203 (IST-1999-10077-WP2.2-TUD-2203-PU-R/b1)

Title: User Guide for End-user Application Toolkit

This deliverable D2203 reports on the application and user interfaces, which the EAT provides for the second AQUILA trial. These are: the QoS API, the QoS GUI/Portal, the Application Profiles, and the Application Level Gateways. The deliverable describes in detail their functionality and shows usage scenarios.

### 5.2.18 D2303

Deliverable N°: D2303 (IST-1999-10077-WP2.3-SPU-2303-PU-R/b1)

Title: Report on the development of measurement utilities for the second trial

This deliverable describes the enhancements of the measurement utilities, enhanced traffic generators on application level and the interface to network information from routers and how they can be exploited in the second trial. It also describes methods how the measurement results can be analysed for the evaluation and validation of the AQUILA QoS architecture.

### 5.2.19 D3301

Deliverable N°: D3301 (IST-1999-10077-WP3.3-BAG-3301-RE-O/b0)

Title: Exploitation Plan

This deliverable D3301 reports on the exploitation plans of the AQUILA project partners. It describes state of the art network services and Internet services within the European market and it explains the differences and commonness between the Central and Eastern European market and the Western European market. Further on, this document presents requirements and methods to develop business plans - within the subsequent deliverable D3302 - based on the exploitation plans.

### 5.2.20 D1202

Deliverable N°: D1202 (IST-1999-10077-WP1.2-SAG-1202-PU-O/b1)

Title: System architecture and specification for the second trial

This deliverable describes the system architecture used for the prototypes in the second trial. Additionally, studies on related topics, which are not going to be implemented, are included in this document. The base for this specification is D1201. For the second trial, a couple of extensions are specified.

### 5.2.21 D1302

Deliverable N°: D1302 (IST-1999-10077-WP1.3-COR-1302-PU-O/b2)

Title: Specification of traffic handling for the second trial

This deliverable specifies the traffic handling mechanisms for the second trial. Traffic handling in AQUILA is composed of four related mechanisms operating at different time scales: provisioning (days to weeks), resource pools (hours), admission control (seconds to minutes), traffic control (milliseconds).

### 5.2.22 D1203

Deliverable N°: D1203 (IST-1999-10077-WP1.2-SAG-1203-PU-O/b1)

Title: Final system specification

This deliverable D1203 specifies the final system architecture of the resource control agent. It may serve as a reference to the structure of the AQUILA approach to QoS. It also includes the software architecture of the resource control layer.

### 5.2.23 D2104

Deliverable N°: D2104 (IST-1999-10077-WP2.1-SAG-2104-PU-R/b1)

Title: Report on implementation of the resource control agent for the second trial

The basic structure of the implementation as well as experience made with several software technologies like JAVA, CORBA, LDAP, XML, is reported in this document. Common mechanisms used throughout the components are described.

### 5.2.24 D2204

Deliverable N°: D2204 (IST-1999-10077-WP2.2-TUD-2204-PU-O/b0)

Title: Description of user applications for the second trial

This deliverable D2204 describes the applications offered to the end-users of the second trial. It firstly demonstrates their functionality and typical usage scenarios. Secondly, the deliverable shows the QoS requirements of the applications in detail and how they are handled by Application Profiles.

### 5.2.25 D3102

Deliverable N°: D3102 (IST-1999-10077-WP3.1-NTU-3102-PU-R/b0)

Title: Second trial integration report

This document describes the results of the second trial integration of the AQUILA network. The tests needed for the verification of its functionality and the procedure for the set up of new trial sites are presented.

### 5.2.26 D3202

Deliverable N°: D3202 (IST-1999-10077-WP3.2-TPS-3202-PU-R/b0)

Title: Second Trial Report

Deliverable D3202 contains the second trial results performed in AQUILA testbeds. The experiments are related to Network Services, Resource Pool Mechanism, RCL performance and real user trials.

### 5.2.27 D004/D3302

Deliverable N°: D3302 (IST-1999-10077-WP3.3-BAG-3302-RE-R/b0)

Title: Dissemination and Use Plan Update

This combined deliverable D004/D3302 reports the current market situation in the Western European and Central and Eastern European market. The report presents revenue scenarios for research as well as for network operators, suppliers and service providers based on the updated dissemination and use plans of all AQUILA project partners. It presents the AQUILA expectations to the market for the business cases subscription based business model, the pay-per-use and revenue-sharing based business model and the advertisement based revenue model.

### 5.2.28 D1303

Deliverable N°: D1303 (IST-1999-10077-WP1.3-COR-1303-PU-R/b0)

Title: Traffic Handling Studies

This deliverable collects the studies about the traffic handling mechanisms in the AQUILA architecture. Traffic handling in AQUILA is composed of four related mechanisms operating at different time scales: provisioning (days to weeks), resource pools (hours), admission control (seconds to minutes), traffic control (milliseconds).

### 5.2.29 D005

Deliverable N°: D005 (IST-1999-10077-WP0-SAG-005-PU-R/b0)

Title: Final Project Report

This deliverable D005 is the Final Project Report of the AQUILA project. It gives a brief overview on the project, lists the main achievements, the deliverables and the results. It also provides a self-assessment.

## 5.3 References

### 5.3.1 Conference papers and presentations

- *"A rate controller for long-lived TCP flows"* (Dorfinger, Brandauer, Hofmann), accepted paper at IDMS/PROMS'2002 (Joint International Workshop on Interactive Distributed

Multimedia Systems/Protocols for Multimedia Systems), Coimbra, Portugal, November 26-29, 2002

- "*AQUILA presentations*" (Eichler (*moderation*), Miettinen / Thomas (*Questions & Answers*), Karadimas, Strohmeier, Winter (*demonstrations*), Dabrowski, Salsano (presentations)) at Premium IP Cluster Workshop & Review, Florence, Italy, November 21-22, 2002

- *"Supplying legacy applications with QoS: a description syntax at application, end-user and network level"* (Thomas), accepted paper at SEA 2002 (IASTED conference on "Software Engineering and Applications"), MIT, Cambridge, MA, USA, November 4-6, 2002

- *"Description of QoS Requests and Offers*" (Thomas, Eichler), accepted paper at EURESCOM Summit 2002 (Powerful Networks for Profitable Services), Heidelberg, Germany, October 21-24, 2002

- *"Applying the BGRP concept for a Scalable Inter-Domain Resource Provisioning in IP Networks"* (Sampatakos, Nikolouzou, Venieris), accepted paper at Interworking'2002 (The 6th International Symposium on Communications Interworking), Perth, Australia, October 13-16, 2002

- "*Adaptive Resource Control for QoS Using an IP-based Layered Architecture*" (Koch), a project presentation at Information Society Technologies for Broadband Europe, Bucharest, Romania, October 9-11, 2002

- SoftCOM 2002 (10th International Conference on Software, Telecommunications and Computer Networks), Split & Dubrovnik (Croatia), Ancona & Venice (Italy), October 8-11, 2002

    - *"Supplying legacy applications with QoS"* (Thomas, Eichler), accepted paper

    - *"On providing a Dynamic QoS Management system for IP networks"* (Dimopoulou, Sampatakos, Nikolouzou, Karadimas, Venieris), accepted paper

- ICTSM10 (10th International Conference on Telecommunication Systems, Modeling and Analysis), Monterey, CA, USA, October 3-6, 2002

    - *"Evaluation of architectures for QoS analysis of applications in Internet environment"* (Hofmann, Miloucheva, Pfeiffenberger, Strohmeier), accepted paper

    - *"Resource Management in QoS enabled IP networks with the AQUILA RCL"* (Engel, Ricciato, Salsano, Winter), accepted paper

- *"PFS scheme for forcing better service in best effort IP network"* (Fudala, Burakowski), accepted paper at PGTS2002 (Second Polish-German Teletraffic Symposium), Gdansk, Poland, September 23-24, 2002

- KST (National Telecommunication Conference), Bydgoszcz, Poland, September 2002
    - "*Comparative studies of declaration-and measurement-based admission control algorithms for IP QoS networks*" (Dabrowski, Burakowski), accepted paper
    - "*Priority Forcing Scheme*" (Fudala, Burakowski), accepted paper
    - "*Admission control for TCP connections in QoS IP network*" (Tarasiuk, Burakowski), accepted paper
- "*Priority Forcing Scheme: A New Strategy for Getting Better than Best Effort Service in IP-based Network*" (Burakowski, Fudala), accepted paper for Internet Technologies, Applications and Societal Impact, Kluwer Academic Publishers, 2002
- *"Measuring the Internet Quality of Service"*, (Hofmann, Strohmeier, Brandauer), e&i Elektrotechnik und Informationstechnik, edition 7/8, July/August 2002
- "*Handling TCP controlled traffic with QoS in IP-based network*" (Burakowski, Tarasiuk, Dabrowski) accepted paper for 6th World Multiconference on Systemics, Cybernetics and Informatics (SCI 2002) Orlando, USA, July 14-18, 2002
- *"A study of QoS Performance for Real Time Applications over a Differentiated Services Network"* (Tsolakou, Nikolouzou, Venieris), accepted paper at ISCC'02 (7th IEEE Symposium on Computers and Communications), Taormina/Giardini Naxos, Italy, July 1-4, 2002
- *"Proven IP Network Services: From End-User to Router and vice versa"* (Eichler, Thomas, Widera), accepted paper at $I^2CS$ (Innovative Internet Computing Systems), Kühlungsborn, Germany, June 20-22, 2002
- *"Use of Premium IP: AQUILA Project"* (Koch), a project presentation at the Global Reseach Networking Summit and GÉANT Commissioning Event, Brussels, Belgium, May 21-22, 2002
- *"On Providing End-To-End QoS introducing a set of Network Services in Large-Scale IP Networks"* (Tsolakou, Nikolouzou, Venieris), accepted paper at Networking 2002 (The second IFIP-TC6 Networking Conference), Pisa, Italy, May 19-24, 2002
- "*AQUILA presentations*" (Koch ("*Project Overview*"), Salsano (*"Dynamic IP QoS: To be or not to be (scalable)?"*), Thomas (*"Application Profiles"*), Karadimas (*"Quality of Service Management Tool"*)) at Premium IP Cluster Workshop & Review, Maastricht, The Netherlands, May 15-16, 2002
- *"Putting the pieces together: Components for end-to-end QoS*" (Winter) at TEQUILA workshop, Maastricht, The Netherlands, May 14, 2002

- "*Multi-service IP QoS network: architectures and testing results*" (Burakowski, Dabrowski), accepted paper for Telecommunication Review no.5, 2002 (in Polish)
- *"Network Services Definition and Deployment in a Differentiated Services Architecture"* (Nikolouzou, Maniatis, Sampatakos, Tsetsekas, Venieris), accepted paper at ICC2002 (IEEE International Conference on Communications), New York City, NY, USA, April 28-May 2, 2002
- *"Adaptive Resource Control for QoS Using an IP-based Layered Architecture"* (Katzengruber, Koch), a project presentation at SEQUIN workshop, Amsterdam, The Netherlands, February 1, 2002
- *"On Shortcomings of the ns-2 Random Number Generator"* (Entacher, Hechenleitner), accepted paper at CNDS 2002 (Communication Networks and Distributed Systems Modeling and Simulation Conference), San Antonio, TX, USA, January 27-31, 2002
- "*On QoS in IP-based Networks*" (Burakowski), invited talk for Commission of Telecommunications, Polish Academy of Science, December 2001
- "*AQUILA presentations*" (Koch ("*Project Overview*"), Eichler / Hofmann (*"Measurement Architecture for Development and Operation of DiffServ Networks"*), Engel (*"Control Loops"*), Winter (*"BGRP Quiet Grafting: An Approach for a Scalable Inter-Domain Resource Control"*) et al.) at Premium IP Cluster Workshop & Review, Dresden, Germany, November 20-22, 2001
- "*ProjectWeb - Eine web-basierte Projektumgebung*" (Koch, Eichler, Fischer, Fünfstück, Hußmann, Konermann, Thomas), accepted paper (in German) at GeNeMe2001 (Gemeinschaften in Neuen Medien), Dresden, Germany, September 27-28, 2001
- QofIS 2001 (2nd International Workshop on Quality of future Internet Services), Coimbra, Portugal, September 24-26, 2001
    - *"Traffic Handling in AQUILA QoS IP Network"* (Bak, Burakowski, Ricciato, Salsano, Tarasiuk), accepted paper
    - *"A QoS Architecture with Adaptive Resource Control -The AQUILA Approach"* (Koch), a project presentation
- *"IP QoS at work: definition and implementation of the AQUILA architecture"* (Koch, Salsano), accepted paper at IWDC 2001 (2001 Tyrrhenian International Workshop on Digital Communications), Taormina, Italy, September 17-20, 2001
- 8th Polish Teletraffic Symposium, Zakopane, Poland, 3-5 September 2001
    - *"On effectiveness of conditional admission control for IP QoS network services with REM scheme"* (Dabrowski, Burakowski, Beben), also published in Journal of Telecommunications and Information Technology, February 2002

- *“AQUILA network architecture: first trial experiment”*, (Bak, Beben, Burakowski, Dabrowski, Fudala, Tarasiuk, Kopertowski), also published in Journal of Telecommunications and Information Technology, February 2002, also published in Archiwum Informatyki Teoretycznej i Stosowanej, tom 13, zeszyt 3, 2001
- *“How to handle Web traffic with QoS?”* (Fudala, Beben, Burakowski), accepted paper

- *"Network Services Deployment for QoS provisioning in a multi-layer DiffServ Architecture"* (Nikolouzou, Tsetsekas, Maniatis, Sampatakos), MIV 2001 (Multimedia, Internet, Video Technologies 2001), Malta, September 1-6, 2001
- *"RSVP as a user signaling protocol in a multilayer bandwidth broker architecture"* (Nikolouzou, Tsetsekas, Maniatis, Venieris), accepted paper at ITCom 2001, Denver, CO, USA, August 19-24, 2001
- *"Distributed Measurement and Monitoring in IP Networks"* (Hofmann, Milouchewa), accepted paper at SCI 2001 (5th World Multi-Conference on Systemics, Cybernetics and Informatics), Orlando, Florida USA, July 22-25, 2001
- ICN'01 (IEEE International Conference on Networking), Colmar, France, July 9-13, 2001
  - "*Supporting QoS for Legacy Applications*" (Tsetsekas, Maniatis, Venieris), accepted paper
  - *"Evaluation of an Algorithm for Dynamic Resource Distribution in a Differentiated Services Network"* (Nikolouzou, Sampatakos, Venieris), accepted paper
- *"Comparison of Tail Drop and Active Queue Management Performance for bulk-data and Web-like Internet Traffic"* (Brandauer, Ziegler, Iannaccone, Diot, Fdida, May), accepted paper at ISCC'2001 (6th IEEE Symposium on Computers and Communications), Hammamet, Tunisia, July 3-5, 2001
- "*Stability Criteria of RED with TCP Traffic*" (Ziegler, Brandauer, Fdida), accepted paper at IFIP ATM & IP 2001 (9th IFIP Working Conference on Performance Modelling and Evaluation of ATM & IP Networks), Budapest, Hungary, June 27-29, 2001
- ComCon 8 (8th International Conference on Advances in Communications and Control), Crete, Greece, June 25-29, 2001
  - *"A QoS Architecture with Adaptive Resource Control: The AQUILA Approach"* (Koch), accepted paper
  - *"AQUILA Network Services"* (Ricciato, Salsano, Eichler, Widera, Thomas), accepted paper

- *"Analysis of Adaptive Resource Distribution Algorithsm in the Framework of a Dynamic DiffServ IP Network"* (Engel, Nikolouzou, Ricciato, Sampatakos), accepted paper
- *"A QoS middleware between users, applications and the network"* (Fünfstück, Karadimas, Maniatis, Thomas, Tsetsekas), accepted paper
- *"Implementation of Traffic Conditioning and PHB mechanisms in OPNET"* (Tsolakou, Brandauer, Venieris), accepted paper
- *"AQUILA Distributed QoS Measurement"* (Strohmeier, Dörken), accepted paper
- *"On handling streaming and elastic traffic in IP-based AQUILA network: measurement results"* (Bak, Beben, Burakowski, Dabrowski, Kopertowski, Tarasiuk), accepted paper

- *"Modern Software Engineering Methods for IP-QoS Resource Pool Management"* (Eichler, Fuenfstueck, Ricciato, Thomas, Tsetsekas, Winter), accepted paper at $I^2CS$ Conference (Innovative Internet Computing Systems), Ilmenau, Germany, June 21-22, 2001
- *"An Adaptive Algorithm for Resource Management in a Differentiated Services Network"* (Nikolouzou, Politis, Sampatakos, Venieris), accepted paper at ICC2001 (IEEE International Conference on Communications), Helsinki, Finland, June 11-15, 2001
- *"A quantitative Model for Parameter Setting of RED with TCP Traffic"* (T. Ziegler, C. Brandauer, S. Fdida), accepted paper at IWQoS 2001 (Ninth International Workshop on Quality of Service), Karlsruhe, Germany, June 6-8, 2001
- "*AQUILA presentations*" (Koch ("*Project Overview*"), Burakowski ("*Trial Scenarios and Results*"), König (*"Complex Internet Service"*), Winter (*"Inter-Domain Architecture"*) et al.) at Premium IP Cluster Workshop, Anacapri, Isola di Capri, Italy, April 3, 2001
- *"Adaptive Resource Control for QoS Using an IP-based Layered Architecture"* (Koch, Salsano), a project presentation at Internet Design for SLS Delivery (TEQUILA workshop), Amsterdam, The Netherlands, January 25-26, 2001
- *"Worst-Case Analysis for Deterministic Allocation in a Differentiated Services Network"* (Listanti, Ricciato, Salsano, Veltri), accepted paper at Globecom 2000, San Francisco, USA, November 27-December 1, 2000
- "*QoS mechanisms for IP based networks*" (Burakowski, Kopertowski, Bak, Wykrota) accepted as plenary paper at INTERNET – Wroclaw 2000, Wroclaw, November 2000 (in Polish)

- *"AQUILA - A QoS architecture with adaptive resource control"* (Koch), a project presentation at AIMS'2000 (Applied IP and Multimedia Services) workshop at EURESCOM, Heidelberg, Germany, October 25-26, 2000
- "*Protocol or Header Indication - Methods to Request Quality of Service for IP-Applications*" (Eichler, Widera), accepted paper at PROMS2000 (Protocols for Multimedia Systems), Cracow, Poland, October 22-25, 2000
- "*Stability of RED with 2way bulk-data TCP*" (Ziegler, Fdida, Brandauer) accepted paper at ICCCN 2000 (9th International Conference on Computer Communication and Network), Las Vegas, NV, USA, October 16-18, 2000
- *"A Middleware Solution for the Support of QoS for Legacy Applications"* (Tsetsekas, Maniatis, Venieris), accepted paper at Softcom 2000 (International Conference on Software, Telecommunications and Computer Networks), Split & Rijeka (Croatia) + Trieste & Venice (Italy), October 10-14, 2000
- *"AQUILA - Quality of Service für IP-Netzwerke"* (Fünfstück, Hußmann, Thomas), accepted paper (in German) at GeNeMe2000 (Gemeinschaften in Neuen Medien), Dresden, Germany, October 5-6, 2000
- Interworking'2000 (Fifth International Symposium on Communications Interworking), Bergen, Norway, October 3-6, 2000
    - *"A QoS architecture with adaptive resource control - The AQUILA approach*" (Koch), project presentation
    - "*Design of a Multi-Layer Bandwidth Broker Architecture*" (Politis, Sampatakos, Venieris), accepted paper
- "AQUILA poster" (Karjalainen) at NORDUnet 2000 (19th Nordic Networking Conference 'Networks in Service of Research and Education'), Helsinki, Finland, September 28-30, 2000
- *"The AQUILA Resource Control Layer Architecture"* (Benini), a project presentation at QofIS'2000 (First International Workshop on Quality of future Internet Services), Berlin, Germany, September 25-27, 2000
- "*QoS IP Networks*" (W.Burakowski, Z.Kopertowski) accepted as plenary paper at National Telecommunications Conference, Bydgoszcz 2000, Poland
- "*On new Strategy for Prioritising the Selected Flow in Queuing System*" (Burakowski, Tarasiuk, Syski), accepted paper at PGTS2000 (First Polish-German Teletraffic Symposium), Dresden, Germany, September 24-26, 2000

- "*Performance of Premium Service in QoS IP Network*", (Burakowski, Fudala, Tarasiuk) accepted for IEEE Workshop on IP-oriented Operations & Management, IPOM '2000, Cracow, Poland, September 2-4, 2000

### 5.3.2 Articles

- *"AQUILA: Adaptive Resource Control for QoS Using an IP-based Layered Architecture"* (Engel, Granzer, Hussmann, Koch, Ricciato, Salsano, Sampatakos, Venieris, Winter), IEEE Communications Magazine, January 2003

- *"QoS issues in the converged 3G wireless and wired networks"* (Maniatis, Nikolouzou, Venieris), IEEE Communications Magazine, August 2002

- *"Quality-of-Service Support for Legacy Applications"* (Thomas, Hussmann) to appear in the Annual Review of Communications, Volume 56, from the International Engineering Consortium in July 2003

- "*A Framework for Providing Differentiated QoS Guarantees in IP-based Network*" (Bak, Burakowski, Ricciato, Salsano, Tarasiuk, accepted for publication at Computer Communications, 2002

- "*AC algorithms in Aquila QoS IP network*" (Brandauer, Burakowski, Dabrowski, Koch, Tarasiuk), accepted for publication at European Transactions on Telecommunications, 2003

# 6 Project Management and Co-ordination Aspects

## 6.1 Performance and co-operation of the consortium

The AQUILA consortium always received the following comments from the five reviews, that perfectly reflect the co-operation of all AQUILA partners:

"*The project is well managed. The effort spent by the partners is commensurate with the results provided. Each partner has a well-defined role. The partners work well together.*"

The effectiveness of the project structure – workpackages (WP), WP leaders, Project Management Committee (PMC), Project Manager (PM) – has been proven by the overall result of the project and all the timely achievements reached during the project's runtime. The information flow within the project as well as to the European Commission and the general public was kept perfectly running by means of project home page, e-mail exchange via exploders, electronic deliverable submission, etc.

## 6.2 Premium IP Cluster

*Premium IP Cluster* projects are: AQUILA, CADENUS, TEQUILA, and from Nov. 2002 MESCAL.

AQUILA co-operated with CADENUS and TEQUILA in many areas of which these were the most important:

- Standardisation activities (see 6.3)
    - SLS: providing IETF drafts and supporting the initiative to launch a new Working Group in the IETF covering this topic,
    - Inter-domain Resource Control: providing IETF drafts on enhanced BGP and on BGRP.
- Providing a Joint Deliverable: IST Premium IP Cluster.
- Organising five joint reviews during the projects' runtime including an additional common workshop.

The project reviews (by the European Commission) were held about every six months. A first joint review took place in Nice, France, November 9-10, 2000.

Further reviews were organised in

- Anacapri, Isola di Capri, Italy, April 3-5, 2001
- Dresden, Germany, November 21-23, 2001
- Maastricht, The Netherlands, May 14-16, 2002
- Florence, Italy, November 21-22, 2002

Before these joint reviews a common workshop (restricted to project participants) took place with presentations coming from these and invited projects.

## 6.3 Standardisation activities

### *6.3.1 SLS*

The TEQUILA project initiated an IETF draft on Service Level Specification (SLS) template definition and Service Level Specification negotiation protocol requirements.

During an AQUILA project meeting extension in Salzburg, Austria, on October 12, 2000, joint activities were discussed and planned in order to gauge interest for the creation of work effort within the IETF on SLS, for a BoF session at the next IETF meeting in San Diego (December 10 - 15, 2000), and for the establishment of an IETF Work Group on these topics.

The Salzburg meeting was one of the first joint meetings of the IST projects AQUILA, CADENUS and TEQUILA, which all work in the area of QoS for the Internet, taking into account different aspects.

The BoF session took place at the 49th IETF meeting in San Diego on December 13, 2000.

Discussions were ongoing - privately organised - during the 51st IETF meeting, London, UK, August 5-10, 2001.

### *6.3.2 BGRP*

During recent months AQUILA carefully watched the ongoing activities in the IETF regarding QoS signalling. Initial plans to launch a working group in this area started in April 2001. After the 52nd IETF meeting in November 2001 in Salt Lake City, the NSIS (Next Steps In Signalling) working group was established.

From the charter: "This working group will develop the requirements, architecture and protocols for the next IETF steps on signalling QoS."

According to the charter of the NSIS WG, the topic of inter-domain signalling mostly correlates to the work of the AQUILA project. AQUILA therefore prepared two Internet drafts addressed to this WG:

- draft-aquila-bgrpp-arch

  This draft outlines the architecture of the AQUILA inter-domain signalling based on BGRP. It describes the basic architectural issues as well as the special implementation choices, protocol message content and message processing.

  This draft has been submitted to the IETF and was announced there as "*draft-salsano-bgrpp-arch-00.txt*" on May 14, 2002. It expired November 2002.

- draft-aquila-bgrpp-sim

  This draft presents the mechanisms used for inter-domain resource management and simulation results, which prove the scalability of this approach.

  This draft has been submitted to the IETF and was announced there as "*draft-nikolouzou-bgrpp-sim-00.txt*" on July 26, 2002. It expired January 2003.

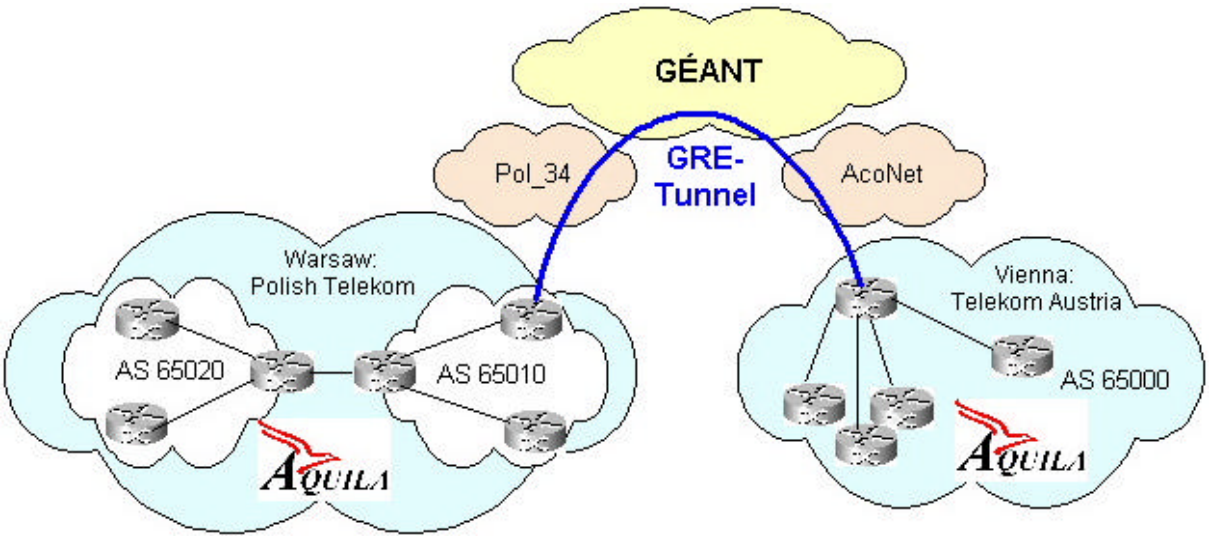
AQUILA members also actively contributed - and still contribute - to the discussion on the NSIS mailing list to promote the AQUILA project's point of view and the submitted drafts.

## 6.4 Co-operation with SEQUIN and use of the GÉANT network

An important aspect of the trials performed in the AQUILA project was to validate QoS in the inter-domain scenarios. A minimal network topology of three domains is needed for testing the inter-domain aspects. Due to the fact that only two domains could be set up in each trial site, the two testbeds, one located in Warsaw (Polish Telecom) and the other one in Vienna (Telekom Austria) were inter-connected via the European GÉANT network, especially built for the purpose of the European Research Projects.

This inter-connection was set-up with active support from the SEQUIN project and from national research networks POL34 and AcoNet. The multi-domain network scenario (see figure) closely represents the conditions in the real Internet and has been used for testing the inter-domain resource management architecture developed within the AQUILA project.

In AcoNet and Pol-34 ATM connections were created whereas in GÉANT network an IP tunnel with the highest priority for the IP traffic (Premium IP service) was configured. Furthermore an end-to-end tunnel (2Mbps) from Warsaw to Vienna was established.


GÉANT
Pol_34
GRE-
Tunnel
AcoNet
Warsaw:
Polish Telekom
AS 65020
AS 65010
Vienna:
Telekom Austria
AS 65000

# 7 Self-Assessment

This chapter compares comments and recommendations given by the reviewers during five project reviews with the consortium's response. In addition we compare the project achievements with the initial objectives.

## 7.1 Review No. 1 (Nice)

### *7.1.1 Conclusions and Recommendations*

1. Analyse and employ realistic operational network topologies.
2. Shift 50% of user application development budget to service and resource control work.
3. Shift budget for subjective user tests to service and resource control.
4. Deliverables that are public should be available on line.

### *7.1.2 Response*

1. The recommendations of the reviewers are believed to be very helpful, and the consortium agreed to take them into account very seriously.
2. Some misunderstanding appears to have taken place regarding the role of application development. The AQUILA position to application development is as follows: The project never intended to develop specialised application software to demonstrate the QoS capabilities of the network architecture. Instead, middleware is developed which enables existing software to make use of the advanced QoS features. Examples of existing applications, which will be supported in the first trial, are RealPlayer and NetMeeting. The mentioned AQUILA API mainly serves as an internal interface of the middleware, which enables existing applications and enhanced Web pages to use the AQUILA features. The project however sees this internal activity as some potential contribution to standardisation. The currently dominant API for QoS (WinSock 2) has the severe disadvantage that it is strictly proprietary and based on relatively old technology, whereas AQUILA will provide a modern platform-independent interface.
3. The consortium follows the recommendations of the reviewers, and it decided not to use subjective tests for validation but for demonstration only.
4. The consortium decided to provide public deliverables on request, trying to collect reasonable information from the requester.

## 7.2 Review No. 2 (Capri)

### *7.2.1 Conclusions and Recommendations*

1. The deliverables can be improved to better bring forward observations and the analysis of their impact. Future deliverables should try to separate technical details from more important issues, such as approaches, achievements, results.

2. The project should more clearly report the results of the analysis of scalability.

3. Before the project ends there should be an analysis of the usability of the proposed architecture, the scenarios it will scale for and the cost of deploying the architecture in terms of effectiveness. As part of this analysis, the impact new overlay networks like CDN will have on the architecture should be included.

4. The project should produce an analysis of the difference and commonality between the three projects in the cluster. This can be a common report for all three projects.

5. Deliverables that are public should be available on line, or at least a better publicity of them should be made on-line to increase requests for information.

6. Implications from trials need to be brought forward. Focus more on lasting results, less on numbers that will change.

### *7.2.2 Response*

1. All new deliverables are now structured following the reviewers recommendations.

2. The project discusses scalability analysis and presents first results from trials and also simulation results.

3. Updates of the architecture, that will be taken into account, address:

    a. MBAC

    b. BGRP

    c. Joint Admission Control

    d. Improvements in Resource Pool mechanism

4. Start of a Joint Deliverable of the projects AQUILA; CADENUS & TEQUILA;
   Joint cluster activities (SLS (in progress), Inter-domain QoS (starting), Measurement (starting), DiffServ conformance tests (proposed)).

5. Executive summaries of deliverables now at the home page and a new URL „http://www.ist-aquila.org/“. Later, all public deliverables have been made available for download from the AQUILA home page.

6. Implications from trials are now included in deliverables D1202 and D1302. These deliverables have been made publicly available, later.

## 7.3 Review No. 3 (Dresden)

### *7.3.1 Conclusions and Recommendations*

1. Pursue the research related to BGRP in a more aggressive manner. The author of the original Internet Draft is not able to continue the work, and there is a risk that interested people will leave the idea if no activities are seen.
   AQUILA should shoulder this role, creating a mailing list, issuing some Internet Drafts where results are shown, etc.

2. Take leadership of the deliverable produced by the three projects in the Premium IP Cluster. This document (which was reviewed in an early draft form) should be completed with (e.g.):

   a. A chapter on measurement/Monitoring (a comparison of the AQUILA and the TEQUILA solutions)

   b. A chapter on business cases

   c. A chapter on common dissemination activities (e.g. IETF)

   d. A chapter on SLS

   e. A chapter on applications used by the three projects

   It is expected that TEQUILA and CADENUS will contribute to this work.

3. Add a chapter to one of the coming deliverables, describing the analysis and simulation of scalability of the AQUILA architecture. In this chapter, the following aspects should be elaborated on:

   a. Identification of potential bottlenecks

   b. limitations imposed by those bottlenecks

   c. suggestions for validating the limits in the second trial.

4. Make a self-assessment and comment in the next Progress Review Report on the applicability of the original objectives and how well they are being fulfilled.

5. Consider publication of the ideas behind the Applications Profiles and to make the profiles developed by the project available to others, e.g. by publicizing them on the project web site.

### 7.3.2 Response

1. Drafts prepared and submitted:

    a. draft-salsano-bgrpp-arch-00.txt (May 14, 2002),

    b. draft-nikolouzou-bgrpp-sim-00.txt (July 26, 2002).

    Publication through AQUILA home page.

2. Premium IP Cluster Joint Deliverable version 2 available covering all requested chapters.

3. Presentation on "scalability" is being given at next Premium IP workshop.

4. Under preparation, first results of 2nd trial should be included.

5. Presentation at next Premium IP workshop and publication through AQUILA home page.

## 7.4 Review No. 4 (Maastricht)

### 7.4.1 Conclusions and Recommendations

1. The project should plan ahead in order to be able to disseminate the results in a convincing way. In order to do this, the project should:
    a. Get data which supports results
    b. Further develop the "puzzle" idea
    c. Make the test plan available so that others can evaluate the test results
2. Considering the size and weight of the project a number of related issues should be studied:
    a. The impact of CDN, Web Caching and IP multicast
    b. The impact of network link failure.

### 7.4.2 Response

1.
    a. We will write the final report according to the comment.
    b. We identified items that are re-usable, such as:
        - Measurement tools
        - Application profiles
        - EAT
        - ACA+RCA
        - Management tools
        - Intra-domain and inter-domain
    c. We have our test plans in the deliverables.

2.
   a. CDN: deliverable D1201-b1 (31.12.2001) contains related information.
      Web caching: we refer to the project EURESCOM 2003
      IP multicast: deliverable D1201-b1 (31.12.2001) contains related information.
   b. Impact of link failures – Answer: Out of scope, interesting project for FP6

## 7.5 Review No. 5 (Florence)

### *7.5.1 Conclusions and Recommendations*

1. The project should identify and document briefly (e.g. 1/2 page per innovation) important innovations and lessons learned (e.g. Application Profiles) in a separate document. The document could provide reading instructions to where further information on these innovations can be found. Such a document is valuable when disseminating the project results. This could be made part of the joint Deliverable.

2. Deliverable 2104 should be made Public

3. Add a table in Deliverable 3202 as it is amended with information as described in section 2.2 above.

4. The project should be more active towards the IETF and to be more active in dissemination and provide the results of these interactions.

5. In the final report, the project should clearly identify the part of the workplan that was changed due to innovations and advancement in the rest of the scientific community during the project's life span. Likewise the report should also identify results that are less relevant due to advances in the field.

### *7.5.2 Response*

1. We will produce it as part of our homepage, not as a separate document or contribution to the Joint Deliverable.

2. Done and submitted on December 12, 2002.

3. We'll do it.

4. Partners continue to trace and to contribute to IETF, even after the end of this project.

5. We'll do it.

## 7.6 Comparison of objectives and achievements

- Objective 1:
  - By means of the AQUILA QoS architecture in conjunction with the definition of suitable network services.
  - The end-to-end-scope was however reduced to an edge-to-edge-scope.
  - Measurement based admission control provides a feedback from the actual load to the admission control decisions.
- Objective 3,1:
  - By means of the application profiles and the reservation GUIs, any kind of application can be supported with several QoS options.
  - The EAT QoS API defines a set of CORBA reservation interfaces.
  - Protocols such as H.323 and SIP are supported by the proxy framework, which can be extended by additional QoS proxies for RSVP, HTTP, etc.
- Objective 3,2:
  - The resource control layer is an add-on to the already established network infrastructure, thus providing a cost-effective way to enhance and re-use former investigations.
  - The distributed implementation provides a high degree of scalability.
  - Different approaches for intra-domain and inter-domain resource control correspond to the different needs in both areas.
- Objective 3,3:
  - The EAT retrieves detailed accounting information for every reservation from the ACA, and saves the data in a local database.
- Objective 3,4:
  - Algorithms and admission control rules are implemented as pluggable components and allow a high degree of flexibility.
- Objective 4,2:

- The EAT is the RCL front-end tool for QoS reservations. They can be made manually (by the AQUILA portal GUI) or automatically (by the EAT API or by the proxies).

- Objective 4,3:
  - A QoS management tool was developed, which controls all configurable parameters of the AQUILA QoS infrastructure, provides monitoring and failure detection features and provides an overall view of the system architecture.

- Objective 4,4:
  - Implementation of a distributed measurement architecture for the evaluation and validation of the QoS architecture as well as for the support of operation and resource control.

- Objective 5:
  - Validation of the QoS architecture by usage of distributed measurements for the emulation of end-user behaviours in the lab trials.
  - Different trials were performed in order to evaluate QoS performances provided by the AQUILA architecture with different load in the network (including worst case of the load),
  - Trials were performed in three testbeds (Warsaw, Helsinki, Vienna) with GEANT network connection between Warsaw and Vienna,
  - User trial were carried out in different testbeds (Warsaw, Vienna) in order to evaluate QoS provided by the AQUILA network for different types of applications,
  - To prove scalability for large networks the RCL performance trials were performed in Helsinki testbed,
  - Validation of the QoS architecture by usage of distributed measurements for the emulation of end-user behaviours in the lab trials.

- Objective 6:
  - The AQUILA architecture allows the inter-operation of domains with different QoS implementations. However it is obvious, that edge-to-edge QoS can only be achieved, if each link in the chain has at least some understanding of QoS.

- Objective 7:
  - The project participated in the efforts to establish a SLSA working group at the IETF. Several Internet Drafts have been published in the SLSA working group as

well as two drafts in the NSIS working group. The partners also contributed to the discussions in these groups. Moreover, a great number of papers have been presented in various conferences and magazines.

# 8 Outlook

## 8.1 Siemens

Siemens is very active in the area of Next Generation Networks. The SURPASS product portfolio is designed to converge the former pure telephony network (PSTN) and the evolved data networks. The special demands for establishing communication sessions require a high availability, stability and ensured quality. Therefore, QoS techniques can get essential for future business.

Ongoing with AQUILA proceeding in the second trial phase, Siemens decided to implement the AQUILA QoS architecture in the main customer presentation area in Munich, called CIC (Customer Information Centre). AQUILA running with all components can be shown there to customers as possible solution for QoS handling inside the Siemens product family.

An AQUILA based and enhanced architecture can be a successor of what SURPASS integrates today in the QoS range. It must be clearly stated, that the available prototype implementation is insufficient for being integrated directly in a SURPASS product. But with the promising results, the available practical verification, the possibility to demonstrate a real-life QoS scenario to customers, Siemens can verify and prove that it is worth to follow this initial way.

Since it is currently not yet clear, if telecommunication operators will integrate or buy a QoS architecture, Siemens currently cannot commit to establish a product in this area. Siemens is using the AQUILA architecture to combine it with several internal prototypes and even products. QoS interfaces to SIP applications as well as to products in the H.323 area are either implemented or in discussion, while Siemens even proceeded one step further with analysing, how QoS as a premium service for voice and video could be charged in the future.

## 8.2 arvato systems

Due to the poor global market situation for Internet service providers (ISP) it is very difficult for arvato systems to assess what kind of new online services might be successful and profitable in the consumer market. On the one hand, new concepts and technologies like QoS are promising to offer attractive and interesting services. On the other hand, the development of such concepts and technologies involves high investments, organisational challenges, and risks.

arvato systems GmbH, a profit centre of arvato AG, is the leading worldwide IT service and solutions provider of Bertelsmann AG. Arvato systems will exploit AQUILA project results for future commercial Internet products and services, as such opportunities will arise. The experience gained from AQUILA will be most helpful in conceptualising, appraising, and developing new Internet services based on QoS.

## 8.3 Elisa Communications

Elisa Communications' areas of strategic focus are access, mobile and network services. We are committed to offering our customers tailored solutions that meet all their communication requirements. Elisa Communications is known for its ability to utilise telecommunication innovations. Elisa Communications is both a network operator and a provider of telecommunication services: fixed, mobile and data communications.

Elisa Research Center focuses on researching and developing a versatile range of technologies and services capable of meeting the versatile needs of people living and working in the 21st Century. Being able to offer new advantaged technologies early is a key issue. Good example of early adaptation of new technology is commercial deployment of DiffServ and MPLS since 2001.

AQUILA project has provided valuable operation procedures, which make it easier to translate standardisation to real services offered to customers. The experience gained with traffic class specification, testing of the capabilities of routers and performing the trials during the project has been helpful in redefining and deploying new services.

The measurement architecture developed in the AQUILA project has been successfully used during the trials. Test tools have been found to be useful and efficient. It is planned to use measurement tools in further research and development.

## 8.4 Q-Systems

Being a commercial partner, Q-Systems will try to exploit the results of the project in several ways and approaches. According to the current high standard know-how, Q-Systems has the ability to develop easily, middleware and applications with integrated QoS functions based on the main modelling issues of the AQUILA project.

The main target group of Q-Systems are Telecommunication Providers and ISPs. After the deregulation of the market the latest years in Greece new players in that field has appeared to break the monopoly of Greek Telecom Organization (OTE). As a result the need for a common management and billing system for the heterogeneous infrastructure of these providers is increasing.

Customer requirements for QoS differ in many ways. Qualitative and quantitative issues are involved in selecting classes of services for fixing QoS requirements. Thus Service Providers need to build a middleware solution for supporting their services.

The achievement within the project will enable Q-Systems to further exploit, the knowledge obtained, designing a common management platform for SLA and QoS management provisioning for ISP‘s. This platform will rely on the provider’s workflow process in order to help the dynamic building of IP products and services, which meet the diverse customer needs.

## 8.5 T-Systems Nova

As innovative service and solution provider T-Systems Nova is active in integration of telecommunication and IT systems in the TIMES markets: telecommunication, in-formation technology, multimedia, entertainment and security. From operators point of view Quality of Service becomes more and more important in the near future. Operators like Deutsche Telekom identified a need for high quality service IP connectivity. From operational and finance point of view such services will be provided on top of existing broadband networks, with a limited percentage of the overall bandwidth. Therefore the light DiffServ model that was chosen within AQUILA is also being deployed in the network of Deutsche Telekom. Using the developed project tools additional adjustments to optimise network services can be taken into consideration. This covers technical aspects as well as user acceptance.

From the Resource Control Layer (RCL), developed within the AQUILA project as a prototypical framework, useful experiences to control and adjust core and access network entities can be extracted. Many lessons have been learnt from the simulation results. Discovered advantages and disadvantages will influence further network management enhancements within the networks of Deutsche Telekom. Besides the concrete results new experiences of modelling, implementing and integrating additional components into existing systems are of high potential value.

During the project a sophisticated measurement tool for performance measurements in IP networks was developed. It is planned to enhance the measurement tool and to use this enhanced version in other projects, e.g. in the IST project NUGGETS (http://www.ist-nuggets.tv/). Measurements in the NUGGETS testbed will show the performance under different load scenarios. For these measurements a new version of the controller program MACON with more functions and a modified measurement agent for the new requirements are planned.

The development of a graphical user interface (GUI) was one result of the project that helped to realise how distributed measurement systems consisting of several components can be controlled. Visualisation of network performance was another point that brought new understandings while working on the AQUILA GUI.

## 8.6 Telekom Austria

While Telekom Austria was among the first to provide ADSL services in Europe in 1999, today 80% of the Austrian population can be provided with an ADSL access, which gives Austria one of the highest ADSL penetration rates. Further products and services comprise value added services, call management, coin and prepaid card telephony, call center, sale of equipment and the publication of telephone books through Herold Business Data AG.

With IT solutions, a comprehensive e-business product portfolio and ASP enabling (Application Service Providing), Telekom Austria offers its customers one-stop-shopping, where all the necessary IT and data services are offered from one source. Individual configurable solution packages are

provided, representing a combination of software, infrastructure, connectivity, security and service, through defined service level agreements (SLA).

To be successful in a keen competition the Telekom Austria AG has to supports intensively the development of new products and services. These new services require new technologies and one of the most important requirements is to provide a reliable QoS architecture.

AQUILA is an activity that is an essential precursor to widespread deployment and use of such QoS networks. The architectural direction that AQUILA offers is a promising outcome for QoS support. Furthermore a sophisticated measurement tool for performance measurements in IP networks was developed during the project.

In a first step it is planned to use this measurement tool for making active and passive performance tests in the IP backbone of Telekom Austria.

## 8.7 Telekomunikacja Polska

Polish Telecom (Telekomunikacja Polska - TP) is the largest network operator and service provider in Poland. TP provides complete portfolio of communication services for home and business customers. Besides standard telephone services (typical PSTN, ISDN) and mobile cellular phones also data transfer services are provided such as Frame Relay, ATM, typical Internet access and VPN services. Polish Telecom provides transmission network for voice and data services. For voice service typical PDH and SDH transmission systems are used. For data transfer services other layers are applied, such as Frame Relay, ATM and IPv.4. Currently, the IP network is based on modern IP routers (Juniper). Up till now, IP and Internet services are typical without QoS guarantees and SLA (only service availability is specified). In the future, the market trends in Poland indicate necessity of providing new IP services with QoS and extended SLA.

Based on AQUILA approach, as the first VoIP service is planned for deployment in existing network. In next step, IP VPN with different levels of QoS inside and video services will be implemented. Also different SLAs for Internet access are planned to provide for the customers. Therefore, TP is strongly interested in implementation of new IP services with QoS guarantees differentiation. AQUILA project is of special importance for TP since it gives new solutions for providing QoS in IP-based networks. In the future, when the Polish market will be widely open for other operators and much stronger competition on the telecommunication services market will appear, IP QoS solutions seem to be very important.

## 8.8 Research institutes

Dissemination will be pursued by exploiting results of the AQUILA project via scientific communities like participation in conferences and workshops, as well as publishing results in scientific journals. Furthermore pilot-projects driven by students together with market participants, like ISPs or network operators or technology providers will be initiated. Another possibility lies in the establishment of QoS in lectures and courses on software engineering methods and technologies. In

this way students get an impression of the complexity and the real problems of industrial projects. Also participation at international projects and conferences improves the public relations.

Besides the above-mentioned actions, TUD particularly exploits the research results of AQUILA for ongoing diploma as well as doctoral theses. In this way the AQUILA results build an interesting base for further research activities on QoS middleware, QoS specification and so on.

The participation of the Warsaw University of Technology in the AQUILA project has had significant impact on the directions of research. In addition, during the project the team had an opportunity for getting the experiences of European project management and methods of other teams working. The dissemination and use plans of the revenue for research can be classified into four groups:

1. publications in the international journals and conferences,
2. direct "contact" with the telecommunication systems and getting a knowledge from experiments in laboratories,
3. promoting Ph.D. and M.Sc. students,
4. updating of education process.

The Warsaw University of Technology contributed to AQUILA mainly in the following topics:

- traffic management aspects; it required to specify new mechanisms and algorithms for providing QOS;
- testing AQUILA network; it required to define test scenarios and tests performing.

In addition, the simulations of AQUILA network were made by using OPNET tool.

The results of the research in AQUILA were published in the form of papers in international journals and conferences (international and national). In total, during three years of the project, the number of publications was about 20.

The important revenue from the AQUILA project was that the team had a chance for getting practical experiences (not only simulations and theoretical work) from the system testing. This experience is very important for the quality of future research, since knowledge about the hardware and software limitations allows for more practical oriented studies. Additionally, such knowledge gives advantages for co-operation with industrial and telecommunication operator partners.

The project gave opportunity for Ph.D. and M.Sc. students to specify the thesis. As a consequence of activities in the AQUILA, three Ph.D. and about eight M.Sc. students started their thesis in the subject of IP QoS networks.

The subject investigated in AQUILA, IP QoS networks, is currently one of the most important topics in telecommunications. Therefore in the Warsaw University of Technology, the following lectures and laboratory exercises have been updated:

- Computer Networks (lecture for M.Sc. course): DiffServ architecture, AQUILA concept including traffic handling mechanisms in IP QoS networks. Additionally, some of the student projects are oriented on practical testing of AQUILA concept (with co-operation with Polish Telecom).

- Modelling and Performance Evaluation of Computer Networks (lecture for M.Sc. and Ph.D. course): students are familiar with analytical methods for providing effective traffic handling mechanisms in AQUILA architecture.

Computer network laboratory (laboratory for M.Sc. course): an extension of the student laboratory is planned, by adding new exercises corresponding to the AQUILA concept.

# 9 Conclusions

For this conclusion there's not much to add.

We presented a brief summary of the project's achievements and results.

Detailed information can be found on our home page http://www.ist-aquila.org including a download facility for all public deliverables. Many of them have been updated to the latest information available.

The project was able not only to touch the subject of QoS in IP networks, but also to develop running prototypes, executing real user trials, and in this way demonstrating the proposed architecture is suitable for provider's and user's needs.

Besides all the eye-catching technical results, the project was again another example for the excellent co-operation of the pan-European research community in Telecom-industry as well as universities and research institutes. The overall achievements have been made possible only by all project's participants engagement in team working and pre-competitive research.

Our last-but-not-least acknowledgements belong to our European Commission Project Officer Paulo De Sousa, who coached and directed us throughout the project and helped and advised us whenever possible and/or necessary. He managed to arrange a stable team of external reviewers for all our five reviews, so that we always had a competent team standby with many recommendations and comments, also providing an interesting platform for many fruitful discussions. For all this splendid support the project consortium is very grateful … and it shows.