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Abstract:	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.
Keyword List:	**AQUILA, IST, trial, measurements, QoS IP**

Executive Summary

This deliverable summarises the experimental results obtained during the second trial. The primary objective of these experiments was to verify the AQUILA architecture for providing QoS in the IP network (described in previous deliverables D1202, D1203 and D1302). In particular, the reported results cover the following areas:

- evaluation of network services (single domain, inter-domain and for secondary access links),
- real users trial (inter- and intra-domain) for different applications (voice, video and audio streaming, interactive games),
- RCL performance (inter- and intra-domain),
- evaluation of network efficiency *(resource pool mechanism)* in deterministic and dynamic scenario.

The presented results are structured in the following way:

- intra- and inter-domain network service performance evaluation (see annex A),
- real users scenarios (intra- and inter-domain) (see annex B)
- RCL performance (see annex C),
- evaluation of network efficiency (see annex D)
- testbeds specification (see annex E)
- measurement tools (see annex F).

An extended summary of the trial results is presented in chapter 3. In Annexes A to D detailed description of trial scenarios and results are included. In Annex E testbeds specification and GEANT connection is presented and in annex F measurement tools are described.

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1 Introduction

After the first trial and evaluation of QoS IP network architecture some enhancements were proposed and implemented. A detailed description of the modified solutions was presented in deliverables D1203 and D1302. Moreover, the specification of potential applications, implementation of Resource Control Layer and measurement tools one can find in deliverables D2103, D2204 and D2303.

This report summarises the experimental results obtained during the second trial carried out in Warsaw, Vienna and Helsinki testbeds. The primary objective of these experiments was to verify the AQUILA architecture for providing QoS in the IP network (described in deliverables D1203 and D1302). In particular, they cover the following areas:

- evaluation of network services (single domain, inter-domain and for secondary access links),
- real users trial (intra-domain) for different applications (voice, video and audio streaming, interactive games),
- RCL performance (inter- and intra-domain),
- evaluation of resource pool management in dynamic scenario.

Trial results are structured in the following way:

- intra-domain PCBR, PVBR, PMM and PMC network service trial (see annex A, chapter 6),
- inter-domain for PCBR network service trial (see annex A, chapter 6),
- real users for voice service trial (intra-domain) (see annex B, chapter 7)
- RCL performance trial (see annex C, chapter 8),
- evaluation of network efficiency trial (see annex D, chapter 9)
- testbed description (see annex E, chapter 10)
- measurement tools (see annex F, chapter 11)

The report is organised as follows. After short introduction (chapter 1), the objectives of the second trial are outlined (chapter 2). In chapter 3, the main achievements and conclusions from the second trial are described. Finally, the detailed description of trial scenarios and results are presented in Annex A to D. Annex E contains the specification of both network configuration for each site and international connection via GEANT network. Last Annex F describes measurement tools used during the second trial.

2 The second trial objectives

In the second trial taking into account different network aspects the following objectives were defined:

1. For evaluation of Network Services (NS)

   - practical verification of AQUILA architecture capabilities for supporting defined set of NSs:
     - QoS guarantees provided by particular NS;
     - NS separation: including impact of traffic carried inside given NS on QoS experienced by traffic submitted to other NSs;
     - QoS differentiation between flows submitted to different NSs
   - QoS verification for NSs corresponding to different network topologies like:
     - Single-domain,
     - Inter-domain; trial was performed by Polish Telecom and Telecom Austria, using the interconnection provided by GEANT (3 domains),
     - Single-domain with secondary access links;
   - In this group of trials new mechanisms were checked: full scheduler (on low and high bandwidth links), joint AC and MBAC (see D1302).

2. For real users trials (intra-domain) subjective and objective evaluation of different applications with QoS guarantees provided by appropriate NS (performed in Warsaw and Vienna testbed):
     - voice,
     - non-interactive video and audio streaming.

3. For RCL performance trials *(inter- and intra-domain)* main two subjects are taken into account (performed in Helsinki testbed):
   - Signalling load between different components of RCL,
   - RCL performance – transaction processing delay.

4. For evaluation of resource pool management the following scenarios was taken into account (performed in Vienna testbed):

- Dynamic trial scenario with resource pools; the trial demonstrates the ability to adapt resource allocation to shifting traffic load;

- Dynamic trial scenario with Joint AC; the trial will demonstrate the improved access link utilisation with the use of joint AC mechanism.

3 Achievements of the second trial

This chapter summarises the experimental results obtained in the second trial. The detailed description of the obtained measurement results is presented in Annex A to D.

In Annex A the results of experiments related to measuring performances of modified network services are reported and referred to PCBR, PVBR, PMM and PMC service for intra- and inter-domain architecture. They focus mainly on traffic studies provided under different system load scenarios. For each of considered network services, the target QoS objectives, at the packet level, were verified assuming the appropriate worst-case traffic pattern. These experiments were carried out in Warsaw testbeds.

In Annex B experiments for the real users are included. The voice, video streaming, videoconference and games for intra- and inter-domain case were carried out in Warsaw and Vienna testbed. The subjective evaluation for perceived application quality was achieved.

Annex C is devoted to evaluation of efficiency and robustness of the Resource Control Layer (RCL) components, with special focus on signalling performance. The main purpose of these experiments was to assess the scalability aspects of AQUILA architecture. Experiments in intra- and inter-domain network architecture were carried out in Helsinki testbed.

Annex D describes results corresponding to resource pool management. In Vienna testbed the resource pool mechanism was tested in dynamic scenario.

3.1 Evaluation of network services

In this section we summarise obtained experimental results corresponding to the network services evaluation for intra- and inter-domain network architecture. In order to evaluate NS performances new admission control on the access link should be taken into account. In the second trial the Joint AC schema was implemented. Currently admission control mechanism for given NS does not take into account only current load in the considered class but also the traffic submitted to the other TCLs. For proving the correctness of the approach it would be desirable to take into account in the trials rather the mix traffic scenarios (with traffic submitted to more than one TCL in the same time). In the system with 4 TCLs, the system state may be described as vector $<n_1, n_2, n_3, n_4>$, where n_i denotes the number of TCLi flows in progress. During the trials, the measurements of QoS parameters should be performed in all TCLs in parallel. Moreover, the submitted traffic should correspond to different "points" in the space $<n_1, n_2, n_3, n_4>$, possibly on the boundary of admission region. From practical purposes we limit our interest to the following test groups:

- PCBR, TCL1: bandwidth available for this class is changed from 0 to C (link capacity). Traffic in all TCLs 3,4 and 5 is of the lower priority and can be modelled as single traffic stream.

- PVBR, TCL2: bandwidth available for TCL2 is changed from 0 to 0.9C. Different sub-cases are considered, with different splitting of remaining bandwidth between TCLs 1, 3 and 4,
- PMM, TCL3: tests corresponded to two cases: (1) with homogenous TCP flows, i.e. each requesting the same value of the rate, and (2) with heterogeneous TCP flows, differing in the requested rates,
- PMC, TCL4: in trial the assumed QoS objectives for PMC service were checked assuming that PMC service was separated from other network services. Two trial cases were taken into account: (1) homogenous case, when all submitted flows have the same characteristics and (2) heterogeneous case, when flows has different characteristic. The trial was performed under the minimum possible RTT value (propagation delay close to 0). This condition constitutes the worst case for the PMC traffic.

3.1.1 Intra-domain trial

The goal of the trial is a practical verification of AQUILA single domain network capabilities for supporting defined set of NSs keeping separation between them and their abilities for providing specified (different, depending of type of NS) QoS requirements. More specifically, we focus on practical verification of:

- QoS guarantees provided by particular NSs;
- NS separation: including impact of traffic carried inside given NS on QoS experienced by traffic submitted to other NSs;
- QoS differentiation between flows submitted to different NSs.

In the reported trials a single-domain network scenario is assumed. In order to evaluate three mentioned aspects of providing QoS in AQUILA network, a series of test cases has been defined. For each test case, the representative packet-level QoS parameters are measured.

3.1.1.1 PCBR network service

PCBR network service was designed to serve the streaming flows requiring low packet loss ratio and low packet delay. It was dedicated to support mainly constant bit rate traffic (circuit emulation, voice trunking). The general aim of the trial experiments was practical verification of the assumed objectives for PCBR service taking into account new mechanisms [see D1302].

Two sets of the experiments were carried out (see annex A, 6.1.1). The experiments were performed in two cases of background traffic: (1) heavy load conditions and (2) permanent congestion on the link. The measured parameters were volume of admitted traffic, packet loss ratio and end-to-end delay.

In the experiments bandwidth available for this class is changed from 0 to C (link capacity). Traffic in PMM, PMC and STD services is of the lower priority and can be modelled as single traffic stream. Foreground traffic submitted to PCBR is a CBR (constant bit rate) flow, while the background is modelled as Poisson stream. Background traffic in other NSs is CBR or Poisson. In this trial, traffic conditions depend on the number of flows submitted to PCBR service, so only one value (n_1) of state vector changes.

Conclusions

Based on the achieved results we can conclude:

- PCBR service meets QoS requirements specified for this service. The measured delay and packet loss ratio does not exceed predefined values.

- In the case of permanent link congestion (it means the system never reaches empty state) one can observe some limits for bandwidth allocated for PCBR in order to keep the required values of QoS parameters; when packet size of STD equals 1500 B, bandwidth allocated to PCBR should be limited to around 20% of total link capacity. The packet loss ratio for PCBR is proportional to both the packet size of STD (more precisely, to residual packet size) and to the arrival rate of the packets from PCBR.

3.1.1.2 PVBR network service

PVBR service was designed to handle streaming variable bit rate flows requiring low packet loss rate and low delay. Therefore, on the contrary to the PCBR service, this service takes into account bursty nature of the submitted traffic. The aim of experiments was practical verification of QoS objectives assumed for PVBR service with MBAC and Joint AC, new traffic control mechanisms.

In the experiments (see Annex A, 6.1.2) bandwidth available for PVBR is changed from 0 to 0.9C (according to defined architecture). Foreground traffic submitted to PVBR is an ON-OFF stream, the background load in PVBR is modelled as MMDP process, and the PCBR traffic is modelled as Poisson stream. Other NSs are permanently congested. In this trial, traffic conditions depend on the number of running connections in PCBR and PVBR services, so two values (n_1, n_2) of state vector are changing.

The experiments for PVBR were carried out under setting permanent congestion conditions for PMM, PMC and STD services and assuming the traffic submitted to PCBR service fills up AC limit (see annex A, 6.1.2). The measured parameters were: packet loss ratio and end-to-end delay. The obtained results correspond to the QoS experienced by the foreground PVBR traffic flows, taking into account the selected points from AC boundary determined by Joint AC schema.

Conclusions

On the basis of the obtained results we can conclude:

- PVBR service with Joint AC algorithm guarantees specified QoS parameters in all tested cases (with different load condition) see chapter 6.1.2;

3.1.1.3 PMM network service

The PMM trial results (see Annex A, 6.1.3) were performed for 2 alternative AC algorithms, which are:

- (1) AC based on TBM (Token Bucket Model) [D1302]

- (2) AC based on advertised window setting [D1303].

The tests corresponded to two cases: (1) with homogenous TCP flows, i.e. each requesting the same value of the rate, and (2) with heterogeneous TCP flows, differing in the requested rates.

The reported results referring to the TCP throughput say that for the case with homogenous sources both considered AC approaches work properly. However, this conclusion can not be extended to the case with heterogeneous TCP flows, where only the AC based on advertised window setting meets requirements. The main reason that the AC based on TBM fails in this case is that the assumed maximum buffer size (25 packets) is shorter than required from theoretical studies (see [D1303]). This is caused by the limitation of the routers used in trial (maximum buffer size for PQWFQ scheduler is only 64 packets for all traffic classes).

3.1.1.4 PMC network service

The PMC service was designed to guarantee very low packet losses and low delay for non-greedy traffic usually controlled by TCP protocol. The potential applications for using PMC are:

- Transaction oriented applications

- www applications

The goal of this trial is to check whether the assumed QoS objectives for PMC service are met. The trial was performed assuming that PMC service was separated from other network services (see Annex A, 6.1.4). During the trial the packet loss ratio was measured. By assuring low packet loss ratio one can expect the low transaction delay by avoiding packet retransmission.

Taking into account the obtained results one can conclude that PMC service is able to guarantee low packet losses (in fact during tests no losses were observed, see chapter 6.1.4). Moreover the AC algorithm designed for PMC service properly determines the maximum number of admitted flows.

3.1.2 Inter-domain trial

The goal of the trial is a practical verification of AQUILA network capabilities for supporting defined set of inter-domain NSs (GWKS), keeping separation between them and their abilities for providing specified (different, depending of type of NS) QoS requirements (see Annex A chapter 6.2).

In the trial performance of PCBR service in the inter-domain scenario was investigated. Packets belonging to PCBR are carried on the link with the highest priority. Packets belonging to any of the other services are treated as lower priority traffic. Therefore, from the point of view of performance of PCBR service, the traffic belonging to other services is indistinguishable and will be modelled as one traffic stream.

The bandwidth statically allocated for traffic in PCBR service (capacity determined by Service Level Agreement, SLA, between the neighbouring domains, denoted as L1) on each of the inter-domain links is changed in the trial from 0.5Mbps to the maximum value, equal to the inter-domain link capacity. We assume, that the rest of the available capacity is equally allocated to PMM service (capacity determined by SLA between the neighbouring domains, denoted as L3) and STD. Such bandwidth assignment is achieved by setting equal WFQ weights in the scheduler. The trial evaluates the performance of inter-domain PCBR service with different allocation of inter-domain link bandwidth between all three services.

Inter-domain PCBR trial results show, that measured QoS parameters corresponding to packet loss ratio and packet delay are almost as expected. Anyway, in some cases the exceeded delay was observed and this is caused by interconnection link, passing by a number of networks (Polpak, POL34, GEANT, AcoNet).

3.1.3 Secondary access link

The aim of secondary access link tests is to verify if the QoS objectives are met. Two different test scenarios, one case for measurement traffic with only best effort background traffic and one case with background traffic in all traffic classes. (see Annex 6.3)

The test network consists of five Cisco routers and there are two secondary access links and one primary access link. The primary access link is the bottleneck.

In first scenario one measurement flow is submitted to network using one traffic class at a time. Measurements were repeated with and without background load. In second scenario the impact of increasing traffic in one traffic class to other traffic classes is observed.

The results show that some QoS targets were not quite reached but sufficient differences between traffic classes were noticed.

3.2 Real user trial

Real user trial was performed for VoIP (see Annex 7.1.1), for videoconference and video streaming application (see chapter 7.1.2). In the trial the subjective measures were obtained.

On the basis of the obtained results for VoIP application one can conclude as following:

- Measured W_L (Average logatom articulation) in the case of reference scenario and PCBR service was similar and on acceptable level in IP network (in telephone network, with 64 kbps voice channel – MOS is 4.4, with 16 kbps voice channel – MOS is 4.2);
- Results obtained with STD service were much worse comparing to PCBR service and evaluated quality was on unacceptable level (hardly acceptable MOS is around 3.0).

Summarizing, the provided experiment 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, one can conclude that such applications can be effectively supported by the PVBR service. It was noticed, that some users were not fully satisfied with the quality of QoS-enabled videoconference. The reason for that was a non-optimal setting of reservation parameters (reservation with PR=180kbps and SR=75kbps, as specified in the Application Profiles, was not enough for this application). In general, problem of setting proper parameters of traffic descriptors for different applications is quite difficult and requires some careful studies.

For video streaming application, like those provided by the Mediazine server we can observe that PMM service in AQUILA network supports non-real-time streaming services in sufficient way.

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

3.3 RCL performance

The aim of trials for RCL performance (see Annex C, chapter 8) is to evaluate the set-up time and signalling load in the AQUILA architecture. RCL performance trial is divided into intra-and inter-domain scenarios. The results will be used for analysing the scalability issues in AQUILA architecture.

3.3.1 Intra-domain scenario

The test environment for intra-domain scenario consists of five routers connected in a chain. The client will make reservations to the server, which will produce signalling traffic between RCL elements. The RCL elements are running on Sun workstations and the client GUI is running on a PC computer.

In this trial transaction processing delays and amount of signalling traffic was measured.

Transaction delay consists of initialisation time and delays for reservation operations. Different traffic classes and AC schemes were used in measurements. Additionally existing reservation, router configuration and resource pool invocation contribution to processing delay is considered.

The results show the following:

- the processing delay 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

In the second part of this trial the amount of signalling traffic between AQUILA RCL components was measured. In these test cases the number and size of signalling packets were collected. To support analysis the signalling traffic was divided into local and global components. Local signalling does not generally traverse the whole network while global signalling does. The results show that for reservation set-up the signalling traffic is much greater than for reservation release. These values should be used for analysis of the scalability problem.

3.3.2 Inter-domain scenario

The test environment consists of four individual domains. The reservations are started from two separated domains, reservations join the same path in the common transient domain and the reservations end point is always in the fourth domain. In this way it is possible to form a sink-tree with two braches. In each domain there is an AQUILA RCL and BGRP agents corresponding to border routers.

In this trial transaction processing delays and amount of signalling traffic was measured.

Transaction delay consists of initialisation time and delays for reservation operations. Existing reservation, router configuration and BGRP agent contribution to processing delay is considered. Additionally the effect of sink-tree existence to reservation set-up was observed.

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

In the second part of this trial the amount of signalling traffic between BGRP agents and RCL components were measured. In these test cases the number and size of signalling packets were collected. The results show that for reservation set-up the signalling traffic is much greater than for reservation release. The amount of reservation traffic was measured with and without existing sink-tree. It was also observed that joining a sink-tree significantly decreases the amount of signalling traffic.

3.3.3 Network load contribution to processing delay

In this scenario reservation set-up and release delays for TCL 1 are measured under different network loads. Slight increase in the reservation set-up times was noticed when the network load was increased. However some routers CPUs got overloaded already when the network load was quite low. Therefore it was not possible to draw complete conclusions from the network load effect.

3.4 Resource pool mechanism

The objective of these scenarios is whether the requests are accepted or rejected, depending on the RP algorithm and on the configured AC limits. Furthermore for TCL1 a long run test was performed in order to test the stability of the algorithm (see Annex D 9.4). In order to test the basic functionalities of the RP-algorithm, resource requests by one host were performed. In a next step resource requests were performed by different hosts and furthermore by different hosts and different ingress points (edge router) to the network. 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 but in the case with different hosts there is a need for further algorithm development and testing.

3.5 AQUILA Measurement Tools

The AQUILA distributed measurement architecture was objected on the validation and evaluation of the AQUILA QoS architecture and the support of network operation and resource control.

For the evaluation and validation of the QoS architecture the application-like load generator with end-to-end QoS measurement was used to evaluate the end-to-end performance of the network and to validate, whether the requested QoS parameters were provided by the network. The parameters were one-way delay, jitter, throughput and packet loss. Different load models were used according to the different network services.

For the support of network operation and resource control, two different time scales are targeted by the AQUILA measurements. Short term to support automatic mechanisms like measurement based admission control (MBAC) and longer term to support resource provisioning of the network operator (see Figure 3-1). In AQUILA two different methods are used for these tasks. To enable measurement based admission the mean rate on the router output ports are collected by the admission control agent (ACA). To support effective resource provisioning an active network probing tool is provided to monitor the path performance characteristics within a providers network.

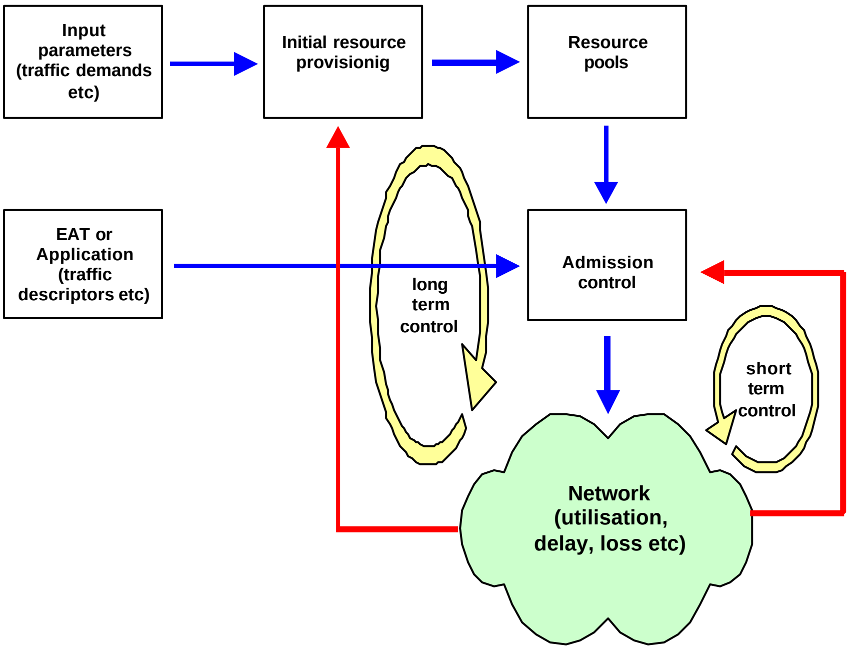

Figure 3-1. Control Loops

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.

Summarising, the 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.

4 List of abbreviations

ACA	Admission Control Agent
AF	Assured Forwarding
BE	Best Effort
BGRP	Border Gateway Routing Protocol
BSP	Bucket Size for PR
BSS	Bucket Size for SR
CAR	Committed Access Rate
CBQ	Class Based Queuing
CBR	Constraint Based Routing
CBWFQ	Class Based Weighted Fair Queuing
CE	Customer Edge
CLI	Command Line Interface
CoS	Class of Service
DHCP	Dynamic Host Configuration Protocol
DiffServ	Differentiated Services
DMA	Distributed Measurement Architecture
DS	Differentiated Services
DSCP	Differentiated Services Code Point
DWFQ	Distributed Weighted Fair Queuing
ECR	Egress Committed Rate
EDA	Edge Device Agent
EF	Expedited Forwarding

FTP	File Transfer Protocol
GUI	Graphic User Interface
GWKS	Globally Well Known Services
IOS	Internetwork Operating System
MBAC	Measurement Based Admission Control
MBS	Maximum Burst Size
MOS	Mean Opinion Score
PCBR	Premium Constant Bit Rate
PHB	Per Hop Behaviour
PMM	Premium MultiMedia
PMC	Premium Mission Critical
POS	Packet over Sonet/SDH
PQ	Priority Queuing
PR	Peak Rate
PVBR	Premium Variable Bit Rate
QoS	Quality of Service
RCA	Resource Control Agent
RCL	Resource Control Layer
RED	Random Early Detection
RIO	RED with In/Out
RSVP	Resource reSerVation Protocol
RP	Resource Pool
RPL	Resource Pool Leaf
SDK	Software Development Kit

SLA	Service Level Agreement
SLS	Service Level Specification
SP	Service Provider
SR	Sustained Rate
STD	Standard network service
TCA	Traffic Conditioning Agreement
TCL	Traffic CLass
TCP	Transport Control Protocol
TCS	Traffic Conditioning Specification
ToS	Type of Service
VLL	Virtual Leased Line
VoIP	Voice over IP
WFQ	Weighted Fair Queuing
WRED	Weighted Random Early Detection
WRR	Weighted Round Robin Scheduling

5 References

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6 Annex A – Evaluation of network services

6.1 Checking QoS guarantees, differentiation and separation in single-domain scenario

Objectives

The goal of the trial is a practical verification of AQUILA network capabilities for supporting defined set of NSs keeping separation between them and their abilities for providing specified (different, depending of type of NS) QoS requirements. More specifically, we focus on practical verification of:

- QoS guarantees provided by particular NSs;
- NS separation: including impact of traffic carried inside given NS on QoS experienced by traffic submitted to other NSs;
- QoS differentiation between flows submitted to different NSs.

In the reported trials a single-domain network scenario is assumed. In order to evaluate three mentioned aspects of providing QoS in AQUILA network, a series of test cases has been defined. For each test case, the representative packet-level QoS parameters are measured.

Topology

Testbed topology, assumed for all single-domain trials, is presented in Figure 6-1.

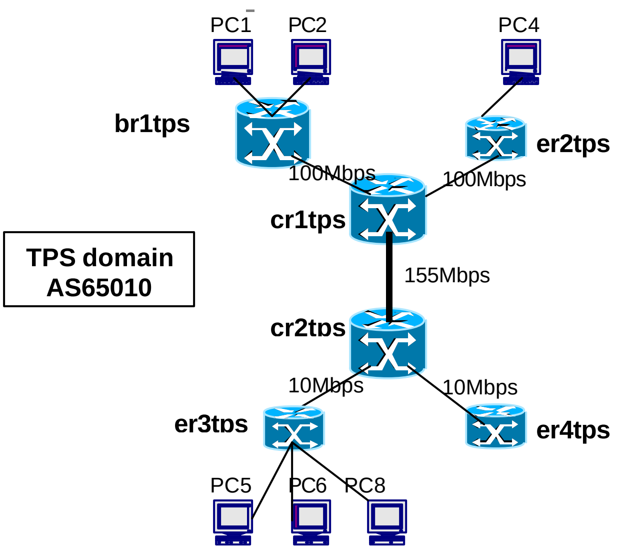


Figure 6-1. Trial topology for single-domain network scenario. PC1-PC8 – traffic generators/analyzers

Trial tools

The trials require specific traffic generators and analysers. Tools available in AQUILA DMA measurement architecture allows us for generating test (foreground) and background traffic. Additionally, hardware traffic generator (HP BSTS) is also used for generating the background traffic.

Measured parameters

We measure the following parameters illustrating QoS offered by particular TCLs (see Table 6-1).

Traffic class	Packet loss ratio	One-way delay	IPDV	Throughput	Goodput
TCL1	Yes	Yes	Yes	No	No
TCL2	Yes	Yes	Yes	No	No
TCL3	Yes	No	No	Yes	Yes
TCL4	Yes	No	No	Yes	Yes

Table 6-1. Measured QoS parameters in NS trials

Definition of measured parameters:

- Packet loss ratio (P_{loss}) denotes the number of lost packets divided to all sent packets;
- The one-way-delay from a source to a destination is ($t_2 - t_1$) means that source sent the first bit of an IP packet to the destination at a time t_1 and that the destination received the last bit of that packet at time t_2 [D2301]
- The Instantaneous Packet Delay Variation (IPDV) of an IP packet, inside a stream of packets, going from the measurement point MP_1 to the measurement point MP_2, is the difference of the one-way-delay of that packet and the one-way-delay of the preceding packet in the stream [D2301];
- Throughput is the traffic bit rate measured at IP packet level, i.e. the carried load is measured;
- Goodput is the traffic bit rate measured at the application level, i.e. the traffic measured at the receiver side.

Traffic conditions

This trial should be performed with using artificial traffic only. One can distinguish between two types of traffic generated inside tested TCL: foreground and background. The proposed representative traffic profiles for particular TCLs are gathered in Table 6-2.

Traffic class	Foreground traffic	Background traffic
TCL1	Constant bit rate (CBR)	Poissonian stream
TCL2	ON/OFF or stored video trace	Superposition of ON/OFF flows (MMDP) or Poissonian stream
TCL3	TCP greedy flow	N TCP greedy flows or Poissonian stream or constant bit rate
TCL4	TCP non-greedy flow	N TCP non-greedy flows or Poissonian stream or constant bit rate
TCL5	-------------------------------	Constant bit rate

Table 6-2. Traffic profiles for NS trials

Admission control on the access link is realized in accordance with the Joint AC schema. It means, that now admission to given traffic class does not take into account only current load in the considered class but also the traffic submitted to the other TCLs. Therefore, for proving the correctness of the approach it would be desirable to take into account in the trials rather the mix traffic scenarios (with traffic submitted to more than one TCL in the same time).

In the system with 4 TCLs, the system state may be described as vector $<n_1, n_2, n_3, n_4>$, where n_i denotes the number of TCLi flows in progress. During the trials, the measurements of QoS parameters should be performed in all TCLs in parallel. Moreover, the submitted traffic should correspond to different “points” in the space $<n_1, n_2, n_3, n_4>$, possibly on the boundary of admission region. From practical purposes we limit our interest to the following test groups (see Figure 6-2):

- Trial of the performance of TCL1. The bandwidth available for TCL1 is changed from 0 to C (link capacity). Traffic in all TCLs 3,4 and 5 is of the lower priority and can be modelled as one traffic stream. Foreground traffic submitted to TCL1 is a CBR (constant bit rate) flow, while the background is modelled as Poisson stream. Background traffic in other TCLs is CBR or Poisson. In this trial, traffic conditions depend on the number of flows submitted to TCL1 class, so only one value (n_1) of state vector changes.

- Trial of the performance of TCL2. The bandwidth available for TCL2 is changed from 0 to 0.9C. Different sub-cases are considered, with different splitting of remaining bandwidth between TCLs 1, 3 and 4. Foreground traffic submitted to TCL2 is an ON-OFF stream, the background load in TCL2 is modelled as MMDP process, and the TCL1 traffic is modelled as Poisson stream. Other TCLs are permanently congested. In this trial, traffic conditions depend on the number of running connections in TCL1 and TCL2 classes, so two values (n_1, n_2) of state vector are changing.

- Trial of the performance of TCL3. The tests corresponded to two cases: (1) with homogenous TCP flows, i.e. each requesting the same value of the rate, and (2) with heterogeneous TCP flows, differing in the requested rates.

- Trial of the performance of TCL4. Two trial cases was taken into account: (1) homogenous case, when all submitted flows has the same characteristics and (2) heterogeneous case, when flows has different characteristic. In the trial the packet loss rate was measured. The number of simultaneous running flows was determined by defined for PMC service AC algorithm (see D1302). The trial was performed under the minimum possible RTT value (propagation delay close to 0). This condition constitutes the worst case for the PMC traffic.

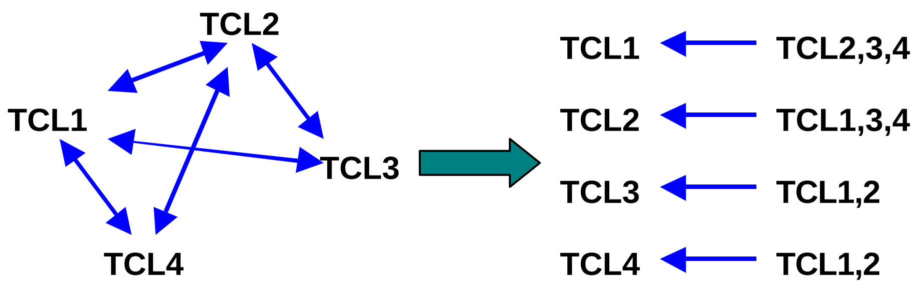


Figure 6-2. Decomposition of the trial cases

The detailed specification of traffic cases is given below.

6.1.1 Trial of PCBR performance

In this trial the performance of TCL1 class is evaluated under heavy load conditions of the link. The bandwidth available for traffic in TCL1 is varied from 0 to 10Mbps according to the Joint AC rules. Packets belonging to TCL1 are carried on the link with the highest priority. Packets belonging to any of the other classes are treated as lower priority traffic. Therefore, from the point of view of performance of TCL1, the traffic belonging to classes TCL2,3,4 and 5 is indistinguishable and is modelled as cumulative lower priority traffic stream.

The following traffic streams are submitted to the system:

Foreground traffic:

- Constant bit rate flow in TCL1 with the bit rate equal to 64kbps and constant packet size 100B. This traffic pattern is typical for CBR voice application. Traffic is generated between PC8 and PC2 (see Figure 6-1).

Background traffic:

- Poisson stream in TCL1. The mean bit rate of the Poisson stream is equal to R1 (bandwidth B1 allocated for TCL1, multiplied by Rho1, according to [D1302]), minus the rate of the foreground flow (64kbps). The value of Rho1=0.52 corresponds to the target packet loss ratio 10^{-4}, with buffer size 5 packets. Packet size is equal to 500B and is constant. Traffic is generated between PC6 and PC4 (see Figure 6-1).

- Poisson stream in class TCL5, with packet size equal to 1500B (constant). The rate of the Poisson stream is such that the total offered load to the congested link is always equal to 1.2*C. In this way we simulate heavy load conditions on the contrary to the permanent congestion scenario[1]. Traffic is generated between PC5 and PC1 (see Figure 6-1).

The bottleneck in the network is the 10Mbps link between edge router er3tps and core router cr2tps. The architecture of the router output port with the scheduler governing the access to the link is presented in the below figure.

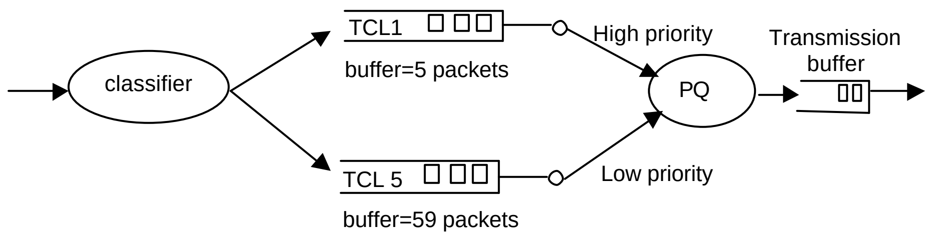


Figure 6-3. Architecture of router output port in TCL1 trials

Duration of each test is 60 minutes. Trial results are presented in table 6-3.

B1 [Mbps]	*Rate of TCL1 Poisson stream (R1-0.064) [Mbps]*	*Rate of TCL5 Poisson Stream [Mbps]*	*Pkts lost/all*	*P_{loss} of TCL1 CBR flow*	*Loss burst*	*Delay [ms]*			*IPDV [ms]*	
						min	*max*	*avg*	*avg*	*max*
1	0.456	11.48	0/287955	0	-	0.6	19.76	4.7	0.7	17.74
2	0.976	10.96	0/287947	0	-	0.59	22.95	4.41	0.89	19.91
4	2.016	9.92	0/287951	0	-	0.59	19.52	4.02	1.04	15.51
5	2.536	9.4	0/287958	0	-	0.6	22.87	3.89	1.08	18.41
7	3.576	8.36	0/287955	0	-	0.59	22.23	3.71	1.1	19.96
9	4.616	7.32	13/287954	$4.5*10^{-5}$	1	0.59	24.59	3.6	1.09	22.26
10	5.136	6.8	26/287958	$9.0*10^{-5}$	1	0.59	19.32	3.57	1.09	14.96

Table 6-3. Trial of TCL1 performance

The reported results say that in this case the impact of TCL5 traffic on the TCL1 is negligible, even if the bandwidth allocated for TCL1 is equal to the link capacity. One can observe that mean delay for the foreground traffic slowly decreases when the bandwidth dedicated for TCL1 increases. This is

[1] In the heavy load conditions mean load exceeds link capacity but probability that system is empty is non-zero. In permanent congestion case, the system never reaches empty state.

caused by the fact that we have smaller packets in the system when TCL1 traffic is growing. The observed packet loss ratio in all cases is below the target value 10^{-4}. Summarising the presented results confirm effectiveness of TCL1.

6.1.1.1 Trial of PCBR performance in permanent congestion conditions

In this trial the performance of TCL1 class is also investigated. The bandwidth available for traffic in TCL1 is changed from 0 to 10Mbps. Packets belonging to TCL1 are carried on the link with the highest priority. Packets belonging to any of the other classes are treated as lower priority traffic. Therefore, from the point of view of performance of TCL1, the traffic belonging to classes TCL2,3,4 and 5 is indistinguishable and will be modelled as one traffic stream. Traffic submitted to lower priority class corresponds to the conditions of permanent congestion. The following traffic streams are submitted to the system:

Foreground traffic:

- Poisson stream in TCL1. The mean rate of the Poisson stream is equal to R1 (bandwidth B1 allocated for TCL1, divided by Rho1). The value of Rho1=0.52 corresponds to the target packet loss ratio 10^{-4}, with buffer size 5 packets. Packet size is equal to 500B. Traffic is generated between PC6 and PC2 (see Figure 6-1).

Background traffic:

- TCL5 is permanently congested (worst case). This is achieved by submitting CBR traffic with rate 15000 kbps, highly exceeding the link capacity. Packet size is 500B, 1000B and 1500B. Traffic is generated by hardware traffic generator (HP BSTS), connected to router er3tps.

The bottleneck in the network is the 10Mbps link between edge router er3tps and core router cr2tps. The architecture of the router output port with the scheduler governing the access to the link is presented in figure 6-1. Trial results are presented in the tables below.

B1 [Mbps]	*Rate of Poisson stream (R1) [Mbps]*	*Test duration [min]*	*Pkts lost/all*	*P_{loss}*	*Loss burst*
1	0.52	60	2/454488	$4.40*10^{-6}$	1
2	1.04	30	7/461100	$1.52*10^{-5}$	1
4	2.08	30	209/944528	$2.21*10^{-4}$	4
5	2.6	10	289/399613	$7.23*10^{-4}$	3
7	3.64	10	1872/543598	$3.43*10^{-3}$	8
9	4.68	10	6204/677773	$9.07*10^{-3}$	6
10	5.2	10	10167/753785	$1.33*10^{-2}$	7

Table 6-4. Trial of TCL1 in permanent congestion, TCL5 packet size 1500B

B1 [Mbps]	*Rate of Poisson stream (R1) [Mbps]*	*Test duration [min]*	*Pkts lost/all*	P_{loss}	*Loss burst*
4	2.08	30	42/945454	$4.44*10^{-5}$	3
5	2.6	10	53/398829	$1.33*10^{-4}$	2
7	3.64	10	436/542375	$8.03*10^{-4}$	7
9	4.68	10	1860/681223	$2.72*10^{-3}$	5
10	5.2	10	5734/757028	$7.51*10^{-3}$	85 (!???)

Table 6-5. Trial of TCL1 in permanent congestion, TCL5 packet size=1000B

B1 [Mbps]	*Rate of Poisson Stream (R1) [Mbps]*	*Test duration [min]*	*Pkts lost/all*	P_{loss}	*Loss burst*
4	2.08	30	4/944684	$4.23*10^{-6}$	1
5	2.6	10	4/398967	$1.00*10^{-5}$	1
7	3.64	10	32/543984	$5.88*10^{-5}$	3
9	4.68	10	135/679958	$1.99*10^{-4}$	5
10	5.2	10	293/755174	$3.88*10^{-4}$	5

Table 6-6. Trial of TCL1 in permanent congestion, TCL5 packet size=500B

Figure below shows the TCL1 packet loss ratio as a function of bandwidth consumed by TCL1 (B1), with packets of different sizes in highly overloaded TCL5 class.

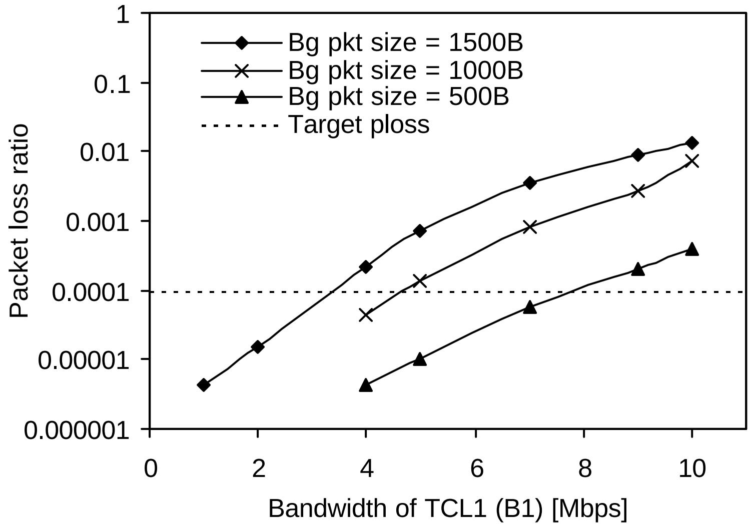


Figure 6-4. Packet loss ratio vs. the bandwidth available for TCL1

In the case of permanent congestion, which can be regarded as a theoretical worst case, one can observe some limits for bandwidth allocated for TCL1. The limitations are more rigorous when the packet size of TCL5 traffic is 1500 B. The measured packet loss ratio for TCL1 is greater than target when the bandwidth allocated for TCL1 exceeds a certain value. For instance, for packet size of TCL5 equals 1500 B, this value is around 20% of total link capacity. The results can be explained in the following way. The packet loss ratio for TCL1 is proportional to the packet size of TCL5 (more precisely, to residual packet size) as well as to the arrival rate of the packets from TCL1.

Summarising, the reported undesirable results correspond to the theoretical worst case of TCL5 traffic, which is unlikely to happen in the network.

6.1.2 Trial of PVBR performance

In this trial the performance of TCL2 class is evaluated. The bandwidth available for TCL2 is changed from 0 to 0.9*link capacity (which is the maximum allowed bandwidth for TCL2, determined by the default WFQ weight setting, w_2=0.9). The remaining bandwidth is allocated for flows from TCL1, TCL3 and TCL4. The following traffic streams are submitted to the system:

Foreground traffic:

- 1 flow in TCL2, which is exponential ON-OFF, with parameters chosen from 3 types of flows:
  - type I: typical parameters for MPEG video source; PR=940kbps, m=135kbps, packet size 500B, duration of ON (OFF) period 200 (1192) ms
  - type II (artificial): PR=500kbps, m=150kbps, packet size 500B, duration of ON (OFF) period 200 (466) ms
  - type III: typical for VBR voice; PR=64kbps, m=32kbps, packet size 500B, duration of ON (OFF) period 1 (1) s

  Foreground traffic is generated between PC8 and PC2 (see Figure 6-1).

Background traffic:

- Superposition of ON-OFF flows in TCL2 (according to MMDP model). Parameters of single flow are the same as in the case of the foreground flow, getting in this way homogenous traffic case. The total number of superposed flows (including the foreground flow) is such that no additional flow could be admitted by AC function, when MBAC algorithm is used. The target loss ratio is 10^{-4}. Traffic is generated between PC6 and PC4 (see Figure 6-1).
- Poisson stream in TCL1. The mean rate of the Poisson stream is equal to R1 (bandwidth B1 allocated for TCL1, divided by Rho1). The value of Rho1=0.52 corresponds to the target packet loss ratio 10^{-4}, with buffer size 5 packets. Packet size is equal to 500B. Traffic is generated between PC5 and PC1 (see Figure 6-1).
- TCL 3,4 and 5 are permanently congested (worst case). This is achieved by submitting CBR traffic with rate highly exceeding the capacity allocated for particular class. Traffic is generated by hardware traffic generator (HP BSTS), connected to router er3tps.

The bottleneck in the network is the 10Mbps link between edge router er3tps and core router cr2tps. The architecture of the router output port with the scheduler governing the access to the link is presented in the figure below.

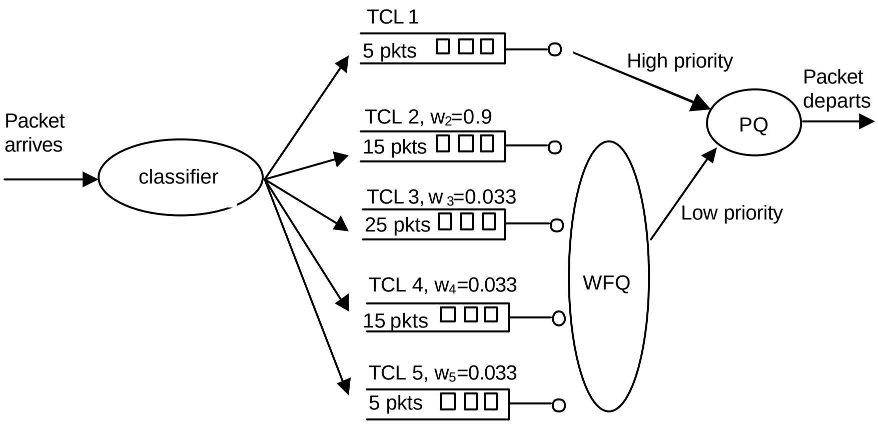


Figure 6-5. Architecture of router output port in TCL2 trials

Duration of each test is 60 minutes. Trial results are presented in the tables below.

Flows of type I (PR=940kbps, m=135kbps)								*Delay [ms]*			*IPDV [ms]*	
B1 [Mbps]	*N2*	*B2 [Mbps]*	*R2 [Mbps]*	*B3=B4 [Mbps]*	*Pkts lost/all*	P_{loss}	*Loss burst*	*min*	*max*	*avg*	*avg*	*max*
0	11	8.98	1.35	2.554	9/33949	$2.65*10^{-4}$	1	2.47	12.48	6.26	0.53	5.78
0	5	5.99	0.54	2.838	12/43333	$2.70*10^{-4}$	1	3.05	8.69	6.28	0.47	2.88
4	4	5.37	0.405	2.214	5/43611	$1.14*10^{-4}$	1	3.51	11.88	6.42	0.72	6.1

Table 6-7. Trial of TCL2 performance with flows of type I

Flows of type II (PR=500kbps, m=150kbps)								*Delay [ms]*			*IPDV [ms]*	
B1 [Mbps]	*N2*	*B2 [Mbps]*	*R2 [Mbps]*	*B3=B4 [Mbps]*	*Pkts lost/all*	P_{loss}	*Loss burst*	*min*	*max*	*avg*	*avg*	*max*
0	23	8.945	3.3	1.965	14/110705	$1.26*10^{-4}$	1	2.84	17.5	3.95	0.49	12.99
0	13	6.168	1.8	2.46	14/109420	$1.20*10^{-4}$	1	3.04	18.36	4	0.41	14.95
0	7	4.238	0.9	2.73	14/107492	$1.30*10^{-4}$	1	2.95	17.37	4.01	0.52	13.04
4	10	5.243	1.5	1.926	15/110171	$1.36*10^{-4}$	1	2.87	23.34	4.16	0.7	19.13
4	5	3.499	0.6	2.196	11/109204	$1.00*10^{-4}$	1	2.66	20.44	4.15	0.65	16.26
4	3	2.658	0.3	2.286	11/108094	$1.00*10^{-4}$	1	2.23	14.88	4.15	0.63	11.44
7	3	2.658	0.3	1.773	13/109481	$1.18*10^{-4}$	1	2.43	21.7	4.41	1.0	17.86

Table 6-8. Trial of TCL2 performance with flows of type II

Flows of type III (PR=64kbps, m=32kbps)								*Delay [ms]*			*IPDV [ms]*	
B1 [Mbps]	*N2*	*B2 [Mbps]*	*R2 [Mbps]*	*B3=B4 [Mbps]*	*Pkts lost/all*	P_{loss}	*Loss burst*	*min*	*max*	*avg*	*avg*	*max*
0	97	4.488	3.072	2.078	0/29613	0	-	2.62	5.17	3.62	0.51	2.08
0	30	1.788	0.96	2.712	3/29447	$1.00*10^{-4}$	1	2.5	5.2	3.67	0.47	2.06
4	120	5.376	3.808	1.224	2/28757	$6.90*10^{-5}$	1	2.74	14.25	3.86	0.76	11.18
4	78	3.74	2.464	1.636	3/28644	$1.00*10^{-4}$	1	2.65	9.93	3.81	0.72	6.51
4	52	2.686	1.632	1.886	1/13981	$7.10*10^{-5}$	1	2.4	10.18	3.8	0.71	7.15
4	15	1.043	0.448	2.241	1/29624	$3.30*10^{-5}$	1	2.58	11.24	3.81	0.68	6.81
7	52	2.686	1.632	1.408	2/29827	$6.70*10^{-5}$	1	2.82	15.27	4.14	1.1	11.89
7	33	1.876	1.024	1.6	4/29532	$1.30*10^{-4}$	1	2.75	16.42	4.09	1.04	13.14
7	21	1.333	0.64	1.716	0/29822	0	-	2.49	13.83	4.1	1.04	10.75
7	5	0.499	0.128	1.854	3/29560	$1.00*10^{-4}$	1	2.69	12.89	4.05	1.0	9.87

Table 6-9. Trial of TCL2 performance with flows of type III

In the tables we collected the results corresponding to the QoS experienced by the foreground TCL2 traffic flows, taking into account the selected points from AC boundary determined by Joint AC schema. In all cases the received results are positive, it means that assumed target QoS it seems to be kept. Anyway, relatively large values of max IPDV are observed. To be honest, the IPDV was not specified for QoS objective.

6.1.3 Trials of PMM performance

The PMM service is designed to provide throughput guarantees for TCP connections of greedy type. The guaranteed throughput per TCP connection should not be below the requested rate value. The aim of the reported trials is to verify whether the requirements for PMM are met. Since two alternative AC methods for PMM are implemented, two groups of tests are performed:

- (1) for AC based on TBM (Token Bucket Model) [D1302]
- (2) for AC based on advertised window setting [D1303]

The measured parameter is the TCP throughput. The obtained results are compared with the declared requested rate values.

6.1.3.1 Trial topology

The assumed trial topology for PMM service is depicted on figure 6-6. This topology consists of 2 CISCO edge routers connected by 2Mbps link (bottleneck link). The PC stations 1/2/3/4 are connected to the er2tps router while PC 5/6 and PC 8 to the er4tps. The PC stations from 1 to 4 play role of TCP senders while the PC stations from 5 to 8 are the TCP receivers. In this configuration the maximum number of running TCP connections is 4.

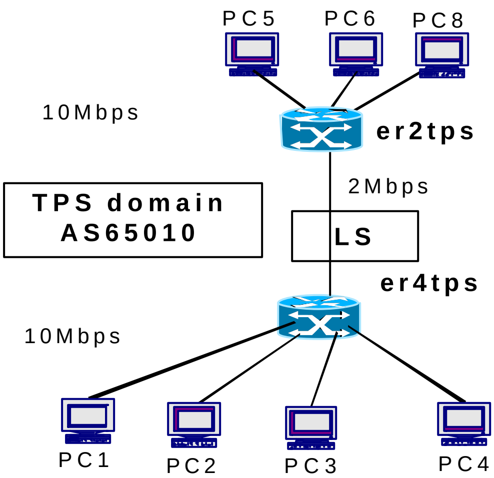


Figure 6-6. PMM trial topology

In this topology we are able to introduce additional transmission delay on the bottleneck link by the Link Simulator (LS). In this way we can verify the effectiveness of the PMM for more realistic RTT values.

6.1.3.2 Edge router output port architecture

The edge router output port architecture is depicted on figure 6-7. WFQ weights are set according to the default values recommended in [D1302] (w_2=0.9; w_3=w_4=w_{STD}=0.033)

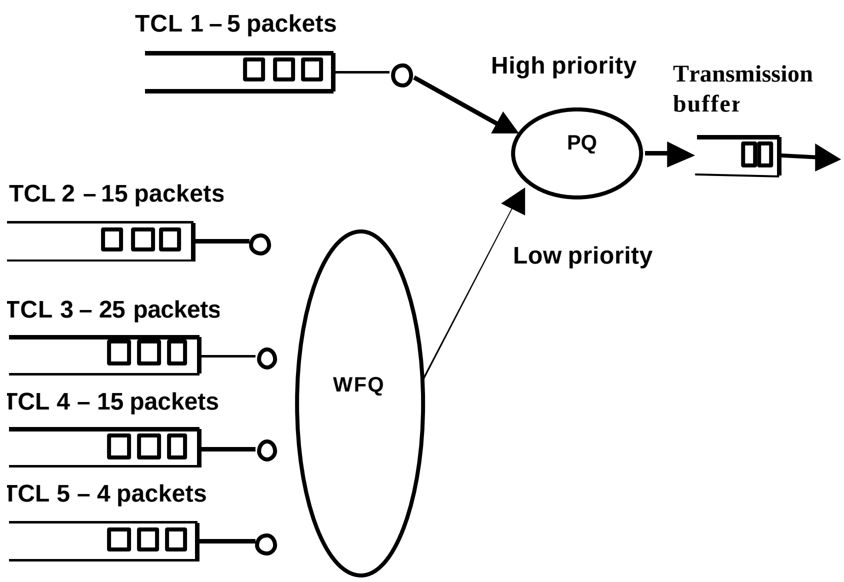


Figure 6-7. Router output port architecture for PMM service

For both considered AC approaches, the assumed traffic description is in the form of single token bucket with parameters (SR, BSS). For the AC algorithm based on TBM the token bucket mechanism uses marker option for out of profile packets, while for the AC based on advertised window setting the out of profile packets (if any) are simply dropped.

Queue management mechanism: for the AC algorithm based on TBM is the WRED while for the AC based on advertised window setting is the tail dropped. The recommended configuration parameters of the WRED are shown in table 6-10.

WRED parameter	Value [packets]
$Minth_{out}$	5
$Maxth_{out}$	23
$Maxp_{out}$	0.2
$Minth_{in}$	24
$Maxth_{in}$	25
$Maxp_{in}$	1
Buffer size	25
Wq	0.5

Table 6-10. WRED parameters

6.1.3.3 Setting advertised window size

The TCP implementation introduces some constraints in setting value of advertised window size. For instance, the table 6-11 shows the list of possible values for advertised window size in the range between 1448 and 20272 bytes.

The observed TCP window size [bytes]
1448
2896
4344
7240
8688
11584
13032
14480
15928
17376
20272

Table 6-11. The observed advertised window size thresholds for TCP version running at Linux SuSE v.7.3 environment in Warsaw AQUILA test-bed

6.1.3.4 Trial results

For both tested algorithms two trial cases are performed: (1) assuming homogenous TCP flows with the same requested rate values, and (2) assuming heterogeneous TCP flows differing in the requested rates. For all tests, the minimum round trip time RTT^{min} is 108ms, including additional one-way transmission delay equal to 50 ms on 2Mbps link. The MTU is 1500 bytes and TCP MSS (Maximum Segment Size) is 1448 bytes.

Traffic parameters

Foreground traffic

- PMM: number of consecutive TCP flows generated by single TCP greedy source. Particular TCP flow starts after the previous one is finished (the consecutive TCP flows start each 8 minutes). A volume of data generated by TCP source corresponding to single flow is fixed to 10 Mbytes;

Background traffic

- PMM: number of parallel running greedy TCP flows; The number of TCP flows, including foreground flow, is admitted according to the joint AC rules (in this case no additional flow could be admitted by ACA); In this trial the bandwidth allocated for PMM is equal to 2Mbps; for AC algorithm based on TBM ρ_{PMM}=0.75; T=202ms (according to the recommendation from [D1303]).

Case #1 Homogenous TCP flows

PMM service - for AC based on TBM: for the case#1, four tests are performed differing in requested rates of TCP connections. For example in the Test #1, 4 TCP connections are admitted up to assumed AC limit (ρ_{PMM} *2Mbps=0.75*Mbps=1.5Mbps), each with RR=375 kbps. Edge router output buffer size is equal to 25 packets (see table 6-10).

Tests	**Test #1**	**Test #2**	**Test #3**	**Test #4**
Number of running TCP connections	**4**	**3**	**2**	**1**
SR (kbps)	232	392	680	1464
BSS (bytes)	60000	60000	60000	60000
RR (kbps)	375	500	750	1500
Throughput (kbps)	**493.5±27.6**	**685±61**	**959±77**	**1594**

RR – Requested Rate, SR, BSS – token bucket parameters, Throughput - measured TCP throughput (with confidence interval 95%)

Table 6-12. Throughput characteristics for AC based on TBM: case #1

PMM service - for AC based on advertised window setting: for the case#1, three tests are performed also differing in requested rates of TCP connections. For example in the Test #1, 3 TCP connections are admitted up to assumed AC limit (in this case 2Mbps), each with RR=521.7 kbps. The router output port buffer size is assumed to avoid packet losses (see [D1303]).

Tests	Test #1 Buffer size=18 packets	Test #2 Buffer size=18 packets	Test #3 Buffer size=15 packets
Number of running TCP connections	3	2	1
SR (kbps)	672	1000	2000
W^{req}(bytes)	8688	13032	26064
BSS (bytes)	8463	12150	21600
RR (kbps)	521.7	809	1714.1
Throughput (kbps)	**564.7±7**	**858±5**	**1778.3**

RR – Requested Rate, SR, BSS – token bucket parameters, W^{req} – advertised window size, Throughput - measured TCP throughput (with confidence interval 95%)

Table 6-13. Throughput characteristics for AC based on advertised window setting: case#1

Conclusions

- Two investigated AC approaches meet the expectations and they guarantee that the measured TCP throughput is above the requested rate.
- For the AC based on TBM the difference between the measured TCP throughput and the requested rate is hard to predict and depends on the number of running TCP flows. One can observe that in some cases this difference is significant.
- For the AC based on advertised window setting the measured TCP throughput, according to the expectations, is between the requested rate and the sustained rate, but rather closed to the requested rate. The reason that the measured TCP throughput is greater than the requested rate is mainly due to the error resulting from the assumed analytical approximation of average RTT (see [D1303]).
- One can observe that the AC based on TBM is more conservative than the AC based on advertised window setting; the cumulative requested rate is less for AC based on TBM.

Case #2 Heterogeneous TCP flows

For the case with heterogeneous TCP flows two tests are performed. The only difference comparing to the case #1 is that now the TCP flows differ in the requested rate values.

Test1: PMM service - for AC based on TBM

Two tests with 3 and 4 TCP connections are performed (Test 1A and Test 1B). For the test with 3 TCP connections, the requested rates are: RR_1=250 kbps, RR_2=500 kbps and RR_3=750 kbps. For the test with 4 TCP connections, the requested rates are: RR_1= RR_2=250 kbps, RR_3=RR_4=500 kbps. Therefore, for both tests the cumulative requested rate is 1.5 Mbps and reaches the assumed AC limit (ρ_{PMM} *2Mbps=0.75*Mbps=1.5Mbps). The measured values of TCP throughput are in table 6-14 and table 6-15.

Flow	#1	#2	#3
SR (kbps)	40	392	680
BSS (bytes)	60000	60000	60000
RR (kbps)	250	500	750
Throughput (kbps)	**517±55**	**630±33**	**807±24**

Table 6-14. Throughput characteristics for AC based on TBM: case#2 – Test1A

Flow	#1	#2	#3	#4
SR (kbps)	40	40	392	392
BSS (bytes)	60000	60000	60000	60000
RR (kbps)	250	250	500	500
Throughput (kbps)	**385±110**	**385±110**	**473±16**	**473±16**

Table 6-15. Throughput characteristics for AC based on TBM: case#2 – Test1B

Test2: PMM service - for AC based on advertised window setting

Two tests with three and four TCP connections are performed (Test 2A and Test 2B). For the test with 3 TCP connections, the requested rates are: RR_1=232 kbps, RR_2=521.7 kbps and RR_3=809 kbps, which gives total requested rate 1507.4 kbps. For the test with 4 TCP connections, the requested rates are: RR_1= RR_2=232 kbps, RR_3=RR_4=521.7 kbps, which gives the total requested rate 1562.7 kbps. The measured values of TCP throughput are in table 6-16 and table 6-17.

Flow	#1	#2	#3
SR (kbps)	328	672	1000
W^{req}(bytes)	4274	8688	13032
BSS (bytes)	4283	8463	12150
RR (kbps)	232	521.7	809
Throughput (kbps)	**276±2**	**569±8.3**	**846±1.4**

Table 6-16. Throughput characteristics for AC based on advertised window setting: case#2 – Test2A (router output port buffer size=18 packets)

Flow	#1	#2	#3	#4
SR (kbps)	328	328	672	672
W^{req}(bytes)	4274	4274	8688	8688
BSS (bytes)	4283	4283	8463	8463
RR (kbps)	232	232	521.7	521.7
Throughput (kbps)	**275±2**	**275±2**	**567.6±2.5**	**567.6±2.5**

Table 6-17. Throughput characteristics for AC based on advertised window setting: heterogeneous case#2 – Test2B (router output port buffer size=18 packets)

Conclusions

- The AC algorithm based on TBM does not meet the expectations. In some cases (see table 6-15) the measured TCP throughput is below the requested rate. In addition, one can observe that by using this algorithm the TCP flows share available bandwidth rather to the fair share than according to the requested rate (see table 6-15).

- The AC algorithm based on advertised window setting meets the expectations. Similarly to the homogenous case, again the measured TCP throughput is between the requested rate and the sustained rate, but rather closed to the requested rate.

6.1.4 Trial of PMC performance

The PMC service was designed to guarantee very low packet losses and low delay for non-greedy traffic usually controlled by TCP protocol. The potential applications for using PMC are:

- Transaction oriented applications
- www applications

The goal of this trial is to check whether the assumed QoS objectives for PMC service are met. The trial was performed assuming that PMC service was separated from other network services. During the trial the packet loss ratio was measured. By assuring low packet loss ratio one can expect the low transaction delay by avoiding packet retransmission.

6.1.4.1 Trial topology

The assumed trial topology for testing PMC service is depicted on figure 6-8. This topology consists of 2Mbps bottleneck link between 2 CISCO edge routers. PC1 and PC2 are connected to the er4tps router while PC5 and PC6 to the er2tps. The foreground traffic was sent between terminals PC2 and PC6, while background traffic between PC1 and PC5.

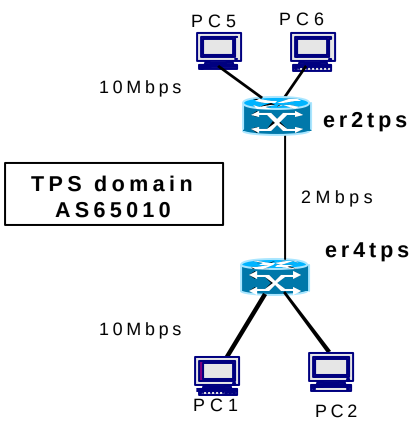


Figure 6-8. PMM trial topology

6.1.4.2 Edge router output port architecture

The edge router output port architecture is depicted on figure 6-9. The WFQ scheduler weights are fixed according to the default values recommended in [D1302] (w_2=0.9; w_3=w_4=w_{STD}=0.033). The almost whole buffer space was dedicated to PMC services (60 packets), because PMC requires relatively large room and in this trial there was no traffic in TCL1-3 classes.

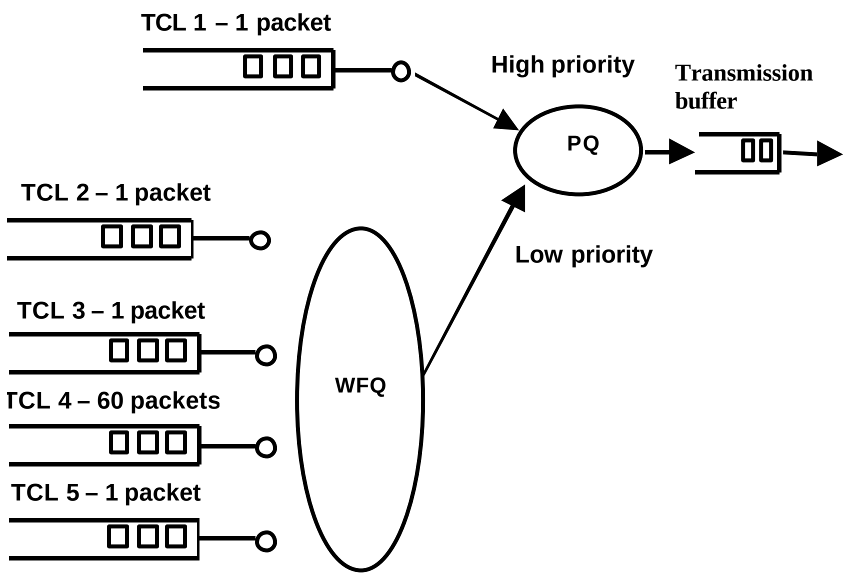


Figure 6-9. Router output port architecture for PMM service

Moreover the buffer management mechanism WRED was applied with parameters fixed according to D1302 (see table 6-18).

WRED parameter	Value [packets]
$Minth_{out}$	2
$Maxth_{out}$	2
$Maxp_{out}$	1
$Minth_{in}$	60
$Maxth_{in}$	60
$Maxp_{in}$	1
Buffer size	60
Wq	1

Table 6-18. WRED parameters settings for PMC trial

6.1.4.3 Evaluation of AC algorithms proposed for PMC service

Two trial cases were taken into account: (1) homogenous case, when all submitted flows have the same characteristics and (2) heterogeneous case, when flows has different characteristic.

In the trial the packet loss rate was measured after 100 measurement cycles. Each measurement cycle begun with simultaneous starting up of a given number of TCP flows and ended after completing all transfers. During single TCP connection a predefined amount of data was transferred corresponding to a typical size of WEB pages. The number of simultaneous running flows was determined by defined for PMC service AC algorithm (see D1302).

The trial was performed under the minimum possible RTT value (propagation delay close to 0). This condition constitutes the worst case for the PMC traffic.

Traffic parameters

Foreground traffic

- PMC: a number of TCP flows were generated simultaneously by one terminal (PC2). Each flow had to send a given amount of data.

Background traffic

- As background traffic a constant bit rate stream of 2Mbps rate was submitted into the STD class. Therefore the studied system was permanently overloaded.

Case #1: Homogenous case

In this case a number of homogenous flows was submitted into the system. Two tests were performed differing in amount of data transferred by particular flow. The obtained results and detailed flow specification are included in table 6-19.

	Test1	**Test2**
Number of flows (admitted according to AC)	**6**	**3**
Amount of transferred data per flow	36200B	73848B
PR (Mbps)	10	10
BSS (bytes)	15000	30000
SR (kbps)	336	168
Ploss	**0**	**0**

PR, SR, BSS – token bucket parameters, Ploss – Packet loss rate

Table 6-19. Packet loss rate for PMC service: homogenous case#1

Comparing to the above tests, now one more flow than AC boundary (it means 7 instead of 6 and 4 instead of 3) was admitted in order to show the accuracy of AC algorithm. Table 6-20 shows the obtained results.

	Test1	**Test2**
Number of flows (admitted according to AC)	**7**	**4**
Amount of transferred data per flow	36200B	73848B
PR (Mbps)	10	10
BSS (bytes)	15000	30000
SR (kbps)	336	168
Ploss	**~10^{-2}**	**~10^{-2}**

PR, SR, BSS – token bucket parameters, Ploss – Packet loss rate

Table 6-20. Packet loss rate for PMC service: homogenous case#2

Case #2: Heterogeneous case

In this case, two different types of flows were simultaneously submitted into the system. As in the case #1, the number of admitted flows was determined by AC limit. The obtained results are collected in table 6-21.

	Test1	
Number of flows (admitted according to AC)	**2**	**2**
Amount of transferred data per flow	36200B	73848B.
PR (Mbps)	10	10
BSS (bytes)	15000	30000
SR (kbps)	340	170
Ploss	**0**	

Table 6-21. Packet loss rate for PMC service: heterogeneous case

As in the homogenous case, now one more flow than AC boundary (it means 3 instead of 2) was admitted in order to show the accuracy of AC algorithm. Table 6-22 shows the obtained results.

	Test1	
Number of flows (admitted according to AC)	**3**	**2**
Amount of transferred data per flow	36200B	73848B.
PR (Mbps)	10	10
BSS (bytes)	15000	30000
SR (kbps)	340	170
Ploss	**$\sim 10^{-2}$**	

Table 6-22. Packet loss rate for PMC service: heterogeneous case

6.1.4.4 Conclusions

Taking into account the above results one can conclude that PMC service is able to guarantee low packet losses (in fact no losses were observed). Moreover the AC algorithm designed for PMC service properly determines the maximum number of admitted flows.

6.2 Checking QoS guarantees, differentiation and separation in inter-domain scenario

Objectives

The goal of the trial is a practical verification of AQUILA network capabilities for supporting defined set of inter-domain NSs (GWKS), keeping separation between them and their abilities for providing specified (different, depending of type of NS) QoS requirements. More specifically, we focus on practical verification of:

- QoS guarantees provided by particular NSs;
- NS separation: including impact of traffic carried inside given NS on QoS experienced by traffic submitted to other NSs;
- QoS differentiation between flows submitted to different NSs.

In the reported trials an inter-domain network scenario is assumed. In order to evaluate three mentioned aspects of providing QoS in AQUILA network, a series of test cases has been defined. For each test case, the representative packet-level QoS parameters are measured.

Topology

Testbed topology, assumed for all inter-domain trials, is presented in figure 6-10.

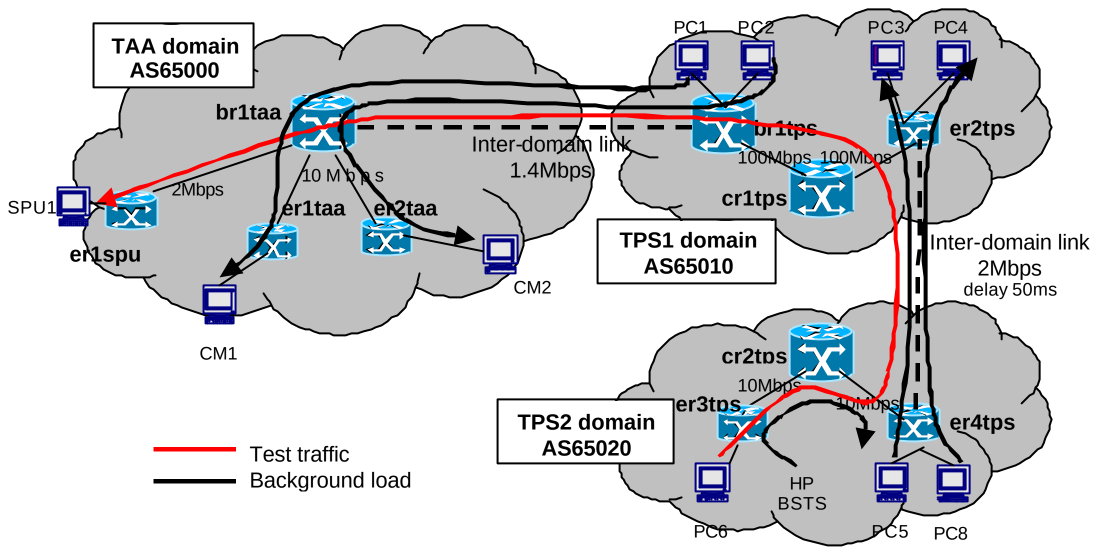


Figure 6-10. Trial topology for inter-domain network scenario

Trial tools

The trials require specific traffic generators and analysers. Tools available in AQUILA DMA measurement architecture allows us for generating test (foreground) and background traffic. Additionally, hardware traffic generator (HP BSTS) is also used for generating the background traffic.

Measured parameters

We measure the following parameters illustrating QoS offered by particular TCLs (see table 6-23).

Traffic class	Packet loss ratio	Loss burst	One-way delay	IPDV	Throughput	Goodput
TCL1	Yes	Yes	Yes	Yes	No	No
TCL3	Yes	Yes	No	No	Yes	Yes

Table 6-23. Measured QoS parameters in iner-domain NS trials

Traffic conditions

This trial should be performed with using artificial traffic only. One can distinguish between two types of traffic generated inside tested TCL: foreground and background. The proposed representative traffic profiles for particular TCLs are gathered in table 6-24.

Traffic class	Foreground traffic	Background traffic
TCL1	Constant bit rate	Poissonian flow
TCL3	TCP greedy flow	N TCP greedy flows or Poissonian flow or constant bit rate
TCL5	-------------------------------	Constant bit rate

Table 6-24. Traffic types for inter-domain NS trials

6.2.1 Trial of TCL1 performance in inter-domain scenarios

In this trial the performance of TCL1 class in the inter-domain scenario is investigated. Packets belonging to TCL1 are carried on the link with the highest priority. Packets belonging to any of the other classes are treated as lower priority traffic. Therefore, from the point of view of performance of TCL1, the traffic belonging to classes TCL2, 3, 4 and 5 is indistinguishable and will be modelled as one traffic stream.

The bandwidth statically allocated for traffic in TCL1 (capacity determined by Service Level Agreement, SLA, between the neighbouring domains, denoted as L1) on each of the inter-domain links is changed in the trial from 0.5Mbps to the maximum value, equal to the inter-domain link capacity. We assume, that the rest of the available capacity is equally allocated to TCL3 (capacity determined by SLA between the neighbouring domains, denoted as L3) and TCL5. Such bandwidth assignment is achieved by setting equal WFQ weights in the scheduler. The trial evaluates the performance of inter-domain TCL1 with different allocation of inter-domain link bandwidth between all three TCLs.

The following traffic streams are submitted to the system:

Foreground traffic:

- Constant bit rate flow with rate equal to 64kbps and packet size 100B. This traffic pattern is typical for CBR voice application. Traffic is generated between PC6 in TPS2 domain and SPU1 in TAA domain (see figure 6-10).

Background traffic:

- Poisson stream in TCL1. The mean rate of the Poisson stream is equal to R1 (bandwidth L1 statically allocated for TCL1, multiplied by Rho1), minus the rate of the foreground flow (64kbps). The value of Rho1=0.52 corresponds to the target packet loss ratio 10^{-4}, with buffer size 5 packets. Packet size is equal to 500B. Traffic is generated:
    - Between PC2 in TPS1 domain and CM2 in TAA domain (see figure 6-10). This traffic loads the inter-domain link between domains TPS1 and TAA.

- Between PC5 in TPS2domain and PC3 in TPS1. This traffic loads the inter-domain link between domains TPS2 and TPS1.

- Poisson stream in class TCL5, with packet size equal to 1500B. The rate of the Poisson stream is such that the total offered load to the congested link is always equal to 1.2*C. Traffic is generated:
  - Between PC1 in TPS1 domain and CM1 in TAA domain (see figure6-10). This traffic loads the inter-domain link between domains TPS1 and TAA.
  - Between PC8 in TPS2domain and PC4 in TPS1. This traffic loads the inter-domain link between domains TPS2 and TPS1.
- Constant Bit Rate stream in TCL5, which emulates the permanent congestion conditions on intra-domain link between routers er3tps and cr2tps. Rate of the CBR stream is equal to 12Mbps and packet size is constant 1500B. Traffic is generated by HP BSTS hardware traffic generator.

Two inter-domain links, TPS1-TAA with capacity 1.4Mbps and TPS2-TPS1 with capacity 2Mbps, constitute the bottlenecks in the trial network. The architecture of the router output port with the scheduler governing the access to the link is presented in figure 6-11.

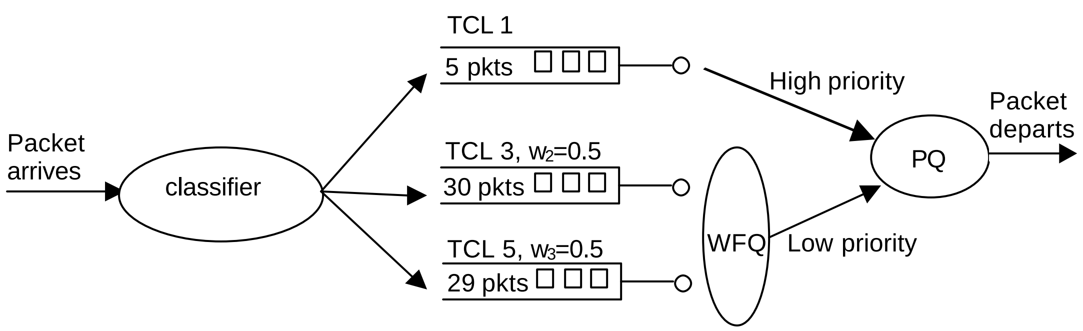


Figure 6-11. Architecture of router output port on the inter-domain link

Traffic case	SLA and traffic conditions in TCL1			SLA for TCL3	Traffic conditions in TCL5
	L1 [Mbps]	R1 [Mbps]	TCL1 Poisson traffic rate (R1-0.064) [Mbps]	L3 [Mbps]	TCL5 Poisson traffic rate [Mbps]
#1	0.5	0.26	0.196	0.45	1.42
#2	1	0.52	0.456	0.2	1.16
#3	1.4	0.728	0.664	0	0.952

Table 6-25. Bandwidth allocation for TCL1 and TCL3 and traffic conditions on inter-domain link TAA-TPS1

Traffic case	SLA and traffic conditions in TCL1			SLA for TCL3	Traffic conditions in TCL5
	L1 [Mbps]	R1 [Mbps]	TCL1 Poisson traffic rate (R1-0.064) [Mbps]	L3 [Mbps]	TCL5 Poisson traffic rate [Mbps]
#1	0.5	0.26	0.196	0.75	2.14
#2	1	0.52	0.456	0.5	1.88
#3	1.6	0.832	0.768	0.2	1.568
#4	2	1.04	0.976	0	1.36

Table 6-26. Bandwidth allocation for TCL1 and TCL3 and traffic conditions on inter-domain link TPS1-TPS2

Duration of each test is 60 minutes. Trial results are presented in table below.

Traffic conditions on link TAA-TPS1	Traffic conditions on link TPS1-TPS2	Pkts lost/all	P_{loss}	Loss burst	Delay [ms]			IPDV [ms]	
					min	max	avg	avg	max
#1	#1	0/287958	0	0	80.19	908.78	134.46	6.53	56.37
#1	#2	248/287961	$8.6*10^{-4}$	13	80.47	969.76	262.83	7.27	57.54
#1	#3	3/287752	$1.0*10^{-5}$	1	79.62	824.58	320.06	6.85	52.76
#1	#4	19/287960	$6.5*10^{-5}$	2	79.43	803.62	187.62	6.91	53.90
#2	#1	16/287955	$5.5*10^{-5}$	1	80.79	844.67	223.96	6.88	50.21
#2	#4	21/287956	$7.2*10^{-5}$	1	79.49	702.77	176.79	6.87	42.72
#3	#1	675/287954	$2.3*10^{-3}$	12	80.26	983.70	486.71	6.46	62.66
#3	#4	42/287960	$1.4*10^{-4}$	2	79.59	659.11	113.35	7.12	58.94

Table 6-27. Results of inter-domain TCL1 trial

In order to get better insight into the large observed maximum delay characteristics, additional experiments were carried out with traffic submitted on the interconnection link between Warsaw and Vienna. Submitted traffic streams correspond to traffic conditions case#1 (see table 6-28). This time, the measured flow is the Poisson stream submitted to TCL1.

Traffic conditions on link TAA-TPS1	Pkts lost/all	P_{loss}	Loss burst	Delay [ms]			IPDV [ms]	
				min	max	avg	avg	max
TCL1: Poisson 0.196Mbps TCL5: Poisson 1.42Mbps	316/176513	$1.7*10^{-3}$	2	30.11	777.80	66.71	5.01	148.82

Table 6-28. Results of measurements on the link TPS1 - TAA

Time-plot of delay of all packets sent during the test is presented in figure 6-12 and figure 6-13. One can observe, that the maximum delay value (777.8ms) was captured during one of several "peaks" in the observed delays. The nature of these "peaks" is difficult to explain taking into account characteristic of submitted traffic and configuration of traffic handling mechanisms. Summarising, unpredictable large maximum delay is caused by the fact, that probably the interconnection link does not keep the assumed 1.4Mbps capacity. Another possible explanation is an additional delay resulting from the router architecture. Anyway, this requires deeper tests.

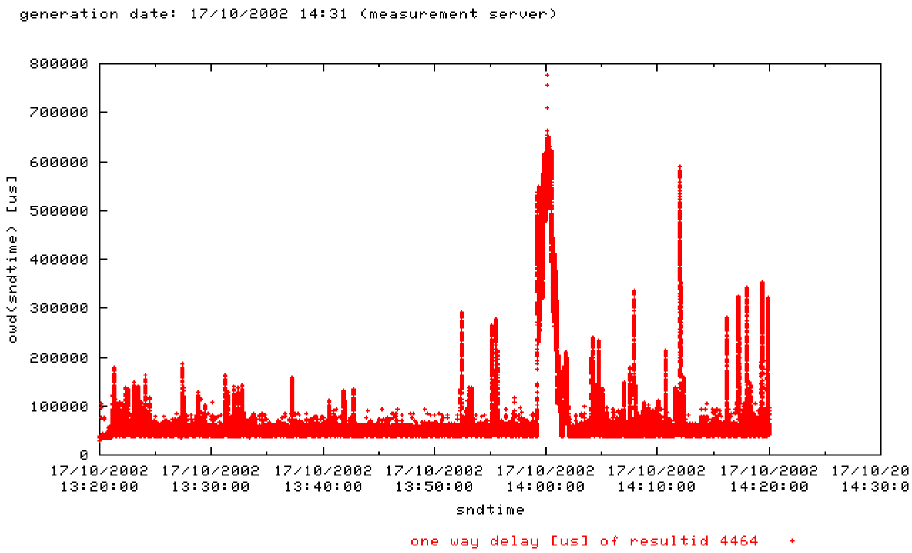


Figure 6-12. Per-packet statistic of one-way delay of TCL1 packets on the interconnection link

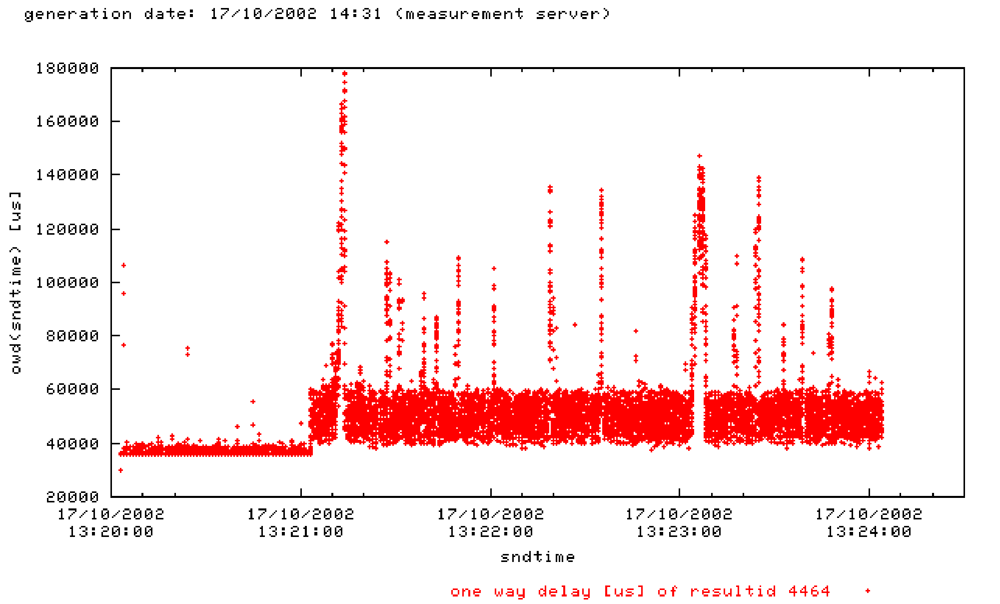


Figure 6-13. Per-packet statistic of one-way delay of TCL1 packets on the interconnection link. The background flow starts about 13:21:00.

Figure 6-14 shows the histogram of one-way delay of TCL1 packets submitted on the interconnection link. It should be noted, that only a small fraction of packets have one-way delay greater than 100ms.

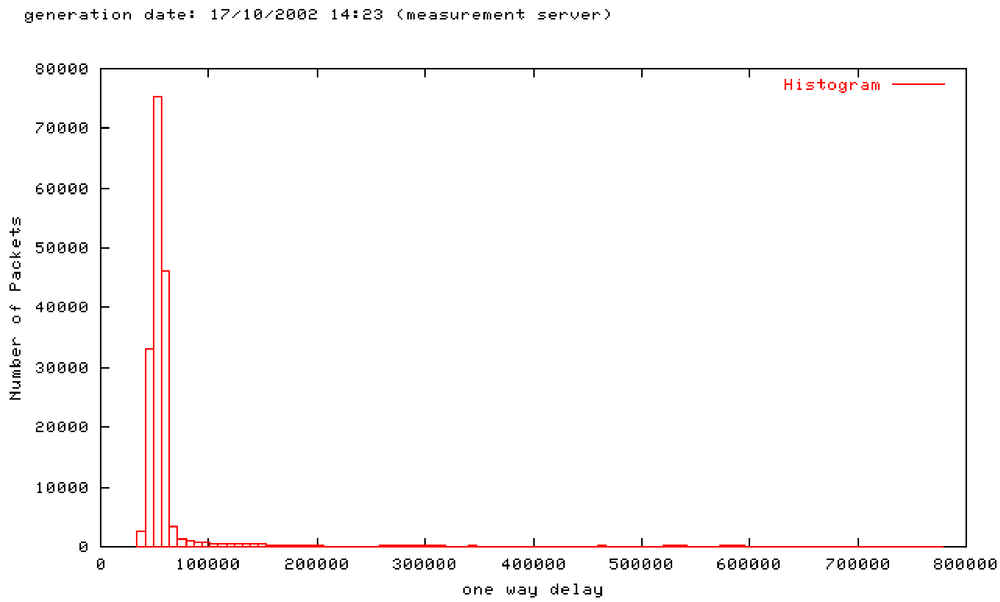


Figure 6-14. Histogram of one-way delay of TCL1 packets on the interconnection link

Concluding, the inter-domain TCL1 trial results could be regarded as positive. Measured QoS parameters corresponding to packet loss ratio and packet delay are almost as expected. Anyway, in some cases the exceeded delay was observed and this is caused by interconnection link, passing by a number of networks (Polpak, POL34, GEANT, AcoNet).

6.3 Secondary access links

6.3.1 Objectives and brief description

The aim of these tests is to verify if the QoS objectives are met. Two different test scenarios, one for measurement traffic with only best effort background traffic and one other with background traffic in all traffic classes.

6.3.2 Test environment

The test network consists of five Cisco routers with the topology shown in the picture. There are two secondary access links and one primary access link. The primary access link is the bottleneck. Flow generators and flow receiver use the AQUILA measurement toolset.

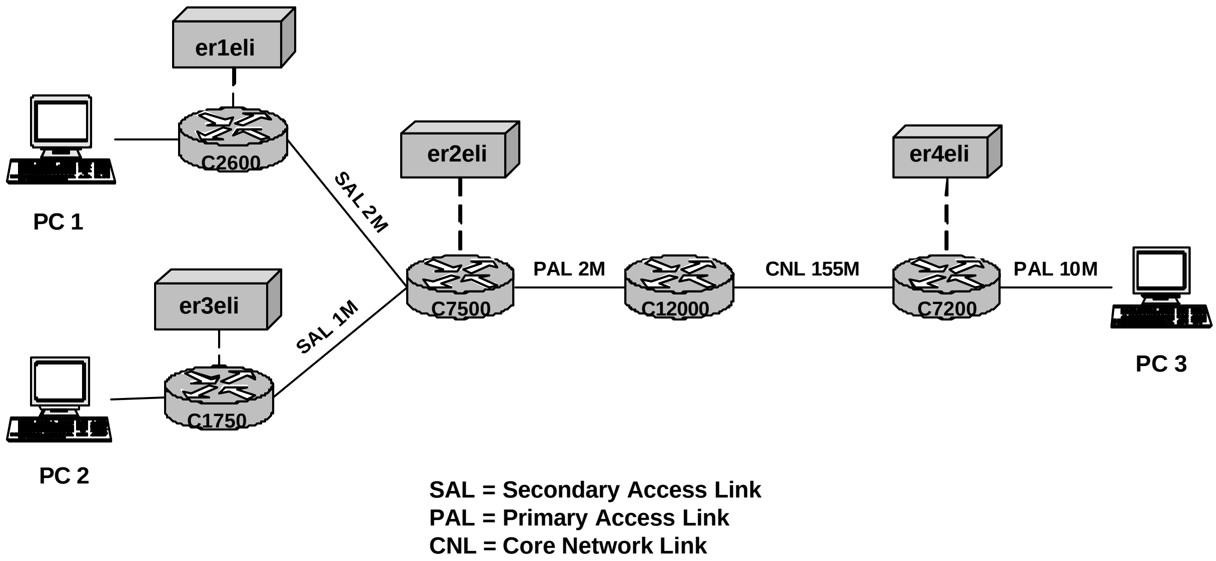


Figure 6-15. Test network

Routers' WFQ weights are set according to D1302 and WRED parameters are configured as follows.

WRED parameter	TCL4 Value [packets]	TCL3 Value [packets]
$Minth_{out}$	25	30

$Maxth_{out}$	35	40
$Maxp_{out}$	0.1	0.1
$Minth_{in}$	10	10
$Maxth_{in}$	20	20
$Maxp_{in}$	0.1	0.1

Table 6-29. WRED parameters

6.3.3 QoS Guarantees

In this scenario one measurement flow is submitted from PC2 to PC3 using one traffic class at a time. The measurement was repeated three times, first without background traffic and then two times with different background traffic. Background traffic consisting of 24 flows was first submitted from PC1 to PC3 in order to fill the primary access link. Then 12 background flows from PC2 to PC3 were added in order to fill both the secondary and primary access links on the measurement path. The following table presents the measurement and background flow traffic specifications.

Delay, delay variation, throughput and packet loss values are measured for the measurement flow. Duration of each test case was 20 minutes and the measurement results are presented in the following subchapters as tables.

Traffic Class	Foreground Traffic	Reservation parameters
TCL 1	IP phone: packet size 128B, interval 100ms Peak rate 10,24kbit/s	PR 10,24kbit/s BSP 2000B
TCL 2	ON/OFF UDP ON period: duration 200ms exponentially distributed, packet size 500B, send interval 15ms OFF period: duration 1000ms exponentially distributed Peak rate 270kbit/s, sustainable rate 44kbit/s	PR: 270kbit/s BSP: 2000B SR: 54kbit/s BSS: 40 000B
TCL 3	Greedy TCP: Packet size 1400B, send interval 0	SR: 200kbit/s BSS: 2000B

TCL 4	ON/OFF Non greedy TCP: ON period: duration 2000ms exponentially distributed, packet size 1000B, send interval 100ms OFF period: duration 14000ms exponentially distributed Peak rate 80kbit/s, sustainable rate 10kbit/s	PR: 80kbit/s BSP: 2000B SR: 10kbit/s BSS: 30 000B
Background traffic	ON/OFF UDP: ON period: duration 10s exponentially distributed, packet size 1000B send interval 100ms OFF period: duration 10s exponentially distributed Peak rate 80kbit/s , sustainable rate 40kbit/s	No reservation

Table 6-30: Foreground and Background Traffic Profiles

6.3.3.1 TCL1

In this scenario performance of TCL1 traffic is evaluated with different background traffic conditions.

Case	Throughput [kbit/s]	Packet loss [Pkts]	Delay [ms]			IPDV [ms]	
			Mean	Min	Max	Mean	Max
No background traffic	10,24	0/12001 (0,00%) Burst: 0	3,28	2,75	210,47	0,22	207,24
Background traffic from PC1 to PC3	10,24	0/12001 (0,00 %) Burst: 0	6,14	3,02	131,39	2,77	123,87
Background traffic from PC1 and PC2 to PC3	10,24	2/12001 (0,02 %) Burst: 1 Pkts	126,84	3,19	281,91	9,01	90,76

Table 6-31: TCL1 traffic with and without background traffic

TCL1 traffic is submitted to the priority queue, which guarantees low packet loss and delay. Adding background traffic on the measurement path causes congestion and increases transmission delay. The target delay (150ms) values are fulfilled in the first two cases but are exceeded in very congested network. In the first case the maximum delay value is high but there are only very few packets with very large delays.

One cause for the high delay values is the background traffic packet size combined with low link bandwidth. Even though TCL1 packets have higher priority than best effort packets, TCL1 packet has to wait until the transmission of big best effort packet has finished. The output interface transmission buffer on ER2 introduces additional delay, because best effort packets can occupy the buffer.

Another reason might be that the same PC was used for generating both the foreground and background traffic. For example when one process is reading the timestamp other processes are sending packets. The first process has to wait for execution before it can send a measurement packet with the timestamp.

Target packet loss ratio (10^{-4}) is reached even though in third case two packets were lost. Loss percentage seems to be high but the error margin is big due to small number of packets.

6.3.3.2 TCL2

In this scenario performance of TCL2 traffic is evaluated with different background traffic conditions.

Case	Throughput [kbit/s]	Packet loss [Pkts]	Delay [ms]			IPDV [ms]	
			Mean	Min	Max	Mean	Max
No background traffic	32,85	73/9930 (0,74 %) Burst: 15 Pkts	8,47	3,25	27,13	0,41	19,36
Background traffic from PC1 to PC3	33,91	34/10208 (0,33 %) Burst: 22 Pkts	19,14	7,86	122,28	4,41	111,14
Background traffic from PC1 and PC2 to PC3	33,41	7/9383 (0,07 %) Burst: 3 Pkts	132,67	11,58	231,42	13,82	183,21

Table 6-32: TCL2 traffic with and without background traffic

TCL2 traffic is submitted to WFQ with high weight, which should provide smaller delay for that class than other WFQ classes. Comparing the delay values on the table with other WFQ classes (TCL3, TCL4) the delay is smaller in this class. Otherwise concerning the delay the same factors as in TCL1 case apply.

Packet loss ratio is slightly above the target value (10^{-4}). The reason for this loss could be the highly bursty nature of the test flow and big error margins due to small number of packets.

6.3.3.3 TCL3

In this scenario performance of TCL3 traffic is evaluated with different background traffic conditions.

Case	Goodput [kbit/s]	Packet loss [Pkts]	Delay [ms]			IPDV [ms]	
			Mean	Min	Min	Mean	Max
No background traffic	960,38	0x/102940 (0,00 %) Burst: 0 Pkts	602,46	3,73	1204,50	22,13	698,44
Background traffic from PC1 to PC3	959,00	0x/102819 (0,00 %) Burst: 0 Pkts	714,10	9,20	1315,04	22,31	716,11
Background traffic from PC1 and PC2 to PC3	484,75	0x/42067 (0,00 %) Burst: 0 Pkts	1409,52	90,00	2397,45	44,15	1201,75

Table 6-33: TCL3 traffic with and without background traffic

The main goal for TCL3 is to have guaranteed goodput and the traffic is not delay sensitive, therefore the high delay values are acceptable. Goodput decreases when background traffic is added but also in the congested network TCL3 is getting its share of the bandwidth.

The measurement software is not able to report packet loss for TCP traffic.

6.3.3.4 TCL4

In this scenario performance of TCL4 traffic is evaluated with different background traffic conditions.

Info	Throughput [kbit/s]	Packet loss [Pkts]	Delay [ms]			IPDV [ms]	
			Mean	Min	Max	Mean	Max
No background traffic	11,25	0/1690 (0,00 %) Burst: 0 Pkts	16,25	3,39	120,83	1,91	91,27
Background traffic from PC1 to PC3	7,67	0/1156 (0,00 %) Burst: 0 Pkts	19,19	9,51	36,13	2,79	19,56
Background traffic from PC1 and PC2 to PC3	10,00	0/1511 (0,00 %) Burst: 0 Pkts	238,43	14,97	828,89	56,97	658,54

Table 6-34: TCL4 traffic with and without background traffic

TCL4 traffic is not delay sensitive. Very high delays in the congested network are due to the very small WFQ weight.

Target packet loss ratio (10^{-6}) is reached.

6.3.4 Separation between Traffic Classes

In this scenario the performance of three traffic classes was measured when the load in the fourth traffic class was increased. Additional background traffic was submitted to every traffic class so that AC limit is reached. The remaining link capacity was filled with best effort traffic.

In each test, the DBAC based admission control using peak rate allocation as specified in [D1302] was used. In TCL3, the TBM -based AC algorithm was used.

Delay, delay variation, throughput and packet loss values are measured for each traffic class.

Traffic Class	Foreground Traffic	Reservation parameters
TCL 1	IP phone: packet size 128B, interval 100ms Peak rate 10,24kbit/s	PR 10,24kbit/s BSP 2000B
TCL 2	ON/OFF UDP ON period: duration 500ms exponentially distributed, packet size 560B, send interval 100ms OFF period: duration 1000ms exponentially distributed Peak rate 45kbit/s, sustainable rate 15kbit/s	PR: 45kbit/s BSP: 2000B SR: 15kbit/s BSS: 55 000B
TCL 3	Greedy TCP: Packet size 1400B, send interval 0	SR: 200kbit/s BSS: 2000B
TCL 4	ON/OFF Non greedy TCP: ON period: duration 2000ms exponentially distributed, packet size 1000B, send interval 200ms OFF period: duration 14000ms exponentially distributed Peak rate 40kbit/s, sustainable rate 5kbit/s	PR: 40kbit/s BSP: 2000B SR: 5kbit/s BSS: 15 000B
Background traffic	UDP constant bit rate: Packet size 1400B send interval 27ms Peak rate 415kbit/s	No reservation

Table 6-35: Foreground and Background Traffic Profiles

6.3.4.1 TCL1

In this scenario effect of other traffic classes to TCL1 performance traffic was observed.

6.3.4.1.1 TCL2 traffic impact on performance of TCL1

Foreground traffic

- 1 flow in TCL1 using traffic specification from Table 6-6.

Background traffic

- TCL2 flows were added one at a time starting from zero flows to AC limit (4)
- 6 flows in TCL1 using traffic specification from Table 6-6.
- 1 flow in TCL3 using traffic specification from Table 6-6.
- 7 flows in TCL4 using traffic specification from Table 6-6.
- 1 best effort flow on measurement path (from PC2 to PC3) and 3 flows from PC1 to PC3

# of TCL2 flows	Throughput [kbit/s]	Packets [lost/total]	Loss		Delay			IPDV	
			%	Burst	Mean	Min	Max	Mean	Max
0	10,176	37/6001	0,62	1	124,61	6,74	298,04	12,48	154,44
1	10,133	62/6001	1,03	2	122,84	7,08	190,29	19,14	112,11
2	10,141	60/6000	1,00	2	124,96	3,43	182,80	21,90	86,85
3	10,214	15/6001	0,25	1	114,53	4,25	347,49	19,23	233,28
4	10,225	10/5999	0,17	1	127,07	7,57	367,55	35,00	262,87

Table 6-36: TCL2 effect to TCL1 QoS parameters

6.3.4.1.2 TCL4 traffic impact on performance of TCL1

Foreground traffic

- 1 flow in TCL1 using traffic specification from Table 6-6.

Background traffic

- TCL4 flows were added one at a time starting from zero flows to AC limit (7)
- 6 flows in TCL1 using traffic specification from Table 6-6.
- 4 flows in TCL2 using traffic specification from Table 6-6.

- 1 flow in TCL3 using traffic specification from Table 6-6.
- 1 best effort flow on measurement path (from PC2 to PC3) and 3 flows from PC1 to PC3

# of TCL2 flows	Throughput [kbit/s]	Packets [lost/total]	Loss		Delay			IPDV	
			%	Burst	Mean	Min	Max	Mean	Max
0	10,171	41/5914	0,69	1	117,25	11,00	183,71	18,08	113,00
1	10,107	77/6001	1,28	1	121,62	6,72	174,77	21,84	134,11
2	10,166	45/6000	0,75	1	127,29	8,51	197,37	34,58	107,42
3	10,164	46/6000	0,77	1	125,87	6,61	352,97	34,75	236,01
4	10,169	41/6001	0,68	1	127,93	7,31	316,21	33,37	213,41
5	10,193	28/6000	0,47	1	126,98	79,30	351,68	26,80	235,14
6	10,171	42/5999	0,70	1	124,18	3,46	200,96	33,22	106,30
7	9,978	153/5999	2,55	2	121,22	8,17	305,68	26,63	178,85

Table 6-37: TCL4 effect to TCL1 QoS parameters

6.3.4.1.3 Conclusions for TCL1 performance

Delay values are slightly high compared to the target value (150ms) for TCL1. One cause for the high delay values is the background traffic packet size combined with low link bandwidth. Even though TCL1 packets have higher priority than best effort packets, TCL1 packet has to wait until the transmission of big best effort packet has finished. The output interface transmission buffer on ER2 introduces additional delay, because best effort packets can occupy the buffer before priority packets.

Another reason might be that the same PC was used for generating both the foreground and background traffic. For example when one process is reading the timestamp other processes are sending packets. The first process has to wait for execution before it can send a measurement packet with the timestamp.

Packet loss ratio is slightly over the target (10^{-4}). ER2 drops the packets and it is likely that the reason is the small queue limit for the priority class. The queue limit can not be changed.

It can be observed from the tables above that TCL1 QoS performance does not degrade when TCL2 or TCL4 traffic is increased.

6.3.4.2 TCL2

In this scenario effect of other traffic classes to TCL2 performance traffic was observed.

6.3.4.2.1 TCL1 traffic impact on performance of TCL2

Foreground traffic

- 1 flow in TCL2 using traffic specification from Table 6-6..

Background traffic

- TCL1 flows were added one at a time starting from zero flows to AC limit (7)
- 3 flows in TCL2 using traffic specification from Table 6-6.
- 1 flow in TCL3 using traffic specification from Table 6-6.
- 4 flows in TCL4 using traffic specification from Table 6-6.
- 1 best effort flow on measurement path (from PC2 to PC3) and 3 flows from PC1 to PC3

# of TCL2 flows	Throughput [kbit/s]	Packets [lost/total]	Loss		Delay			IPDV	
			[%]	Burst	Mean	Min	Max	Mean	Max
0	15,15	142/2174	6,53	5	197,05	9,13	380,03	13,06	189,42
1	15,34	59/2115	2,79	11	185,91	6,05	240,04	13,49	156,40
2	15,27	48/2095	2,29	12	148,99	11,45	212,49	12,80	143,02
3	14,96	17/2022	0,84	12	164,29	10,89	209,89	13,60	123,86
4	15,36	188/2245	8,37	19	157,58	13,36	199,47	14,23	128,56
5	14,91	17/2021	0,84	7	149,49	14,54	340,34	15,59	185,12
6	15,23	19/2060	0,92	6	143,28	9,85	211,56	21,25	142,01
7	14,09	1/1891	0,05	1	139,47	11,47	342,71	28,87	219,42

Table 6-38: TCL1 effect to TCL2 QoS parameters

6.3.4.2.2 TCL4 traffic impact on performance of TCL2

Foreground traffic

- 1 flow in TCL2 using traffic specification from Table 6-6..

Background traffic

- TCL4 flows were added one at a time starting from zero flows to AC limit (7)
- 7 flows in TCL1 using traffic specification from Table 6-6.

- 3 flows in TCL2 using traffic specification from Table 6-6.
- 1 flow in TCL3 using traffic specification from Table 6-6.
- 1 best effort flow on measurement path (from PC2 to PC3) and 3 flows from PC1 to PC3

# of TCL2 flows	Throughput [kbit/s]	Packets [lost/total]	Loss		Delay			IPDV	
			[%]	Burst	Mean	Min	Max	Mean	Max
0	14,68	17/1982	0,86	17	132,41	0,27	200,88	21,92	107,51
1	15,15	41/2078	1,97	17	139,62	15,18	201,61	26,45	92,90
2	15,43	117/2185	5,35	11	141,48	13,09	237,13	32,17	126,39
3	14,76	20/1996	1,00	15	126,72	12,42	240,23	29,74	134,59
4	14,97	35/2039	1,72	17	141,65	8,88	369,70	31,28	218,30
5	15,40	231/2295	10,07	24	140,44	9,49	234,36	32,15	135,11
6	15,17	0/1953	0,00	0	132,09	12,45	238,04	31,37	134,94
7	15,18	63/2092	3,01	4	139,64	9,06	287,36	29,67	156,49

Table 6-39: TCL4 effect to TCL2 QoS parameters

6.3.4.2.3 Conclusions for TCL2 performance

Delay values for TCL2 are higher than the target values (150ms) for TCL2. One cause for the high delay values is the background traffic packet size combined with low link bandwidth. Even though TCL2 packets have higher WFQ weight than best effort packets, TCL2 packet has to wait until the transmission of big best effort packet has finished. The output interface transmission buffer on ER2 introduces additional delay, because best effort packets can occupy the buffer before TCL2 packets.

Another reason might be that the same PC was used for generating both the foreground and background traffic. For example when one process is reading the timestamp other processes are sending packets. The first process has to wait for execution before it can send a measurement packet with the timestamp.

Packet loss ratio is slightly over the target (10^{-4}). One reason for packet loss might be that the test traffic was very bursty and the policer in the ingress router ER3 dropped the packets from bursts.

It can be observed from the tables above that TCL2 QoS performance does not degrade when TCL1 or TCL4 traffic is increased.

6.3.4.3 TCL3

In this scenario effect of other traffic classes to TCL3 performance traffic was observed.

6.3.4.3.1 TCL1 traffic impact on performance of TCL3

Foreground traffic

- 1 flow in TCL3 using traffic specification from Table 6-6..

Background traffic

- TCL1 flows were added one at a time starting from zero flows to AC limit (7)
- 4 flows in TCL2 using traffic specification from Table 6-6.
- 7 flow in TCL4 using traffic specification from Table 6-6.
- 1 best effort flow on measurement path (from PC2 to PC3) and 3 flows from PC1 to PC3

# of TCL2 flows	Goodput [kbit/s]	Packets [lost/total]	Loss		Delay			IPDV	
			[%]	Burst	Mean	Min	Max	Mean	Max
0	496,54	0x/26656	0,00	17	1378,93	6,93	2750,80	43,14	1480,33
1	481,40	0x/25823	0,00	17	878,42	17,58	1801,18	43,69	1049,57
2	472,62	0x/25361	0,00	11	931,06	4,04	2026,90	44,71	1212,38
3	458,69	0x/24603	0,00	15	894,57	20,70	1805,52	45,69	1080,56
4	449,51	0x/24119	0,00	17	978,58	27,96	1991,73	46,87	1187,08
5	432,41	0x/23197	0,00	24	1057,50	28,13	2089,22	48,94	1067,23
6	420,39	0x/22555	0,00	0	1046,31	22,75	2113,00	50,23	1154,34
7	410,91	0x/22044	0,00	4	946,29	25,97	2107,45	51,12	1156,51

Table 6-40: TCL1 effect to TCL3 QoS parameters

6.3.4.3.2 TCL2 traffic impact on performance of TCL3

Foreground traffic

- 1 flow in TCL3 using traffic specification from Table 6-6..

Background traffic

- TCL2 flows were added one at a time starting from zero flows to AC limit (4)
- 7 flows in TCL1 using traffic specification from Table 6-6.

- 7 flow in TCL4 using traffic specification from Table 6-6.
- 1 best effort flow on measurement path (from PC2 to PC3) and 3 flows from PC1 to PC3

# of TCL2 flows	Goodput [kbit/s]	Packets [lost/total]	Loss		Delay			IPDV	
			[%]	Burst	Mean	Min	Max	Mean	Max
0	471,30	0x/25316	0,00	0	1454,99	3,76	2533,89	45,54	1272,22
1	457,58	0x/24557	0,00	0	1394,85	21,21	2689,49	46,76	1267,46
2	438,62	0x/23546	0,00	0	1001,86	21,59	1958,70	48,10	1196,13
3	427,67	0x/22964	0,00	0	985,31	6,88	2075,18	48,99	1138,77
4	412,39	0x/22128	0,00	0	1024,27	16,09	2458,28	51,02	1334,46

Table 6-41: TCL2 effect to TCL3 QoS parameters

6.3.4.3.3 TCL4 traffic impact on performance of TCL3

Foreground traffic

- 1 flow in TCL3 using traffic specification from Table 6-6..

Background traffic

- TCL4 flows were added one at a time starting from zero flows to AC limit (7)
- 7 flows in TCL1 using traffic specification from Table 6-6.
- 4 flow in TCL2 using traffic specification from Table 6-6.
- 1 best effort flow on measurement path (from PC2 to PC3) and 3 flows from PC1 to PC3

# of TCL2 flows	Goodput [kbit/s]	Packets [lost/total]	Loss		Delay			IPDV	
			[%]	Burst	Mean	Min	Max	Mean	Max
0	447,09	0x/24015	0,00	0	1532,04	24,85	2623,68	47,98	1332,41
1	439,41	0x/23574	0,00	0	833,09	6,21	1656,09	47,44	1009,79
2	439,49	0x/23586	0,00	0	961,36	24,43	1983,79	47,72	1071,23
3	435,27	0x/23362	0,00	0	919,53	14,43	1816,79	48,24	1071,05
4	432,72	0x/23225	0,00	0	1051,99	23,22	2021,84	48,89	1135,73
5	421,43	0x/22624	0,00	0	1043,65	4,46	2153,12	50,16	1200,38
6	423,12	0x/22707	0,00	0	946,50	15,93	2097,51	49,71	1173,37
7	412,16	0x/22107	0,00	0	888,37	46,49	1979,10	50,55	1072,71

Table 6-42: TCL4 effect to TCL3 QoS parameters

6.3.4.3.4 Conclusions for TCL3 performance

The main goal for TCL3 is to have guaranteed goodput and the traffic is not delay sensitive, therefore the high delay values are acceptable. TCL3 is getting more bandwidth than is specified in its reservation. This happens because the RTT value is different in the testbed than specified in QMTool. The value in QMTool is different because otherwise it was not possible to make small TCL3 reservation.

The measurement software is not able to report packet loss for TCP traffic.

It can be observed from the tables above that TCL3 goodput is slightly decreased when TCL1, TCL2 or TCL4 traffic is increased. However the goodput is still much above the requested bandwidth. This could also affect other traffic classes

6.3.4.4 TCL4

In this scenario effect of other traffic classes to TCL4 performance traffic was observed.

6.3.4.4.1 TCL1 traffic impact on performance of TCL4

Foreground traffic

- 1 flow in TCL4 using traffic specification from Table 6-6..

Background traffic

- TCL1 flows were added one at a time starting from zero flows to AC limit (7)
- 4 flows in TCL2 using traffic specification from Table 6-6.
- 1 flow in TCL3 using traffic specification from Table 6-6.
- 1 best effort flow on measurement path (from PC2 to PC3) and 3 flows from PC1 to PC3

# of TCL2 flows	Throughput [kbit/s]	Packets [lost/total]	Loss		Delay			IPDV	
			[%]	Burst	Mean	Min	Max	Mean	Max
0	7,05	0/519	0,00	0	221,36	19,68	277,70	14,31	197,12
1	5,81	0/414	0,00	0	200,39	16,87	269,06	13,44	170,46
2	5,95	0/459	0,00	0	174,79	15,09	255,19	14,11	182,37
3	5,77	0/429	0,00	0	157,56	17,44	357,54	14,27	194,82
4	4,50	0/364	0,00	0	179,21	10,43	234,67	16,95	180,69
5	4,33	0/347	0,00	0	176,53	19,09	359,63	16,32	200,44
6	5,81	0/440	0,00	0	172,03	31,69	237,52	18,02	144,71
7	5,13	0/373	0,00	0	170,28	15,52	246,47	16,89	162,27

Table 6-43: TCL1 effect to TCL4 QoS parameters

6.3.4.4.2 TCL2 traffic impact on performance of TCL4

Foreground traffic

- 1 flow in TCL4 using traffic specification from Table 6-6..

Background traffic

- TCL2 flows were added one at a time starting from zero flows to AC limit (4)
- 7 flows in TCL1 using traffic specification from Table 6-6.
- 1 flow in TCL3 using traffic specification from Table 6-6.
- 1 best effort flow on measurement path (from PC2 to PC3) and 3 flows from PC1 to PC3

# of TCL2 flows	Through-put [kbit/s]	Packets [lost/total]	Loss		Delay			IPDV	
			[%]	Burst	Mean	Min	Max	Mean	Max
0	5,65	0/431	0,00	0	165,45	4,15	229,64	15,34	149,21
1	2,49	0/191	0,00	0	165,73	9,60	212,84	16,39	138,90
2	5,09	0/393	0,00	0	168,03	16,04	237,31	17,05	152,89
3	4,62	0/372	0,00	0	167,27	31,13	236,26	19,39	158,26
4	3,84	0/304	0,00	0	167,30	14,87	258,55	19,83	154,13

Table 6-44: TCL2 effect to TCL4 QoS parameters

6.3.4.4.3 Conclusions for TCL4 performance

For TCL4 traffic there is no target delay value defined. However measured delay values are acceptable for TCL4 type of traffic.

Packet loss was zero, which is less than the target packet loss value. Throughput for TCL4 is above requested sustainable rate.

It can be observed from the tables above that TCL4 is not degraded when TCL1 or TCL2 traffic is increased.

7 Annex B – real users

7.1 Trial scenarios with real users

7.1.1 Listening-opinion trial with VoIP application

7.1.1.1 Objectives

Measurements of logatom articulation, which give us statistical information about voice transfer quality. In other words, we estimated the probability of successful speech transfer on the basis of the perceived phonetic speech elements.

7.1.1.2 Measured parameters

$$W_{n,k} = \frac{P_{n,k}}{T_k} \cdot 100 \ [\%] \qquad (1)$$

where:

$W_{n,k}$ - logatom articulation measured during listening logatoms from k-th test list by n-th listener;

$P_{n,k}$ – the number of correctly received logatoms from k-th test list by n-th listener;

T_k- the number of read logatoms from k-th test list.

$$W_L = \frac{1}{N \cdot K} \sum_{n=1}^{N} \sum_{k=1}^{K} W_{n,k} \quad [\%] \qquad (2)$$

where:

W_L – average logatom articulation;

N – the listener number, K – the number of read test list;

$$s = \left[\frac{1}{N \cdot K - 1} \sum_{n=1}^{N} \sum_{k=1}^{K} (W_{n,k} - W_L)^2 \right]^{1/2} \qquad (3)$$

where s is the mean square deviation, which is used for calculation of logatom articulation dispersion.

7.1.1.3 Trial tools

Applications

The tested application was Helmsman SIP User Agent (VoIP).

7.1.1.4 Topology of Warsaw testbed

Network topology consisted of Warsaw testbed and is depicted in Figure 7-1.

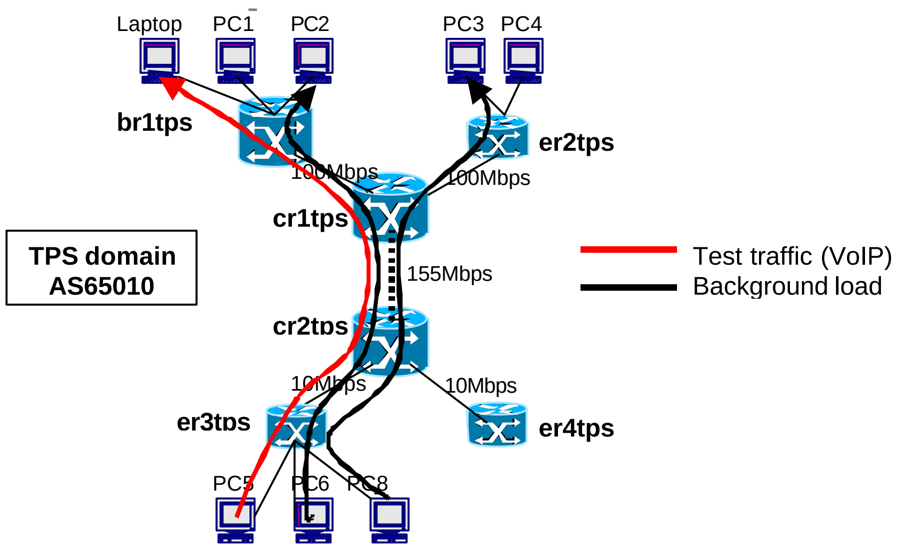


Figure 7-1. Real user trial network topology.

Traffic conditions

Trial was repeated under different traffic conditions:

(1) **Scenario #1 –** only single VoIP connection (tested connection) was established in the network (reference scenario);

(2) **Scenario #2 -** both tested VoIP connection as well as background traffic was handled by Aquila QoS network services (including STD);

- The foreground traffic (VoIP flows) was submitted into TCL1 class.
- Background traffic in TCL1: Poisson stream with mean rate 5.136Mbps. The load in TCL1 corresponded to the value of B1=10Mbps.
- Background traffic in TCL5: Poisson stream with mean rate 6.8Mbps. The total offered traffic to the link er3tps – cr2tps was equal to 1.2*link capacity (this traffic produced overload condition).

(3) **Scenario #3 -** comparing to (2), tested VoIP traffic was submitted to STD.

Trial procedure

5 listeners tested VoIP application. Before starting experiment, the listeners passed the training with the speaker, by listening to the selected logatom lists. For this purpose, they used an acoustic separate room. The speaker was reading the earlier prepared logatom lists, while listeners tried to write down the perceived logatoms. Finally, voice quality was estimated based on the probability of correctly received logatoms.

The timetable presented in the Table 7-1 shows schedule of real user logatoms trial.

Step	Scenario	List (100 logatoms per list)	Duration [min]	Users involved
1	Scenario #1	List 1 List 2 List 3	10 10 10	Listener 1, 2, 3, 4, 5 Listener 1, 2, 3, 4, 5 Listener 1, 2, 3, 4, 5
2	Scenario #2	List 4 List 5 List 6	10 10 10	Listener 1, 2, 3, 4, 5 Listener 1, 2, 3, 4, 5 Listener 1, 2, 3, 4, 5
3	Scenario #3	List 7 List 8 List 9	10 10 10	Listener 1, 2, 3, 4, 5 Listener 1, 2, 3, 4, 5 Listener 1, 2, 3, 4, 5

Table 7-1 Timetable with schedule of real user logatoms trial.

7.1.1.5 Results and conclusions – Warsaw testbed

We have calculated logatom articulation ($W_{n,k}$) measured during listening logatoms from k-th test list by n-th listener according to formula (1). We have made the calculations for three traffic conditions (scenarios #1, #2, #3). The results are summarized in Tables 1-2, 1-3, 1-4.

Scenario #1: reference scenario

$W_{n,k}$ (n=5, k=3)	List 1	List 2	List 3
Listener 1	73%	73%	76%
Listener 2	71%	80%	79%
Listener 3	68%	83%	80%
Listener 4	64%	81%	74%

Listener 5	64%	76%	69%

Table 7-2 . $W_{n,k}$ - logatom articulation measured during listening logatoms from k-th test list by n-th listener in scenario #1 (reference scenario).

Scenario #2: PCBR service

$W_{n,k}$ (n=5, k=3)	List 4	List 5	List 6
Listener 1	75%	64%	65%
Listener 2	79%	77%	79%
Listener 3	73%	63%	79%
Listener 4	79%	80%	79%
Listener 5	67%	66%	53%

Table 7-3 . $W_{n,k}$ - logatom articulation measured during listening logatoms from k-th test list by n-th listener in scenario #2.

Scenario #3: STD service

$W_{n,k}$ (n=5, k=3)	List 7	List 8	List 9
Listener 1	37%	54%	53%
Listener 2	36%	43%	56%
Listener 3	33%	56%	46%
Listener 4	39%	46%	57%
Listener 5	38%	50%	47%

Table 7-4 . $W_{n,k}$ - logatom articulation measured during listening logatoms from k-th test list by n-th listener in scenario #3.

Finally for each traffic condition average logatom articulation (W_L) and mean square deviation (s) was counted accordingly to formulas (2) and (3). On the basis of the W_L, we also evaluated MOS index, in approximate way, according to the conversion rate given by the polish standard.

	Average logatom articulation (**W_L**)	Mean square deviation (**s**)	Mean Opinion Score (**MOS**)

(1) Scenario #1 (reference scenario)	74.1%	7.1%	4
(2) Scenario #2 (PCBR service)	71.9%	9.8%	3.8
(3) Scenario #3 (STD service)	46.1%	9.6%	1.9

Table 7-5 . Average logatom articulation (W_L) and mean square deviation (s) calculated under different traffic conditions.

On the basis of the obtained results one can conclude as following:

- Measured W_L in the case of reference scenario and PCBR service was similar and on acceptable level in IP network (in telephone network, with 64 kbps voice channel – MOS is 4.4, with 16 kbps voice channel – MOS is 4.2);
- Results obtained with STD service were much worse comparing to PCBR service and evaluated quality was on unacceptable level (hardly acceptable MOS is around 3.0).

Summarizing, the provided experiment confirms the expectations that VoIP needs a prioritised service in IP network. PCBR service in AQUILA network supports VoIP in sufficient way.

7.1.1.6 Topology of Vienna testbed

The network topology of the TAA trial site is shown in figure 7-2. For the second and third test, background traffic had to be generated from CM1 (10.0.5.1) to BAG (10.0.9.1). As shown in Figure 7-2 CM1 and BAG are connected via 100 Mbit/s to the edge routers, because using 10 Mbit/s links would not congest the core network.

Real user trials using a poisson traffic generator were already made by TPS. On the other hand the TAA chose IPERF to simulate a worst-case scenario. In other words this means that a background load of 100 percent in the core network was generated. As traffic generator IPERF was used, which is a free, flexible and very powerful tool. Further information can be found on http://dast.nlanr.net/Projects/Iperf1.1.1/release.html.

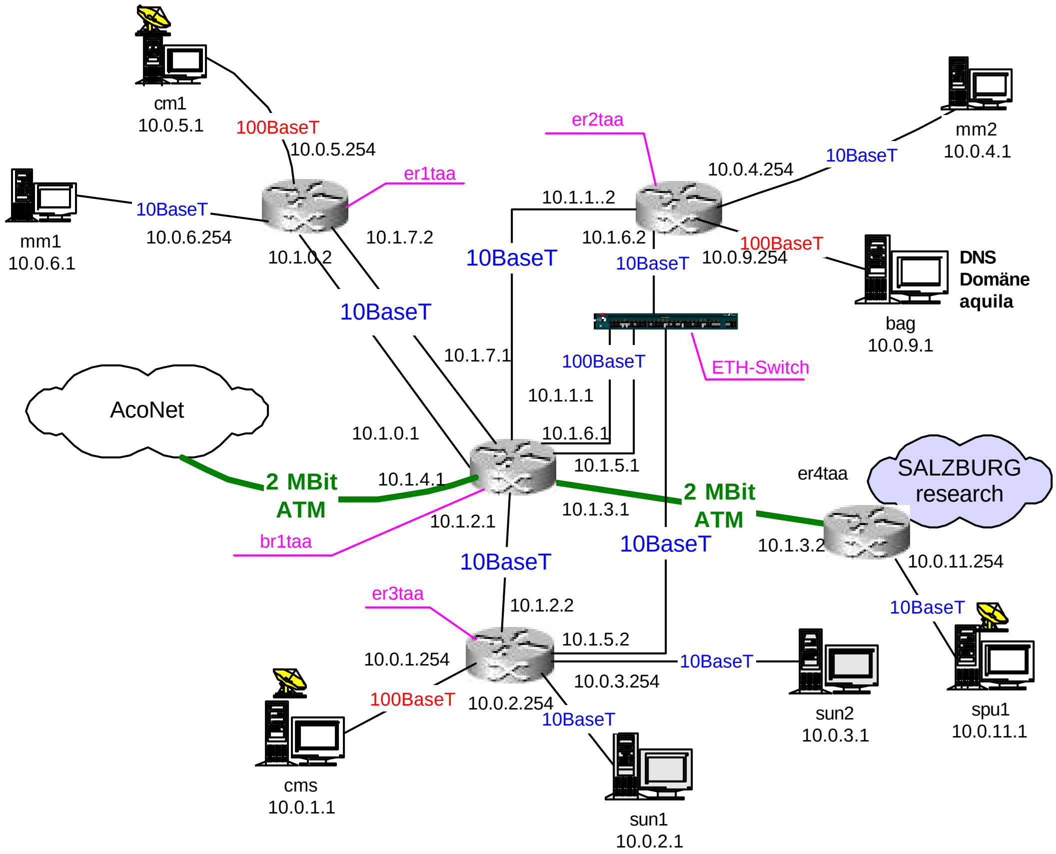


Figure 7-2. TAA network topology.

7.1.1.7 Trial tools

The tested application was the Helmsman SIP User Agent (VoIP).

Figure 7-3. Helmsman Sip User Agent

7.1.1.8 Traffic conditions

A voice conversation was established from MM1 (10.0.6.1) to MM2 (10.0.4.1) whereas the person who read the logatoms was located at MM1 and the listening person at MM2. The Trial was repeated under different traffic conditions:

Scenario 1

Only one single VoIP connection was established across the network (reference scenario) from MM1 to MM2, which is represented by the line in the Figure 7-4.

Scenario 2

A VoIP connection as well as background traffic were transmitted over the network without using the QoS AQUILA architecture. To set the core network under heavy load a UDP background traffic with 100 Mbit/s was transmitted from CM1 to BAG. This background load is represented by the dashed line in Figure 7-4.

Scenario 3

The same background traffic as for the second trial was produced. The voice traffic was submitted to TCL 1 and processed prioritised. In other words the AQUILA QoS features were used.

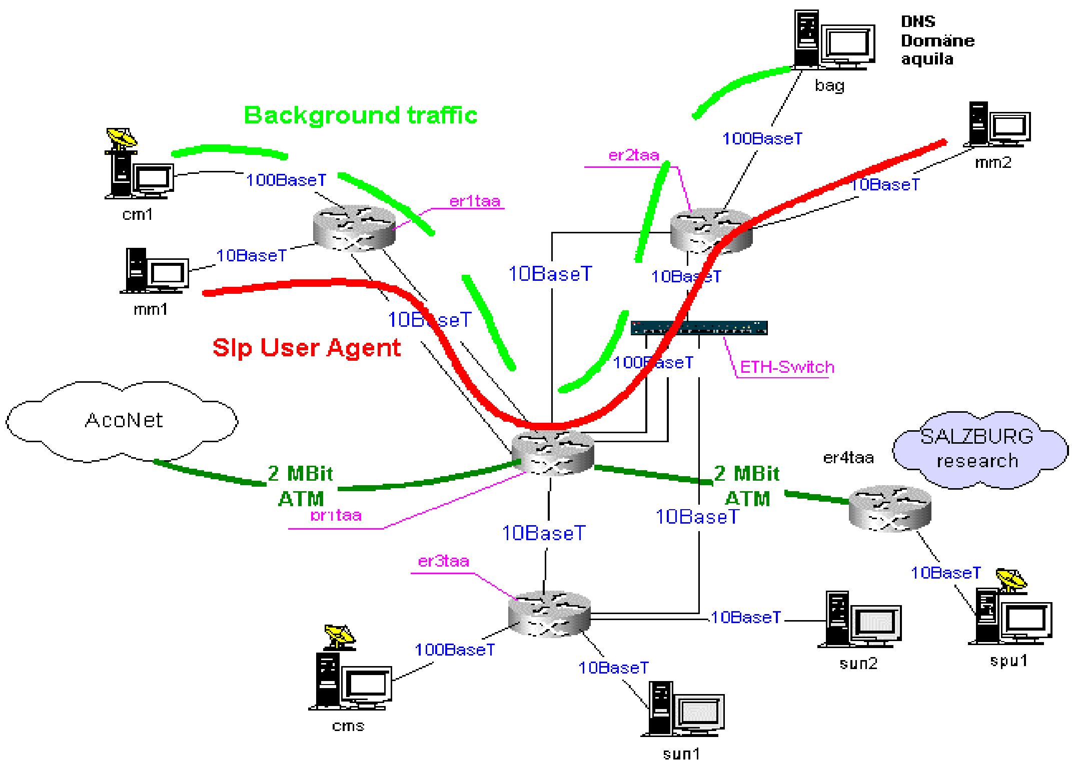


Figure 7-4. TAA network with SIP User Agent and background traffic

7.1.1.9 Trial procedure

Thirteen listeners tested the VoIP application. The trial started with the reference scenario, followed by the second scenario. The real user trial was finished by the third test. The speaker (located at MM1) read 30 different German logatoms for each test. The listeners (located at MM2) had the task to write down the perceived logatoms. The speaker tried to speak properly and slowly. Important to mention here is that the speaker and listener were located in different rooms to guarantee no interference. Finally, the voice quality was calculated based on the probability of correctly received logatoms. Worth mentioning here is that it is very difficult to write down a high percentage of logatoms correctly even if the voice quality is excellent. This is caused by the same pronunciation of certain speech elements. So for example the following letters and speech elements sound very similar:

F = V, EN = N, EM = M, Z = C, Z = TS, X = KS, GE = G, BE = B, PE = P, DE = D, ER = R, BE = B

After each test the test persons had to rate the voice quality ranging from 1 to 5 (MOS) whereas 5 = excellent, 4 = good, 3 = fair, 2 = poor and 1 = bad.

The lists of the used German logatoms are shown in the next tables.

gescho	Ksbe	Deli
ilpe	Gelei	Emde
ichde	Enle	Enbu
nren	Boami	Liju
eilva	Eral	Gaukt
tsde	Angbe	Meine
pehoe	Lukei	Tescht
enab	Erni	Fote
ipge	Umung	Erung
sevi	Arzi	Einas

Table 7-6. Logatoms used for the reference-scenario

oger	Endi	Ermei
cheda	Ichte	Zits
fere	Enbu	Asich
josn	Omus	Psen
klaf	Nefa	Uteim
nten	Ingun	Enen
gise	Einet	Imen
kauer	Urlt	Isen
igeng	Lien	Xrel
bedi	Steid	Alux

Table 7-7. Logatoms used for the second scenario

lafe	Zias	Flab
ener	Mifo	Oxme
kunt	Inaus	Olde
tezi	Lezo	Esat
dant	Teimp	Amki
gune	Sebas	Usen
webi	Nere	Ulnt
optu	Isim	Enst
ekta	Atwa	Pelei
inech	Arga	Deva

Table 7-8. Logatoms used for the third scenario

The timetable presented in the Table 7-9 shows the schedule of the real user logatom trial.

Step	Scenario	List (30 logatoms per list)	Duration [min]	Users involved
1	Scenario 1	List 1	3	Listener 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
2	Scenario 2	List 2	3	Listener 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
3	Scenario 3	List 3	3	Listener 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13

Table 7-9. Timetable with schedule of real user logatoms trial.

7.1.1.10 Results and conclusions

In Table 7-10 the logatom articulation for each user and each test is shown. These values are based on formula (1).

W_n (n=13)	Test 1	Test 2	Test 3
Listener 1	50%	0%	66,6%
Listener 2	46,6%	0%	53,3%
Listener 3	33,3%	0%	46,6%
Listener 4	43,3%	0%	36,6%

Listener 5	56,6%	1%	63,3%
Listener 6	40%	1%	43,3%
Listener 7	53,3%	0%	63,3%
Listener 8	40%	0%	50%
Listener 9	46,6%	0%	60%
Listener 10	50%	0%	40%
Listener 11	70%	0%	60%
Listener 12	36,6%	0%	53,3%
Listener 13	40%	0%	36,6%

Table 7-10. Percentage of correctly perceived logatoms for all tests

Finally for each test the average logatom articulation (W_L) and mean square deviation (S) were calculated. The formulas that were used can be found in chapter 7.1.1.2 (formula 2 and 3). On the basis of the users perceived and rated quality we calculated the Mean Opinion Score for each test.

	Average logatom articulation (**W_L**)	Mean square deviation (**S**)	Mean Opinion Score (**MOS**)
Scenario 1 (reference scenario)	46,7%	9,7%	3,5
Scenario 2 (congested scenario)	0,51%	1,25%	1
Scenario 3 (QoS scenario)	51,8%	10,5%	3,2

Table 7-11. Average logatom articulation (W_L), mean square deviation (S), and MOS calculated under different traffic conditions.

The following conclusion can be drawn:

- The percentage of correctly understood logatoms for the first and third test scenario are low, due to the fact that the headset has had a bad quality, that the background noise in the used rooms was high and that the bgatoms could be written in a lot of different ways with the same pronunciation. The first two reasons mentioned above are also responsible for the low MOS values of 3,5 for the reference scenario and 3,2 for the QoS scenario. A very important fact is that for the reference scenario W_L is slightly smaller and MOS is slightly higher than for the QoS scenario. A possible conclusion for this effect is that the voice quality for the first and third test scenario was nearly the same. The high mean square deviation of the reference scenario and the QoS scenario is also an indicator that the test persons had difficulties in perceiving the logatoms correctly.

- The W_L value for the second scenario is 0,51 percent, which is a very low value. Consequently absolutely no conversation was possible in this test. The MOS value of 1 also indicates an unacceptable speech quality. As a consequence a MOS value of 3,2 and a W_L value of 51,8 for the QoS scenario compared to the low values of the background scenario indicate a dramatic increase of voice quality using QoS.

Summarising, the provided experiment confirms the expectations that VoIP needs a prioritised service in heavily loaded IP networks. PCBR service in AQUILA network supports VoIP in a very good way.

7.1.2 Trial with video streaming and videoconference applications using Mediazine server in single-domain network scenario

Objectives

To test overall quality experienced (subjective assessment) by particular users participating in trial and using services available within the Mediazine application. The test was carried out in three different network scenarios:

- Underloaded network, where traffic streams related with tested application are the only traffic in the network
- Overloaded network, where tested application traffic is carried by AQUILA QoS network services
- Overloaded network, where tested application traffic is carried by STD service without any QoS guarantees

Measured parameters

QoS evaluation will be done by real user subjective opinion, using rough MOS scale: 5 – excellent, 4 – good, 3 – fair, 2- poor, 1- bad.

A user will evaluate:

- inconveniences with set-up procedure (complexity, latency);

- end-to end speech and video transmission quality with videoconference application (comprehensibility, latency, picture quality, synchronization between audio and video signals etc.);
- end-to end video transmission quality with video streaming application (picture and sound quality etc.);

Topology

Trial network topology is presented in the Figure 7-5.

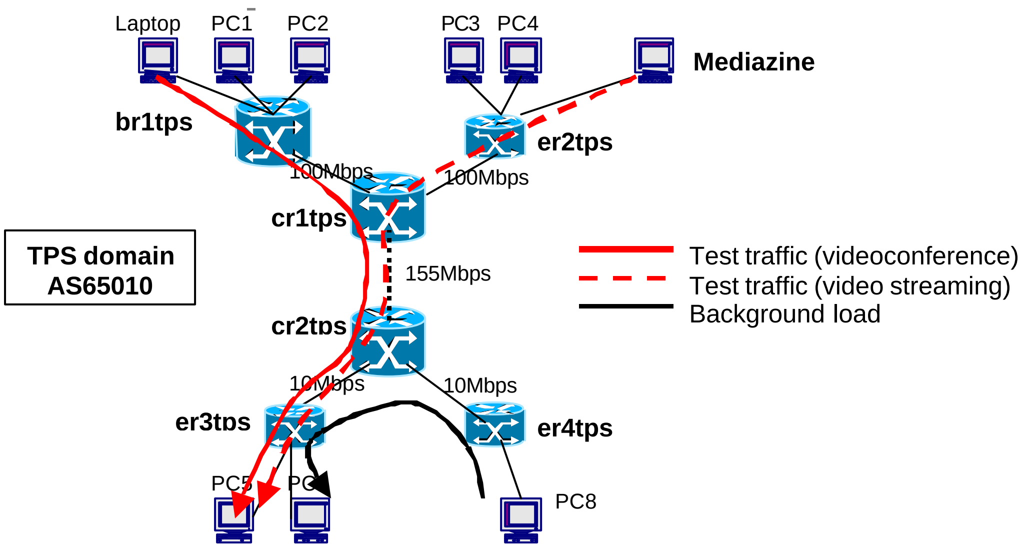


Figure 7-5. Trial topology in Mediazine tests.

Trial tools

Applications

The tested applications are: NetMeeting (videoconference), and RealSystem (video streaming), integrated into the Mediazine.

Traffic conditions

Trial was repeated under different traffic conditions:

(4) **Scenario #1 –** only the application traffic was submitted to the network, without any background load (reference scenario);

(5) **Scenario #2 -** both tested application as well as background traffic was handled by AQUILA QoS network services (including STD);

- The foreground traffic (video streaming) was submitted into TCL3 class. Mediazine server was connected to er2tps, while the client was running on PC5 connected to er3tps.
- The foreground traffic (video-conference) was submitted into TCL2 class. Videoconference was started between two terminals: ‘laptop’ connected to br1tps and PC5 connected to er3tps.
- Background traffic in TCL3: 2 greedy TCP flows submitted between PC2 and PC6. Reservations were set-up in TCL3 with RR=500kbps
- Background traffic in TCL5: Poisson stream with mean rate 9.5Mbps. The total offered traffic to the link cr2tps – er3tps produced the overload condition.

(6) **Scenario #3 -** comparing to (2), tested application traffic was submitted to STD.

Trial procedure

Five users (sitting at the terminal PC5) took part in a test. The users behaviour followed a predefined timetable with three trial steps, corresponding to different network conditions and QoS options. In each step, users watched a fragment of a movie (about 5 minutes) and took part in a short videoconference with a testing person in another room. The timetable is presented in the Table 7-12.

Step	**Scenario**	**Call duration**	**Users involved**
1	Reference scenario	5 min	User1 User2 User3 User4 User5
2	Overloaded network, QoS network services	5 min	User1 User2 User3 User4 User5
3	Overloaded network, STD service	5 min	User1 User2 User3

			User4 User5

Table 7-12. Exemplary timetable for the audio and video streaming tests

Results

In each step, each user filled in two questionnaires, where they assessed the perceived quality of video streaming and videoconference applications. The results collected during the consecutive steps of the trial were evaluated in form of the percentage of answers in each category. The rough mean opinion score was also calculated, assuming that the rating categories are related with numbers from 1 to 5. The results of questionnaire concerning the video streaming application are collected in Table 7-13.

Question	Number of answers (in brackets – percentage of total number of answers)		
	Scenario #1	Scenario #2	Scenario #3
1. How would you rate the over-all quality? **Excellent** **Good** **Fair** **Poor** **Bad**	 2 (40%) 3 (60%) 	 5 (100%) 	 3 (60%) 2 (40%)
Rough Mean Opinion Score (MOS)	**4.4**	**4**	**1.6**
2. Did you have any difficulty during the connection? **Yes** **No**	 5 (100%)	 5 (100%)	 3 (60%) 2 (40%)
3. If the answer is “yes”, what was the nature of the difficulty? …………………………………… ………………………………			Breaks, Pauses during transmission
4. Was the connection accept-able? **Yes** **No**	 5 (100%) 	 5 (100%) 	 2 (40%) 3 (60%)

Table 7-13. Video-streaming questionnaire filled by the users after each step of the trial

The results of questionnaire concerning the videoconference application are collected in Table 7-14.

Question	Number of answers (in brackets – percentage of total number of answers)		
	Scenario #1	Scenario #1	Scenario #1
1. How would you rate the over-all audiovisual quality?			
Excellent			
Good	5 (100%)	3 (60%)	
Fair		1 (20%)	1 (20%)
Poor		1 (20%)	3 (60%)
Bad			1 (20%)
Rough Mean Opinion Score (MOS)	**4**	**3.4**	**2**
2. How would you rate the video quality of the connection?			
Excellent			
Good	4 (80%)	2 (40%)	
Fair	1 (20%)	2 (40%)	1 (20%)
Poor		1 (20%)	3 (60%)
Bad			1 (20%)
3. How would you rate the audio quality of the connection?			
Excellent			
Good	5 (100%)	4 (80%)	
Fair		1 (20%)	
Poor			5 (100%)
Bad			
4. How would you judge the ef-fort needed to interrupt the other party?			
No effort			
Minor effort	5 (100%)	5 (100%)	2 (40%)
Moderate effort			1 (20%)
Considerable effort			2 (40%)
Extreme effort			
5. Did you have any difficulty during the connection?			
Yes	4 (80%)	3 (60%)	
No	1 (20%)	2 (40%)	5 (100%)
6. If the answer is "yes", what was the nature of the difficulty? ………………………………… ………………………….		Some video dis-tortions, unclear picture	Large video dis-tortions, Cannot see, can-not understand the speaking person
7. Was the connection accept-able?			
Yes	5	4	
No		1	5

Table 7-14. Videoconference questionnaire filled by the users after each step of the trial

8 Annex C – RCL performance

8.1 Intra-domain scenario

The main goal of these measurements is to evaluate the set-up time and signalling load in the AQUILA intra-domain architecture. The results are analysed to verify the scalability of AQUILA architecture.

8.1.1 Test environment

The test environment for intra-domain scenario consists of five routers connected in a chain. The client will make reservations to the server, which will cause signalling traffic between RCL elements as indicated in the picture. The RCL elements are running on Sun workstations and the GUI is running on a PC computer.

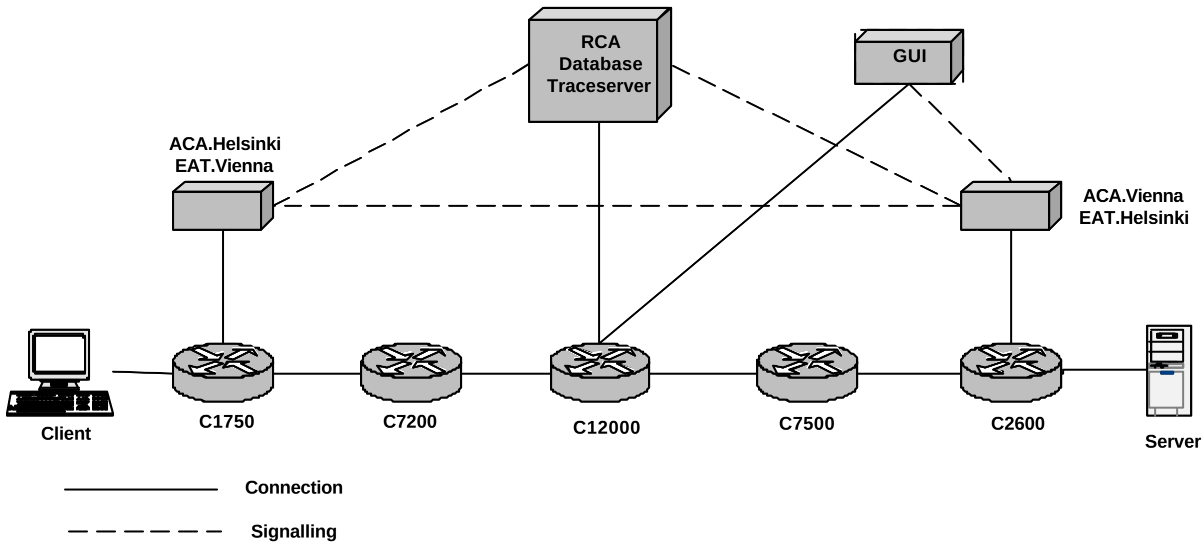


Figure 8-1. Intra-domain scenario test network

8.1.2 Transaction processing times

Transaction processing times measured in this chapter consist of initialisation time and times for reservation setup and release. Different traffic classes and AC schemes as well as different background loads were used in measurements. Additionally router configuration, resource pool invocation and existing reservations contributions to total processing time were considered. The transmission delays are negligible and ignored.

8.1.2.1 Initialisation time

As the first task each RCL component was started and the start-up time was measured. The transaction timestamps were read from the AQUILA log files and the initialisation times were calculated from them.

	EAT	ACA	RCA
Initialisation Time	**8s**	**13s**	**10s**

Table 8-1. Initialisation time for different RCL components

As the table above shows the initialisation times are rather large but the components need to be started only once and therefore these times have no effect on scalability.

8.1.2.2 Impact of TCL and AC scheme on processing times

In this scenario the effect of traffic class on reservation request and release times was measured. The measurement was performed using both declaration based admission control and measurement based admission control. All possible tracing traffic was switched off to minimize additional delays caused by logging. The timestamps were measured with the LoadClient, which measured the time between sending the request to EAT and receiving the acknowledgement of established reservation.

Initial reservation after RCL initialisation has longer duration than subsequent reservations where it is not always necessary to ask for additional resources from the resource pools, make the initial connection to the edge device or make first time initialisation of reservation related Java classes.

Initial reservations were considered as a particular case and each individual test was repeated five times contrary to subsequent tests where each individual test was repeated twenty times. The average times and deviations calculated from the test results are presented in the following tables.

	Setup Time [s]		Release Time [s]	
	Average	Deviation	Average	Deviation
TCL 1 Reservation	4,51	0,19	0,61	0,012
TCL 2 Reservation	4,66	0,29	0,84	0,009
TCL 3 Reservation	4,61	0,13	0,65	0,013
TCL 4 Reservation	4,19	0,22	0,89	0,004

Table 8-2. Processing times for initial reservations with DBAC

	Setup Time [s]		Release Time [s]	
	Average	Deviation	Average	Deviation
TCL 1 Reservation	0,90	0,026	0,46	0,065
TCL 2 Reservation	1,12	0,114	0,66	0,088
TCL 3 Reservation	0,97	0,071	0,50	0,011
TCL 4 Reservation	1,04	0,065	0,72	0,060

Table 8-3. Processing times subsequent resrvations with DBAC

	Setup Time [s]		Release Time [s]	
	Average	Deviation	Average	Deviation
TCL 1 Reservation	0,96	0,128	0,44	0,009
TCL 2 Reservation	1,09	0,043	0,64	0,011

Table 8-4. Processing times for subsequent reservations with MBAC

From the above tables it can be seen that different traffic classes or different admission control mechanisms have no significant impact on reservation set-up and release times. The initial reservation set-up time after system initialisation is around four seconds, which can be considered to be relatively slow. However majority of the reservations is subsequent reservations, which have significantly faster reservation processing. Set-up times for subsequent reservation are around one second, which is acceptable. Reservation release times are between half a second and one second however the duration of release is not as important as the duration of set-up for the user.

8.1.2.3 Router and resource pool contribution to total processing times

In this scenario a TCL 1 reservation was set up and released and the total, router configuration and resource pool invocation times were measured. All logging traffic was activated to allow the separation of different signalling components. These processing times were taken from the log file, where ACA writes a timestamp when it receives the request from EAT and sends the acknowledgement of reservation back.

	Setup Time (ACA) [s]			Release Time (ACA) [s]		
	Total	**Router**	**RP**	**Total**	**Router**	**RP**
Initial	**4,508**	**1,188**	**0,199**	**0,676**	**0,464**	**0**
Subsequent	**1,102**	**0,754**	**0**	**0,665**	**0,435**	**0**

Table 8-5. Router and resource pool contribution to total processing times

Activating tracing traffic slightly increases reservation processing times. On the other hand the total time is smaller than in previous case because client-EAT delay is not include. From the table above it can be observed that the router configuration time is a large part of total reservation set-up time. This is mainly because telnet connection is rather time consuming and finding a better way to communicate with routers would significantly improve the reservation set-up times.

8.1.2.4 Existing reservations contribution to processing times

In this scenario it was measured if the number of the ongoing reservations has an impact to reservation set-up time. Thirty reservations were set-up from ACA1 (ER1) to ACA4 (ER4), and the reservation set-up time was measured. A summary of reservation set-up times is presented in the following table. The average reservation set-up time is calculated from all reservations except the initial reservation.

Reservation set-up	Time [s]
Reservation 1 (initial)	6,012
Reservation 5	0,908
Reservation 10	0,935
Reservation 15	0,917
Reservation 20	0,902
Reservation 25	0,923
Reservation 30	0,889
Average (initial excluded)	0,937
Deviation (initial excluded)	0,033

Table 8-6. Reservation setup times with number of ongoing reservations

It can be seen from the results that the increasing number of ongoing reservations does not increase the reservation set-up time, which is a requirement for a scalable system.

8.1.3 Amount of signalling traffic

Amount of signalling traffic measurements covered the message exchange between AQUILA RCL components. In these test cases the number and size of signalling packets were measured. TCPDump [TCPDump] is used to capture the signalling traffic. The capture files are processed using AWK scripts in order to separate the useful information.

The results of the measurements are presented in tables. The table columns are: the amount of data without packet headers and with packet headers, the number of packets and the average packet size. The values in the tables are also illustrated graphically.

To support analysis the signalling traffic was divided into local and global components. Local signalling does not generally traverse the whole network while global does. Tables and figures show first the local components and then global components of the signalling. At the end of each subchapter a small table summarise the local and global components of the signalling traffic.

8.1.3.1 Initialisation

Each RCL component was started and the initialisation traffic was captured and converted to numbers.

RCL Initialisation

Source	Destination	Data [bytes]	Data+header	# of packet	average size
RCA	CORBA name server	34135	43375	231	147,77
RCA	Trace server	28089	36169	202	139,05
RCA	Database	14827	19347	113	131,21
ACA_ER4	RTR_ER4	8773	162293	3838	2,29
ACA_ER1	RTR_ER1	8287	160487	3805	2,18
GUI	EAT_ER1	0	0	0	
EAT_ER1	ACA_ER1	0	0	0	
ACA_ER4	Database	49332	57372	201	245,43
ACA_ER1	Database	47642	54602	174	273,80
ACA_ER4	Trace server	34128	43728	240	142,20
ACA_ER1	Trace server	33784	43144	234	144,38
ACA_ER1	CORBA name server	9937	12777	71	139,96
ACA_ER4	CORBA name server	9937	12777	71	139,96
EAT_ER1	Trace server	3869	5189	33	117,24
EAT_ER1	CORBA name server	2069	2869	20	103,45
EAT_ER1	Database	1971	2491	13	151,62
Trace server	ACA_ER1	605	885	7	86,43
Trace server	ACA_ER4	605	885	7	86,43
Trace server	EAT_ER1	605	885	7	86,43
ACA_ER1	RCA	0	0	0	
ACA_ER4	RCA	0	0	0	
ACA_ER1	ACA_ER4	0	0	0	

Table 8-7. Signalling traffic for RCL initialisation

As the table shows the amount of initialisation traffic is rather large but the components need to be started only once and therefore this load has no effect on scalability.

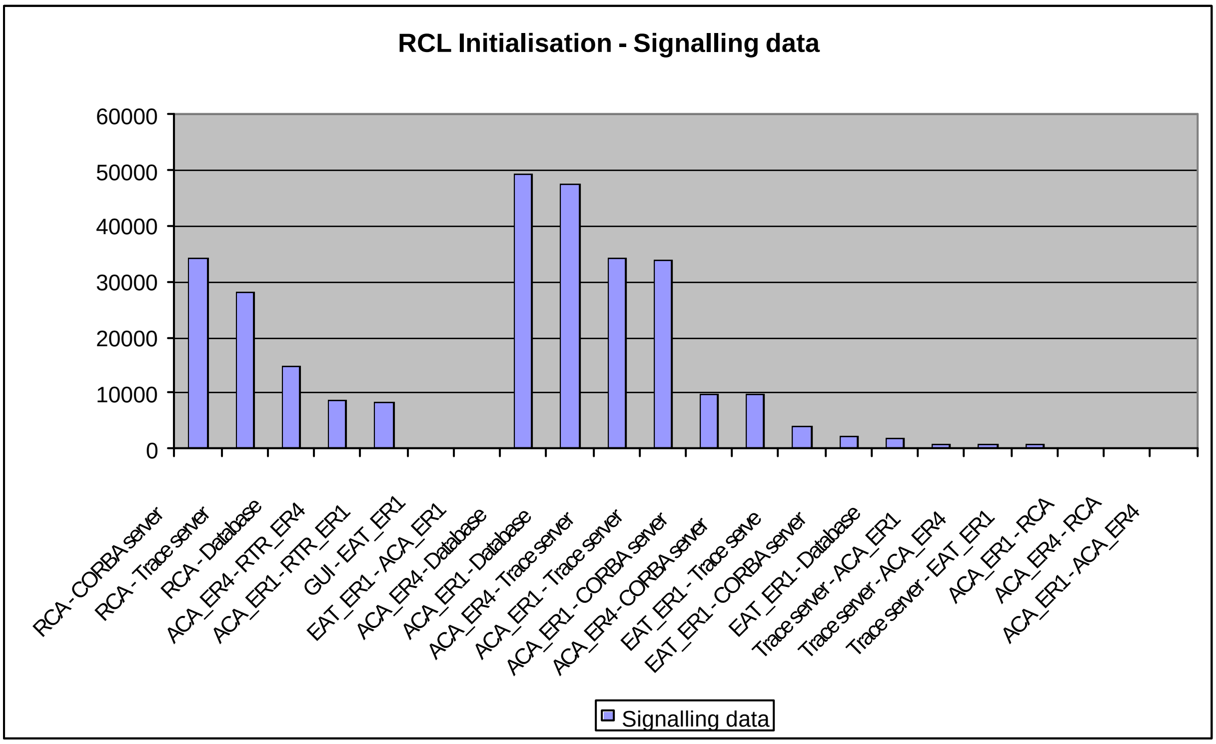


Figure 8-2. Signalling traffic for RCL initialisation

During the initialisation phase the RCL components retrieve information from the database and write log information to trace server. All debug logging was activated so the trace server traffic will be much smaller in normal RCL operation.

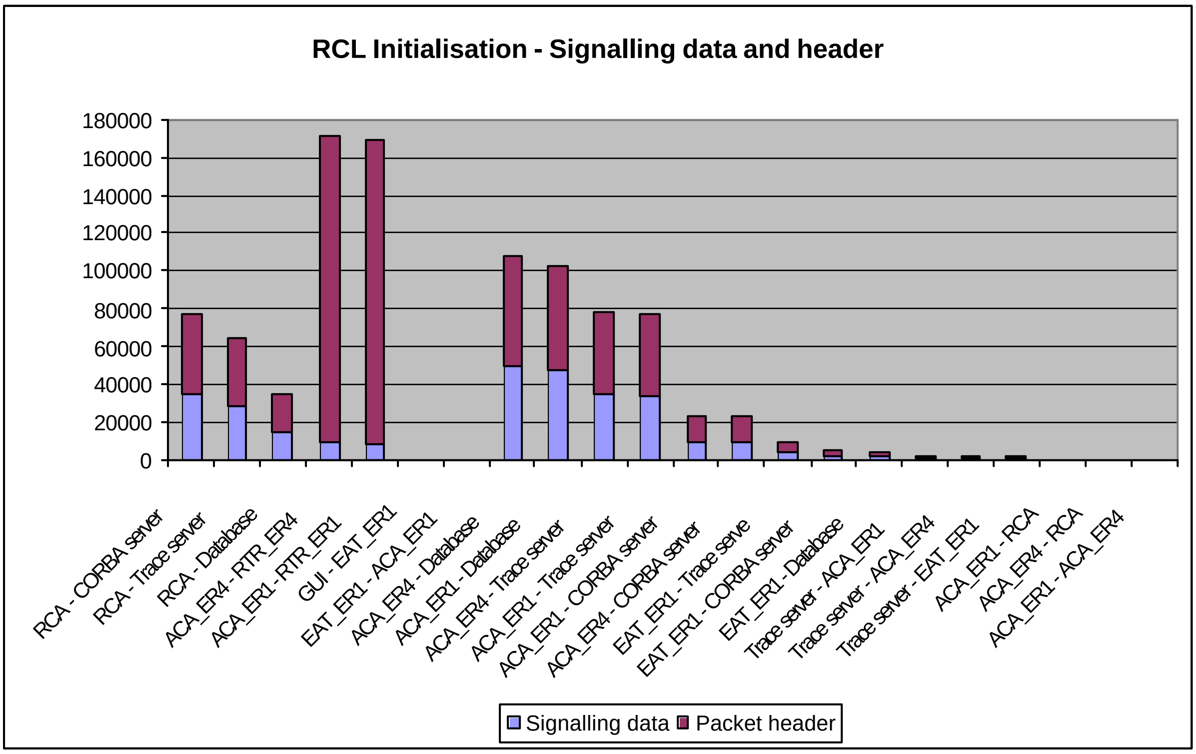


Figure 8-3. Signalling traffic with packet headers for RCL initialisation

In Figure 8-3 the packet headers are added to signalling traffic. The big increase in router traffic is caused by the router telnet implementation. The router echoes the commands back one character at a time.

Table 8-8 is a summary of signalling traffic during the initialisation phase of the RCL components. Tracing traffic is not included.

RCL Initialisation summary	Data [bytes]	Data+header	# of packet
Local traffic	66022	385502	7987
Global traffic	122703	145543	571
All Signalling traffic	188725	531045	8558

Table 8-8: Summary of the RCL initiasation traffic

8.1.3.2 Reservation set-up

One TCL 1 reservation is made from ER1 to ER4 and the signalling traffic between all RCL components is measured. The results are presented in the following table.

Reservation Set-up					
Source	**Destination**	**Data [bytes]**	**Data+header**	**# of packets**	**Average size**
GUI	EAT_ER1	4112	5992	47	87,49
ACA_ER1	RTR_ER1	2132	27692	639	3,34
EAT_ER1	ACA_ER1	1965	2565	15	131,00
RCA	Database	836	1236	10	83,60
ACA_ER4	RTR_ER4	293	2573	57	5,14
RCA	Trace server	0	0	0	
RCA	CORBA name server	0	0	0	
ACA_ER1	Trace server	18468	22868	110	167,89
ACA_ER1	Database	11631	12791	29	401,07
EAT_ER1	Trace server	4453	5733	32	139,16
ACA_ER4	Trace server	4144	5184	26	159,38
EAT_ER1	Database	2659	3619	24	110,79
ACA_ER1	ACA_ER4	1257	1697	11	114,27
ACA_ER1	CORBA name server	1254	1614	9	139,33
ACA_ER1	RCA	1188	1708	13	91,38
ACA_ER4	RCA	1188	1668	12	99,00
ACA_ER4	CORBA name server	412	532	3	137,33
EAT_ER1	CORBA name server	411	531	3	137,00
ACA_ER4	Database	0	0	0	

Table 8-9: Signalling traffic for reservation set-up

The values measured here are for initial reservation. The total amount of signalling traffic with headers was 98 kBytes. The largest component is trace server logging traffic, which will be much smaller in the production use of RCL. The second largest component is the traffic between ACA and database. This component no longer exists in subsequent reservation set-ups. The results without trace server and database components are visualised in the following figure.

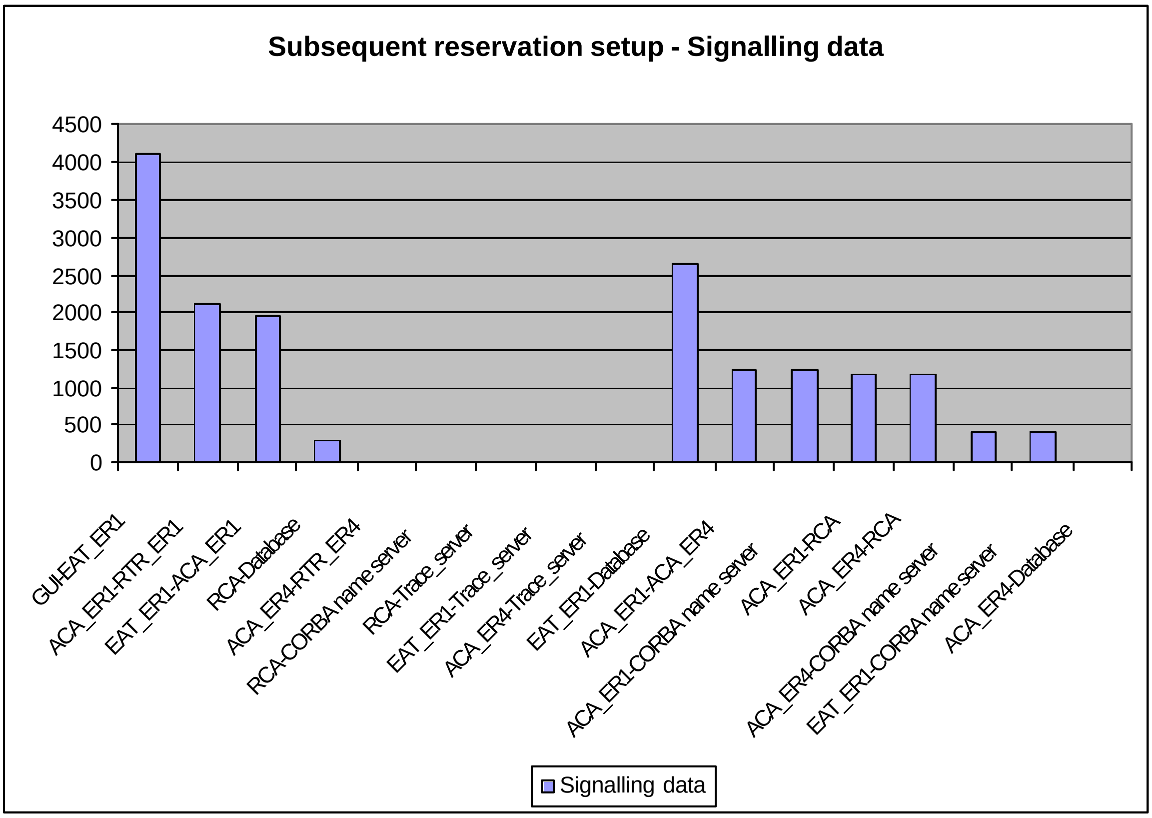


Figure 8-4. Signalling traffic for subsequent reservation setup

Figure 8-4 presents the signalling data without packet overheads in case of subsequent reservations without database and trace server components. The amount of traffic in figure is 16,8 kBytes, which is significantly less than the amount for initial reservation with database and trace service components.

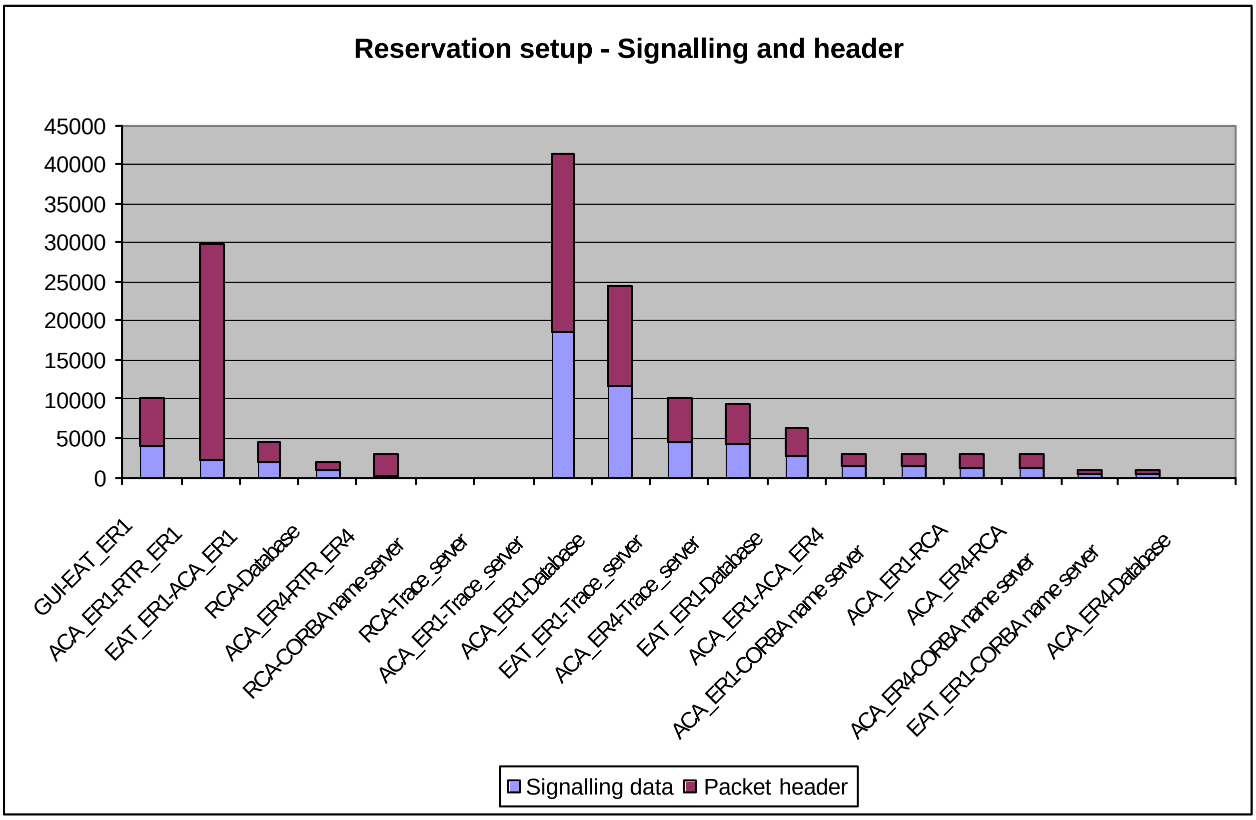


Figure 8-5. Signalling traffic for reservation setup with packet headers

In Figure 8-5 all signalling components from Table 8-9 are presented and the packet headers are added to signalling traffic. The big increase in router traffic is caused by the router telnet implementation. The router echoes the commands back one character at a time.

Table 8-10 is a summary of signalling traffic of the RCL components during the reservation set-up. Tracing traffic is not included.

Reservation Setup summary	Data [bytes]	Data+header	# of packets
Local traffic	9338	40058	768
Global traffic	20000	24160	104
All signalling traffic	29338	64218	872

Table 8-10. Summary of the reservation setup traffic

8.1.3.3 Reservation release

The reservation is released and the signalling traffic between all RCL components is measured.

Reservation Release					
Source	**Destination**	**Data [bytes]**	**Data+header**	**# of packets**	**Average size**
GUI	EAT_ER1	915	1435	13	70,38
ACA_ER1	RTR_ER1	1042	16402	384	2,71
EAT_ER1	ACA_ER1	360	520	4	90,00
RCA	Database	0	0	0	
ACA_ER4	RTR_ER4	0	80	2	0,00
RCA	CORBA name server	0	0	0	
RCA	Trace server	0	0	0	
ACA_ER1	Trace server	5036	6316	32	157,38
ACA_ER1	Database	0	0	0	
EAT_ER1	Trace server	1094	1414	8	136,75
ACA_ER4	Trace server	934	1174	6	155,67
EAT_ER1	Database	0	0	0	
ACA_ER1	ACA_ER4	336	496	4	84,00
ACA_ER1	CORBA name server	0	0	0	
ACA_ER1	RCA	0	0	0	
ACA_ER4	RCA	0	0	0	
ACA_ER4	CORBA name server	0	0	0	
EAT_ER1	CORBA name server	0	0	0	
ACA_ER4	Database	0	0	0	

Table 8-11. Signalling traffic for reservation release

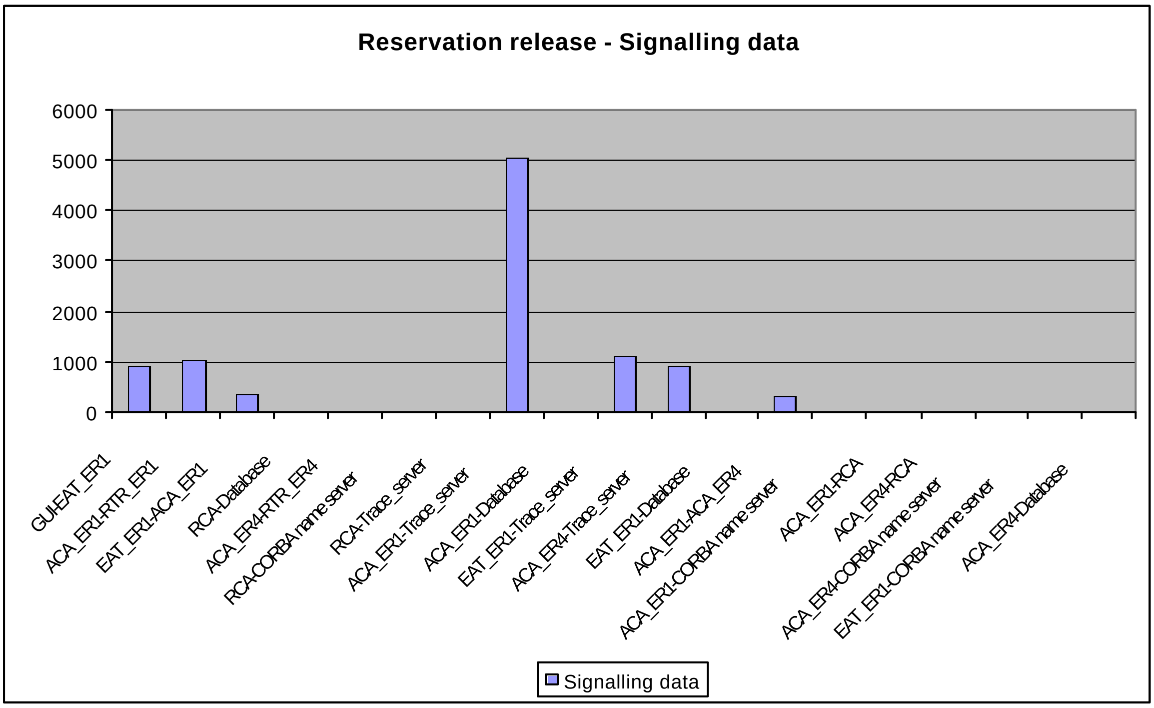


Figure 8-6. Signalling traffic for reservation release

During reservation release most traffic is generated by trace server logging, which will be much smaller in the normal RCL operation.

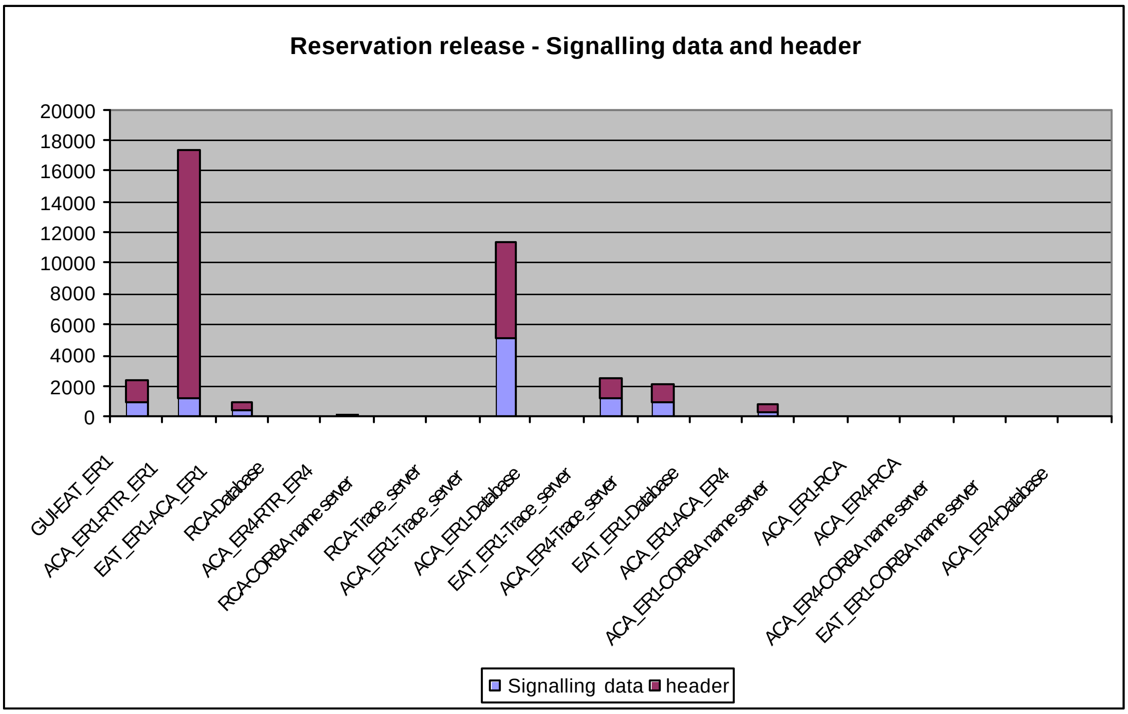


Figure 8-7. Signalling traffic for reservation release

In Figure 8-7 the packet headers are added to signalling traffic. The big increase in router traffic is caused by the router telnet implementation. The router echoes the commands back one character at a time.

Table 8-12 is a summary of signalling traffic between the RCL components during the reservation release. Tracing traffic is not included.

Reservation Release summary	Data [bytes]	Data+header	# of packets
Local traffic	2317	18437	403
Global traffic	336	496	4
All signalling traffic	2653	18933	407

Table 8-12. Summary of the reservation release traffic

8.1.3.4 MBAC signalling traffic

MBAC is activated in the ACA and the signalling traffic generated by MBAC between ACA and edge device is measured. The polling interval for traffic measurements is defined by the network operator. The following table shows the amount of data transferred during one interval. The amount of signalling depends a lot on the router implementation.

Source	Destination	Data [bytes]	Data+header	# of packets
ACA_ER1	RTR_ER1	4777	9697	123

Table 8-13. Summary of the MBAC signalling traffic

8.1.3.5 Keep-alive

During the reservations keep-alive connections, sending periodically hello messages, occur between RCL components. QMTool uses keep-alive mechanism for failure detection.

The sending interval for keep-alive messages can be defined by the network operator. The amount of the signalling traffic for keep-alive messages in one interval are summarised in the following table.

Source	Destination	Data [bytes]	Data+header	# of packets	Connection
EAT_ER1	ACA_ER1	292	412	3	unidirectional
ACA_ER1	ACA_ER4	584	824	6	bidirectional
ACA_ER1	RCA	584	824	6	bidirectional
ACA_ER4	RCA	584	824	6	bidirectional
QMTool	RCA	276	396	3	unidirectional

Table 8-14. Summary of the keep-alive signalling messages

8.2 Inter-domain scenarios

The main goal of these measurements is to evaluate the set-up time and signalling load in the AQUILA inter-domain architecture. The results are analysed to verify the scalability of AQUILA architecture.

8.2.1 Test environment

The test environment consists of four individual domains. Domains Poland and Finland have one virtual edge router and one border router each. Domain Austria consists of three border routers. Domain Germany consists of one border router and one edge router. The reservations are started either from domain Germany or domain Poland and the reservations end point is in domain Finland. In each domain there are AQUILA RCL and BGRP corresponding to border routers.

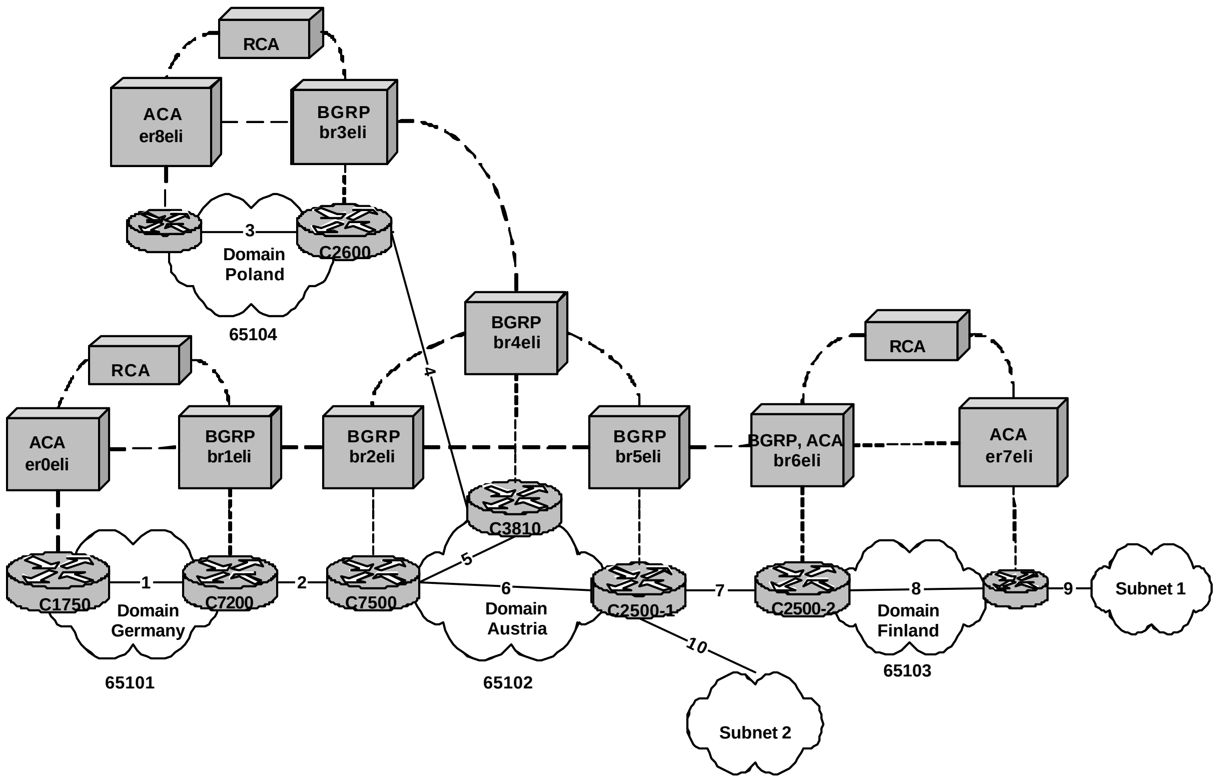


Figure 8-8. Inter-domain scenario test network

8.2.2 Reservation processing time

In the following test scenarios the reservation processing times in the inter-domain test network was measured. BGRP agent, router configuration and existing reservations contributions to total processing time were considered. The transmission delays are negligible and ignored.

8.2.2.1 Initialisation time

In this scenario each RCL component and BGRP Agent was started and the start-up time was measured. Each individual test was repeated five times. The transaction timestamps were read from the AQUILA log files and the average processing times were calculated from them.

	EAT	ACA	RCA	BGRPA
Initialisation Time	**8s**	**13s**	**10s**	**17,5s**

Table 8-15. Initialisation time for different RCL components

As the table shows the initialisation times are rather large but the components need to be started only once and therefore these times have no effect on scalability.

8.2.2.2 Signalling processing times without tracing

In this scenario reservations from domain Germany (ER0) to domain Finland (ER7) were set-up and released. All possible tracing traffic was switched off to minimize additional delays caused by logging. Initial reservations were considered as a particular case and each individual test was repeated five times contrary to subsequent tests where each individual test was repeated twenty times. The average times and deviations calculated from the test results are presented in the following table.

	Set-up Time [s]		**Release Time [s]**	
	Average	**Deviation**	**Average**	**Deviation**
Initial reservation	**25,8**	**14,1**	**0,849**	**0,22**
Subsequent reservation	**1,452**	**0,1**	**0,506**	**0,03**

Table 8-16. Signalling processing time without tracing

From Table 8-18 can be noticed a huge difference between the reservation set-up times in the initial and subsequent reservations. The difference is caused by the initial telnet connection to the router, requesting resources from RCA and first time initialisation of reservation related Java classes.

8.2.2.3 Router and BGRP agent contribution to total processing time

In this scenario a TCL 1 reservation was set up from domain Poland (ER8) to domain Finland (ER7) and after short time the reservation was released. Total, router configuration and BGRP agent processing times were measured for the reservation set-up and release. All logging traffic was activated so that log information could be used to separate the contributions of different components. However the drawback is that logging traffic increases the reservation processing times. Part of BGRP agent time is spent accessing the router, which is also included in router time. These processing times were taken from the log file, where ACA writes a timestamp when it receives a request from EAT and sends the acknowledgement of reservation back.

	Set-up Time [s]			Release Time [s]		
Domain	**Total**	**Router**	**BGRP Agent**	**Total**	**Router**	**BGRP Agent**
Requester	**6,85**	**2,85**	**2,60**	**0,68**	**0,47**	**0,022**
Transit	**11,49**	**6,50**	**7,70**	**-**	**-**	**-**
Receiver	**8,92**	**4,70**	**3,88**	**0,10**	**-**	**-**
All	**27,25**	**14,05**	**14,18**	**0,79**	**0,47**	**0,022**

Table 8-17. Component contribution to processing times without existing sink-tree

When examining the reservation set-up times for different domains it should be noted that both the requester and the receiver domain have only one real router. In the requester domain the ingress router and in the receiver domain the egress router is replaced with a virtual router. A shortcut file is used as a virtual router so there are no telnet connections to these routers and the reservation set-up times are reduced.

In the next scenario a TCL1 reservation from domain Poland (ER8) to domain Finland (ER7) was active. Another TCL1 reservation was set up from domain Germany (ER0) to domain Finland (ER7) and after a short time it was released. Total, router configuration and BGRP agent processing times were measured for reservation set-up and release. All logging traffic was activated so that log information could be used to separate the contributions of different components. However the drawback is that logging traffic increases the reservation processing times. Part of BGRP agent time is spent accessing the router, which is also included in router time. These processing times were taken from the log file, where ACA writes a timestamp when it receives a request from EAT and sends the acknowledgement of reservation back.

	Set-up Time [s]			Release Time [s]		
Domain	**Total**	**Router**	**BGRP Agent**	**Total**	**Router**	**BGRP Agent**
Requester	**12,94**	**5,35**	**2,32**	**1,07**	**0,73**	**0,048**
Transit	**4,30**	**2,30**	**3,14**	**-**	**-**	**-**
Receiver	**1,08**	**0,08**	**0,34**	**0,12**	**-**	**-**
All	**18,32**	**7,73**	**5,80**	**1,19**	**0,73**	**0,048**

Table 8-18. Component contribution to processing times with sink-tree

The requester domain Poland consists of two real routers; ingress and egress router, and it can be seen from the above tables that the reservation processing time is approximately twice as much as in the earlier case. However the total processing time is noticeably smaller than earlier because in the transient domain the second reservation is joining the reservation sink-tree formed by the earlier reservation. In the transit domain where both reservations have separate ingress routers and common egress router the reduction of time is slightly less than in the receiver domain where both reservations have the same path.

8.2.2.4 Existing reservations contribution to processing time

In this scenario it was measured if the number of the ongoing reservations has an impact to reservation set-up time. Thirty reservations were set-up from the domain Germany (ER0) to domain Finland (ER7) and the reservation set-up time was measured. The test was performed with minimum tracing traffic and summary of the results is in the following table. The average reservation set-up time is calculated using all the flows.

Reservation set-up	Time [s]
Reservation 1	1,404
Reservation 5	2,046
Reservation 10	2,099
Reservation 15	2,061
Reservation 20	1,876
Reservation 25	2,058
Reservation 30	2,045
Average	2,037
Deviation	0,187

Table 8-19. Reservation setup times with number of ongoing reservations

It can be seen from the results that the increasing number of ongoing reservations does not increase the reservation set-up time, which is a requirement for scalability.

8.2.3 Amount of signalling traffic

In the following test scenarios the amount of the signalling traffic in the inter-domain test network was measured. TCPDump [TCPDump] was used to capture the signalling traffic. The capture files were processed using AWK scripts in order to separate the useful information. Signalling traffic was observed between the following components:

- BGRPA-BGRPA
- BGRPA-ACA
- BGRPA-Database
- BGRPA -Trace server
- BGRPA/ACA – Name server

8.2.3.1 Initialisation

BGRP agent (BR1) in domain Germany and BGRP agents (BR2 and BR5) in domain Austria were started and the initialisation signalling traffic was measured.

Source	Destination	Data [bytes]	Data+header	# of packets	average size
BGRP_BR1	ACA_BR1	1978	2618	16	163,63
BGRP_BR5	ACA_BR5	1978	2618	16	163,63
BGRP_BR2	ACA_BR2	1978	2618	16	163,63
BGRP_BR2	Database	1385	2225	21	105,95
BGRP_BR2	Name server	644	924	7	132,00
BGRP_BR2	Name server	4273	5513	31	177,84
BGRP_BR2	Database	9692	11612	48	241,92
BGRP_BR1	Database	1382	2182	20	109,10
BGRP_BR1	Name server	644	924	7	132,00
BGRP_BR1	Name server	4273	5473	30	182,43
BGRP_BR1	Database	7948	9748	45	216,62
BGRP_BR5	Database	1385	2225	21	105,95
BGRP_BR5	Name server	644	924	7	132,00
BGRP_BR5	Name server	4273	5473	30	182,43
BGRP_BR5	Database	8546	10426	47	221,83
BGRP_BR2	Trace server	3007	4087	27	151,37
Trace server	BGRP_BR2	605	885	7	126,43
BGRP_BR1	Trace server	3007	4087	27	151,37
Trace server	BGRP_BR1	605	885	7	126,43
BGRP_BR5	Trace server	2543	3503	24	145,96
Trace server	ACA_BR5	605	885	7	126,43

Table 8-20. Signalling load for BGRP agent initialisation

As the table shows the amount of initialisation traffic is rather large but the components need to be started only once and therefore this load has no effect on scalability.

8.2.3.2 Reservation set-up and release

In this chapter reservation set-up scenarios with and without existing sink-trees are observed.

8.2.3.2.1 Initial reservation without existing sink-tree

One TCL 1 reservation is set-up from domain Germany (ER0) to domain Finland (ER7), which creates the sink-tree to domain Finland. The signalling traffic additional to intra-domain case in all domains is measured. All debug logging was activated so the trace server traffic will be much smaller in normal RCL operation.

Ingress Domain Germany					
Source	**Destination**	**Data [bytes]**	**Data+header**	**# of packets**	**average size**
ACA_BR1	Name server	1282	1802	13	98,62
BGRP_BR1	Database	30156	31756	40	753,90
ACA_BR1	BGRP_BR1	1309	1749	11	119,00
BGRP_BR1	Trace server	6984	8864	47	148,60

Table 8-21. Signalling load in ingress domain

Ingress domain Germany consists of two routers, one edge router ER0 and one border router BR1, but the edge router is not involved in inter-domain signalling.

Transit Domain Austria					
Source	**Destination**	**Data [bytes]**	**Data+header**	**# of packets**	**average size**
BGRP_BR2	Database	30268	32228	49	617,71
BGRP_BR2	Name server	426	546	3	142,00
BGRP_BR5	Database	30063	31663	40	751,58
BGRP_BR2	BGRP_BR5	760	960	5	152,00
BGRP_BR5	BGRP_BR2	812	1012	5	162,40
BGRP_BR2	ACA_BR2	981	1221	6	163,50
BGRP_BR2	Trace Server	7935	10055	53	149,72
BGRP_BR5	Trace server	7219	9219	50	144,38

Table 8-22. Signalling load in transit domain

In the transit domain two border routers, the ingress router BR2 and egress router BR5 are involved in reservation set-up.

Egress Domain Finland					
Source	**Destination**	**Data [bytes]**	**Data+header**	**# of packets**	**average size**
BGRP_BR6	Name server	426	546	3	142,00
BGRP_BR6	ACA_BR6	1124	1404	7	160,57
BGRP_BR6	Database	30051	31651	40	751,28
BGRP_BR6	Trace Server	5395	6915	38	141,97

Table 8-23. Signalling load in egress domain

Egress domain in the test network consists of one real router, ingress router BR6. Even if this domain would have more real routers, they would be core or edge routers for this reservation and therefore not involved in inter-domain signalling.

Signalling traffic of ingress, transit and egress domains is illustrated in the following figure. Trace server traffic is excluded from the picture because it consists mostly of logging traffic which would not exist in production use. The largest signalling component in all domains is between the BGRP agent and database, however only initial reservations have this component.

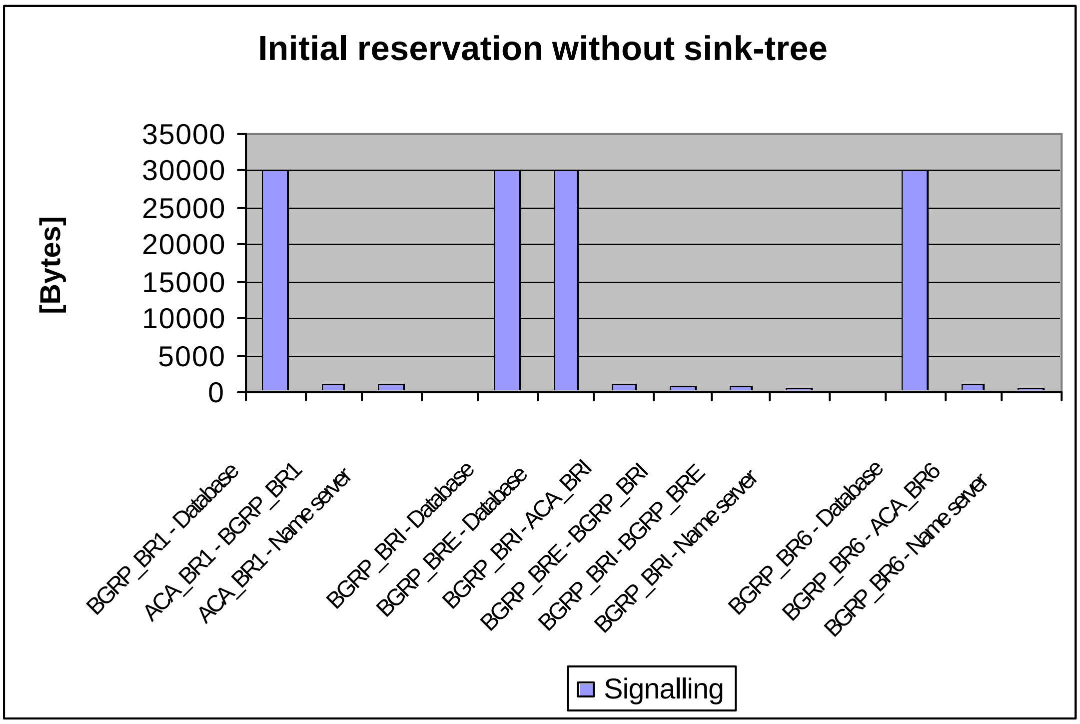


Figure 8-9. Initial reservation without existing sink-tree

The inter-domain signalling within the domains was presented above; however there is also some signalling between the neighbour BGRP agents and this traffic is presented in the following table.

Between two domains					
Source	**Destination**	**Data [bytes]**	**Data+header**	**# of packets**	**average size**
BGRP_BR1	BGRP_BR2	620	820	5	124,00
BGRP_BR2	BGRP_BR1	672	872	5	134,40
BGRP_BR5	BGRP_BR6	900	1100	5	180,00
BGRP_BR6	BGRP_BR5	952	1152	5	190,40

Table 8-24. Signalling load between the domain

Additional to real signalling traffic between BGRP agents presented in Table 8-24, there are bi-directional keep-alive messages between neighbour BGRP agents. Keep-alive messages are UDP packets of size 292B and there is one packet in every 15s.

8.2.3.2.2 Second reservation joining existing sink-tree

Second TCL 1 reservation was set-up from domain Poland (ER8) to domain Finland (ER7). This reservation should join the sink-tree between the domains Germany and Finland at domain Austria. The signalling traffic between RCL components is measured and compared to the previous case.

Ingress Domain Poland					
Source	**Destination**	**Data [bytes]**	**Data+header**	**# of packets**	**average size**
BGRP_BR3	Database	30242	31842	40	756,05
BGRP_BR3	Trace server	6927	8807	47	147,38

Table 8-25. Signalling load in ingress domain

Ingress domain in the test network consists of one real router, egress router BR3. Even if this domain would have more real routers they would be core or edge routers for this reservation and therefore not involved in the inter-domain signalling. For ingress domain this is an initial reservation and therefore the database signalling component is present.

Also in this case there would be similar amount of signalling traffic between ACA_BR3 and BGRP_BR3 as in the previous case was between ACA_BR1 and BGRP_BR1. This signalling component is not measured here because of the limited amount of PCs in the test network these two components were running in the same PC.

Transit Domain Austria					
Source	**Destination**	**Data [bytes]**	**Data+header**	**# of packets**	**average size**
BGRP_BR4	Database	30252	31852	40	756,30
BGRP_BR4	Name server	426	546	3	142,00

BGRP_BR4	ACA_BR4	981	1261	7	140,14
BGRP_BR4	BGRP_BR5	760	960	5	152,00
BGRP_BR5	BGRP_BR4	812	1012	5	162,40
BGRP_BR4	Trace Server	7895	10055	54	146,20
BGRP_BR5	Trace server	5408	6808	35	154,51

Table 8-26. Signalling load in transit domain

In the transit domain two border routers, the ingress router BR4 and egress router BR5 are involved in reservation set-up. Border router BR5 belongs to the sink-tree formed by the previous reservation and because of existing reservation there is no signalling between BGRP agent and database for second reservation.

Egress Domain Finland					
Source	**Destination**	**Data [bytes]**	**Data+header**	**# of packets**	**average size**
BGRP_BR6	Name server	426	546	3	142,00
BGRP_BR6	Trace Server	3151	3951	20	157,55

Table 8-27. Signalling load in egress domain

Egress domain belongs to sink-tree formed by the previous reservation. There is no signalling between BGRP agent and database for this second reservation.

Signalling traffic of transit and egress domains is illustrated in Figure 8-10. Ingress domain is not included to the figure because both reservations have separate ingress domains and the signalling in ingress domains is the same for both reservations. Trace server traffic is excluded from the picture because it consists mostly of logging traffic, which would not exist in production use.

In the transient domain ingress border routers (BRI) are two separate routers. First reservation has BR2 as a border router and the second reservation has BR4 as a border router and in Figure 8-10 BGRP agents for both routers have high amount of signalling traffic with database. The egress border router (BRE) is the same router (BR5) for both reservations and therefore only the first reservation has signalling traffic with database.

In the egress domain the reservations belong to the same sink-tree and only the initial reservation needs to have signalling traffic towards database.

The amount of signalling traffic was decreased when another reservation joined the sink-tree because database traffic was non-existent. This behaviour is because the reservation is a subsequent one for BGRP agents.

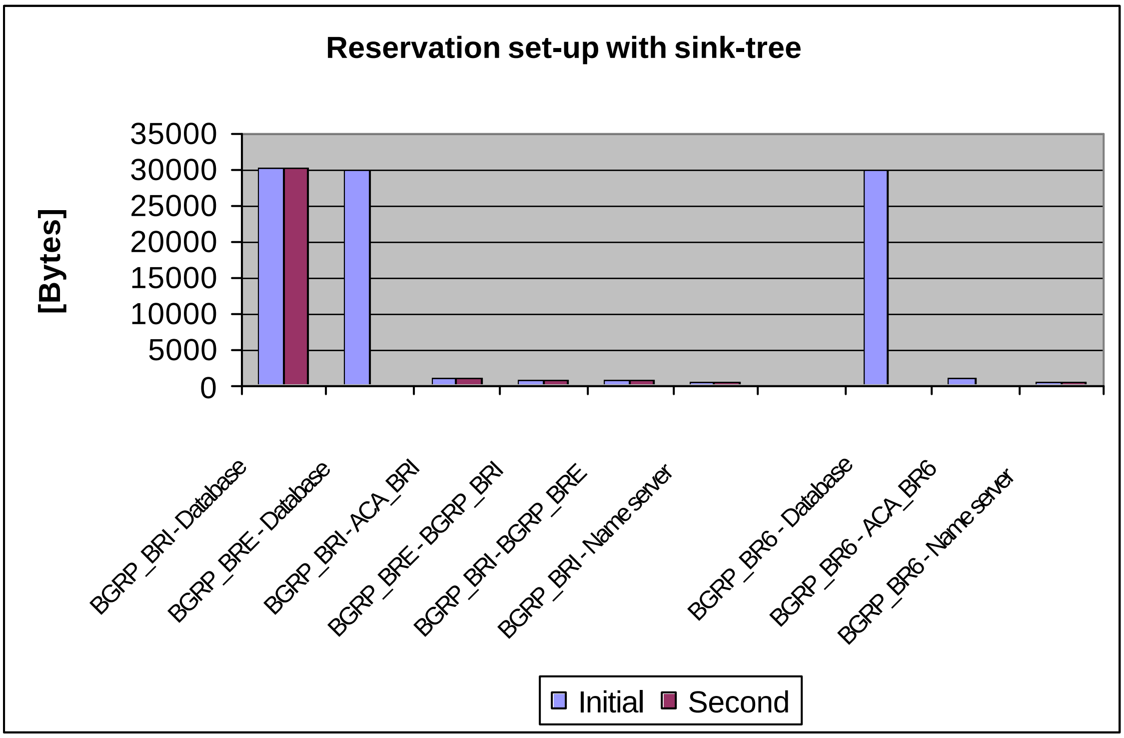


Figure 8-10. Reservation set-up with existing sink-tree

The inter-domain signalling within the domains was presented above; however there is also some signalling between the neighbour BGRP agents and this traffic is presented in Table 8-28.

Between two domains					
Source	**Destination**	**Data [bytes]**	**Data+header**	**# of packets**	**average size**
BGRP_BR3	BGRP_BR4	620	820	5	124,00
BGRP_BR4	BGRP_BR3	672	872	5	134,40
BGRP_BR5	BGRP_BR6	736	816	2	368,00
BGRP_BR6	BGRP_BR5	776	856	2	388,00

Table 8-28. Signalling load between domains

The results show that signalling load between transit and receiver domain is slightly decreased because of sink-tree.

Additional to real signalling traffic between BGRP agents presented in Table 8-28, there are bi-directional keep-alive messages between neighbour BGRP agents. Keep-alive messages are UDP packets of size 292B and there is one packet in every 15s.

8.2.3.2.3 Reservation release with existing sink-tree

The reservations made in previous subchapters are released. Reservation from ER8 to ER7 is released first.

First the intra-domain reservations are released in the ingress and egress domains at time 00:00. Reservation releases in the transit domain between BGRP agents are done with REFRESH messages, which are discussed in next subchapter. When the resource control algorithm in BGRP agent decides to release/modify the transit domain reservation, BGRP agent signals ACA to release the reservation. This causes also ACA to ACA signalling.

As a result the transit domain reservation from ER2 to ER5 is reduced to correspond to the current sink-tree need and the sink-tree branch from BGRP_BR3 to BGRP_BR5 is removed. The signalling traffic is listed in Table 8-29.

Source	Destination	Data [bytes]	Data+header	# of packets	Avg. size [bytes]	Time [mm:ss]
ACA_BR3	BGRP_BR3	144	264	3	48	00:00
BRGP_BR6	ACA_BR6	144	264	3	48	00:00
BRGP_BR4	ACA_BR4	341	581	6	56,83	07:36
ACA_BR4	ACA_BR5	248	408	4	62	07:36
BRGP_BR4	ACA_BR4	144	264	3	48	17:05
ACA_BR4	ACA_BR5	340	500	4	85	17:05
BRGP_BR2	ACA_BR2	341	581	6	56,83	24:51
ACA_BR2	ACA_BR5	264	384	3	88	24:51

Table 8-29. Reservation (ER8-ER7) release signalling traffic

Reservation from ER0 to ER7 is then released. First the intra-domain reservations are released in the ingress and egress domains at time 00:00. Reservation release in the transit domain between BGRP agents is done with REFRESH message. This causes the removal of the whole sink-tree therefore the intra-domain reservation is released instead of modification. The signalling traffic is listed in Table 8-30.

Source	Destination	Data [bytes]	Data+header	# of packets	Avg. size [bytes]	Time [mm:ss]
ACA_BR1	BGRP_BR1	144	264	3	48	00:00
BRGP_BR6	ACA_BR6	144	264	3	48	00:00
BRGP_BR2	ACA_BR2	144	264	3	48	16:13
ACA_BR2	ACA_BR5	339	459	3	113	16:13

Table 8-30. Reservation (ER0-ER7) release signalling traffic

8.2.3.2.4 Maintaining soft state

BGRP agents maintain soft state of the reservations using REFRESH messages. These messages are send in user configurable intervals. The size of the messages is 300 bytes towards the reservation destination and 444 bytes to reverse direction.

8.3 Network load contribution to processing time

In this scenario the reservation set-up and release times for TCL 1 are measured under different network loads. Measurements were performed on both 1Mbit/s and 2Mbit/s links in the inter-domain testbed. The test was first performed on 2Mbit/s links and then repeated on 1Mbit/s links because some routers could not handle the load.

The neighbouring BGRP agents were located in different computers, one in domain Germany and one in domain Finland. The background traffic for all classes was generated between these two points.

In each case twenty reservations were made and the average time was calculated. The results are presented in the following tables.

Network Load (1Mbit/s links)				
Load [%]	**25**	**50**	**75**	**100**
Setup time [s]	2,05	2,19	2,47	3,05
Release time [s]	0,516	0,554	0,654	0,613

Table 8-31. Network load contribution to reservation processing time on 1Mbit/s links

Network Load (2Mbit/s links)				
Load [%]	**0**	**12,5**	**25**	**50**
Setup time [s]	3,02	3,06	3,23	3,86
Release time [s]	0,487	0,527	0,561	0,614

Table 8-32. Network load contribution to reservation processing time on 2Mbit/s links

In the 1Mbit/s case a slight increase in the set-up and release times can be observed when the load is increased. In the 2Mbit/s case it was possible to increase load only to 50% of the links' capacity. When the network load was 75% ER5 router stopped responding to telnet connections due to CPU overload. Therefore it was not possible to make any reservations.

8.4 Failure scenarios

In this scenario one network element at a time was shut down and its impact to the whole system in terms of system operation was observed.

RCA, EAT and ACA scenarios were tested in the secondary access network (see Chapter 6 Figure ZZ). EAT was connected to ACA_ER2.

BGRP agent, router and database scenarios were tested in the inter-domain test network. In all scenarios, all RCL component and BGRP agents were running before the actual test. EAT was connected to ACA_ER1.

8.4.1 RCA

In this scenario RCA was shutdown and restarted to observe how it affects system operation. The following procedure was used:

1) Set-up TCL1 reservation from ER3 to ER4 using peak rate of 10 000bit/s
2) RCA was shut down
3) Reservation was released
4) RCA was restarted
5) New TCL1 reservation using peak rate of 30 000bit/s was set-up
6) Another TCL1 reservation using peak rate of 30 000bit/s was set-up

After restarting the RCA it was possible to make new reservations. ACAs were able to get new resources from RCA and everything except keep-alive messages between ACA and RCA was working just fine.

8.4.2 EAT

In this scenario EAT was shutdown and restarted. It was required to restart also Tomcat to be able to make reservations.

8.4.3 ACA

In this scenario ACA was shutdown and restarted to observe how it affects system operation. The following procedure was used:

1) TCL1 reservation was set-up from ER3 to ER4

2) ACA_ER2 was shut down

3) ACA_ER2 was restarted

4) EAT and Tomcat restarted

5) ACA_ER3 was shut down

6) ACA_ER3 was restarted

7) New TCL1 reservation from ER3 to ER4 was successfully made

On step 3 after restarting ACA2 EAT is not able to find the right ACA. At the same time RCA notices that keep-alive connection to ACA_ER2 is broken. ACA_ER3 and ACA_ER4 also notice that keep-alive to ACA_ER2 is not active and then the reservation is released by ingress and egress ACA.

On steps 5 to 6 secondary ACA_ER3 was shutdown and restarted and after that reservation set-up was successful.

8.4.4 Router

In this scenario router was shutdown and restarted to observe how it affects system operation. The following scenario was used:

1) TCL1 reservation from ER0 to ER7 was set-up

2) Router ER0 was shut down

3) Router ER0 was restarted

4) Reservation release was tried but it failed

After step 2 ACA_ER0 does not notice that router is down. Router shutdown causes the link between the adjacent BGRP agents to disappear. Therefore no messages between the BGRP agents are exchanged. Releasing the reservation failed because ACA_ER0 did not find the reservation on router.

8.4.5 Database

In this scenario database was shutdown and restarted to observe how it affects system operation. The following scenario was used:

1) Database was shut down

2) TCL1 reservation was tried to set-up from ER0 to ER7

3) Database is restarted

4) TCL1 reservation was tried to set-up from ER0 to ER7

On step 2 ACAs made the reservation in the first domain and BGPR_BR1 crashes because it was not able to connect to the database. On step 4 BGRP_BR1 is able to connect to the database but reservation set-up fails because BGRP agents' neighbour relations are not clear.

8.4.6 BGRPA

In these scenarios BGRP agent was shutdown and restarted to observe how it affects system operation. The following scenario was first used:

1) BGRP_BR1 agent was shut down

2) TCL1 reservation was tried to set-up from ER0 to ER7 but set-up failed

3) BGRP_BR1 agent was restarted

4) TCL1 reservation was tried to set-up from ER0 to ER7 but set-up failed again

It was not possible to make reservation after just restarting BGRP agent but all the RCL components needed to be restarted. The BGRP_BR2 removes BGRP_BR1 from its neighbour table on step 1 and does not update the table after BGRP_BR1 restarts. Therefore on step 4 BGRP_BR2 rejects the reservation.

Second scenario was:

5) TCL1 reservation from ER0 to ER7 was set-up

6) BGRP_BR2 was shut down

7) BGRP_BR2 was restarted

8) The reservation was released

After step 2 BGRPA_BR5 notices that the neighbour is missing and sends an error message but the reservation is still active. On step 4 the reservation is released only on ingress domain and still exists on the other domains until the refresh messages tear down the reservation.

Third scenario was:

1) BGRP_BR2 was shut down

2) TCL1 reservation set-up from ER0 to ER7 failed

3) BGRP_BR2 was restarted

4) TCL1 reservation set-up from ER0 to ER7 failed

On step 4 no response from the BGRP_BR2 was received and therefore nothing happened on reservation GUI after trying to activate the reservation.

Forth scenario was:

1) ACA_BR2 was shut down

2) TCL1 reservation set-up from ER0 to ER7 failed

3) ACA_BR2 was restarted

4) TCL1 reservation was set-up from ER0 to ER7

5) ACA_BR2 was shut down

6) The reservation was released

7) ACA_BR2 was restarted

On step 6 the reservation was released in the first domain but in the second domain it was not possible to connect ACA_BR2 and the release failed in that domain. On step 7 after restart ACA_BR2 tries to re-establish the domain reservation. Final state is unclear; the reservation might stay active between ACA_BR2 and ACA_BR5 even though it is released in other domains.

9 Annex D - Evaluation of resource pool management

All tests are performed with the Signalling Load Client. (see chapter 11.6)

The evaluation of the following tests was performed with the help of the log-files and the router settings.

9.1 Testbed configuration

Based on the link capacity in the Vienna testbed, resource pool resources are 34 Mbit/s for ingress and also for egress are available (as the sum of link capacities). During the start-up configuration procedure, the RP is assigned their initial resources. Resources of 9,5 Mbit/s in each direction are reserved in the RP for QoS traffic, the rest for best-effort traffic. Since there is a one level hierarchy in the TAA testbed, 9,5 Mbit/s is the upper limit that can be allocated to QoS traffic.

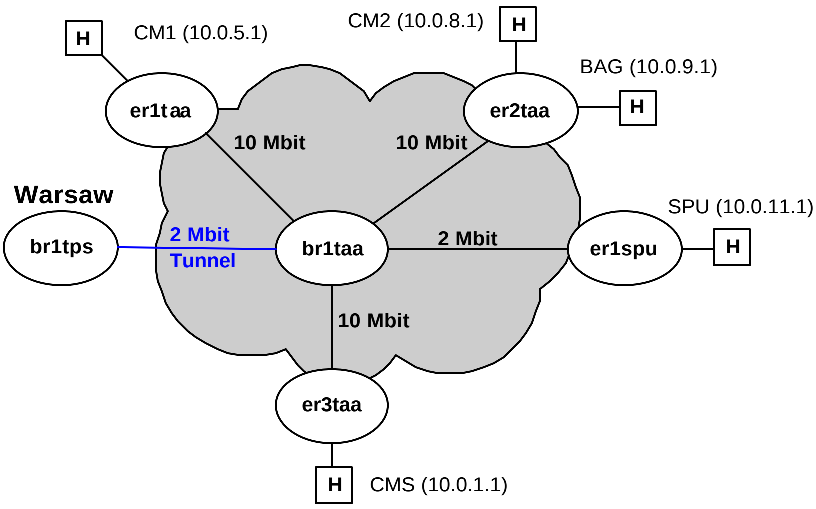


Figure 9-1. Link capacity in the Vienna network topology

9.2 Root Pool configuration

For the 2nd trial, the following start-up configuration was used. Please note that for ingress and egress, the same start-up values are used.

	Root Pool		
TCL	Ingress / Egress	RS max [kbit/s]	RS Tot [kbit/s]
TCL1	Ingress	1900	1900
	Egress	1900	1900
TCL2	Ingress	2850	2850
	Egress	2850	2850
TCL3	Ingress	3800	3800
	Egress	3800	3800
TCL4	Ingress	950	950
	Egress	950	950

Table 9-1. RP initial configuration

The following Table 9-2 shows the parameter settings for the RP algorithm.

Parameter	Amax	Amin	WL	BlockSize	Counter	ReleasePeriod
Value	5	1	0,9	100kbps	10	5 min

Table 9-2. Parameter settings for the RP algorithm

9.3 Load distribution among TCLs for different links

In order to reach the resource limits of allowed QoS traffic by some requests, for QoS only a minimum of resources were allocated. Minimum guaranteed BW and maximum allowed BW were set equal. The separation of resources per traffic class was defined different for 10 Mbit/s and for 2 Mbit/s links. Detailed description of the resource pool algorithms and the traffic handling for the second trial can be found in D1302.The following tables show the load distribution as well as the DBAC configuration for the TAA testbed.

TCL	Percent of QoS traffic	Resources of QoS traffic	Rule Map
TCL1	5%	500 kBit/s	Pra 1
TCL2	7,5%	750 kBit/s	Pra 2
TCL3	10%	1 MBit/s	Pra 31
TCL4	2,5%	250 kBit/s	Pra 4

Table 9-3. Reference load distribution among TCLs on a 10 Mbit link

TCL	Percent of QoS traffic	Resources of QoS traffic	Rule Map
TCL1	10%	200 kBit/s	Pra 1
TCL2	15%	300 kBit/s	Pra 2
TCL3	20%	400 kBit/s	Pra 31
TCL4	5%	100 kBit/s	Pra 4

Table 9-4. Reference load distribution among TCLs on a 2 Mbit link

Rule Map	Rho ingress	Rho egress	bufferSpace	Packet-DropProb	rttInterDorn	rttIntraDorn
Pra 1	1	1				
Pra 2	1	1				
Pra 31	0,7	0,7	40	0,1	0,01	0,31
Pra 4	1	1				

Table 9-5. DBAC parameter for TCLs

9.4 Dynamic RP performance trial

The objective of these scenarios is whether the requests are accepted or rejected, depending on the RP algorithm and on the configured AC limits. Furthermore for TCL1 a long run test was performed in order to test the stability of the algorithm. The requested resources are indicated by bars, squares or triangles. The amount of requested resources are drawn cumulative in the figures.

In order to test the basic functionalities of the RP-algorithm, resource requests by one host were performed. In a next step resource requests were performed by different hosts and furthermore by different hosts and different ingress points (edge router) to the network. These scenarios demonstrate that the algorithm could also manage this challenge.

9.4.1 Resource requests by one host

In this test reservations are created from host MM1 (10.0.6.1) to host MM2 (10.0.4.1).

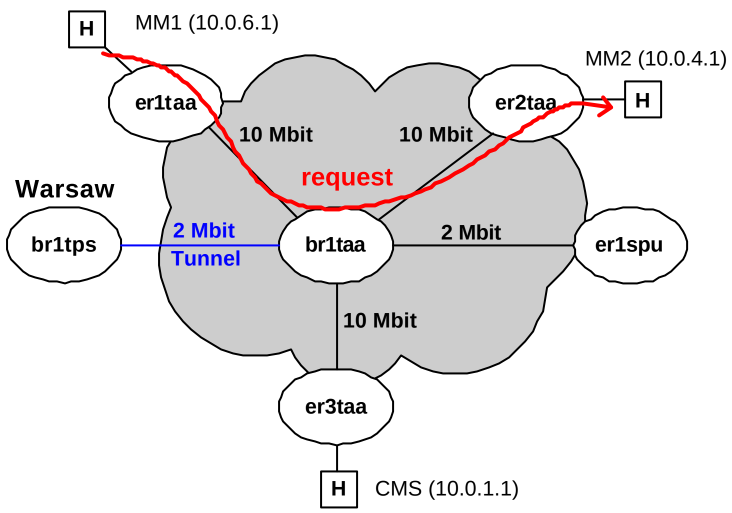


Figure 9-2. Resource requests by one host

Separate scenarios for each TCL are carried out.

9.4.1.1 Resource Requests for TCL1

The following parameters are used to set up the resource reservations for all TCL1 tests.

PR	10 kBit/s
BSP	125 Bytes

Table 9-6. Parameter for resource requests for TCL1

9.4.1.1.1 Scenario for resource requests for TCL1

The resource requests are shown in Figure 9-3.

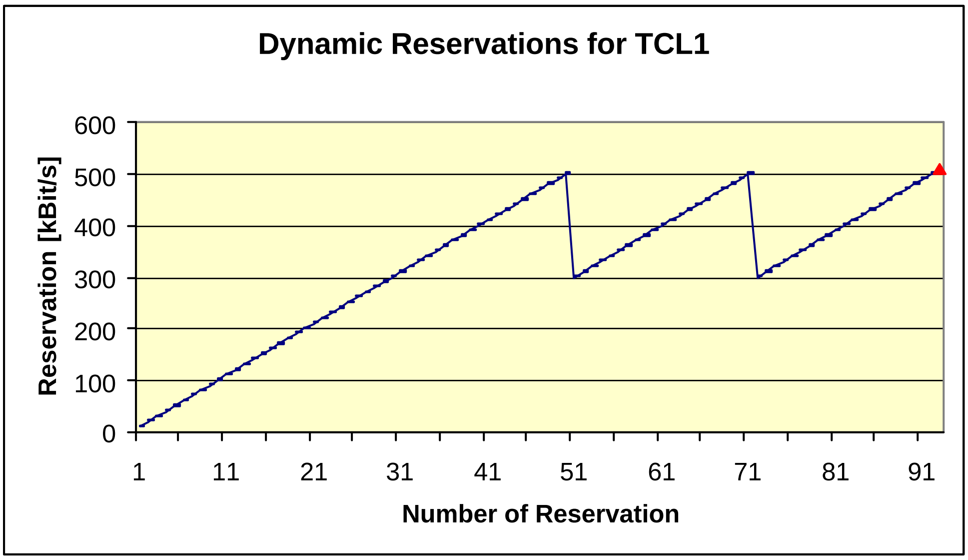


Figure 9-3. TCL1 requests

<u>Result:</u>

The x-axis shows the number of reservation whereas the y-axis shows the amount of requested resources. Each request of 10 kBit/s was correctly set up in the router. After the limit of 500 kBit/s was reached, no more requests could be executed. The triangle indicates a test for a further resource request, which was rejected correctly.

9.4.1.1.2 Scenario for "long run resource requests" for TCL1

The resource requests are shown in Figure 9-4.

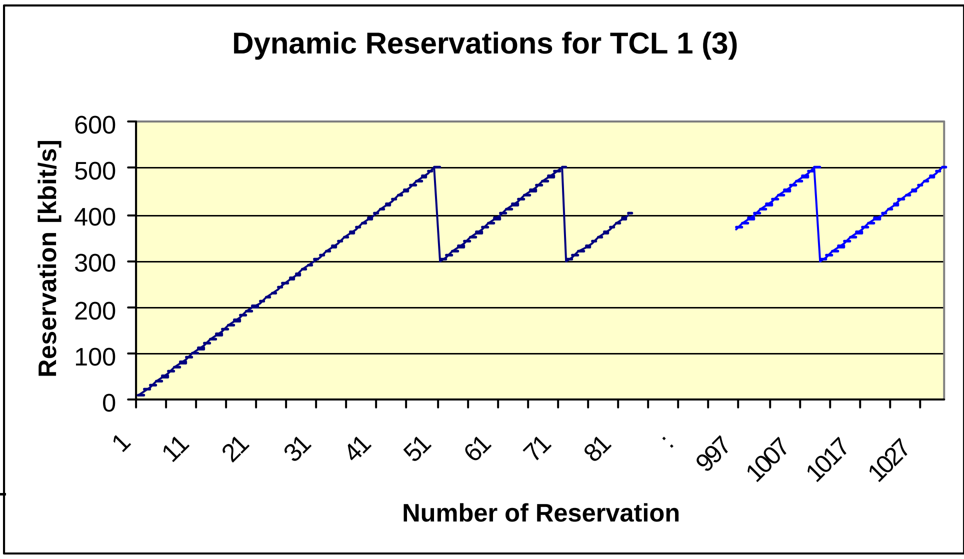


Figure 9-4. TCL1 test for long run requests

Result:

The x-axis shows the number of reservation whereas the y-axis shows the amount of requested resources. Each request of 10 kBit/s was correctly set up in the router. After the limit of 500 kBit/s was reached, 20 reservations were released and again requested. This procedure was repeated for 50 times and there were no errors in the log-files. This test lasted for approximately 3 hours and demonstrated the stability of the algorithm.

9.4.1.2 Resource Requests for TCL2

The following parameters were used to set up the resource reservations for all TCL2 tests.

PR	250 kBit/s
SR	125 kBit/s

Table 9-7. Parameter for resource requests for TCL2

9.4.1.2.1 Scenario for resource requests for TCL2

The resource requests are shown in Figure 9-5.

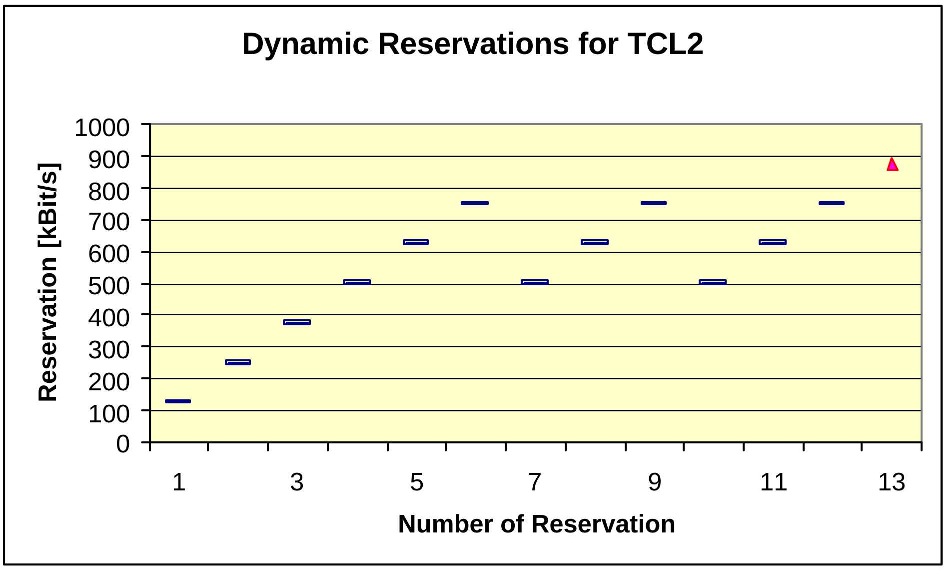


Figure 9-5. TCL2 requests

Result:

The x-axis shows the number of reservation whereas the y-axis shows the amount of requested resources. Each request of 125 kBit/s was correctly set up in the router. After the limit of 750 kBit/s was reached, no more requests could be executed. The triangle indicates a test for a further resource request, which was rejected correctly.

9.4.1.3 Resource Requests for TCL3

9.4.1.3.1 Scenario for resource requests for TCL3 (SR = 150 kBit/s)

The following parameters are used to set up the resource reservations for this test.

SR	150 kBit/s
BSS	125 Bytes

Table 9-8. TCL3 parameter for resource requests

The resource requests are shown in the figure below.

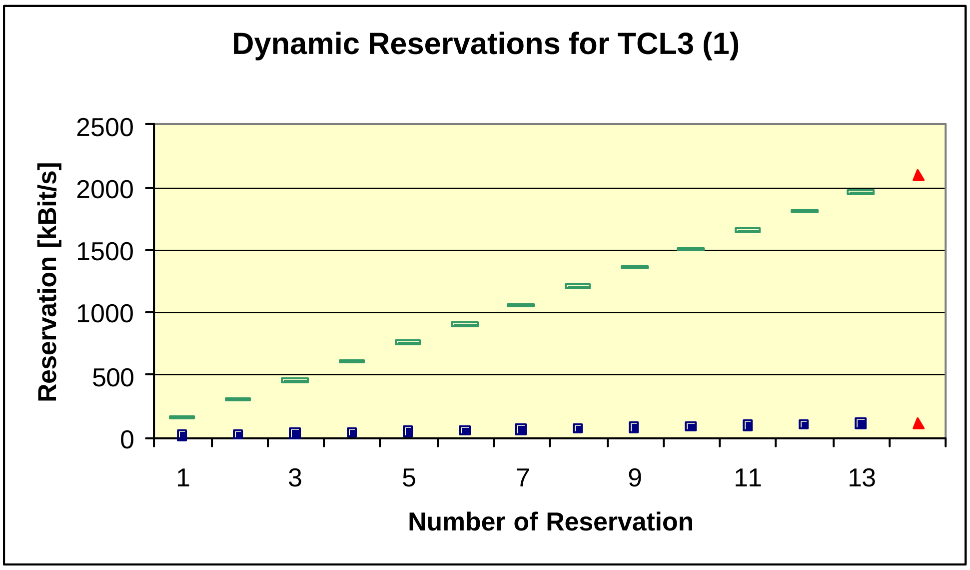


Figure 9-6. TCL3 requests (SR = 150 kBit/s)

Result:

The x-axis shows the number of reservation whereas the y-axis shows the amount of requested resources. The bars indicate the requested resources of 150 kBit/s each whereas the squares show the amount of reservations (8kBit/s each) in the ingress router. The triangles indicate an unsuccessful request due to the failed policy check.

In the following table, the output of the aca-log-file of the 13th reservation and the 14th request are shown. The 13th request represents the last successful reservation. During the execution of the function checkPolicy() of the 14th request the following output was shown in the aca-log-file: “Policy constraint check failed; Equation P2: 1.025E7 <= 10000000”.

Nr. of request	New calculated AC values	checkQoS():	checkPolicy():	CheckPolicy():
13th	RI: 104000 BI: 2785714 TI: 104000	q1: 0.0 <= linkC: 10000000; q2: 8357142.0 <= linkC: 10000000; q3: 0.0 <= linkC: 10000000;	p1: 1325000.0 <= linkC: 10000000; p2: 9607142.0 <= linkC: 10000000; p3: 2000000.0 <= linkC: 10000000;	t1: 0 <= gMax1: 500000; t2: 0 <= gMax2: 750000; t3: 104000 <= gMax3: 1000000; t4: 0 <= gMax4: 250000;
14th	RI: 112000 BI: 3000000 TI: 112000	q1: 0.0 <= linkC: 10000000; q2: 9000000.0 <= linkC: 10000000; q3: 0.0 <= linkC: 10000000;	Policy constraint check failed; Equation P2: 1.025E7 <= 10000000	

Table 9-9. Policy constraint check failed in reservation 14th

The output of this test indicates a bug in the implementation or in the specification for TCL3, which was not solved until the end of the trial phase.

9.4.1.3.2 Scenario for resource requests for TCL3 (SR = 250 kBit/s)

The following parameters are used to set up the resource reservations for this test.

SR	250 kBit/s
BSS	125 Bytes

Table 9-10. TCL3 parameter for resource requests

The resource requests are shown in Figure 9-7.

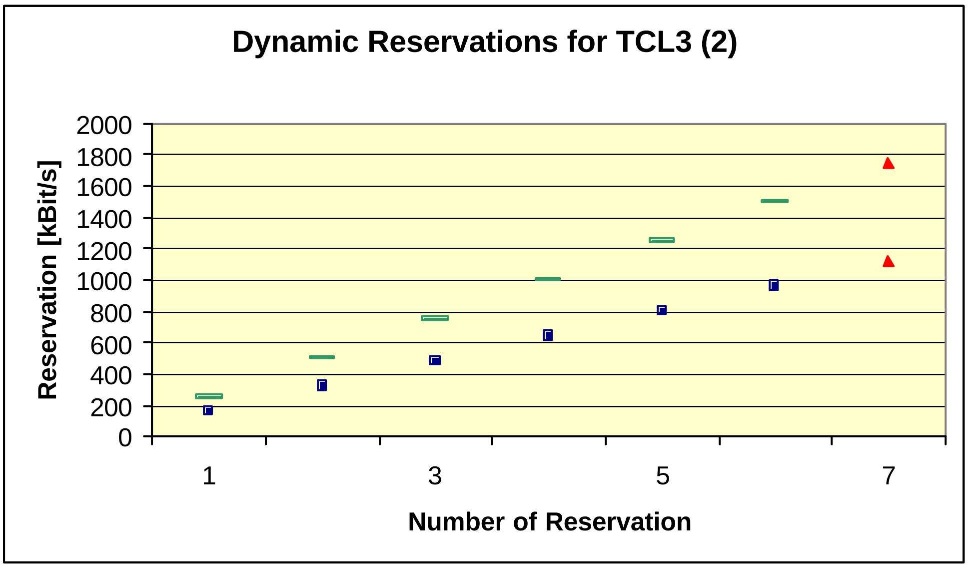


Figure 9-7. TCL3 requests (SR = 250kBit/s)

Result:

The x-axis shows the number of reservation whereas the y-axis shows the amount of requested resources. The bars indicate the requested resources of 250 kBit/s each whereas the squares show the amount of reservations (160,094 kBit/s each) in the ingress router. The triangles indicate an unsuccessful request due to the failed policy check because of the AC-Limit of 1000 kBit/s for TCL3.

Again, the output of this test indicates a bug in the implementation or in the specification for TCL3, which was not solved until the end of the trial phase.

9.4.1.4 Resource requests for TCL4

The following parameters are used to set up the resource reservations for this test.

PR	8 kBit/s
BSP	125 Bytes

Table 9-11. TCL4 parameter for resource requests

9.4.1.4.1 Scenario for resource requests for TCL4

The resource requests are shown in the following figure.

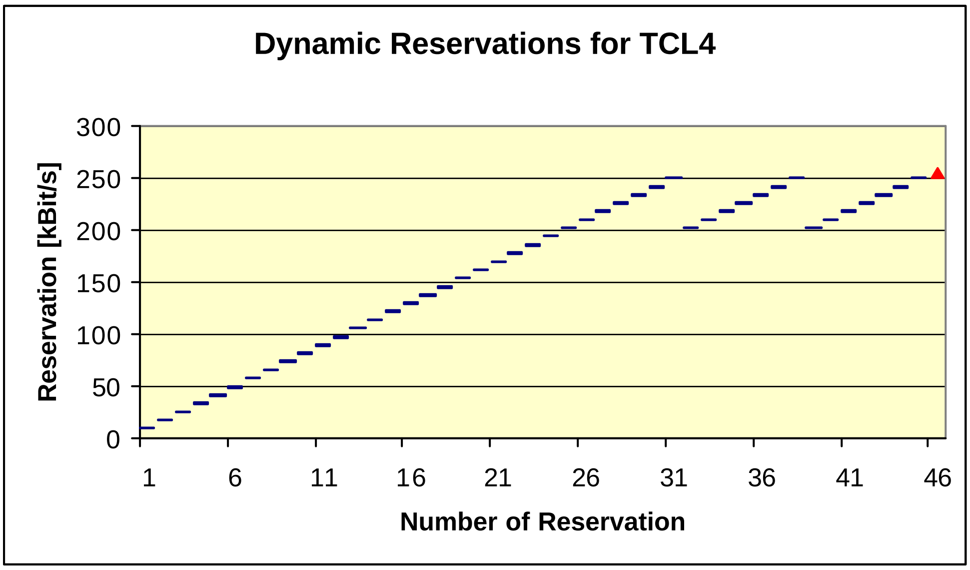


Figure 9-8. TCL4 requests

Result:

The x-axis shows the number of reservation whereas the y-axis shows the amount of requested resources. Each request was correctly set up in the router. After 31 requests the maximum amount of TCL4 reservations (248 kBit/s) was reached – no more reservations could be executed. The triangle indicates a test for a further resource request, which was rejected correctly, because of the AC-Limit of 250 kBit/s for TCL4.

9.4.2 Resource requests by different hosts

In this test reservations are created from host CM1 (10.0.5.1) to CMS (10.0.1.1) and from host BAG (10.0.9.1) to CMS.

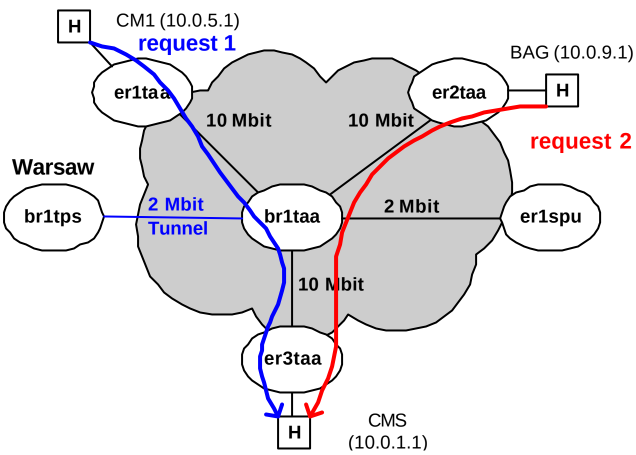


Figure 9-9. Resource requests by different hosts

The objective of these tests are to verify the RP algorithm and there to check the AC limits. As a representative scenario could be, to start from 2 different hosts (CM1 and BAG) a file download from one file-server (CMS). Therefore TCL3 resource requests were initiated in 2 different ways.

9.4.2.1 Resource Requests for TCL3

9.4.2.1.1 Scenario 1

The resource requests are shown in Figure 9-10.

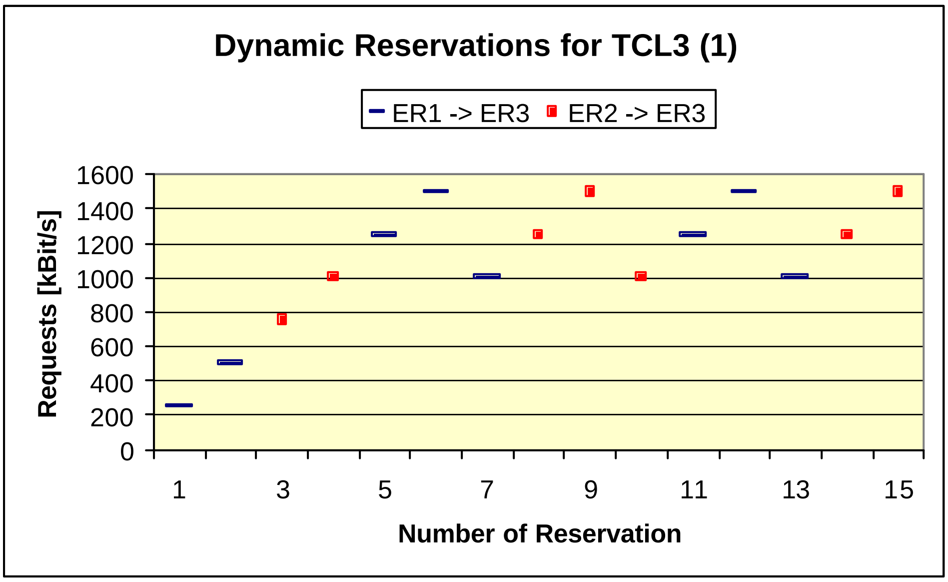


Figure 9-10. TCL3 requests by different hosts (1)

<u>Result:</u>

The x-axis shows the number of reservation whereas the y-axis shows the amount of requested resources. Each request was correctly set up in the router.

The first 2 reservations of 250 kBit/s were requested from CM1 to CMS. The next 2 reservations of 250kBit/s were requested from BAG to CMS. Furthermore the next 2 reservations were again requested from CM1 to CMS and it was recognized that no more requests could be handled successfully.

Then 2 reservations from CM1 to CMS were released and these released resources were given back to the root pool. Furthermore 2 new reservations could be established from BAG to CMS. This procedure was repeated for 4 times and there were no errors in the log-files.

As the resource limit for TCL3 was set to 1 Mbit/s – again the output of this test indicates a bug in the implementation or in the specification for TCL3, which was not solved until the end of the trial phase.

9.4.2.1.2 Scenario 2

The resource requests are shown in Figure 9-11.

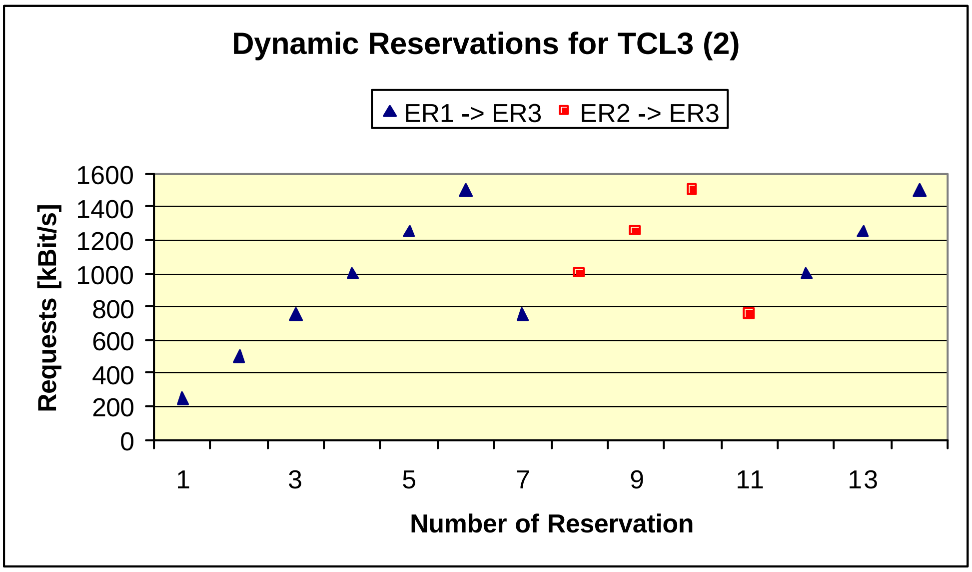


Figure 9-11. TCL3 requests by different hosts (2)

<u>Result:</u>

The x-axis shows the number of reservation whereas the y-axis shows the amount of requested resources. Each request was correctly set up in the router.

The first 6 reservations of 250 kBit/s were requested from CM1 to CMS and it was recognized that no more requests could be handled successfully. Then 3 reservations were released and again the resources were given back to the root pool. The next 3 reservations of 250kBit/s were requested from BAG to CMS and again no more requests were possible from both sides (CM1 to CMS and BAG to CMS). Furthermore after releasing the 3 reservations from BAG to CMS it was possible to request for 3 reservations successfully.

As the resource limit for TCL3 was set to 1 Mbit/s – again the output of this test indicates a bug in the implementation or in the specification for TCL3, which was not solved until the end of the trial phase.

9.4.3 Resource requests by different hosts and different TCLs

In this test reservations are created from host MM1 (10.0.6.1) to MM2 (10.0.4.1) and from host CM1 (10.0.5.1) to CMS (10.0.1.1).

The objective of these tests are to verify the RP algorithm and there to check the AC limits. Furthermore resource for 2 different TCLs are requested in order to test the independency of the TCLs. In the following, two scenarios are defined which represents file downloads (TCL3) and transactions (TCL4) sessions. In this scenarios, all requests were performed via the same edge router (er1taa).

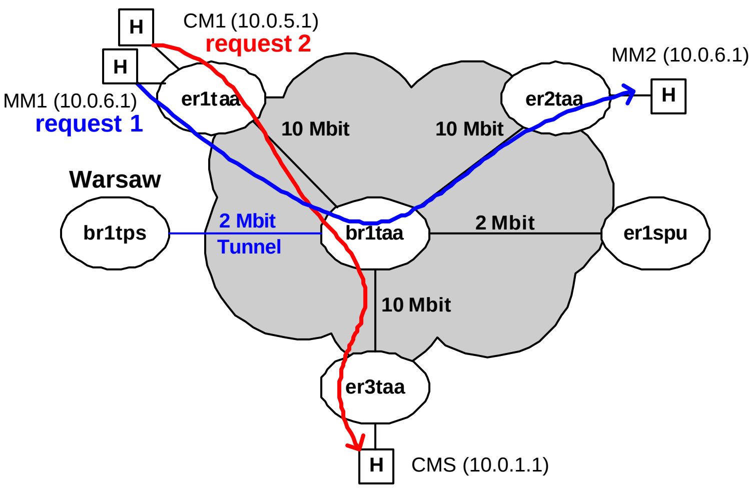


Figure 9-12. Resource requests by different hosts and different TCLs

9.4.3.1 Resource requests for TCL 3 and TCL 4

9.4.3.1.1 Scenario 1

The resource requests are shown in figure below.

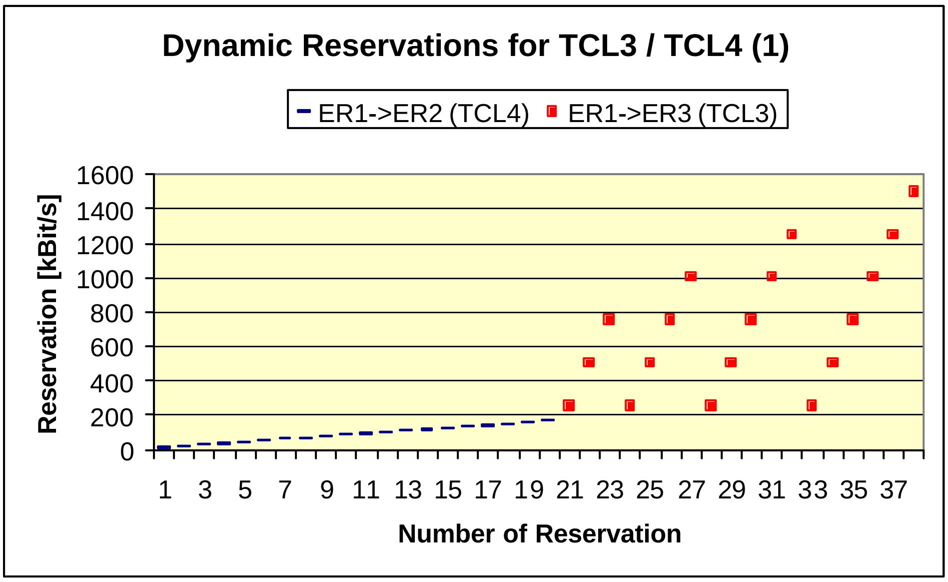


Figure 9-13. TCL3 / TCL4 requests by different hosts (1)

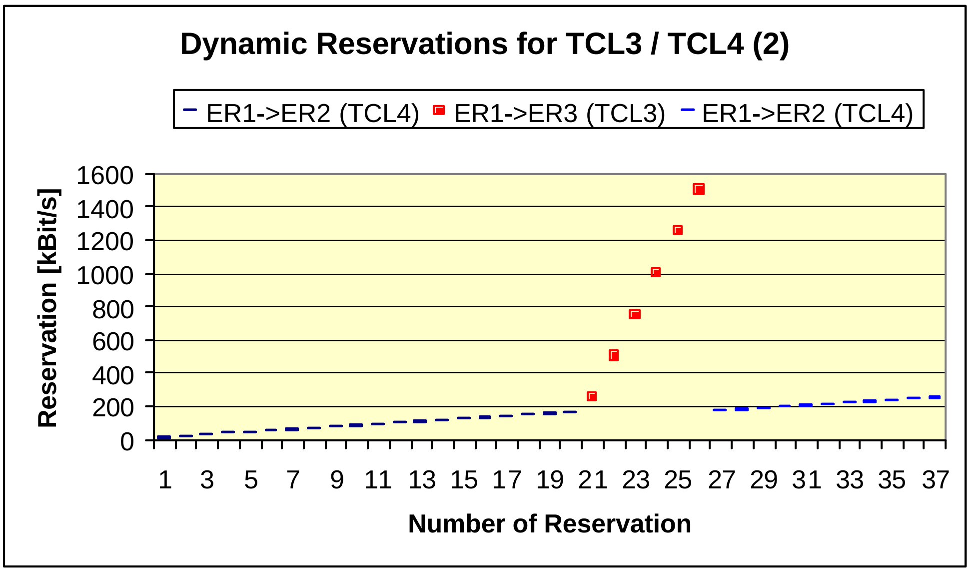
Result:

The x-axis shows the number of reservation whereas the y-axis shows the amount of requested resources. Each request was correctly set up in the router.

The first 20 reservations of 8 kBit/s were requested for TCL4 from MM1 to MM2. The next 3 reservations of 250kBit/s (TCL3) were requested from CM1 to CMS. Furthermore the TCL3 requests were released and further 4 TCL3 reservations were requested. This procedure was repeated until no more resources in TCL3 were available.

No influence of the TCLs could be verified. All reservations could be performed until the appropriate limit was reached. As the resource limit for TCL3 was set to 1 Mbit/s – again the output of this test indicates a bug in the implementation or in the specification for TCL3, which was not solved until the end of the trial phase.

9.4.3.1.2 Scenario 2



The resource requests are shown in figure below.

Figure 9-14. TCL3 / TCL4 requests by different hosts (2)

The x-axis shows the number of reservation whereas the y-axis shows the amount of requested resources. Each request was correctly set up in the router.

The first 20 reservations of 8 kBit/s were requested in TCL4 from MM1 to MM2. The next 6 reservations of 250kBit/s were requested for TCL3 from CM1 to CMS. At this point the limit of TCL3 was reached. In order to check the independency of TCL3 and TCL4 no TCL3 re-quests were released but further 11 TCL4 reservations were established. As a result of this, no more reservations could be handled, neither in TCL3 nor in TCL4, because both limits were reached.

No influence of the TCLs could be verified. All reservations could be performed until the appropriate limit was reached. As the resource limit for TCL3 was set to 1 Mbit/s – again the output of this test indicates a bug in the implementation or in the specification for TCL3, which was not solved until the end of the trial phase.

10 Annex E – testbeds description and GEANT connection

10.1 Warsaw testbed

10.1.1 Equipment available in the Warsaw trial site

The following routers will be used in the trial network:

- CISCO 7507 (3 routers).

IOS software release	IOS (tm) RSP Software (RSP-ISV-M), Version 12.1(4)E, EARLY DEPLOYMENT RELEASE SOFTWARE (fc1) rsp-isv-mz.121-4.e.bin
Router central processor	Cisco RSP4+ (R5000) processor with 131072K/2072K bytes of memory. R5000 CPU at 200Mhz, Implementation 35, Rev 2.1, 512KB L2 Cache
Interface processors	4 VIP4-50 RM5271 controllers

- CISCO 3640 (3 routers).

IOS software release	IOS (tm) 3600 Software (C3640-IS-M), Version 12.1(2), RE-LEASE SOFTWARE (fc1) c3640-is-mz.121-2
Router processor	Cisco 3640 (R4700) processor (revision 0x00) with 36864K/12288K bytes of memory. R4700 CPU at 100Mhz, Implementation 33, Rev 1.0

Other available equipment:

SUN workstations
2x Sun Ultra 60 with Solaris 8
PC computers
8 PentiumIII 700MHz computers • 2 with Windows 2000/Linux SuSe 7.3 operating systems • 5 with Windows NT4.0/Linux SuSe 7.3operating systems • 1 with Linux only (Measurement Station) 1 PentiumII 450MHz • Linux SuSe 7.3 operating system
Cameras
2 USB Creative WebCam cameras
GPS equipment
1 antenna with distributor
4 GPS cards
Commercial measurement equipment
Agilent BSTS
Agilent Router Tester
InterWatch 95000

10.1.2 Testbed topology and addressing

10.1.2.1 Topology with 1 domain in the Warsaw Testbed

This topology will be used for Network Services and Real Users trials.

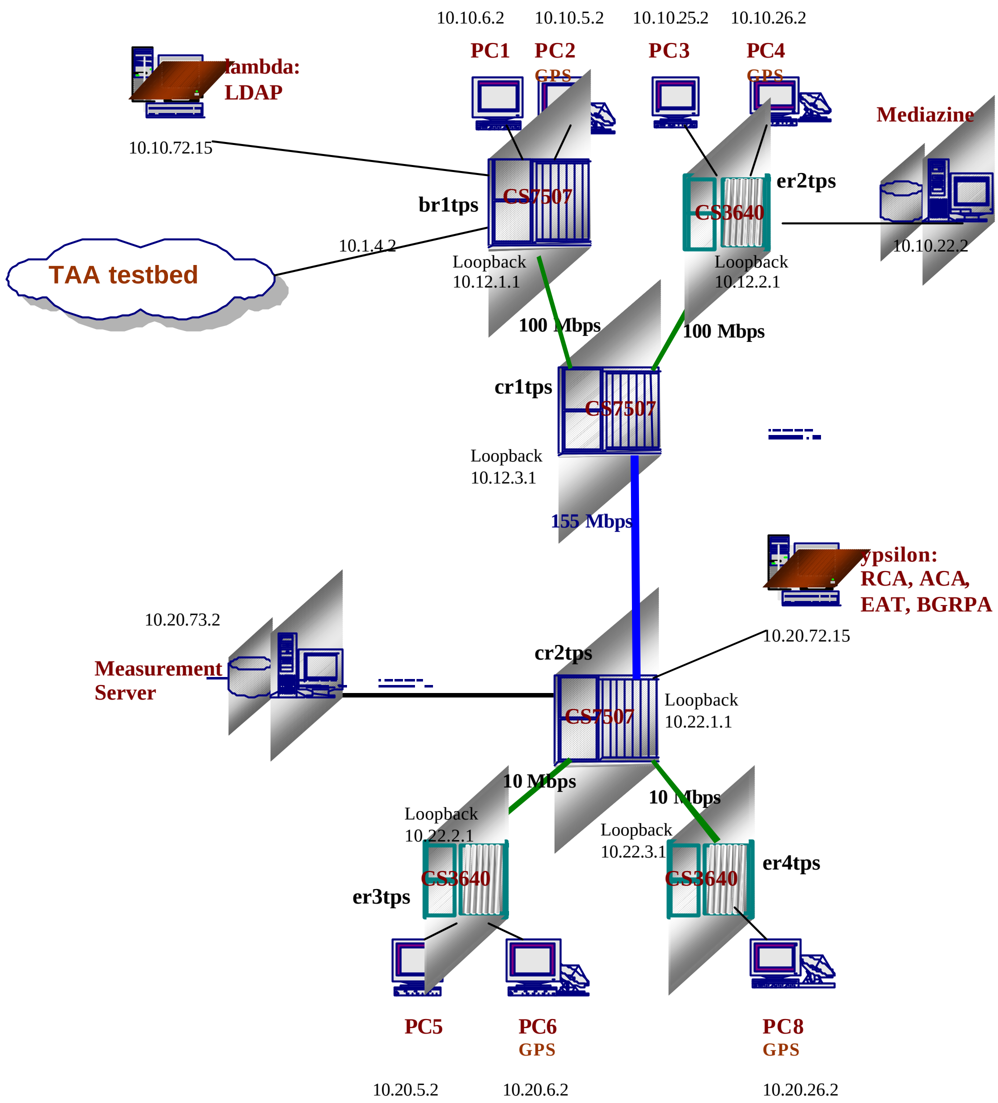


Figure 10-1. Warsaw network topology for one domain.

The addressing scheme is the following:

	Domain TPS	
	IP / Subnet	IP / Subnet
Autonomous System (AS)	65010	
LAN Segments	10.10.x.1 /24	10.20.x.1 /24
Loopback address	10.12.x.1 /30	10.22.x.1 /30

10.1.2.2 Topology with 2 domains in the Warsaw Testbed

This topology will be used for Inter-Domain Network Services trial

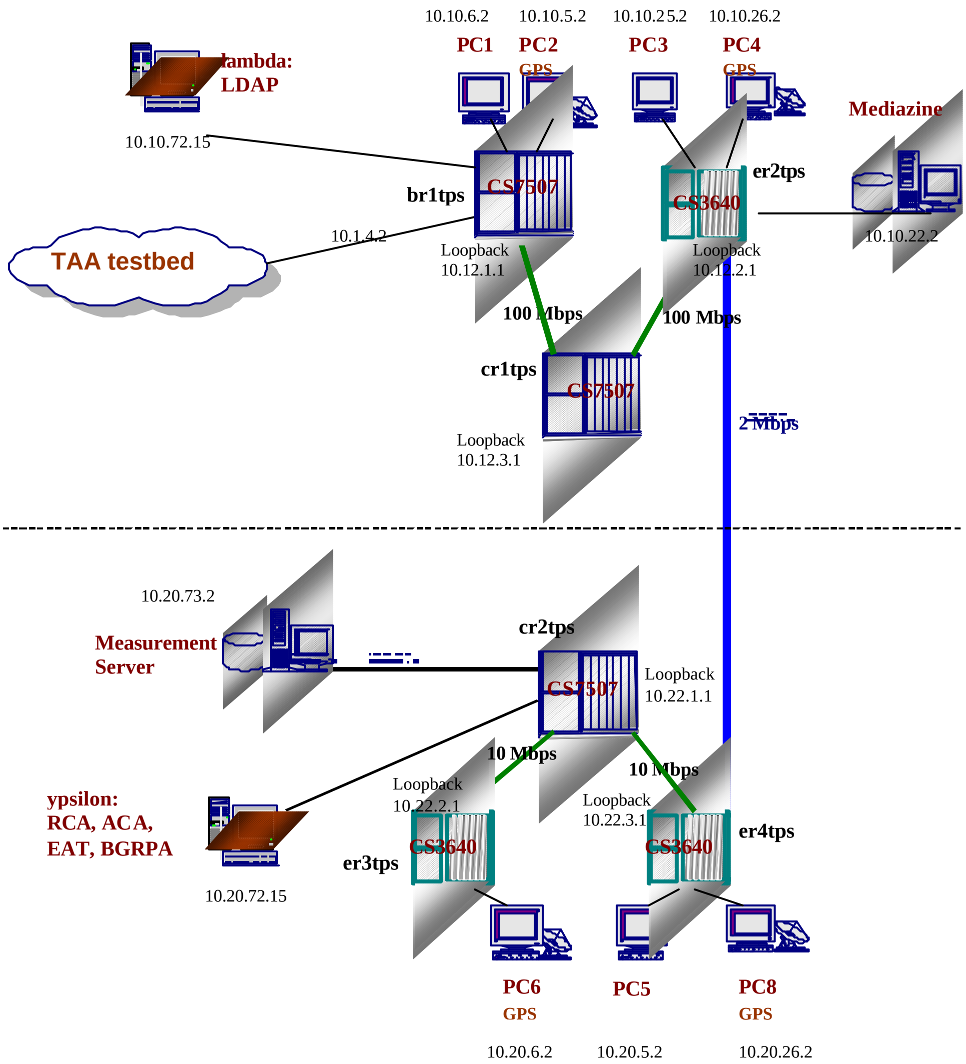


Figure 10-2. Warsaw network topology for two domain.

The addressing scheme is the following:

	Domain TPS 1	Domain TPS 2
	IP / Subnet	IP / Subnet
Autonomous System (AS)	65010	65020
LAN Segments	10.10.x.1 /24	10.20.x.1 /24

Loopback address	10.12.x.1 /30	10.22.x.1 /30

10.2 Vienna testbed

The equipment described below is dedicated to the AQUILA project for the whole period of its duration. Cisco routers were used exclusively.

10.2.1 List of routers

4 CISCO routers were available in the TAA network laboratory. 1 additional router situated in Salzburg and connected via a 2Mbit/s ATM link was also available in the TAA testbed.

Router Cisco 7500 - (1 router)	
Description	**Number of modules**
CISCO 7500	1
IOS: 12.1(4)E, Feature Set: IP	
4 Ethernet 10BaseT Ports	1
2 Fast-Ethernet Ports	1
1 ATM module	1

Router Cisco 3640 (3 routers)	
Description	**Number of modules**
CISCO 3600 4-slot Modular Router	1
IOS: 12.2(7)T, Feature Set: IP PLUS	
4-Port Ethernet Network Module	1
1-Port Fast Ethernet Network Module	1

10.2.2 Terminals – hardware

In the testbed the following terminals were used:

- 4 (relatively) Hi-Performance Client-PCs

CASE	NN Case MIDI-Tower ATX
MAINBOARD	MSI K7T-PRO DURON Socket A Audio
CPU	AMD T800 Socket A (800 MHz)
RAM	128M-168P SDRAM 100MHz
HD	Seagate ST320423 20,4GB; U10, U/66, 8,9ms, 5400RPMs
CD	Creative 52x DIE
NIC	3Com PCI10/100 TP/BNC/AUI
AUDIO	Soundblaster Live 1024 (for 2 PCs)
VIDEO	3D Prophet II Gforce2 MX

Table 10-1. Client PC hardware description

- 2 (relatively) Hi-Performance Server-PCs

CASE	NN Case MIDI-Tower ATX
MAINBOARD	MSI K7T-PRO DURON Socket A Audio
CPU	AMD T800 Socket A
RAM	256M-168P SDRAM 100MHz
HD	Seagate ST320423 20,4GB; U10, U/66, 8,9ms, 5400RPMs
CD	Creative 52x DIE
NIC	3Com PCI10/100 TP/BNC/AUI
VIDEO	ATI XPERT2000 AGP 16MB

Table 10-2. Server PC Hardware description

- 2 Hi-Performance Client-PCs

CASE	IBM Desktop (NetVista)
MAINBOARD	?
CPU	Intel® Pentium III, 1GHz
RAM	256MB
HD	20,4GB
CD	Samsung CD-ROM SC-148C
NIC	Intel® PRO/100 VE Desktop Connection
AUDIO	Creative Soundblaster AudioPCI
VIDEO	Intel® 82815 Graphics Controller

Table 10-3. IBM-Client PC description

- Sun Solaris

Type	SUN Ultra 30
MAINBOARD	PCI Bus mit 66 MHz
CPU	300 MHz Ultra Sparc II Prozessor
RAM	256 MB RAM
HD	5 GB Harddisk
NIC	10 Mbit/s

Table 10-4. Server PC Hardware description

10.2.3 Additional equipment

For the user impressions, we propose to use standard PC "WebCams" and headsets as used most commonly.

WebCam	Creative WebCam3 USB, (Colour video writes at 30 fps at 320x240 in 16 million colours, at 640X480 v up to 15 fps)
Headset	Plantronics headset

Table 10-5. Additional equipment

10.2.4 Operating Systems

The following table summarises the available operating systems and their usage.

OS	Usage
Windows 98 SE	NetMeeting
Windows 2000	NetMeeting, SIP-User Agent, Mediazine
Linux 7.3	Measurement (Server and Client)
Sun Solaris 5.6	RCL (RCA, ACA, EAT)

Table 10-6. Operating system and usage

10.2.5 TAA testbed for the 2nd trial

In the topology for the 1st trial each Edge Router was connected via a 10 Mbit/s ethernet interfaces to the Core Router. Worth mentioning here is that the 10 Mbit/s ethernet interfaces of the Core Router are not capable of operating in full duplex. Consequently a workaround had had to be found: The idea was to connect each edge router with two cables to the border router and to use each link for only one direction of the traffic (quasi full duplex). Therefore new networks (10.1.5.0/10.1.6.0/10.1.7.0) and the ospf routing configuration had to be adapted. Furthermore the routing metric had to be changed to direct the traffic to the desired interfaces. On the outgoing interface a value of one was applied with the command “ip ospf cost 1”. On the incoming interface a metric of 65535 was used.

Due to the fact, that it was not possible to decrease the speed of the fastethernet interface to 10Mbit/s a 10/100Mbit/s switch was used to connect these interfaces.

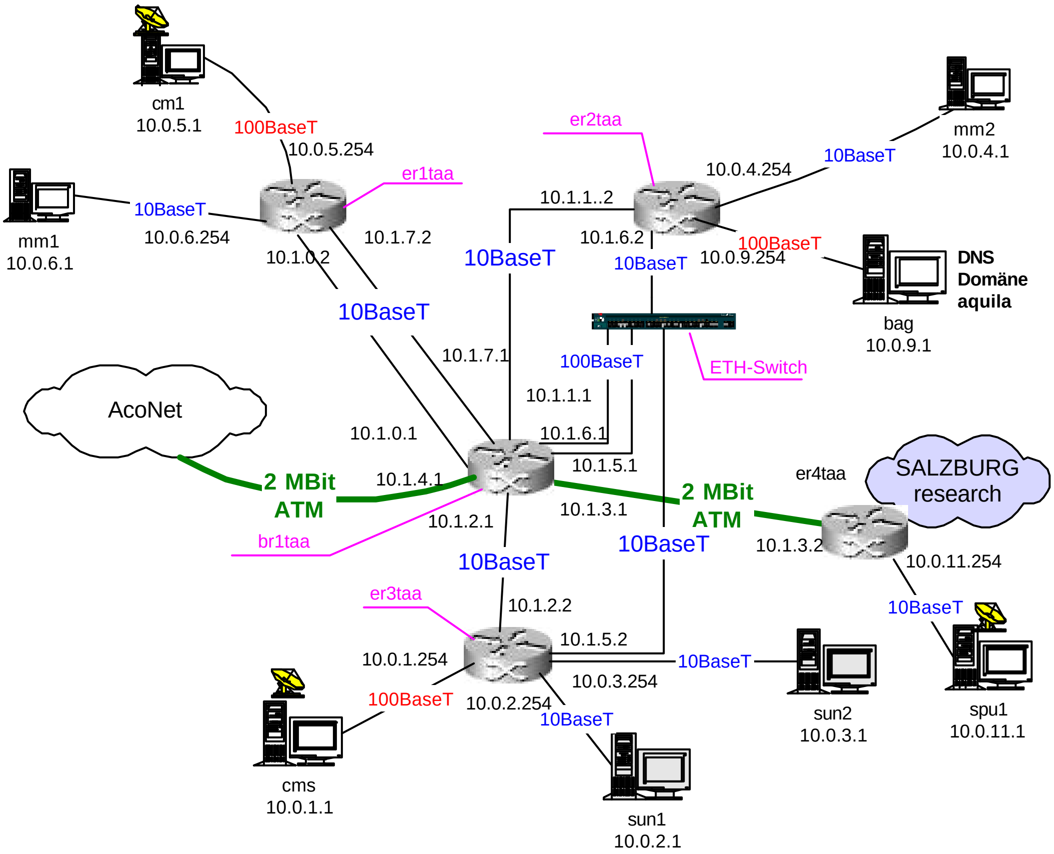


Figure 10-3. TAA testbed for the 2nd trial

10.2.6 Network addressing scheme

In order to guarantee reachability in networks for each router a loopback interface (address) is configured.

	CORE1TAA	ED1TAA	ED2TAA	ED3TAA	ED1SPU
Loopback IP	10.2.0.1 /30	10.2.1.1 /30	10.2.2.1 /30	10.2.3.1 /30	10.2.4.1 /30

Table 10-7. Loopback addresses

Please note that the router interface address of the connected hosts is 10.0.x.254, which represents the default gateway for the hosts.

The addressing scheme is summarised in the following table:

	IP-address	Subnet mask
LAN Segments	10.0.x.1	255.255.255.0
Router addresses	10.1.x.1 – 10.1.x.2	255.255.255.252
Default Gateway	10.x.x.254	255.255.255.0
Loopback address	10.2.x.1	255.255.255.252

Table 10-8. TAA addressing scheme

The following table indicates the hosts and their designated usage.

Host	Usage	GPS	OS	Software
CMS	Measurement Server	✓	Linux7.3	
CM1	Measurement Client	✓	Linux7.3	
CM2	Measurement Client	✓	Linux7.3	
BAG	Server		Linux7.3	DNS
MM1	Client		Linux7.3 / W98	NetMeeting
MM2	Client		Linux7.3 / W98	NetMeeting
IBM1	Client		Linux7.3 / W2k	NetMeeting, SIP-User Agent
IBM2	Client		Linux7.3 / W2k	NetMeeting, SIP-User Agent
SUN1	RCA, ACA, EAT		Solaris 5.6	
SUN2	RCA, ACA, EAT		Solaris 5.6	

Table 10-9. Designated usage of the hosts

10.2.7 Interconnection addressing scheme

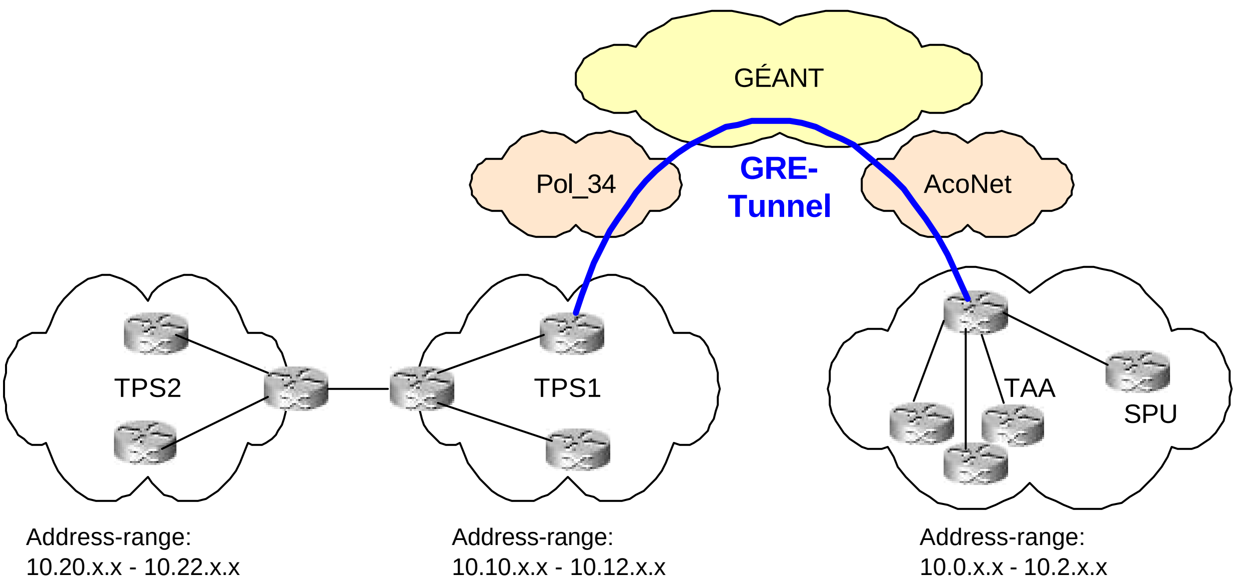


Figure 10-4. Interconnection addressing scheme

The addressing scheme is summarised in the following table:

	TPS 2	TPS 1	TAA
	IP / Subnet	IP / Subnet	IP / Subnet
Autonomous System (AS)	65020	65010	65000
LAN Segments	10.20.x.1 /24	10.10.x.1 /24	10.00.x.1 /24
Router addresses	10.21.x.x /30	10.11.x.x /30	10.01.x.x /30
Default Gateway	10.2x.x.254 /24	10.1x.x.254	10.0x.x.254 /24
Loopback address	10.22.x.1 /30	10.12.x.1 /30	10.02.x.1 /30

Table 10-10. Interdomain addressing scheme

The various x represents the different network addresses, which have to configured. Please have a look to the detailed configuration example in Figure 10-3.

The addressing scheme could also be extended by the Helsinki testbed (10.30.x.x – 10.32.x.x).

10.3 Helsinki testbed

10.3.1 Intra-domain Testbed for signalling

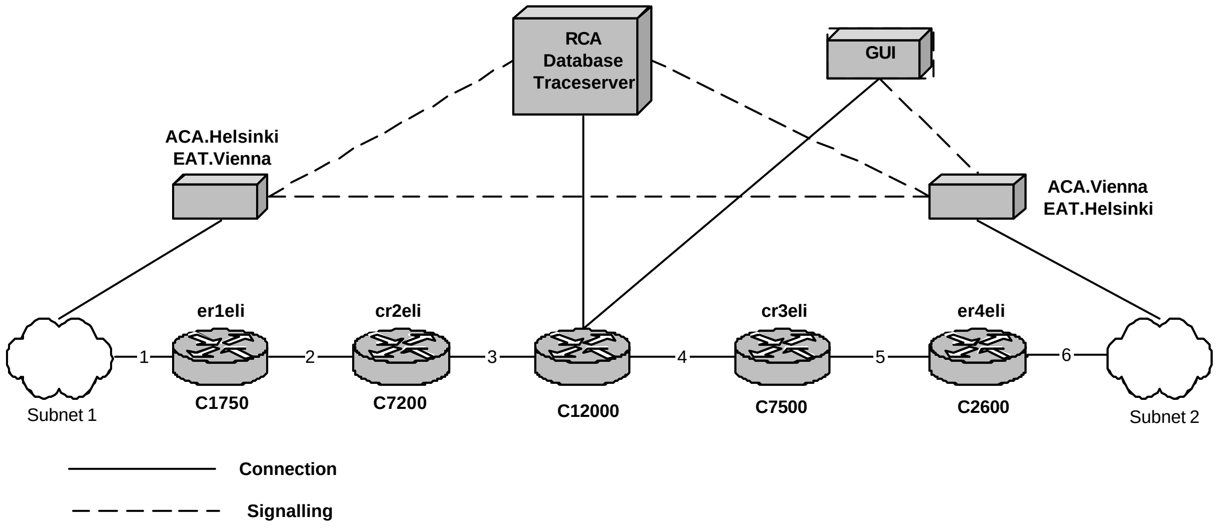


Figure 10-5. Intra-domain testbed for signalling

Router	Host-Name	Link / Interface	IP Address
Subnet 1		1	192.168.0.0/24
C1750	er1eli	1 / FastEthernet 0	192.168.0.1
C1750	er1eli	2 / Serial 0	192.168.1.102
C7200	cr2eli	2 / Serial 4/0	192.168.1.101
C7200	cr2eli	3 / POS 3/0	192.168.1.78
C12000	cr5eli	3 / POS 0/1	192.168.1.77
C12000	cr5eli	4 / ATM 3/0.40	192.168.1.29
C7500	cr3eli	4 / ATM 1/0.10	192.168.1.30
C7500	cr3eli	5 / Serial 0/1/0	192.168.1.113
C2600	er4eli	5 / Serial 0/0	192.168.1.114
C2600	er4eli	6 / FastEthernet 0/0	192.168.2.0/24
Subnet 2		6	192.168.2.1
RCA/DB/Traceserver	rca1eli		Pulivari
ACA.Helsinki	aca_er1eli		Paarma
ACA.Vienna	aca_er4eli		MSM

Table 10-11. IP addresses and names of the testbed devices

10.3.2 Inter-domain Testbed for signalling

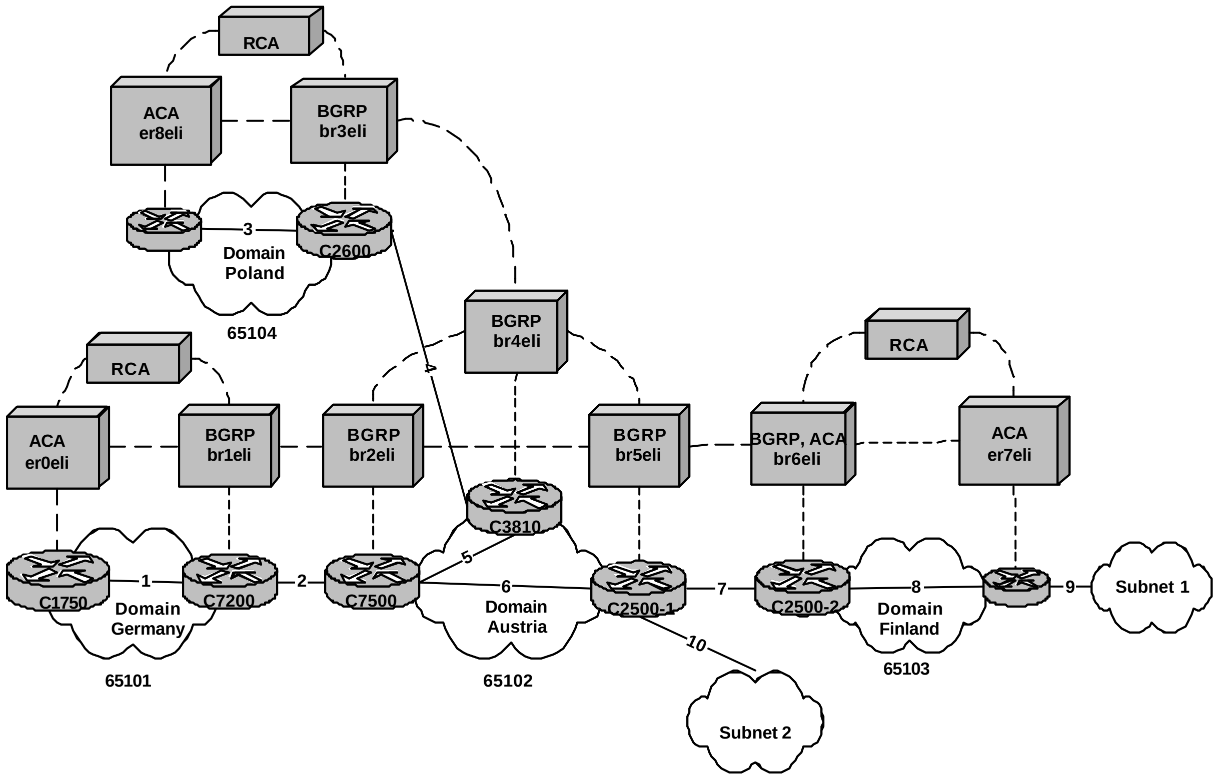


Figure 10-6. Inter-domain testbed for signalling

Router	Name	Link / Interface	IP Address	Loopback
Domain Germany			192.168.2.0/24	
C1750	er0eli	0 / Serial 0	192.168.2.2/24	192.168.12.7
C1750	er0eli	1 / FastEthernet 0	192.168.14.1/24	
C7200	br1eli	1 / FastEthernet 2/0	192.168.2.1/24	192.168.12.1
C7200	br1eli	2 / ATM 1/0.40	192.168.3.1/24	
C7500	br2eli	2 / ATM 1/0/0.30	192.168.3.2/24	192.168.12.2
Domain Poland			192.168.4.0/24	
C2600	br3eli	3 / FastEthernet 0/0	192.168.4.1/24	192.168.12.3
C2600	br3eli	4 / Serial 0/1	192.168.5.1/24	
C3810	br4eli	4 / Serial 0	192.168.5.2/24	192.168.12.4
C7500	br2eli	5 / Serial 0/1/1	192.168.6.1/24	
C3810	br4eli	5 / Serial 1	192.168.6.2/24	

C7500	br2eli	6 / Serial 0/1/2	192.168.7.1/24	
C2500-1	br5eli	6 / Serial 0	192.168.7.2/24	192.168.12.5
C2500-1	br5eli	7 / Serial 1	192.168.8.1/24	
C2500-2	br6eli	7 / Serial 0	192.168.8.2/24	192.168.12.6
C2500-2	br6eli	8 / Serial 1	192.168.9.1/24	
Subnet 1		9	192.168.10.0/24	
C2500-1	br5eli	10 / Ethernet 0	192.168.11.1/24	
Subnet 2		10	192.168.11.0/24	
RCA for all domains / DB			Pulivari	192.168.13.1
ACA br1eli, br2eli, br3eli, br4eli, br5eli, br6eli, br7eli			Pulivari	
BGRPA br1eli, br3eli, br5eli		br1eli / port 2001, br3eli / port 2003, br5eli / port 2005	Paarma	192.168.13.2
BGRPA br2eli, br6eli		br2eli / port 2002, br6eli / port 2006	MSM	192.168.13.3
BGRPA br4eli		br4eli / port 2004	Verkkolab 3	192.168.13.4
EAT br1eli, br3eli, er7eli			Pulivari	

Table 10-12. IP addresses and names of the testbed devices

10.3.3 Secondary Access Link Testbed

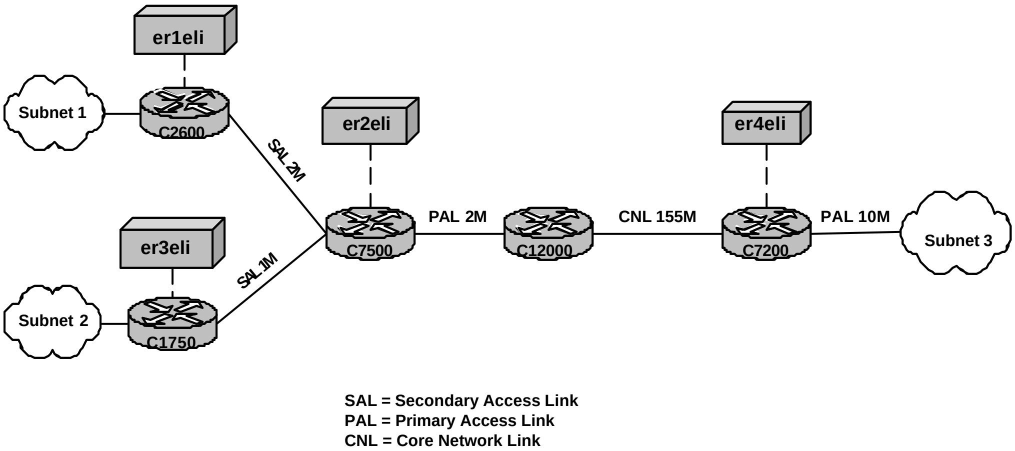


Figure 10-7. Secondary access link testbed

Router	Host-Name	Link / Interface	IP Address / Name
Subnet 1			192.168.2.0/24
C2600	er1eli	FastEthernet 0/0	192.168.2.1/24
C2600	er1eli	SAL 2M / Serial 0/0	192.168.3.1/24
C7500	er2eli	SAL 2M / Serial 0/1/0	192.168.3.2/24
Subnet 2			192.168.4.0/24
C1750	er3eli	FastEthernet 0	192.168.4.1/24
C1750	er3eli	SAL 1M / Serial 0	192.168.5.1/24
C7500	er2eli	SAL 1M / Serial 0/1/0	192.168.5.2/24
C7500	er2eli	PAL 2M / ATM 1/0/0.30	192.168.6.1/24
C12000	cr5eli	PAL 2M / ATM 3/0.40	192.168.6.2/24
C12000	cr5eli	CNL 155M / POS 0/1	192.168.7.1/24
C7200	er4eli	CNL 155M / POS 3/0	192.168.7.2/24
C7200	er4eli	PAL 10M / FastEthernet 2/0	192.168.8.1/24
Subnet 3		PAL 10 M	192.168.8.0/24
RCA / Database / Trace-			Pulivari
ACA.Rhodes, ACA.Naxos, EATAthens			Paarma
ACA.Athens, ACA.Capri			MSM

Table 10-13. IP addresses of the testbed devices

10.4 Connection via GEANT between TPS and TAA

For the second trial the interconnection between Warsaw and Vienna testbeds was organised. The only one possibility of setting up the connection with guaranteed QoS parameters was via GEANT network. For this purpose, the co-operation between AQUILA and SEQUIN project was established. In the figure below the configuration of the interconnection is shown.

In AcoNet and Pol-34 ATM connections were created and in GEANT network the IP tunnel with the highest priority for the IP traffic (Premium IP service) was configured. Then, end-to-end tunnel from Warsaw to Vienna was established. The bandwidth of the connection was equal to 2 Mbps. GEANT Premium IP service give possibility, that interconnection link is transparent from the point of view of achieved QoS.

Such interconnection allows for performing the inter-domain trials in AQUILA project. So, three domains as a minimal target scenario for AQUILA architecture was possible to create (in separated sites only two domains were possible to configure). For inter-domain trials (with usage of GEANT connection) the evaluation of network services performance was performed.

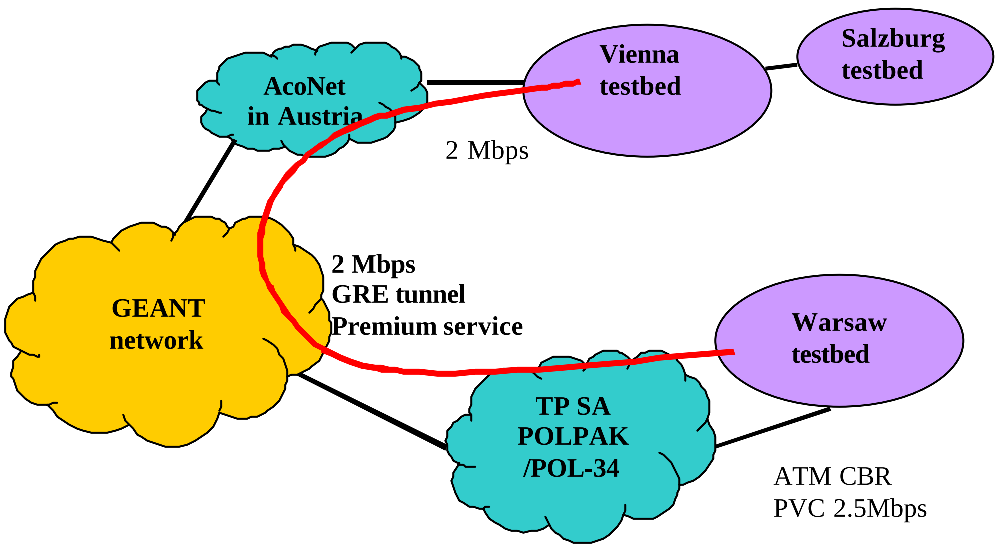


Figure 10-8. Connection between TPS and TAA.

Connection will be available until end of 2nd trial (31.01.2003).

11 Annex F – Final Status of AQUILA Measurement Tools

For the 2nd trial the tools, which implement the distributed measurement architecture (AQUILA-DMA) have been enhanced and finalised. The AQUILA-DMA supports the following functions:

- **Application-like measurement flows** for end-to-end QoS measurement,
- **Active network probes** for path performance measurements,
- **Router monitoring** for bottleneck detection.

The AQUILA-DMA has been used in the trials to

- **Evaluate and validate** the AQUILA QoS architecture,
- **Support network and resource control.**

Details about the architectural approach and the implementation can be found in [D2301] and [D2303]. All components can be controlled via a web-based user interface. The DMA is depicted in figure 11-1 consists of 5 main parts described in this section.

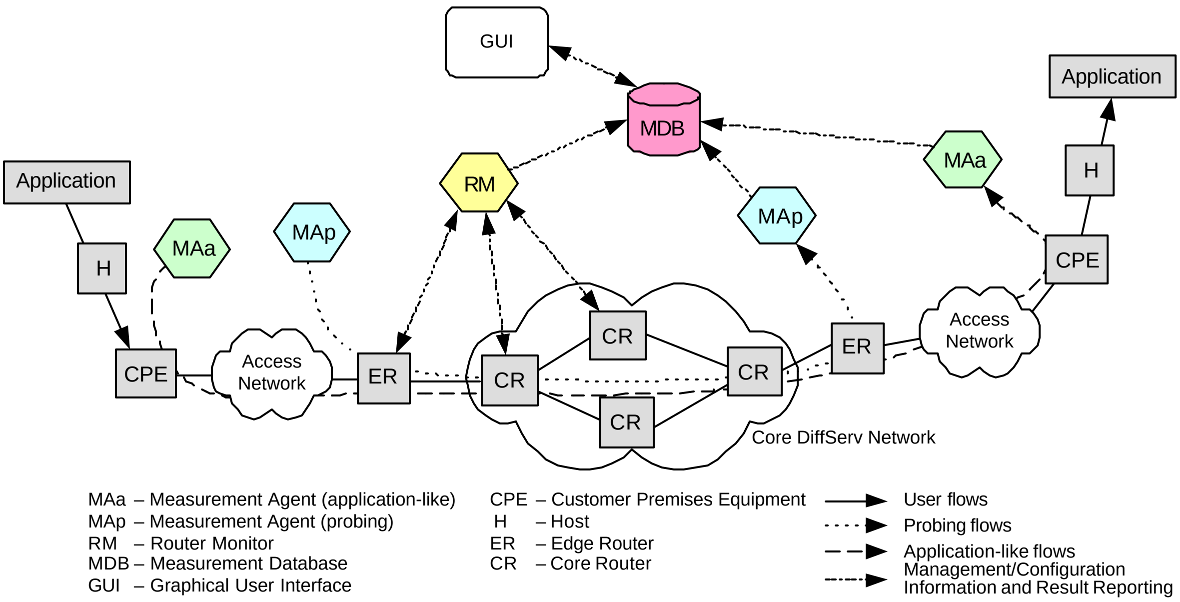


Figure 11-1. Distributed Measurement Architecture

11.1 Measurement Database

The final version of the measurement database supports all necessary data fields to store measurement results like one-way-delay, packet loss, etc., topology information and network status together with the configuration information of the measurement scenario. The database model integrates functionality for the prototypes of three different tools. For further developments it is recommended to use a more modular approach for the database design, as this integrated approach is hard to handle.

The support for the following functionality has been added to the database for the second trial.

11.1.1 Traffic Models

For modelling application-like traffic behaviours, some generic traffic generators, which can be configured by several parameters, are provided:

- **Distribution-based Load Generator:** The packet size as well as the packet inter-departure time can be parameterised by constant, exponential and uniform distribution. This is used for generating CBR-Streams or Poissonian distributed VBR-Streams.

- **State-based Load Generator:** The state-based load generator changes between different states. Each state can either be an ON-state or an OFF-state. The state-duration is defined either by a time or by a number of packets. The ON-states can be parameterised like the distribution-based load generator (i.e. packet size distribution, packet inter-departure time distribution).

- **Trace-based Load Generator:** A trace-file can be provided by the user, which contains two rows with packet size and packet inter-departure times. Traces can be taken e.g. by tcpdump or other packet capturing tools.

The behaving of the active network probing part can be configured by several parameters. The packet size as well as the packet inter-departure time can be parameterised by constant, exponential, uniform or pareto distribution (For details see [D2303]).

11.1.2 Resource Reservation

To enable the support for automatic resource reservation for active measurement flows the database has been extended. For performing AQUILA resource reservations, an automatic reservation invocation has been integrated to the measurement agents of the DMA. If a flow is configured with a reservation, the measurement server contacts the configured EAT and requests the resources. After the flow has been finished, the reservation will be automatically released again. Additionally it can be configured, whether the flow starts on a reservation failure or not.

11.2 Application-like Load Generator

The aim of the application-like load generator is to generate measurement flows with typical application behaviours. Measurement flows are specified by a pair of sender & receiver, the traffic model and several result options. The flows are scheduled by specifying the start time and the end time or a number of packets to be sent. Equal flows can start simultaneously by a multiplex option.

Depending on the different trial scenarios, the application-like load generator was either used for the generation of foreground or background traffic. Different performance requirements have to be met, depending on the scenarios. While background traffic usually generates bulks of traffic following different behaviours without measuring the performance parameters, foreground traffic is used to measure the QoS parameters. Therefore foreground traffic generators need high accuracy but less performance and background traffic generators need high performance but less accuracy.

For different performance requirements, the measurement agents can be started in two different modes:

- **usleep:** using this mode, the accuracy of the minimum packet inter-departure time is limited depending on the system environment. In the AQUILA case, where a specific Linux kernel of the SuSE distribution was used, this limit was 10ms (due to the process time-slicing mechanisms). Having e.g. a packet size of 1460 bytes on application level (e.g. above UDP), the sending rate is limited to approx. 1Mbps per measurement flow. Furthermore some traffic models, e.g. Poissonian flows, MPEG traces, etc., can be reproduced only limited.

- **nousleep:** with this mode, the accuracy of the packet inter-departure times can be reduced to microseconds. The drawback in this mode is, that the system is very stressed when sending massive flows (with several Mbps). Therefore it is recommended to use this mode only with a limited number of flows per measurement agent (up to 3).

11.3 Active Network Probing

The active network probing tool measures end-to-end QoS parameters between a pair of sender and receiver. The idea of these active measurements is to inject small independent measurement packets into a network to get “online” results of the achieved performance metrics like end-to-end packet delay, packet delay variation, packet loss rate etc. Therefore the active network probing tool contributes to network performance monitoring during the network operation.

Another usecase for the network probing part of the AQUILA-DMA is the generation of background traffic, for testing the behaviour of the AQUILA architecture under “real” conditions. Therefore it is important to have a background traffic generator that mimics the population of real network users.

11.4 Router QoS Monitoring

Router QoS Monitoring is a function of the Measurement tools, which uses the AQUILA RCL Router component to retrieve performance statistics from network routers. The tool saves these statistics to the Measurement Database. These parameters include the number of bytes/packets transmit / dropped in each traffic class. In addition CPU Utilisation, WRED mean queue length are collected.

The statistics are retrieved in user-specified intervals from the routers to the corresponding Router – software element, and then to the Router QoS Monitoring part of the DMA, which then saves the data to the database.

The results can be viewed using the Measurement GUI, which shows the results as a function of time.

The tool was finished and installed to the testbeds during the second trial.

11.5 GUI

The GUI as the front-end to the user is the most extensible part of the measurement architecture. For the AQUILA trials the GUI was targeted for professional users, i.e. the approach for the design of the GUI was, that the user knows, what he wants to do and is aware of the consequences of configuration errors. For AQUILA purposes it was sufficient to provide a generic prototype of a GUI for the measurement database, including some graphical functions to get a quick view into the measurement results. More complex data evaluation is possible via downloading the measurement data as comma-separated-values and further use it for deeper analyses together with 3rd party tools like Microsoft Excel.

For further developments on the GUI it is recommended to reduce the functions on the specific application area of the measurement tools and to provided several GUIs depending on the application area. E.g. for AQUILA a simple GUI for probing flows has been developed separately (see below).

The following major features have been added to the GUI for the second trial.

11.5.1 Multiflows

To simplify a scenario configuration with several flows, a so-called “multiflow” function was provided from the GUI for the second trial. With this function the inter-arrival time and the holding time of several flows can be specified. However, this function has some performance limitations. If several flows are scheduled at the same time (within the same second) the prototype implementation is not able to handle this. This limitation had some implication on the trial scenarios.

11.5.2 Result Aggregation – Online Monitoring

To provide data for the flow monitor, aggregated results are calculated after configurable constant time intervals. The results can be monitored during the runtime of a flow. The aggregated results include throughput, packet loss, packet loss patterns, mean/max/min delay and mean/max IP delay variation. The online monitoring graphically displays one or two of these results within one chart.

11.5.3 Scenario repetition

To simplify the repetition of measurement scenarios a new feature has been added to the copy function of the test scenario. This new feature allows copying all measurement flow within a test scenario and shifting their start-/endtimes to the desired time into future.

11.5.4 MACON

As an outcome of the first trial a simple to use GUI for the active network probing part of the AQUILA-DMA called MACON (Measurement Agent CONtroller) has been implemented. measurement agents. The controller is a Java2 application, and so executable on any Computer, where the Sun JDK 1.3 is installed.

The MACON can control up to 10 measurement agents and 5 traffic classes. The Controller makes it easy to configure a measurement between the agents. MACON starts automatically a full meshed measure between the listed agents and traffic classes. Therefore no data base or web server is needed (For details see [D2303]).

11.6 Signalling Load Client

Together with the EAT of the AQUILA architecture a sample client is provided, which has been extended to perform exhaustive test scenarios for RCL performance. The extensions allow the user to specify, how many reservations are made, and how much time is spent idle between the reservations. The tool can also be used for testing the Admission Control implementation.

The tool was successfully used by ELI in the RCL performance measurements and Admission Control implementation tests.

11.7 Time Synchronisation

A main drawback in the first trial was that the measurement agents for application-like traffic and active network probing were not able to run on the same host simultaneously, because both of them needed direct access to the GPS hardware. In the second trial the system clock of the host is used to generate the timestamps. For time synchronisation NTP, which uses the GPS hardware as absolute time source is used. With the chosen configuration NTP polls the GPS-clock in intervals of 16 seconds. Long-term measurements have shown that the deviation between the GPS time and the system time is constant below 100µs and approximately equal at all measurement clients.