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Abstract:	This deliverable D3201 contains the first trial results performed in AQUILA testbeds. The experiments are related to network services, Admission Control algorithm, Resource Pool mechanism and RCL performance.
Keyword List:	**AQUILA, IST, trial, measurements, QoS IP**

Executive Summary

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

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

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

  - PMM service is well suited for serving traffic produced by greedy TCP-controlled sources (like FTP) and adaptive streaming video (like Real-Player) while PMC service is better suited for serving traffic produced by non-greedy TCP sources;

- Regarding RCL layer:

  - Resource pool mechanism works correctly for TCL1, TCL3 and TCL 4, but should be re-designed for TCL2, the trial will continue;

  - In the initialisation phase, most of the signalling is produced by the connection between the RCA and database; the second largest part of signalling is produced by ACAs (for configuration of edge devices);

  - During reservation set-up the largest contribution to signalling traffic is produced by ACA logging; the second largest contribution to signalling came from the ACA; the third largest contribution to signalling was the database communication;

  - The set-up and release times were reasonable for production use. Times for making and releasing the reservation were the same, about two seconds each;

  - The most critical point of failure is the database; the second critical point is the RCA.

An extended summary of the first trial results is presented in chapter 3. In Annexes A and B (chapter 6 and 7) a detailed description of trial scenarios and results is included.

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1 Introduction

The aim of the AQUILA project is to create, implement and evaluate a scalable, enhanced, end-to-end Quality of Service architecture for IP networks. During the first year of the project the QoS IP network architecture was defined and implemented. Detailed description of the proposed solution, including hardware and software specification was presented in deliverables D1101, D1201 and D1301. Moreover, the description of potential applications and the implementation of the Resource Control Layer and measurement tools were presented in deliverables D2101, D2201 and D2301. After the implementation and integration stage [D3101], first trial experiments were prepared and performed in three sites: Warsaw (main side), Vienna and Helsinki.

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

- PCBR network service including tests with WinSIP application (see annex A, 6.2),
- PVBR network service including tests with NetMeeting application (see annex A, 6.3),
- PMM network service including tests with Real Player application (see annex A, 6.4),
- PMC network service including tests with Unreal game application (see annex A, 6.5),
- Mixture of network services (see annex A, 6.6),
- AC mechanism validation (see annex A, 6.7),
- Resource pool mechanism validation (see annex A,7.1),
- RCL performance (see annex A, 7.2).

The report is organised as follows: after short introduction (chapter 1), the objectives of the first trial are outlined (chapter 2). In chapter 3, the main achievements, conclusions and hints for the project are described. At the end, the list of abbreviations and references are included. Then, the detailed description of trial scenarios and results are presented in Annexes A and B. In Annex C the measurement tool description is included. Annex D contains the specification of the network configuration in each site.

2 Objectives of the trials

For the first trial, two main objectives were defined: verification of network service implementation and evaluation of RCL layer performance.

The network services should be verified from the following viewpoints:

- QoS traffic differentiation submitted for different network services, including:
    - each TCL should offer QoS according to the assumptions;
    - each flow served within a TCL should experience similar QoS;
    - flows served by different TCLs should experience different QoS;
- effectiveness of associated AC algorithms;
- correctness of mapping from application parameters (like good, medium, acceptable) to traffic descriptor (to parameters of the token bucket).

The effectiveness of the RCL layer implementation should be evaluate from the following viewpoints:

- validation of the resource pool mechanism;
- validation of AC algorithm implementation;
- evaluation of performance of RCL signalling, including measurement of signalling load;
- robustness of RCA implementation (e.g. in the case of data base failure, router failure, etc.)

Additionally, for the measurement tools, the following objectives were defined:

- to support the other work packages,
- to enable evaluation and validation of the AQUILA architecture,
- to integrate the single parts of the measurement system in the overall architecture,
- to evaluate the usability of the measurement tools for the trial requirements,
- to get input for further enhancements from the evaluation of the measurement tools.

3 First trial achievements

This chapter summarises the achievements of the first trial experiments. The detail description of specific experiments in the test-bed installations (Warsaw, Vienna, and Helsinki) is presented in Annex A and B.

In Annex A the experiments aimed at measuring performances of proposed network services (PCBR, PVBR, PMM and PMC) are reported. They focused mainly on traffic studies provided under different system load scenarios. For each network service, the target QoS objectives, at the packet level, was verified assuming the worst case traffic (different for each network service). The QoS performances were expressed in terms of such parameters as throughput (for TCP-controlled traffic), packet loss ratio and packet delay characteristics (mean, variability...). These experiments were carried out in Warsaw test-bed, which has the largest number of available routers.

In Annex B the experiments aimed at validation, efficiency and robustness of implementation of the Resource Control Layer (RCL) components, as EAToolkit, ACA, RCA, and resource pool mechanism were carried out. In Vienna test-bed the resource pool mechanism was tested, while in Helsinki test-bed were made the experiments corresponding to the rest of the RCL functionality.

In the following sections of this chapter we shortly summarise the results of the carried out experiments and compare them to the assumptions made in the project. Finally, we conclude about the future directions the project should evolve. The lessons learned from the first trial will be taken into account in the second phase of the project.

3.1 Network services

In this section we summarise the experimental results corresponding to the network service evaluation. The experiments were organised in this way, first each network service was tested separately (the traffic class corresponding to given network service was loaded with maximum traffic allowed by AC, the rest of the traffic classes were loaded up to the dedicated capacity). Next, a mix of chosen network services was assumed and their co-existence in the network was examined (the main goal of this tests was to measure the QoS differentiation between traffic classes).

3.1.1 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 [see D1301].

Two sets of the experiments were carried out. The first part of the experiments was oriented for checking the impact of edge and core routers architecture on quality of PCBR service (see annex A, 6.2.2). For this purpose, each type of router used in trial (see Figure 6-1. Trial topology), i.e. Cisco1605, 3640 and 7507 with different type of interfaces (with PoS, FastEthernet and V.35), was examined.

The second set of the experiments was focused on efficiency studies of implemented AC algorithm (see annex A, 6.2.3). The measured parameters were volume of admitted traffic, packet loss ratio and end-to-end delay. The experiments assumed under link of 2 Mbps in the access. Furthermore, the submitted traffic had the form of artificial flows or was generated by real voice application WinSip (see annex A, 6.2.4).

Conclusions and feedback to the project

The reported results say the following:

- limitations of edge and core routers architecture have essential impact on quality of PCBR service (see annex A, 6.2.2). Concerning the AQUILA scheduling algorithm (CBWFQ) the presence of additional transmission buffer with FIFO discipline (named tx ring) can degrade quality of the service. In all experiments, this buffer introduces additional delay for PCBR packets (served with the highest priority). The maximum observed delay was 13 ms (see annex A, 6.2.2.1). Generally, this additional delay depends on the packet size (at the background traffic) and is out of control.

- PCBR service fulfils specified for this service QoS requirements: delay (see annex A, 6.2.3.1, 6.2.3.2) and packet loss ratio (see annex A, 6.2.3.3, 6.2.3.4);

- WinSip application can be effectively supported by this service, but rather smaller packets should be used in order to decrease packetisation delay (see annex A, 6.2.4);

- PCBR service (with it AC algorithm and PHB specification) effectively supports constant bit rate applications;

3.1.2 PVBR network service

PVBR service (see D1301) was designed to serve streaming variable bit rate flows requiring low packet loss rate and low delay. Therefore, on the contrary to the PCBR service, it takes into account variability of the submitted traffic. A profit from multiplexing gain is expected in this case. This service is mainly dedicated to such applications as video and VoIP (with compression).

The aim of experiments was to practical verification of QoS objectives assumed for PVBR service. For this purpose, the worst-case traffic (artificial) of the form of MMDP model (superposition of a number of ON/OFF traffic) was submitted to the service. The obtained results are reported in annex A (see chapter 6.3). Additionally, the quality of NetMeeting application (voice) over PVBR service was tested.

Conclusions and feedback to the project

On the basis of the obtained results we conclude:

- PVBR service meets the expectations (see annex A, 6.3.2),
- AC algorithm guarantees QoS objectives (see annex A, 6.3.2),
- bandwidth for PVBR service (300kbps) for 2Mbps access links, assumed in trial network, is not sufficient for serving video traffic produced by NetMeeting application; even in the case of choosing option with small window and low quality, the required PR = 380kbps is above the dedicated capacity (see annex A, 6.3.3.1);
- tuning the appropriate values of traffic descriptors for NetMeeting application is very difficult to do. This can be done only experimentally (see annex A, 6.3.3.1); Therefore, there is a suggestion to simplify traffic descriptors. In order to do it, new AC algorithms based on some measurements should be considered;
- good speech quality for NetMeeting over PVBR service can be achieved (see annex A, 6.3.3.3);
- PVBR service is suitable for variable bit rate applications but router limitations should be taken into account (packet size influence, etc.);

3.1.3 PMM network service

PMM network service is designed for effective transfer of long-lived greedy TCP-controlled flows, like FTP. For accepted flows, the PMM guarantees the minimum throughput at the level of declared SR value. The aim of the experiments was practical verification of the assumed objectives for PMM service.

The experiments were carried out assuming a number of TCP connections with different traffic declarations. The efficiency of Real Player application over PMM was practically verified. Additionally, the effectiveness of AC was checked. The details of the results are included in Annex A, section 6.4.

Conclusions and feedback to the project

On the basis of the measured results we conclude:

- PMM service is implemented according to the specification.
- TCP flows served by PMM service can adapt their rate to the maximum available link capacity. Fair service of the flows is observed, the obtained throughput is in proportion to the declared SR value (see annex A, 6.4.2.2 and 6.4.2.3).
- WRED algorithm used in TCL3 assures that the packets conforming to the traffic profile are dropped during congestion period with lower probability than the packets marked as “out-of-profile”. Anyway, the assumed target value for “in-packets” loss

ratio on the level of 10^{-3} is not guaranteed (see annex A, 6.4.2.4). The observed packet loss ratio is significantly higher. This is caused mainly by the fact that out of profile packets are allowed to enter the network. The solution for that could be optimisation of the thresholds for in and out-of-profile packets in WRED algorithms or AC mechanism should be more conservative.

- PMM service is well suited for applications that generate greedy TCP flows (like FTP) as well as non-real time streaming video (like Real-Player). Care must be taken with respect to proper setting of SR value in traffic descriptor, which in case of Real Player should be set a little higher then the rate of traffic generated by the application (see annex A, 6.4.3.1).

- For PMM service, the Real Player application should use rather TCP protocol than UDP (see annex A, 6.4.3.2). In the case of UDP the TCP streams in PMM service causes degradation of quality of UDP stream.

3.1.4 PMC network service

The PMC service was designed for non-greedy short-life TCP sources e.g. database lookup, web browsing etc. The PMC network service should guarantee low packet loss and relatively low delay (comparing to PMM service). For each flow submitted to PMC service the system reserves capacity equal to the value of effective bandwidth (calculated on the basis of the declared traffic parameters PR and SR). The amount of network resources allocated to PMC flows should guarantee no packet losses. As the value of effective bandwidth is greater then SR, the PMC service provides lower delay than PMM (assuming maximum admissible loads and the same buffer lengths assigned for PMM and PMC).

The objective of the PMC service trial was to verify whether this network service could provide assumed quality of service (see annex A,6.5.2). The measured characteristics were: throughput (at application and network layer), packet loss ratio and packet delay. The following experiments were carried out: throughput and goodput measurement for different reservation scenarios, validation of AC algorithm with verification of QoS objectives and test with Unreal Tournament application served by PMC service.

Conclusions and feedback to the project

On the basis of the measured results we conclude:

- PMC service is implemented according to the specification.

- The offered traffic is correctly divided to “in” and “out of profile” packets according to the specified flow descriptors. The individual flows obtain service rates in accordance with the requested effective bandwidths. In the case when the TCP sources became greedy, each flow receives capacity equal to the effective bandwidth and the total served traffic is close to the assigned capacity (assigned for PMC service).

- In general case the target packet loss ratio for “in-packets” (10^{-6}) is not guaranteed (see annex A, 6.5.2.1, 6.5.2.2 and 6.5.2.3). In the current specification of PMC service there is no protection against greedy sources. Such sources can submit large number of out-of-profile packets to the network. This increases system load and causes losses of in-profile packets. In theory the AC algorithm should guarantee no packet loss for in profile packets. But in practice, for the reason explained above, the AC does not work in this way.

- The PMC service specification should be redesigned in order to mitigate the above problem. More strict control over the number of out-of-profile packets that can enter the network is desirable e.g. by policing (dropping out-of-profile packets), optimisation of WRED parameters or using different buffer management mechanism (e.g. push-out buffer management scheme to give "in-profile" packets priority in access to the buffer)

- The observed packet loss ratio and packet delay (even for non-greedy sources) suggest that the CBWFQ scheduler works differently than theoretical WFQ scheduler. Too large packet delay was observed (even on the level of seconds). The large delay could be caused by higher service rate variability than in theoretical WFQ scheduler (larger periods of time between transmission of consecutive PMC packets). During such events the PMC queue can build up causing larger delay and larger packet loss rate (see annex A, 6.5.2.3). This requires further study during the first trial extension.

- Tests with Unreal application underlined a need for more strict control over the number of packets the greedy TCP connection can send using PMC service. The presence of greedy sources degrades the quality of service experienced by the users of the Unreal application (irrespectively of the values of the reservation parameters) (see annex A, 6.5.3).

3.2 Mix of network services

Evaluation of each network service in separate way, as it was discussed above, is not sufficient for proving that the assumed AQUILA architecture really meets the expectations. For this purpose, we must test the forced approach in more complex way. In particular, there is required an evaluation of the system under more than single network service scenarios. This is especially desirable for showing QoS differentiation between considered network services. Only in this way we can prove that the assumed set of network services is justified, since each of them offers different guarantees for packet transferring. Another point of these studies is to illustrate system ability for fair sharing the link capacity among the supported network services.

Several experiments were carried out for illustrating system behaviour under different mix of network services. The results of these experiments are described in details in Annex A, 6.6. Below we shortly review the main received results, allowing us for more general conclusions about the system behaviour.

3.2.1 Differentiation of traffic service quality

Quality of service experienced by a particular flow should depend on the network service type the flow is submitted. One can expect that a flow served by one network service to be treated in a different way than by another one. For instance, a streaming flow can be submitted for the PCBR or PVBR service, and this flow should be “better” served rather by PCBR than PVBR.

We will describe below the experiments illustrating capabilities of the AQUILA architecture for differentiation traffic service quality depending on the network service (PCBR, PVBR, PMM, PMC, STD) and traffic type (streaming, TCP-controlled...)

Mix of streaming and elastic traffic submitted to a single network service

The objective of the first experiment (see annex A, 6.6.1.1) was to illustrate what happens when a mix of two different traffic types, streaming (UDP traffic) and elastic (TCP traffic), are both submitted to the system with one network service. It was observed that when number of TCP connections increases the delay and packet loss experienced by UDP traffic also increases. The UDP traffic degrades the TCP traffic, but despite this the quality experienced by UDP packets is not acceptable for most of the streaming applications (e.g. for NetMeeting). The conclusion is that the streaming and elastic traffic should not be mixed and, as a consequence, different network services should be designed for them.

In the second experiment we used the PQ and WFQ schedulers for serving the streaming and elastic traffic in separate way. In the case of PQ scheduler, the UDP traffic had been assigned high priority. As it was expected, in this case we can control the quality of service offered for these different types of traffic.

Influence of low priority traffic on PCBR service

The aim of the experiment was to illustrate whether by increasing traffic load submitted to the STD service we can keep the quality offered by PCBR service (see annex A,6.6.1.2). As it was expected, the PCBR service can guarantee the assumed QoS even when the system is overloaded by STD traffic. Remind that the volume of traffic submitted to the PCBR service is limited by associated AC algorithm.

3.2.2 Traffic separation

Several experiments were carried out for illustrating ability of the implemented system mechanisms for traffic separation with respect to its assignment to particular network services. This issue is very important in the context when a number of network services share the same network resources (e.g. link capacity). Notice that each network service has been dedicated exclusive part of link capacity. AC algorithm for particular network service is performed only within assigned capacity.

Separation of network services using WFQ scheduler

The aim of the first experiment was to verify whether the applied WFQ scheduler provides bandwidth guarantees assumed for each network service (see annex A, 6.6.2.1).

The obtained results confirm that the WFQ scheduler gives the bandwidth guarantees (according to assigned weight values) for each traffic class. Notice that in the studied case, the sum of configured scheduled rates was equal to 1900 Kbps, which is smaller value than the link capacity (2000 Kbps). The classes served by the WFQ fairly share non-allocated 100 Kbps.

Influence of the PCBR traffic on the PMM traffic

The aim of the second experiment was practical verification, whether the high priority traffic (in our case, PCBR traffic) can disturb the quality of low priority but QoS traffic (in our case, PMM traffic) (see annex A, 6.6.2.2). Recall that PMM service, similarly to the PVBR and PMC services, uses WFQ scheduler. As it was expected, the low priority traffic can be served with assumed guarantees only in the case when the high priority traffic is limited to the value specified by AC algorithm.

This result confirms that the traffic control mechanisms assumed in AQUILA (scheduler, admission control) are sufficient for guaranteeing appropriate handling of traffic submitted to particular network services.

3.3 AC mechanism validation

The aim of the experiment was to validate the implementations of AC algorithms in ACA agents of AQUILA network (see annex A, 6.7). Detailed description of assumed AC one can find in deliverable D1301.

The received results confirm that the implemented algorithms for traffic classes TCL1, TCL3, and TCL4 are in accordance with the specification D1301. In the case of TCL2 class, some differences were discovered, so the correction is necessary to be done.

3.4 Resource pool mechanism

One of the objectives for the 1st trial is evaluation of the resource pool mechanism used by the RCL for distribution and re-distribution of resources in the underlying network. The proposed algorithm provides a high performance and a great adaptability, even in a highly random traffic model, while the network resources are used really efficiently.

For checking the functionality of the resource pools, an appropriate topology is necessary. So far, one level hierarchy was used in the Vienna trial site, while for the continuation of the 1st trial a two level hierarchy is planned.

The minimum topology consists only of one RP having its resources shared between the two RPLs. This is used to test the basic functionality of the RP, i.e. how the algorithm shares resources among the RPLs, how it manages resource reservation requests and resource release requests.

The algorithm was examined under two basic cases:

- with zero initial resources in RPL (Rtot = 0)
- with certain initial resources, *Rtot*, in RPL

The first condition can be preferred when there are no definite forecasts of the traffic load of the network sub-area, so resources are distributed according to the demand. Only the root of the tree has initial *Rtot* values.

The results of the 1st trial are summarised in the table below:

Traffic Class	Results	Interpretation
TCL1	The first two tests were passed successfully	The algorithm works properly.
TCL2	After start-up of procedure the values were according to the implemented algorithm.	The algorithm should be re-designed.
TCL3	The reservation worked correctly.	The algorithm works properly.
TCL4	Not all tests finalised yet (trial continues)	The algorithm seems to work properly.

Table 3-1. Resource Pool mechanism trial results

3.5 RCL performance

The purpose of this trial was to evaluate the performance of the RCL. In the experiments, three level resource pool with four leaves was used. Detailed network topology located in Helsinki trial site can be found in Annex B 7.1.4.

The RCL performance trial scenarios were divided into three groups:

- Signalling load, where the signalling load between different AQUILA architecture components was measured in different reservation scenarios.
- Set-up time measurements, where the set-up time for making and releasing the reservation was measured.
- Measurement under error conditions, where the purpose was to evaluate the behaviour of the resource control layer in the case when one of the network components was down or was working under error conditions.

3.5.1 Signalling load measurements

Signalling load measurements covered the message exchange between each AQUILA RCL component. The amount of traffic in terms of packet count, average packet size and total bytes transferred in signalling was measured. The signalling load was measured during system start-up and during making and releasing a reservation.

RCL initialisation signalling

This measurement was done in order to find out the amount of signalling when starting up the whole system. Signalling messages between every component were captured. Detailed results of the signalling traffic can be found in annex B, 7.2.2.

Most of the signalling was produced by the connection between the RCA and database. This connection was used to get the resource shares for the network from the database. This signalling is necessary for the operation of the RCL and cannot be reduced. The amount was 142,5 kilobytes.

Second largest part of signalling load was produced between ACAs and edge devices when ACAs configured the edge routers. About 90 kilobytes was transferred between each ACA and edge device.

During start-up a keep-alive connection between RCA and ACA was established. It also contributed to the signalling traffic.

Reservation signalling

Sender oriented and third party oriented reservation styles were tested with two traffic classes: PCBR and PVBR. PMM and PMC were not tested since from the signalling point of view all point-to-point reservations generate almost identical signalling load. Also two different resource pool configurations for access links were used; high bandwidth and low bandwidth.

The largest contribution to signalling traffic was produced by ACA logging. This was mostly debug-logging, so this signalling load is significantly reduced in production use, and its total amount will become very small compared to other signalling traffic.

The second largest contribution to signalling came from the ACA. It consisted of two parts: configuring the ingress router and querying the database for traffic classes.

The router configuration was done using a telnet-connection to the router. Currently the commands were sent one character at a time, and this made the load relatively high due to packet headers. However, sending one line at a time can significantly reduce this load.

The third biggest contribution to signalling was the database communication, which cannot be reduced, since it is a vital part of ACA operation. If the ACA is behind a slow link, the database signalling contributes to the reservation set-up time. The amount of ACA database signalling was 19,4 kilobytes.

When a reservation was fixed, keep-alive signalling between ingress and egress ACA was established. If the reservation lasted for five minutes, the keep-alive signalling amount between the ingress ACA and egress ACA was the same as the signalling between ACA and database when making and releasing the reservation. If several reservations are active between the same ACAs, only one keep-alive connection is used.

The only difference between high and low bandwidth access links signalling load was 409 bytes which was introduced by ACA getting the resources from RCA, since in low bandwidth case the initial resources of the ACAs were set to zero.

The difference between sender oriented and third party oriented reservation style was the third ACA generating signalling load to the other two ACAs, database, traceserver and RCA.

Unsuccessful reservation was tested with two cases. First case was to test signalling when reservation exceeded the maximum allowed traffic in its class, e.g. PCBR reservation over 200 kilobits. Second case was to test signalling when ten reservations were already made and the eleventh reservation exceeded the total traffic specification of the traffic class.

It was observed that the volume of signalling traffic associated to an unsuccessful reservation is essentially less comparing to a successful reservation. The majority of this traffic was between the EAToolkit and the GUI. For unsuccessful reservation, the total volume of signalling load was only 12 kilobytes, and half of that was logging information. In the second case signalling load was a bit higher. Differences of these cases are described in Annex B 7.2.2.

Because most of the signalling was produced by ACA logging information and ACA configuring, the edge router by Telnet one character by character, the total effect of signalling load when making a reservation was quite high, 126,8 kilobytes. It must be noticed that both of these high load-signalling sources are to be removed in production use. Without logging information and enhanced Telnet, the load will be about 45 kilobytes.

Detailed results with number of packets sent, average packet size, bytes sent, keep-alive bytes sent and number of TCP-connections can be found in annex B, 7.2.2.

3.5.2 Set-up time measurement

The overall set-up and release time of reservation was measured without logging information, which is the usual case in production environment.

Logging in via the GUI was quick. The time consumed was less than half of a second.

The set-up and release times were reasonable for production use. Times for making and releasing the reservation were the same, about 2 seconds each. The typical response time of a web server is not much lower.

Average set-up times and standard deviation for 10 measurements can be found in annex B, 7.2.3.

3.5.3 Measurements under error conditions

These measurements were intended for evaluating the amount of signalling messages in the case when one of the network components has a failure. The measurements were carried out in this way that one of the network element was shut down. Next, the impact of this event on signalling was observed. It appeared that no additional signalling was produced. Therefore, the actions made by implemented recovery procedure were only observed.

Point-to-point sender oriented PCBR reservation was used in all test scenarios. The impact of the shutdown of the following components was measured:

- RCA shutdown and start-up,
- Ingress router reboot,
- Database shutdown and start-up.

The measurements showed that the most critical point of failure is the database. If the database fails, the RCL is totally unavailable. Also, if the database fails, the RCL has to be restarted.

The second critical point is the RCA. When RCA came down, the RCL was still partly active, and the ACAs were still able to handle reservations locally. However, if ACA needed more resources or wanted to release resources, it failed.

Ingress router reboot was the last fatal error condition. When the ingress router was rebooted, the ACA for that router got blocked, and did not respond to keep-alive messages. Therefore the reservation was released. When the router was stable again, RCL operation continued normally.

Detailed information on the measurements can be found in the Annex B chapter 7.2.4.

3.6 AQUILA Measurement Tools

The measurements in the trials were performed using:

- Commercial available measurement equipment (HP BSTS, Interwatch 95000) for generating background traffic
- AQUILA measurement tools [D2301] for
  - generating foreground traffic,
  - active network probes and
  - collecting QoS monitoring information from the routers.

Using the AQUILA measurement tools together with the commercial equipment extensive tests of the AQUILA architecture were performed. The results produced by the measurement tools were used for the evaluation and validation of the algorithms for resource control developed within AQUILA.

The following points were identified for further development and enhancements of the DMA:

The feedback from the trial sites

- provided valuable input for improvements and enhancements
- mainly concerned user friendliness (e.g. GUI) and new functionality (e.g. new traffic sources, interface to the AQUILA architecture)
- will be investigated for realisation for the second trial.

Also a new aspect was intended for the second phase of AQUILA. Control loops were planned as extension to the RCL deployed in the first trial. Within control loops feedback from the network (by measurements of a predefined set of parameters) is used for the decision process of the RCL both supporting redistribution of resources and leading to a higher network utilisation. The necessary measurements have to be provided by the DMA.

Concerning the set of parameters

- some possible input parameters for control loops have been identified
- input from the specification work packages according to the ongoing discussion is welcome.

Based on this input the decision about parameters has to be made.

Concerning the realisation of the control loops

- the measurement tools have to be enhanced for the selected parameters (if not already supported)
- interface(s) between measurement tools and the resource control layer have to be defined.

In conclusion, the experiments performed during the first trial showed that the distributed measurement architecture (DMA) worked. The raised issues for further development of the measurement tools were identified and will be covered during the second phase of AQUILA. Further details about measurement tools are included in Annex C (chapter 8).

4 List of Abbreviations

AF	Assured Forwarding
BE	Best Effort
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
IOS	Internetwork Operating System

MBS	Maximum Burst Size
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
TCA	Traffic Conditioning Agreement
TCL	Traffic CLass
TCP	Transport Control Protocol

TCS	Traffic Conditioning Specification
ToS	Type of Service
VLL	Virtual Leased Line
WFQ	Weighted Fair Queuing
WRED	Weighted Random Early Detection
WRR	Weighted Round Robin Scheduling

5 References

[D1101] IST-1999-10077-WP1.1-DTA-1101-PU-R/b0, Analysis and Requirements Report, March 2000

[D1201] IST-1999-10077-WP1.2-SAG-1201-PU-O/b0, System architecture and specification for first trial, June 2000

[D1301] IST-1999-10077-WP1.3-COR-1301-PU-O/b0, Specification of traffic handling for the first trial, July 2000

[D2301] IST-1999-10077-WP2.3-SPU-2301-PU-R/b0, Report on the development of measurement utilities for the first trial, September 2000

[D3101] IST-1999-10077-WP3.1-NTU-2301-PU-R/b0, First Trial Integration Report, March 2001

6 Annex A – Network services trial scenarios and results

6.1 Trial network

The assumed trial network topology is shown in Figure 6-1. The routers (access and core) are connected in the form of chain for achieving maximum number of hops the packets have to cross in the network. In this configuration, end terminals are connected to the routers by Ethernet ports.

The trial topology consists of 8 CISCO routers (as suggested in deliverable D1101) and 8 PC stations. The following types of routers were used:

- 1 router CS 1605 (aq1605_1),
- 4 routers CS 3640 (aq3640_1, aq3640_2, aq3640_3, aq3640_4),
- 3 routers CS 7507 (aq7507_1, aq7507_2, aq7507_3).

More details about configurations of each element in the trial topology are described in Annex D.

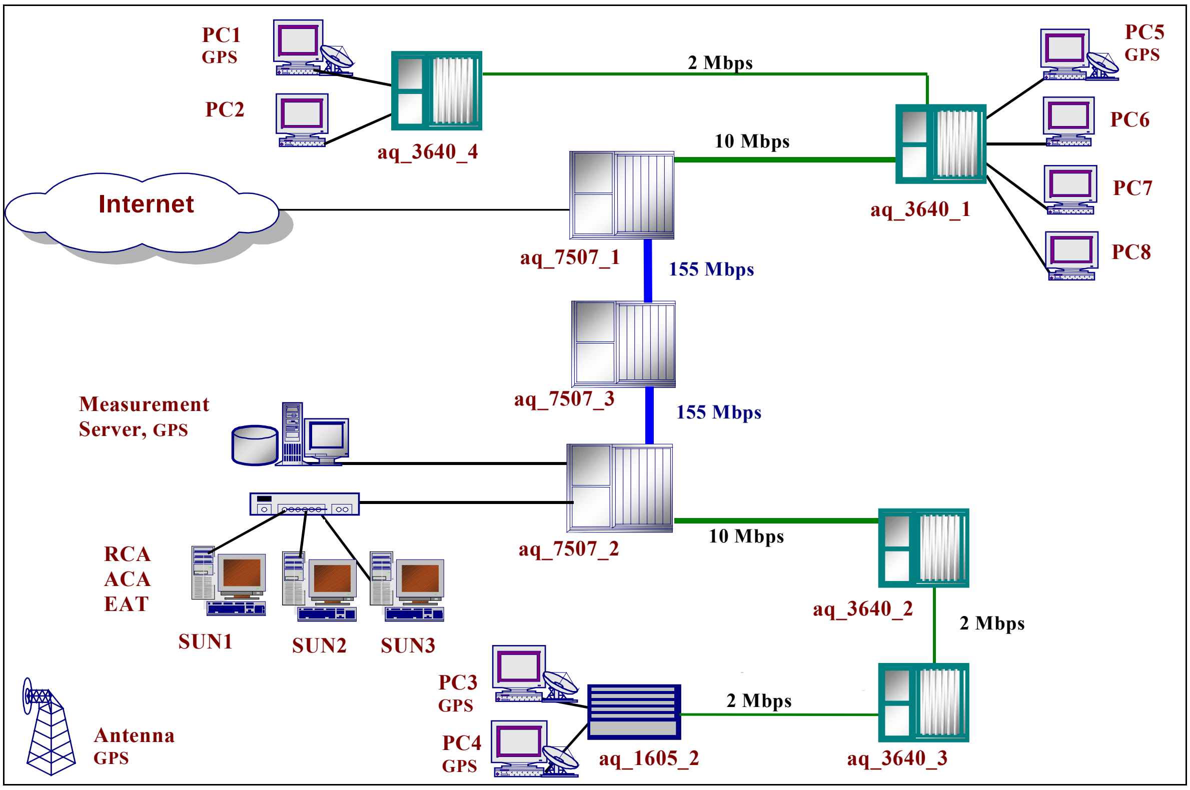

Figure 6-1. Trial topology

6.2 Premium CBR network service

The Premium CBR (Constant Bit Rate) service is proposed for streaming flows, where the packets represent an audio or video signal. Moreover, this service should constitute a base for providing VLL (Virtual Leased Line) link, similarly to the role played by Circuit Emulation Service (CES) in ATM. Premium CBR service uses TCL1 traffic class [see D1301]. The network serves the packets associated with this service with the highest priority.

The QoS parameters of the Premium CBR service should guarantee both low packet delay and packet loss ratio. More precisely, loosely assumed maximum values of the above parameters are [see D1301]:

- delay $\leq$150 ms
- packet loss ratio $\leq 10^{-8}$

Additional assumptions are the following:

- Reservation style: p2p
- Traffic characteristics at the packet level are provided in the form of single token bucket description (Single_Rate).

Assumed values of traffic descriptors for a potential user of PCBR service are shown in Table 6-1 (see [D1301]).

Parameter	***Minimum admitted***	***maximum admitted***	***Default***
PR	0	200 kb/s	…
m	40 B	256 B	40 B
M	n.a	n.a.	256 B
BSP	n.a	n.a	256 B

Table 6-1. Possible values of traffic descriptors

6.2.1 Trial setup

The main goal of the trial experiments was practical verification of expectations from PCBR service, defined in D1301 document. The experiments are divided into two parts. The aim of the first part is to identify limitations of edge and core routers, which have an impact on quality of PCBR service. In these experiments artificial test and background flows are used. The second part of the trials answers for the question: if, for the assumed trial topology (with high-speed links: 2, 10, 155 Mbps), the values of measured QoS parameters (e.g. packet loss ratio, end-to-end delay) are satisfying. The measured values are compared with target values, which are assumed in the AQUILA project [see D1301]. In this case, quality of PCBR service was checked for artificial flows (QoS parameters) as well as for a real voice application – WinSip (the speech quality).

In both parts of the trials two TCL classes are used only. TCL1 class serves foreground traffic (PCBR flows) while TCL5 class serves background traffic. The background traffic is the traffic corresponding to all traffic classes/network services, which are not under test. Such assumption is possible due to the fact that packets of TCL1 class are served with the highest priority in the routers. Packets of classes: TCL2, 3, 4, and 5 are served with the lower priority. To investigate an impact of classes served with the lower priority on TCL1 class (PCBR service), it is enough to assume one worst-case background flow, which represents flows from the other classes.

6.2.1.1 Routers output ports architecture

The simplified output port architecture of CISCO routers for the trials of PCBR service is depicted in Figure 6-33. Output port configuration for TCL2, 3, and 4 classes are omitted. The values of buffer sizes for PCBR trials are the following:

- for TCL1 class: 5 packets
- for TCL5 class: 59 packets

Incoming packets are classified to appropriate queues in the output port according to their code-points. Packets served by TCL1 class have the high priority while packets of TCL5 class have the low priority. Before transmission process, packets are queued in transmission buffer (tx ring mechanism with FIFO discipline). Size of transmission buffer depends on type of routers.

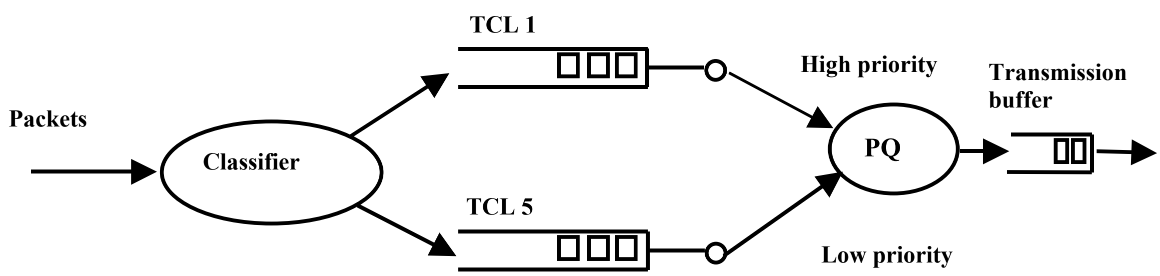

Figure 6-2. Router output ports architecture

The admission control limits of PCBR service for 2 Mbps links is the following:

	Serial (2Mbps)
AC Limit	200kbps

The value of target utilisation of TCL1 class (called ρ parameter) is obtained from the following formula: $\rho_1 = \frac{2B^1}{2B^1 - \ln(P_{loss})}$, where B is buffer size of TCL1 class, P_{loss} - denotes packet loss ratio (see [D1301]).

QoS objectives of PCBR service trials:

- TCL1: Buffer size=5 packets,
- AC limit=200kbps (for 2Mbps links),
- Target packet loss ratio=10^{-2} ⇒ ρ=0.685 ⇒ TCL1 target utilisation=137 kbps**.**

In trial experiments, the value of target packet loss ratio (10^{-2}) was higher than the target value assumed for PCBR service in D1301. It was assumed to obtain more reliable results in shorter time.

Admission control and policing mechanisms of the AQUILA architecture were active in trials of WinSip application only. In the other cases traffic generators include code-points of packets served by PCBR.

6.2.1.2 Specification of worst case traffic patterns

To investigate all performances of PCBR service, the worst-case traffic patterns based on artificial flows are used. It is necessary because there are no possibilities to realise all test of this service in a real network since now. The following specification of worst case traffic patterns correspond to both individual and aggregated flows and are limited by the measurement tools available in the first trial.

Worst case traffic patterns for tested flow (foreground traffic - FT):

- Flow with constant bit rate;
- Flow with variable bit rate – ON/OFF traffic pattern with constant bit rate in ON period and constant burst size;

Worst-case traffic patterns for aggregated flows submitted inside the tested traffic class/network service:

- Superposition of CBR flows – Poissonian flow;

Worst-case traffic pattern for background traffic - BT

- Flow with constant bit rate sufficient to load the network resources dedicated to not-tested traffic classes/network services.

6.2.2 TX ring influence

The objective of the following experiments was to verify the influence the CISCO router architecture on the performance of the PCBR service. The interface cards in the CISCO routers series 16xx, 36xx and 75xx are equipped with transmission buffers (tx ring) that store packets already scheduled for transmission to the output links. These buffers are FIFO queues and are logically placed after all scheduling modules. The aim of the tx ring is to accommodate any delay that may arise between the time the link becomes idle and the time the next packet is scheduled for transmission. The size of the tx ring depends on the worst case delay between the request made for the selection of new packet and the moment the requested packet is placed in tx ring ready to be transmitted to the link. By keeping tx ring occupancy at certain level (depending on routers parameters such as link speed, card and router processors power, router configuration etc.) the 100 % throughput can be obtained. In CISCO routers the tx ring size is expressed in so called allocation unit (512 bytes). The delay introduced by tx ring depends on the allocation unit size, packet length and tx ring buffer length.

The tx ring can have significant influence on the performance of PCBR service. Concerning the AQUILA scheduling algorithm (CBWFQ) the presence of additional buffering level after the scheduler's queues with FIFO discipline can degrade the QoS parameters of traffic served in priority queue. If any of the lower priority queues (WFQ queues) is overloaded the low priority packets will be placed in the tx ring. The high priority packets arriving to the system will see the tx ring always full. In effect the delay experienced by the priority traffic will be higher. The experiments described in the following subsections quantifies the influence of the tx ring on the delay experienced by TCL1 class packets for various router models and interface cards used in AQUILA testbed network.

6.2.2.1 Router 1605, interface 2Mbit/s

Description

The goal of this trial is to verify the impact of the transmission buffer (tx-ring) size in the CISCO router 1605 (interface 2Mbps) on the PCBR packet delay. The delay introduced by tx ring buffer was measured as the difference between the min and max latency experienced by TCL1 traffic served together with on-off background traffic. The background traffic was served with lower priority (in STD class). The background traffic rate during ON period fills up the tx ring. The comparison of the TCL1 packet delay with (ON period) and without (OFF period) background traffic allows to asses the size of the tx ring buffer.

Trial set-up

- Trial topology is shown in Figure 6-3. The Active network probing tool from PC3 to PC1 generated foreground traffic. The HP BSTS measurement equipment from aq1605_2:eth1 port to aq3640_3:eth0/1 port generated the background traffic.
- Traffic parameters case #1:

- FT: constant bit rate flow, traffic rate=133 kbps, packet size 100B, transport protocol UDP, traffic class TCL1 (PCBR network service).
- BT: ON/OFF flow with parameters: ON period 55ms (peak rate=10 Mbps), OFF period 500ms, variable BT packet size, transport protocol UDP, traffic class TCL5 (STD network service)
- Traffic parameters case #2:
- FT: constant bit rate flow, traffic rate=133 kbps, packet size 100B, transport protocol UDP, traffic class TCL1 (network service PCBR).
- BT: ON/OFF flow with parameters: ON period 55ms (peak rate=3Mbps), OFF period 500ms, variable BT packet size, transport protocol UDP, traffic class TCL5 (network service STD)
- Traffic parameters case #3: the same as in case #2
- Tx ring size was set to default value (2) (it is no possibility to change default value)
- Test duration: 60 sec.

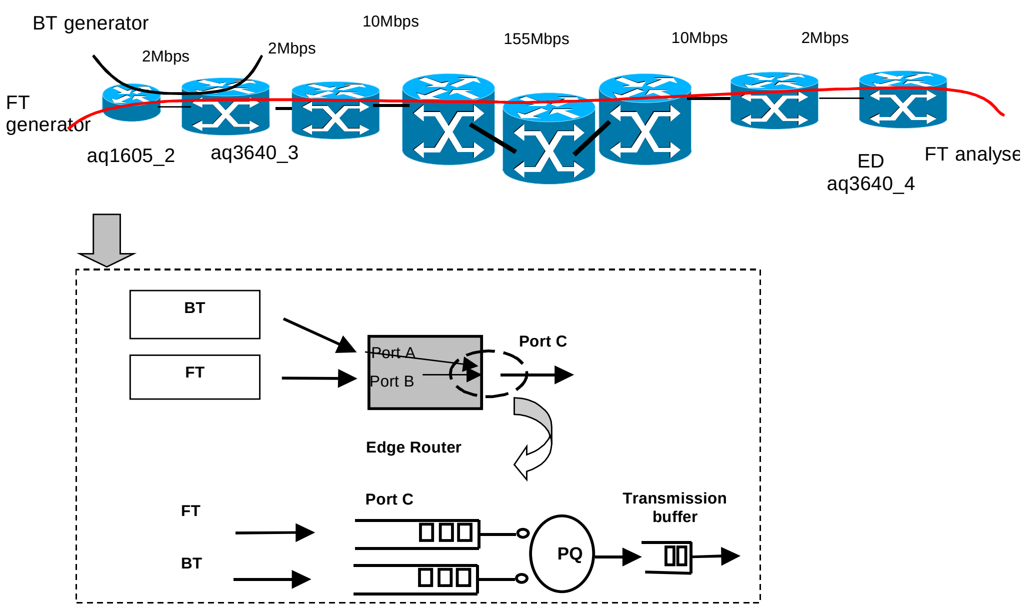

Figure 6-3. Trial topology - 1

Trial procedure

- Traffic generators generate streams of packets according to the specified traffic descriptions.

- Traffic analyser within tested flow measures packet loss rate, maximum, minimum and average packet end-to-end delay.

Case #1 results

The trial results are presented in Table 6-2. The difference between the maximum and minimum (max-min column) end-to-end delay was measured for different packet sizes of background traffic. The delay introduced by tx ring is between 9 and 13 ms depending on background packet size except for shorter packets. The length of packets below 950 bytes caused router processor overload and thus uncontrolled increase in the packet latency (the results for smaller packet sizes are presented in case #2). The delay introduce by tx ring is proportional to the background packet size and is equivalent to two background packet transmission times (see Figure 6-4).

packet size [B]	BT packet size [B]	Min. Delay [ms]	Avg. Delay [ms]	Max. Delay [ms]	Max-min [ms]	2*BT packet transmission time
100	------------	2.853	2.907	6.106	-----------	----------
100	700	2.867	7.07	60.826	57.959	5.6
100	800	2.374	6.763	56.298	53.924	6.4
100	900	2.846	4.933	17.249	14.403	7.2
100	950	2.847	4.869	12.127	9.28	7.6
100	1000	2.853	4.944	12.205	9.352	8
100	1100	2.855	5.214	12.335	9.48	8.8
100	1200	2.853	5.488	13.543	10.69	9.6
100	1300	2.85	5.776	14.127	11.277	10.4
100	1400	2.853	6.06	14.66	11.807	11.2
100	1500	2.853	6.167	16.053	13.2	12

Table 6-2. Results for CISCO router 1605 for 2 Mbps interface

Packet losses within tested flow were not observed (as it was expected).

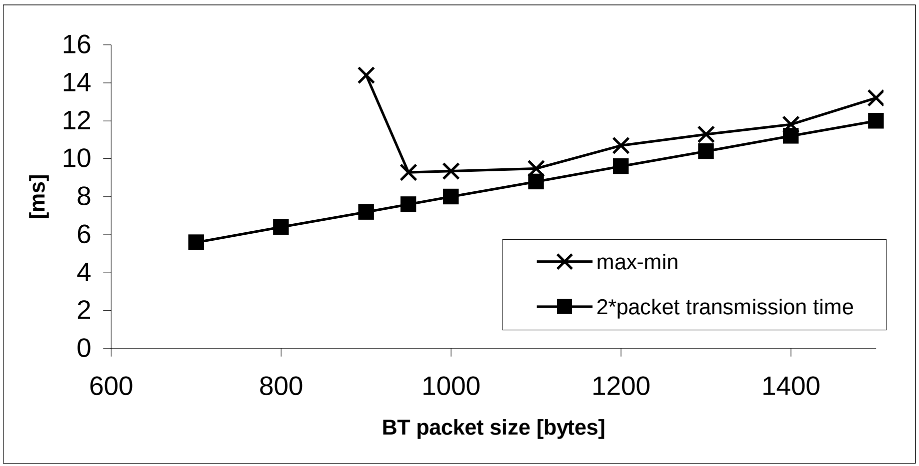

Figure 6-4. Tx-ring delay for V.35 interface of CISCO router 1605

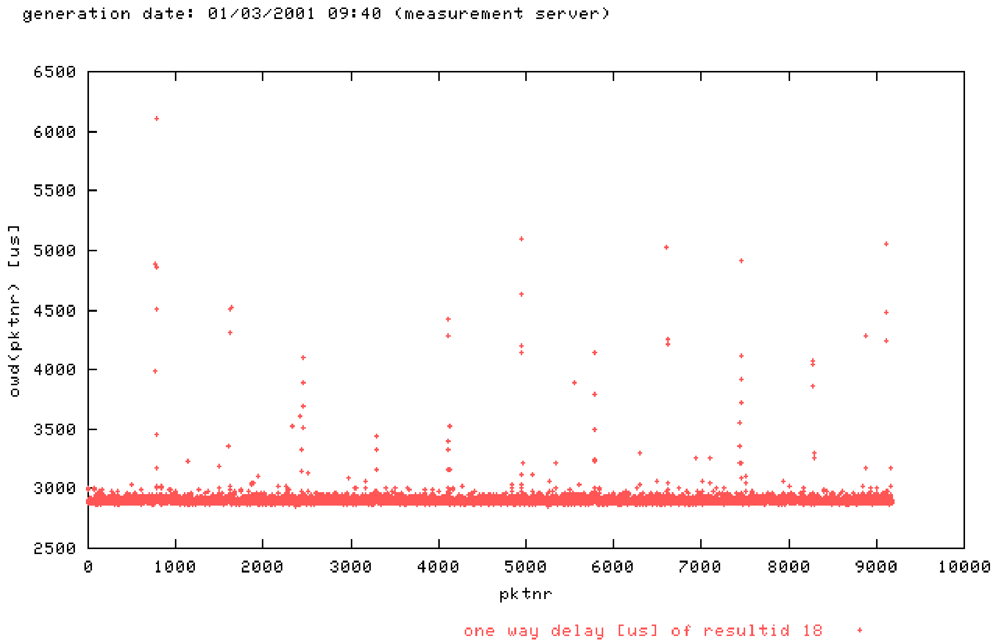

Figure 6-5. One way delay as a function of packet number (FT packet size = 100 bytes; no BT

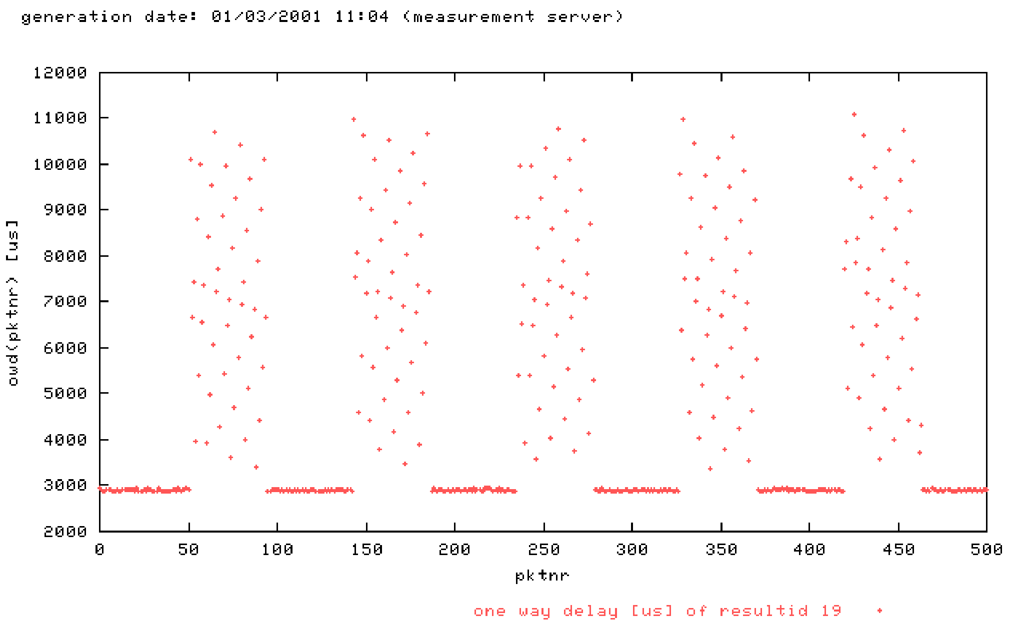

Figure 6-6. One way delay as a function of packet number (FTpacket size = 100 bytes; BG packet size = 1000 bytes)

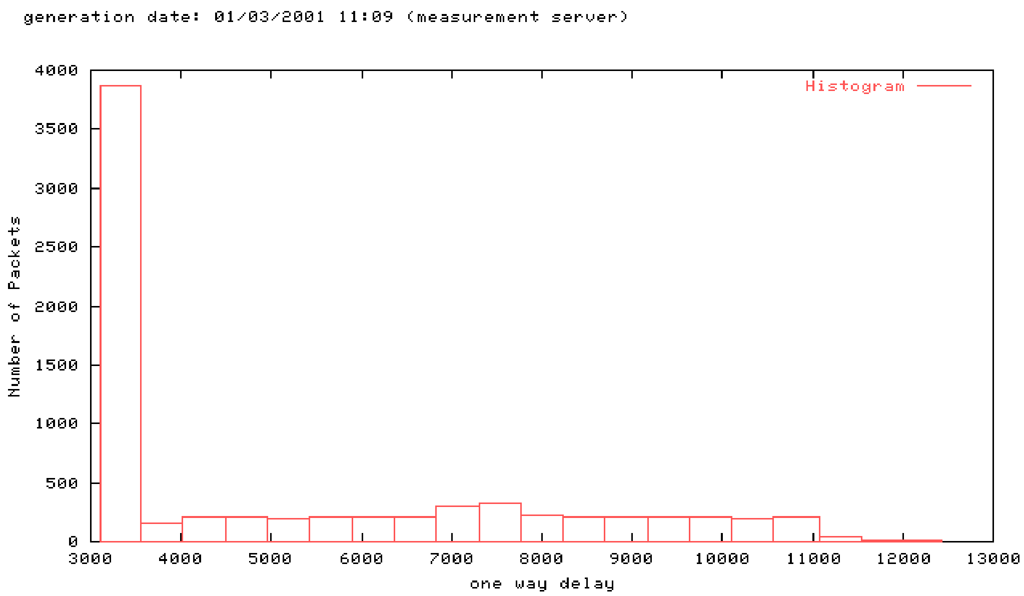

Figure 6-7. Histogram of one-way delay as a function of packet number (FT packet size = 100 bytes; BT packet size = 1000 bytes)

Figure 6-5 and Figure 6-6 present one-way delay for foreground packets with and without background traffic. In case of no background traffic the packet delay experienced by TCL1 class is almost constant with very few packets having grater delay than 3 ms. (The increase of packet transmission time above 3 ms is caused probably by the measurements tool itself. This effect was not observed with hardware measurement equipment). In case of background traffic the delay of TCL1 packets increases significantly during ON periods even though the TCL1 packets have strict priority over the STD packets. The maximum delay is introduced from 3 ms to 11 ms in this case. The delay distribution of foreground packets during ON periods is uniform (see Figure 6-7).

Figure 6-8 presents the IPDV as defined by IETF for the case of background packet length of 1000 bytes. The IPDV takes mainly three values 0, -4 ms or +4 ms. The IPDV function shows how the latency of a given packet changes relative to the previous packet. In the considered case the latency can be increased or decreased by the delay equivalent to the transmission time of the background packet (in 4 ms steps).

The maximum delay introduced by tx ring is in the order of two background packet transmission times.

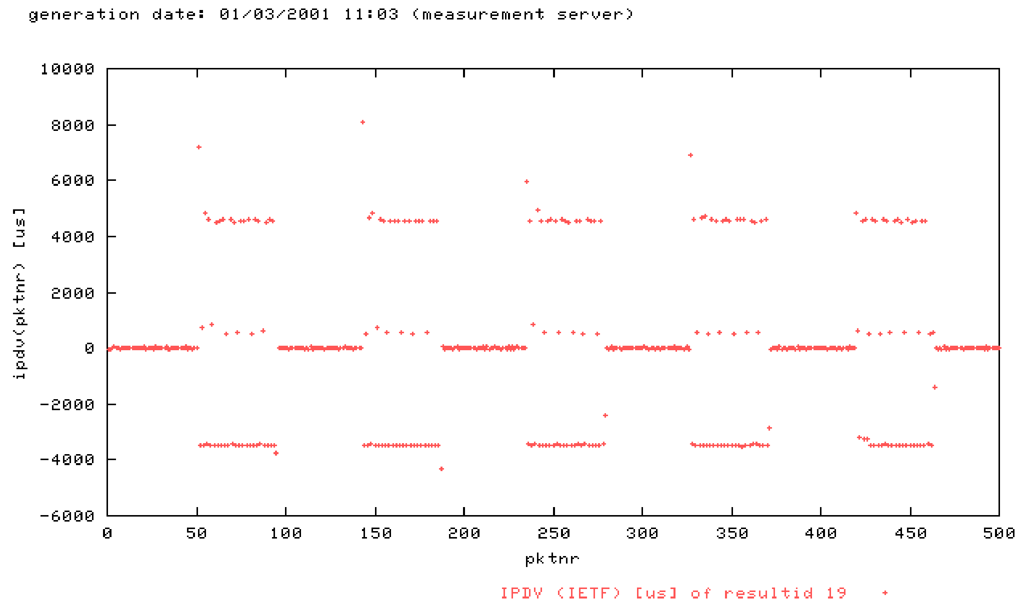

Figure 6-8. IPDV IETF as a function of packet number (FT packet size = 100 bytes; BT packet size = 1000 bytes)

Case #2 results

The trial results for smaller sizes of background packets are presented in Table 6-3. The background traffic rate was limited to 3 Mbps. This rate was not enough to keep the tx ring full all the time so the IPDV function differs from previous case.

The delay introduce by tx ring is proportional to the background packet size and is equivalent to two background packet transmission times.

FT packet size [B]	BT packet size [B]	Min. Delay [ms]	Avg. Delay [ms]	Max. Delay [ms]	Max-min [ms]	2*BT packet transmission time [ms]
100	300	2.855	3.223	9.253	6.4	2.4
100	400	2.852	3.253	7.772	4.9	3.2
100	500	2.855	3.316	8.453	5.6	4
100	600	2.858	3.355	8.352	5.5	4.8
100	700	2.857	3.391	9.111	6.3	5.6
100	900	2.855	3.445	10.744	7.9	7.2

Table 6-3. Results for CISCO router 1605 for 2 Mbps interface

Packet losses within tested flow are not observed (as it was expected).

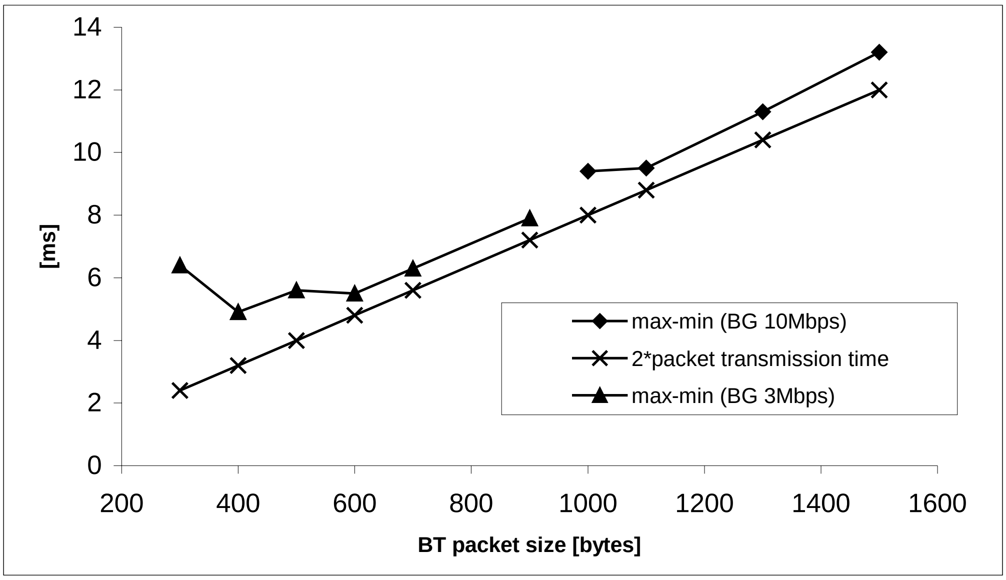

Figure 6-9. Tx-ring delay for V.35 interface of CISCO router 1605

Case #3 results

The measurements made in case #2 were repeated with different measurement equipment. In the following experiments the HP BSTS tester was used. The obtained results are generally similar to those from case #2. The delay measured by AQUILA measurements tools are higher then measured by hardware tester.

FT packet size [B]	BT packet size [B]	Min. Delay [ms]	Avg. Delay [ms]	Max. Delay [ms]	Max-min [ms]	2*BT packet transmission time
100	------------	2.6	2.7	2.9	--------	----------
100	100	2.6	4.3	14.0	11.4	0.8
100	200	2.6	4.6	14.8	12.2	1.6
100	300	2.6	3.5	7.7	5.1	2.4
100	400	2.7	3.7	6.9	4.2	3.2
100	500	2.6	3.9	6.9	4.3	4
100	700	2.7	4.0	8.3	5.6	5.6
100	900	2.7	4.9	10.2	7.5	7.2
100	1000	2.6	4.8	11.4	8.8	8
100	1100	2.7	5.4	11.9	9.2	8.8
100	1300	2.7	5.9	13.3	10.6	10.4
100	1500	2.6	5.8	14.4	11.8	12

Table 6-4. Results for CISCO router 1605 for V.35 (2 Mbps) interface

Packet losses within tested flow were not observed (as it was expected).

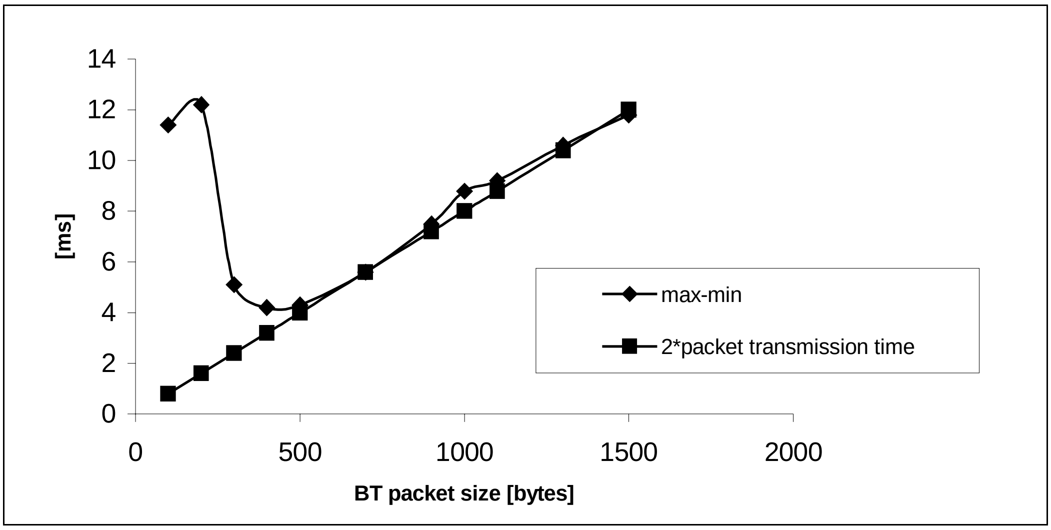

Figure 6-10. Tx-ring delay for V.35 interface of CISCO router 1605

6.2.2.2 Router 3640, interface 10Mbit/s

Description

The goal of this trial is to verify the impact of the transmission buffer (tx-ring) size in the CISCO router 3640 (interface 10Mbps) on the PCBR packet delay. As in previous experiment the background traffic was assumed to be ON/OFF type.

Trial set-up

- Trial topology is shown in Figure 6-11. The Active network probing tool from PC3 to PC1 generated foreground traffic. The IW measurement equipment generated the background traffic from aq3640_2:eth0/1 port to aq7507_2:eth0/0/3 port.
- Traffic parameters:
- FT: constant bit rate flow, traffic rate=133 kbps, packet size 100B, transport protocol UDP, traffic class TCL1 (network service PCBR).
- BT: ON/OFF flow with parameters: ON period 200 ms (peak rate =10 Mbps), OFF period 500ms, variable BT packet size, transport protocol UDP, traffic class TCL5 (network service STD)
- The tx ring size was set to 1
- Test duration: 30 sec.

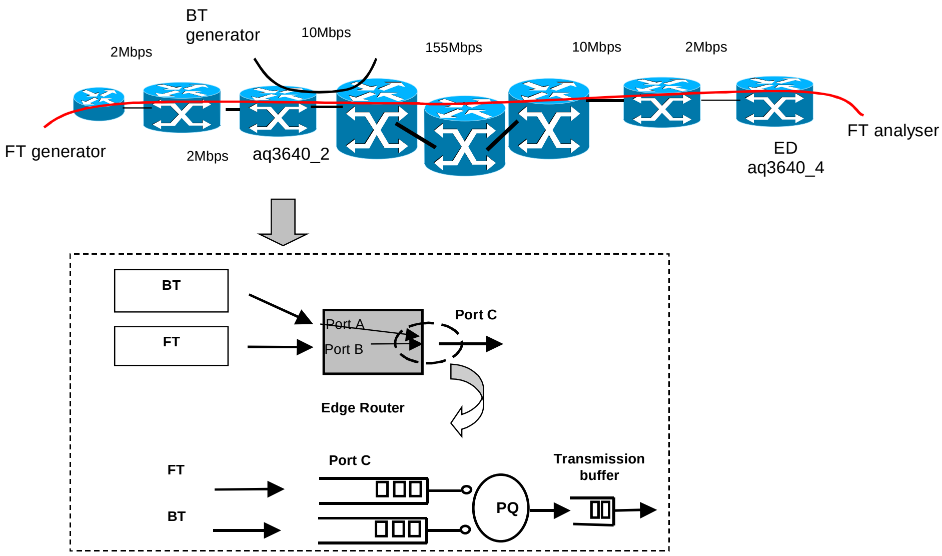

Figure 6-11. Trial topology – 2

Trial procedure

- Traffic generators generate streams of packets according to the specified traffic descriptions.
- Traffic analyser within tested flow measures packet loss rate, maximum, minimum and average end-to-end packet delay.

Results

FT packet size [B]	BT packet size [B]	Min. Delay [ms]	Avg. Delay [ms]	Max. Delay [ms]	Max-min [ms]	2*BT packet transmission time
100	------------	2.6	2.7	2.9	-----------	----------
100	100	2.6	2.8	5.9	3.3	0.16
100	200	2.6	2.7	3.1	0.5	0.32
100	300	2.6	2.78	3.2	0.6	0.48
100	400	2.6	2.79	3.2	0.6	0.64
100	500	2.6	2.8	3.3	0.7	0.8
100	700	2.6	2.86	3.4	0.8	1.12
100	900	2.6	2.89	3.6	1	1.44
100	1000	2.6	2.89	3.7	1.1	1.6
100	1100	2.6	2.9	3.8	1.2	1.76
100	1300	2.6	2.94	3.9	1.3	2.08
100	1500	2.6	2.95	4.0	1.4	2.4

Table 6-5. Results for CISCO router 3640 for Ethernet (10 Mbps) interface

Packet losses within tested flow were not observed (as it was expected).

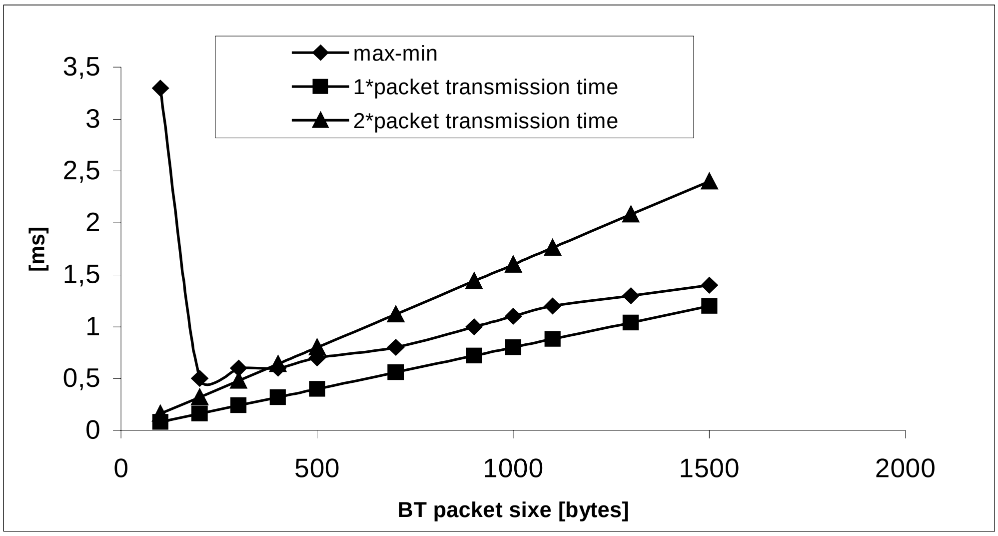

Figure 6-12. Tx-ring delay for Ethernet interface of CISCO router 3640

Conclusions

The experiment results, for Ethernet interface of 3640 CISCO router, are shown in above table. As in previous case the difference between the maximum and minimum end-to-end delay (max-min column) was measured for different background packet sizes. The delay introduced by tx ring is between 0.5 and 1.5 ms. Only for background packet size of 100 bytes the observed delay is higher (3 ms). For such short packets the router becomes overloaded and the overall packet processing time is increased (not only due to the tx ring). The delay introduce by tx ring is proportional to the background packet size and is between one and two background packet transmission times. For the V.35 interface of 1605 router the default value of tx ring is 1.

6.2.2.3 Router 3640, interface 2Mbit/s

Description

The goal of this trial is to verify the impact of the transmission buffer (tx-ring) size in the CISCO router 3640 (interface 2Mbps) on the PCBR packet delay. As in previous experiment the background traffic was assumed to be ON/OFF type.

Trial set-up

- Tested topology is shown in Figure 6-13. The Active network probing tool from PC3 to PC1 generated foreground traffic. The IW measurement equipment generated the background traffic from aq3640_3:eth0/2 port to aq3640_2:eth0/2 port.

- Traffic parameters:

- FT: constant bit rate flow, traffic rate=133 kbps, packet size 100B, transport protocol UDP, traffic class TCL1 (network service PCBR).

- BT: ON/OFF flow with parameters: ON period 55 ms (traffic rate =10 Mbps), OFF period 500 ms, variable BT packet size, transport protocol UDP, traffic class TCL5 (network service STD)

- The tx ring size was set to 1

- Test duration: 30 sec.

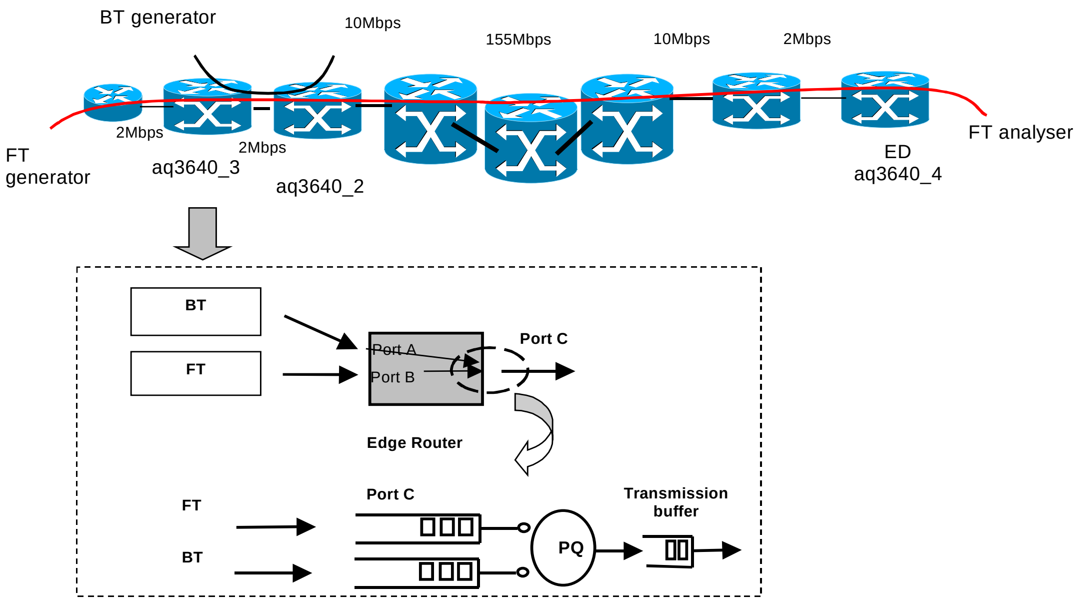

Figure 6-13. Trial topology - 3

Trial procedure

- Traffic generators generate streams of packets according to the specified traffic descriptions.

- Traffic analyser within tested flow measures packet loss rate, maximum, minimum and average packet transfer delay.

Results

FT	BT	Min.	Avg.	Max.	Max-	1*BT packet	2*BT packet

packet size [B]	packet size [B]	Delay [ms]	Delay [ms]	Delay [ms]	min [ms]	transmission time	transmission time
100	----------	2.6	2.7	2.9	--------	--------	----------
100	100	2.6	3.0	7.0	4.4	0.4	0.16
100	200	2.7	2.88	3.9	1.2	0.8	0.32
100	300	2.6	2.9	4.2	1.6	1.2	0.48
100	400	2.6	3.0	4.6	2	1.6	0.64
100	500	2.6	3.1	5.0	2.4	2	0.8
100	700	2.6	3.4	5.8	3.2	2.8	1.12
100	900	2.6	3.7	6.6	4	3.6	1.44
100	1000	2.6	3.7	6.9	4.3	4	1.6
100	1100	2.6	3.8	7.4	4.8	4.4	1.76
100	1300	2.6	4.1	8.1	5.5	5.2	2.08
100	1500	2.6	4.3	8.9	6.3	6	2.4

Table 6-6. Results for CISCO router 3640 for V.35 (2 Mbps) interface

Packet losses within tested flow were not observed (as it was expected).

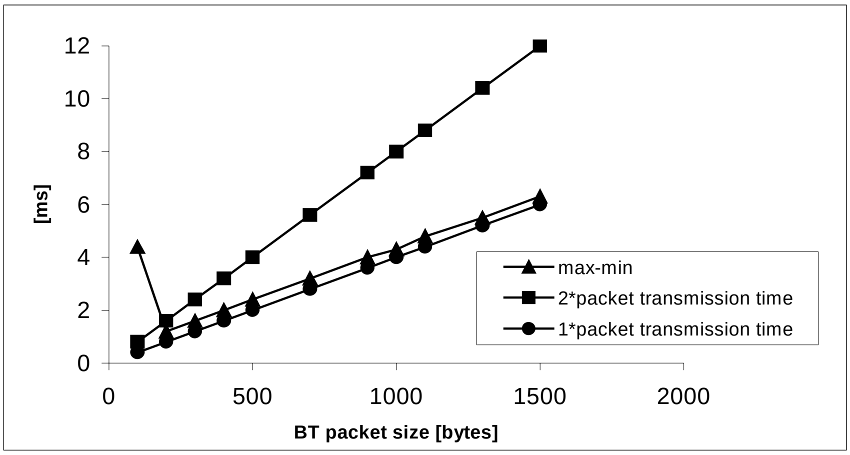

Figure 6-14. Tx-ring delays for V.35 interface of CISCO router 3640

Conclusions

The experiment results, for V.35 interface of CISCO router 3640, are shown in Table 6-6. The difference between the maximum and minimum (max-min column) was measured for different background packet sizes. The delay introduced by tx ring is between 1 and 6 ms. As in previous case for background packet size of 100 bytes the observed delay is higher then expected (4.4 ms). For 100 bytes packets the router becomes overloaded and the overall packet processing time is increased. The delay introduce by tx ring is proportional to the background packet size and is in the order of one background packet transmission times. This result agrees with the size of the tx ring (for V.35 interface the tx ring was set to one).

6.2.2.4 Router 7507, interface 10Mbit/s

Description

The goal of this trial is to verify the impact of the transmission buffer (tx-ring) size in the CISCO router 7507 (interface 10Mbps) on the PCBR packet delay. The background traffic was assumed to be ON/OFF type.

Trial set-up

- Tested topology is shown in Figure 6-15. The Active network probing tool from PC3 to PC1 generated foreground traffic. The IW measurement equipment generated the background traffic from aq7507_1:eth 4/0/2 port to aq_3640_1:eth0/1 port.
- Traffic parameters:
- FT: constant bit rate flow, traffic rate=133 kbps, packet size 100B, transport protocol UDP, traffic class TCL1 (network service PCBR).
- BT: ON/OFF flow with parameters: ON period 200 ms (peak rate =10 Mbps), OFF period 500 ms, variable BT packet size, transport protocol UDP, traffic class TCL5 (network service STD)
- Tx ring size was set to default value (it is no possibility to change this value)
- Test duration: 30 sec.

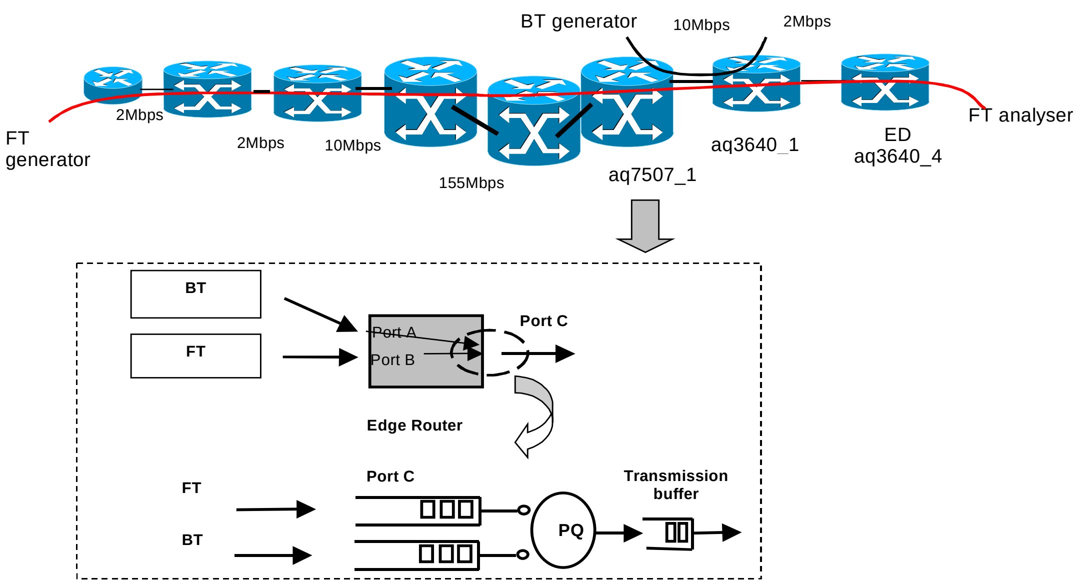

Figure 6-15. Trial topology - 4

Trial procedure

- Traffic generators generate streams of packets according to the specified traffic descriptions.
- Traffic analyser within tested flow measures packet loss rate, maximum, minimum and average end-to-end packet delay.

Results

FT packet size [B]	BT packet size [B]	Min. Delay [ms]	Avg. Delay [ms]	Max. Delay [ms]	Max-min [ms]	2*BT packet transmission time
100	------------	2.6	2.7	2.9	-----------	----------
100	100	2.6	2.8	3.3	0.7	0.16
100	200	2.6	2.8	3.4	0.8	0.32
100	300	2.6	2.8	3.6	1	0.48
100	400	2.6	2.8	3.8	1.2	0.64
100	500	2.6	2.8	3.5	0.9	0.8
100	700	2.6	2.8	3.7	1.1	1.12
100	900	2.6	2.8	3.8	1.2	1.44
100	1000	2.6	2.9	3.9	1.3	1.6
100	1100	2.6	2.9	4.0	1.4	1.76
100	1300	2.6	2.9	4.1	1.5	2.08
100	1500	2.6	2.9	4.3	1.7	2.4

Table 6-7. Results for CISCO router 7507 for Ethernet (10 Mbps) interface

Packet losses within tested flow were not observed (as it was expected).

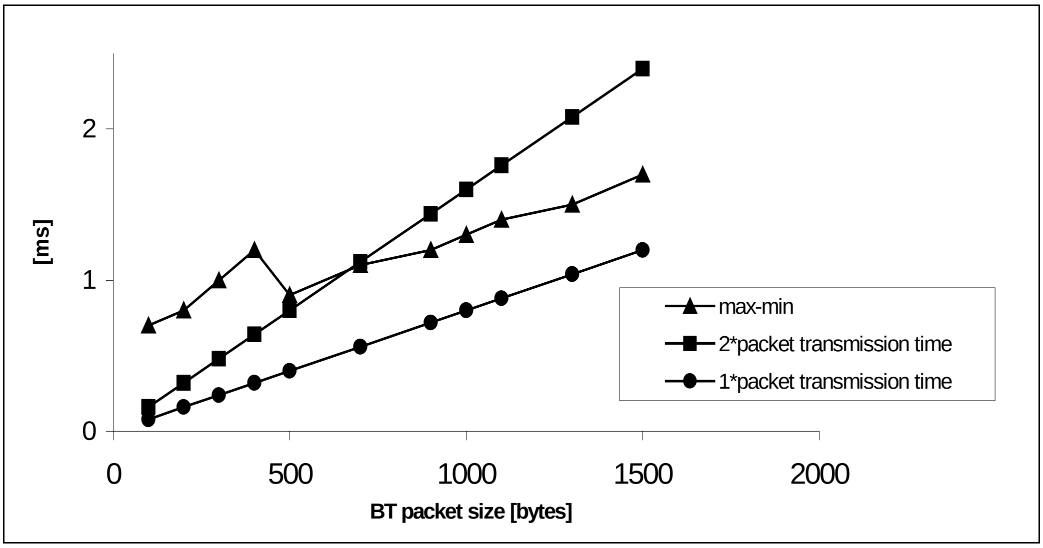

Figure 6-16. Tx-ring delay for Ethernet interface of CISCO router 7507

Conclusions

The experiment results, for Ethernet interface of the CISCO router 7507, are shown in Table 6-7. The difference between the maximum and minimum end-to-end delay (max-min column) was measured for different background packet sizes. The delay introduced by tx ring for the considered case is between 0.7 and 1.7 ms.

6.2.2.5 Router 7507, interface 155Mbit/s

Description

The goal of this trial is to verify the impact of the transmission buffer (tx-ring) size in the CISCO router 7507 (interface 155Mbps) on the PCBR packet delay. The background traffic was assumed to be constant bit rate flow.

Trial set-up

- Tested topology is shown in Figure 6-17. The Active network-probing tool from PC3 to PC1 generated foreground traffic. The IW measurement equipment generated the background traffic from aq7507_3:POS1/1/0 port to aq7507_1:POS1/1/0 port.
- Traffic parameters:
- FT: constant bit rate flow, traffic rate=133 kbps, packet size 100B, transport protocol UDP, traffic class TCL1 (network service PCBR).
- BT: constant bit rate flow, traffic rate=150Mbps, variable BT packet size, transport protocol UDP, traffic class TCL5 (network service STD).
- Test duration: 30 sec.

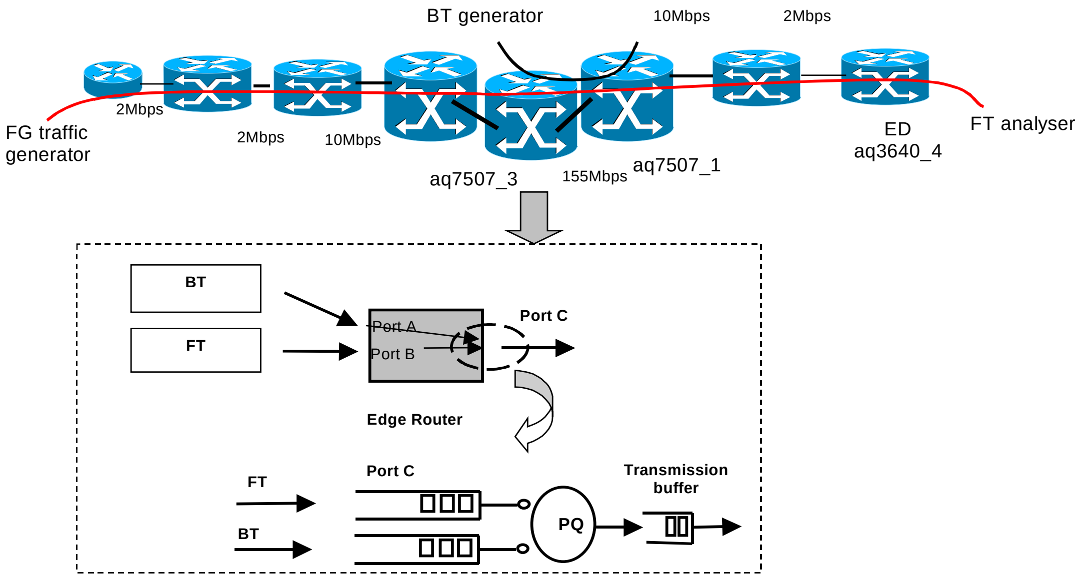

Figure 6-17. Trial topology - 5

Trial procedure

- Traffic generators generate streams of packets according to the specified traffic descriptions.
- Traffic analyser within tested flow measures packet loss rate, maximum, minimum and average end-to-end packet delay.

Results

FT packet size [B]	BT packet size [B]	Min. Delay [ms]	Max. Delay [ms]	Max-min
100	------------	2.6	2.9	-----------
100	100	2.6	----------	-----------
100	200	2.6	----------	-----------
100	300	2.6	12.5	9.9
100	400	2.6	8.5	5.9
100	500	2.6	8.9	6.3
100	700	2.6	8.1	5.5
100	900	2.6	8.7	6.1
100	1000	2.6	9.0	6.4
100	1100	2.6	8.2	5.6
100	1300	2.6	8.6	6
100	1500	2.6	8.8	6.2

Table 6-8. Results for CISCO router 7507 for STM-1 interface

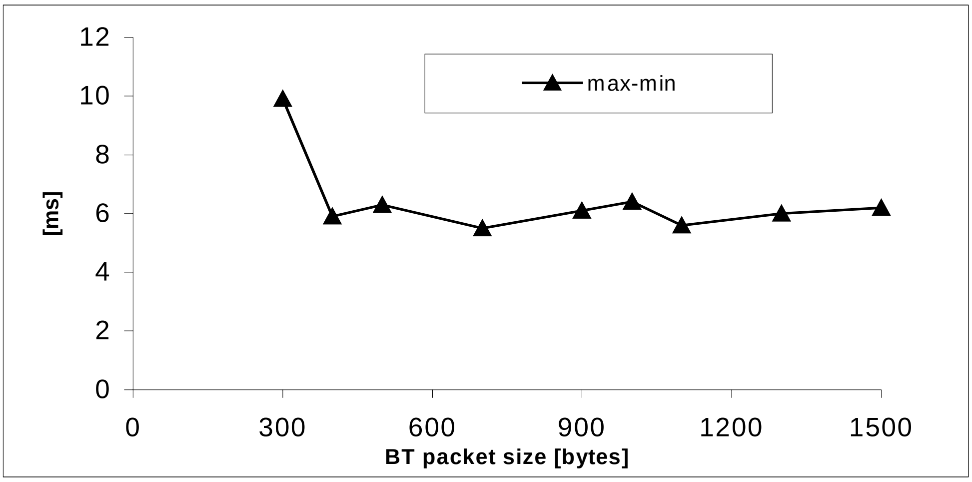

Figure 6-18. Tx-ring delays for STM-1 interface of CISCO router 7507

Conclusions

The experiment results for STM-1 interface of CISCO router 7507 are shown in Table 6-8. The difference between the maximum and minimum end-to-end delay (max-min column) was measured for different background packet sizes. Unlike in for slower interfaces the tx ring delay for 155 Mbps (POS) interface is almost constant for different values of background packet size. For higher interface rates the tx ring size is larger (the default value is about 220 allocation units). The measurement results suggest that the allocation unit size is 512 bytes. The resulting tx ring delay is a combination of packet size, allocation unit and the size of tx ring buffer. The delay introduce by tx ring in the considered case is about 6 ms.

6.2.3 QoS verification for PCBR service

In this part of document the trials of QoS verification for PCBR service are presented. The following QoS parameters were measured: minimum, maximum and average end-to-end packet delay as well as packet loss ratio. Generally, one can distinguish two groups of experiments. The first one was made for artificial traffic patterns, the second one for WinSip application (see point 6.2.4 of this document). In trials of artificial flows, minimum, maximum and average end-to-end delay was measured while in trials of WinSip application quality of speech was assessing.

6.2.3.1 Trial of end-to-end packet delay (with independent background traffic in each node of the trial topology)

Description

The aim of this trial is to verify the assumptions made for development of admission control algorithms for PCBR service. Minimum, maximum and average end-to-end packet delays were measured assuming the worst-case traffic scenarios for PCBR service (Poissonian flow) [D1301] and background flows (constant bit rate flows). In this trial, the assumed worst-case background traffic patterns allowed to load output links of all routers through the way of foreground traffic.

Trial set-up

- Tested topology is shown in Figure 6-19. The Synthetic flow generator from PC3 to PC1 generated foreground traffic. Five background traffic flows (BT1, BT2, BT3, BT4, and BT5 traffic) were loaded into the links of up-direction of the PC3 user. The HP BSTS measurement equipment from aq1605_2:eth 1 port to aq3640_3:eth0/1 port generated the BT1 traffic. The IW equipment from aq3640_3:eth0/2 port to aq3640_2:eth0/2 port generated the BT2 traffic and from aq3640_2:eth0/1 port to aq7507_2:eth0/0/3 port generated BT3 traffic. RT measurement equipment from aq7507_2:POS1/1/0 port to aq7507_1:POS4/1/0 port generated BT4 traffic and from aq7507_1:fast_eth1/0/0 port to aq3640_1:fast_eth2/0 port generated BT5 traffic.

- Traffic parameters:

- FT: traffic class TCL1 (network service PCBR), Poissonian flow (minimum packet inter-arrival time = 1 ms), traffic rate=133kbps, variable packet size, transport protocol UDP.

- Background traffics characteristics:

  - BT1: ON/OFF flow with parameters: ON period 100 ms (peak rate =3Mbps), OFF period 500 ms, packet size=1000B.

  - BT2: ON/OFF flow with parameters: ON period 100 ms (peak rate =3 Mbps), OFF period 500 ms, packet size=1000B.

  - BT3: ON/OFF flow with parameters: ON period 100 ms (peak rate =10 Mbps), OFF period 100 ms, packet size=1000B.

  - BT4: ON/OFF flow with parameters: ON period (peak rate 155 Mbps, 1000 packets), SR=100 Mbps.

  - BT5: ON/OFF flow with parameters: ON period (peak rate=15Mbps, 1000 packets), SR = 6Mbps.

  - Transport protocol UDP, traffic class TCL5 (network service STD).

- QoS objectives

- TCL1: Buffer size=5 packets, AC limit=200kbps (for 2Mbps links), target packet loss ratio=$10^{-2} \Rightarrow \rho=0.685 \Rightarrow$ TCL1 target utilisation=137 kbps.

- Test duration: 1h.

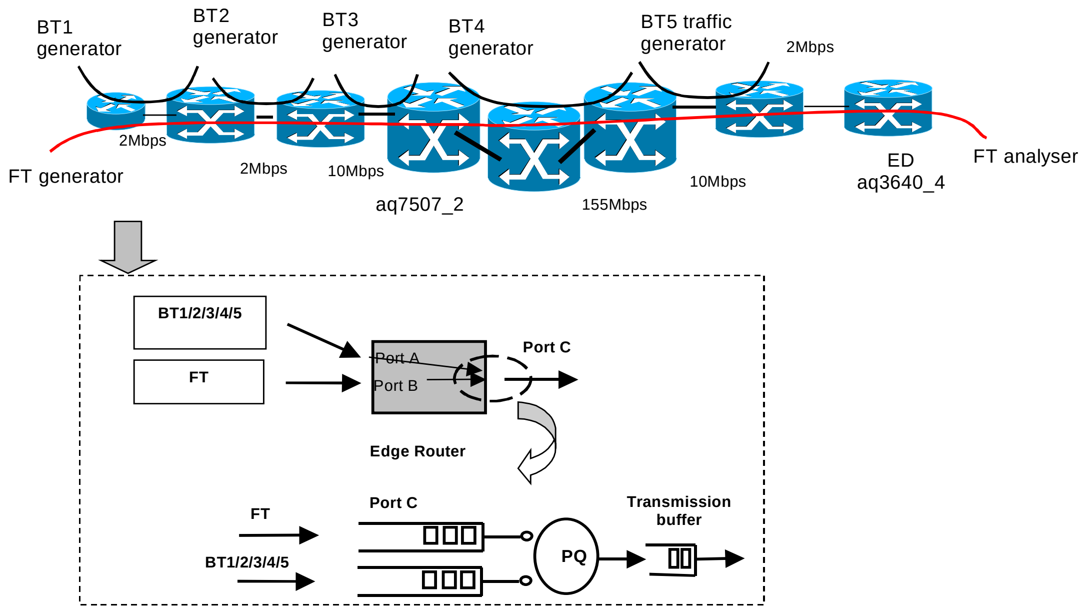

Figure 6-19. Trial topology - 6

FT packet size [bytes]	Min. Delay [ms]	Max. Delay [ms]	Avg. Delay [ms]
64	20.1	35.2	27.5
128	20.9	36.9	28.6
256	26.2	37.6	31.7
512	29.6	41.5	35.3
1024	37.1	48.4	42.7

Table 6-9. Results for trial of minimum, maximum, and average end-to-end packet delay

Packet losses within tested flow were not observed (as it was expected).

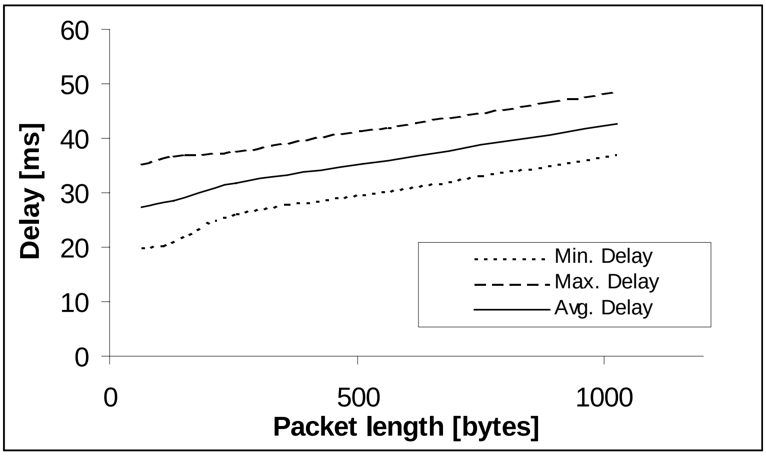

Figure 6-20. One-way delay vs. PCBR packet length

Conclusions

The measured values of maximum delay for all types of foreground traffic packets: 64, 128, 256, 512, and 1024 bytes are less than target value for PCBR service (<<150 ms). Additionally, one can conclude that the values of maximum, minimum and average end-to-end delay depend on size of foreground traffic packets directly. These values are growing up along with values of background traffic packet sizes.

6.2.3.2 Trial of end-to-end packet delay (with mix of packet sizes in background traffic)

Description

The aim of this trial is to verify the assumptions made for development of admission control algorithms for PCBR service. Minimum, maximum, and average packet delay values were measured assuming the worst-case traffic scenario for PCBR service (Poissonian flow), tested flow (flow with constant bit rate) and background traffic (mix of packets with different sizes – proportionally to the percentage of packets observed in the Internet).

Trial set-up

- Tested topology is shown in Figure 6-21. The Synthetic flow generator from PC3 to PC1 generated foreground traffic. The HP BSTS measurement equipment from aq1605_2:eth1 port to aq3640_3:eth0/2 port generated the background traffic and from aq1605_2:eth1 port to aq_3640_4:eth1 port generated the tested flow.
- Traffic parameters:
- FT: traffic class TCL1 (network service PCBR), Poissonian flow (minimum packet inter-arrival time = 1 ms), traffic rate = 133kbps, packet size=100B or 200B, transport protocol UDP.
- BT: traffic class TCL5 (network service STD), constant bit rate flow with traffic rate=3Mbps, packet size: 7% of volume – 44 B, 21% of volume – 256 B, 72% of volume – 1280 B, transport protocol UDP.
- Tested flow: CBR flow with traffic rate=1 or 2 packets/sec, packet size= 100B
- QoS objectives
- TCL1: Buffer size=5 packets, AC limit=200kbps (for 2Mbps links), target packet loss ratio=$10^{-2} \Rightarrow \rho=0.685 \Rightarrow$ TCL1 target utilisation=137 kbps.
- Test duration: 1h.

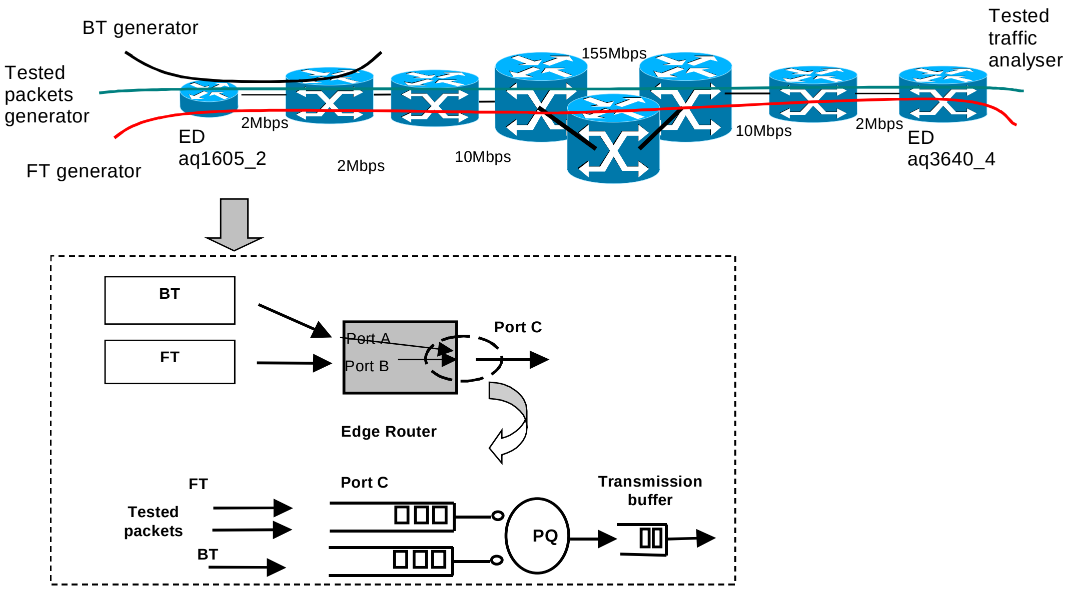

Figure 6-21. Trial topology - 7

Tested traffic [packets/sec]	FT packet size [bytes]	Minimum delay [ms]	Maximum delay [ms]	Average delay [ms]
2	100	3.1	11.1	7.5
2	200	5.2	12.9	9.4
2	300	7.2	14.1	11.0
2	400	9.0	15.7	13.0
1	500	9.7	17.4	14.4
1	800	16.7	23.9	19.2
1	1000	19.1	27.6	22.2
1	1400	26.7	35.0	28.5

Table 6-10. Results for trial of minimum, maximum, and average packet delay (with background traffic)

Conclusions

The values of maximum delay for all packet sizes of foreground traffic are less than the target values (<<150ms). These values are growing up along with values of the foreground traffic packet sizes.

6.2.3.3 Trial of packet loss rate (without background traffic)

Description

The aim of this trial is to verify the assumptions made for development of admission control algorithms for PCBR service. QoS parameter: packet loss rate values were measured assuming Poissonian flow as the worst-case traffic scenario for PCBR service. In this trial the whole input link capacity (2Mbps) was used as the AC limit of TCL1 class.

Trial set-up

- Tested topology is shown in Figure 6-22. The Synthetic flow generator from PC3 to PC1 generated foreground traffic.
- Traffic parameters:
- FT: traffic class TCL1 (network service PCBR), Poissonian flow (minimum packet inter-arrival time = 1 ms), traffic rate 1.33Mbps, constant packet size=1000B, transport protocol UDP.
- QoS objectives
- Buffer size=5 packets, AC limit=2Mbps, target packet loss = 10^{-2} ⇒ ρ=0.685⇒ TCL1 target utilisation=1.37 Mbps.
- Test duration: 10 min.

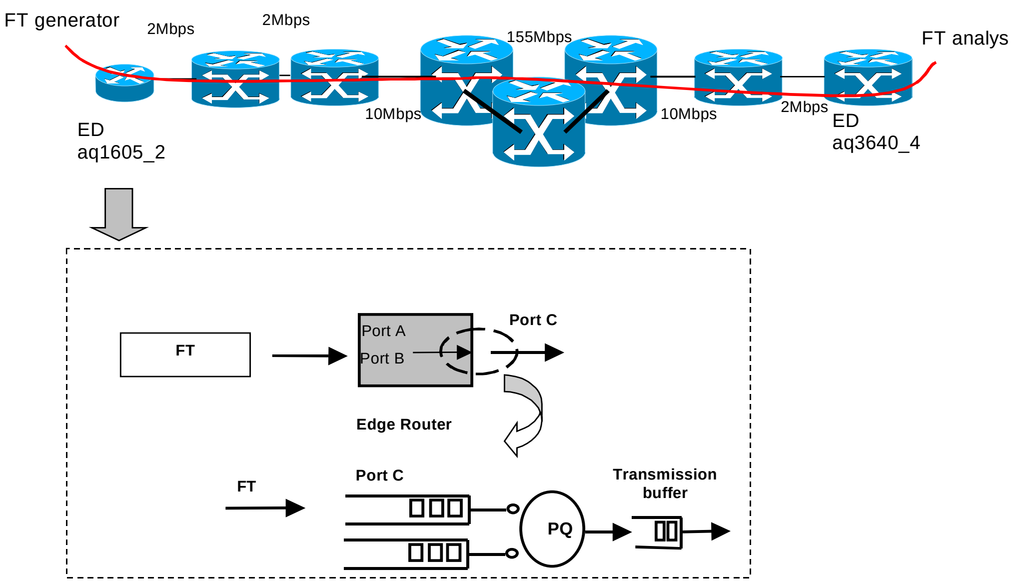

Figure 6-22. Trial topology - 8

Trial procedure

- Traffic generators generate streams of packets according to the specified traffic description.
- Traffic analyser within tested flow measures packet loss ratio

Results

Packet loss ratio = $3*10^{-4}$

Conclusions

The level of measured packet loss ratio is satisfying. The measured value is less than value obtained from the formula: 10^{-2}.

6.2.3.4 Trial of packet loss ratio (with background traffic), for output link - 2 Mbps

Description

The aim of this trial is to verify the assumptions made for development of admission control algorithms for PCBR service. Packet loss ratio was measured assuming the worst-case traffic scenario for PCBR service (Poissonian flow) and background traffic (mix of packets with different sizes – proportionally to the percentage of packets observed in the Internet).

Trial set-up

- Tested topology is shown in Figure 6-23. The Synthetic flow generator from PC3 to PC1 generated foreground traffic. The HP BSTS measurement equipment from aq1605_2:eth1 port to aq3640_3:eth0/2 port generated the background traffic.
- Traffic parameters:
- FT: traffic class TCL1 (network service PCBR), Poissonian flow (minimum packet inter-arrival time = 1 ms), variable traffic rate, packet size=100B or 200B, transport protocol UDP.
- BT: CBR flow with traffic rate=3Mbps, packet size: 7% of volume -44B, 21% of volume – 256B, 72% of volume – 1280B, transport protocol UDP, traffic class TCL5 (network service STD).
- QoS objectives
- TCL1: Buffer size=5 packets, AC limit=200kbps, target packet loss = $10^{-2} \Rightarrow \rho=0.685 \Rightarrow$ TCL1 target utilisation=137 kbps.
- Test duration: 1h.

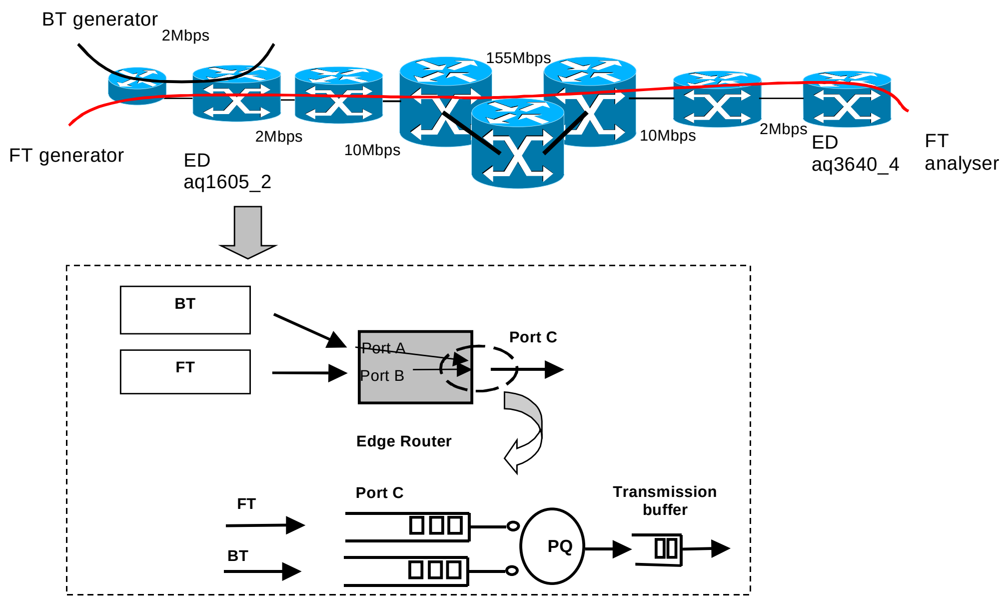

Figure 6-23. Trial topology – 9

FT traffic [kbps]	FT packet size [bytes]	Number of transmitted packet	Number of lost packets	Packet loss ratio
100	100	415537	2	$4*10^{-6}$
133	**100**	**543223**	**7**	$\mathbf{1*10^{-5}}$
160	100	641689	5	$7*10^{-6}$
200	100	783082	44	$5*10^{-5}$
400	200	783082	31	$3*10^{-5}$

Table 6-11. Results from trial of packet loss ratio

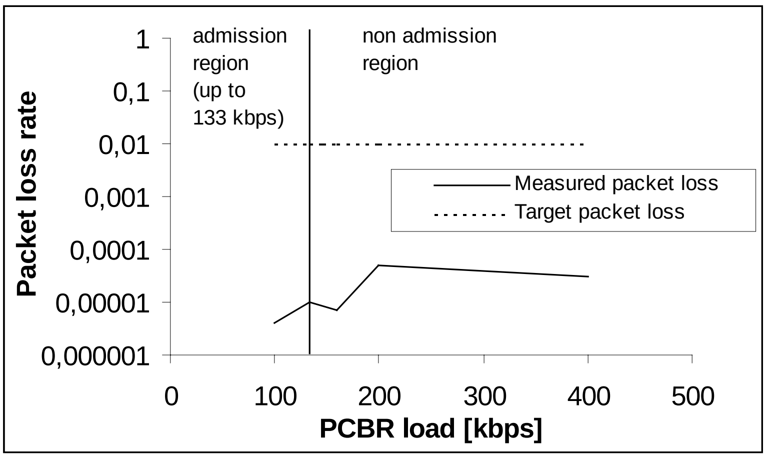

Figure 6-24. Packet loss rate vs. PCBR traffic load

Conclusions

One can conclude that the level of packet loss ratio is satisfying for each rate of foreground traffic. It is smaller than target packet loss ratio = 10^{-2}.

6.2.4 Trials of WINSIP application

Siemens AG Österreich and the Institut für Computertechnik Technische Universität Wien develop WinSip application. It is an IP Telephony software component based on the Session Initiation Protocol (SIP). SIP is an IETF recommendation [RFC2976]. The simplified trials of this part provide the subjective speech assessments as well as end-to-end delay measurements using artificial foreground traffic. The assumed traffic patterns of artificial flows were eligible with values of Single_Rate characteristic for WinSip application traffic.

6.2.4.1 Trial of WINSIP application – assessing of speech quality using PCBR service (background traffic: constant bit rate)

Description

The aim of this trial is to assess quality of speech. The trial conversation was realised by WinSip application. Traffic generated by WinSip application was served by PCBR service (TCL1 class). Speech quality was measured in two cases: without and with background traffic in the network. Background traffic flows were constant bit rate type.

Trial set-up

- Tested topology is shown in Figure 6-25. Two persons spoke using WINSIP application. One of them was user of the PC1 computer while the second one used the PC3 computer. The quality of speech was assessing by user of the PC1. In the first case, no background traffic was loaded into the network. In the second case (case#2), two background traffic flows (BT1 and BT2 traffic) were loaded into the links of up-direction of the PC3 user. The HP BSTS measurement equipment from aq1605_2:eth 1 port to aq3640_3:eth0/1 port generated the BT1 traffic. The IW equipment from aq3640_2:eth0/2 port to aq7507_2:fast_eth1/0/1 port generated the BT2 traffic.

Case#1

- Traffic parameters:

- WINSIP application generated the following traffic (in up- or down-direction): 16 Ethernet frames/sec, it means 71.4 kbps. TCL1 class (network service PCBR) served this traffic. The coded voice information is conveyed with RTP/UDP/IP protocols.

Case#2

- Traffic parameters:

- WinSip application generated the following traffic (in up- or down-direction): 16 Ethernet frames/sec, it means 71.4 kbps. TCL1 class (network service PCBR) served this traffic. The coded voice information is conveyed with RTP/UDP/IP protocols.

- Background traffic characteristics:

  – BT1: constant bit rate flow with traffic rate=3 Mbps, packet size=1000B

  – BT2: constant bit rate flow with traffic rate=10 Mbps, packet size=1000B

  Transport protocol UDP, traffic class TCL5 (network service STD).

- QoS objectives

- TCL1: Buffer size=5 packets, AC limit (for link bandwith 2Mbps)=200kbps, target packet loss = 10^{-2} $\Rightarrow$ ρ=0.685$\Rightarrow$ TCL1 target utilisation=137 kbps.

- Policing parameters: Single_Rate (PR=72 kbps, BSP=2000 B)

- Test duration: 3 min.

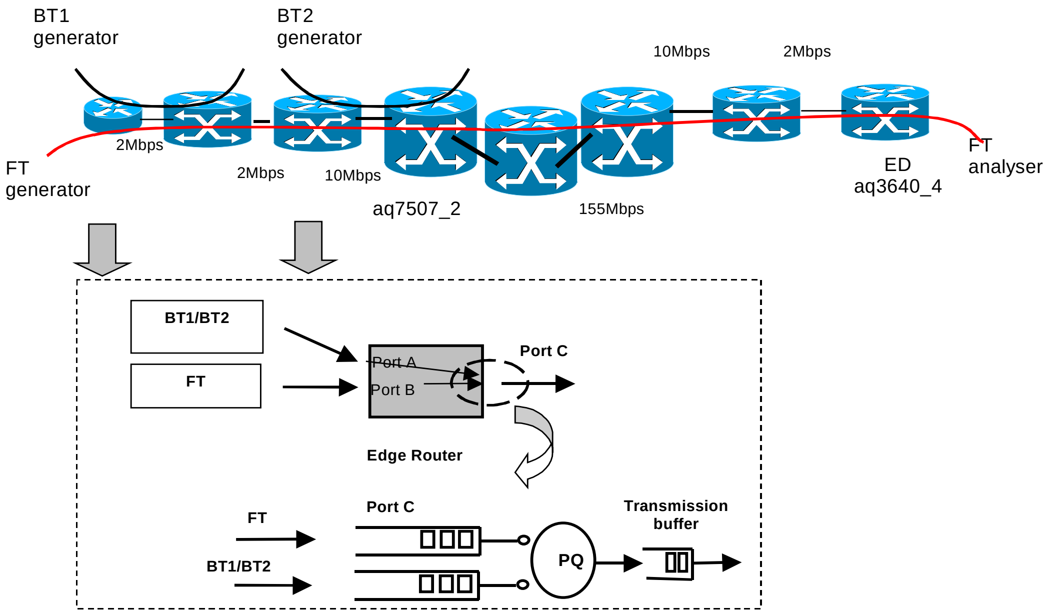

Figure 6-25. Trial topology – 10

Results

Quality of the trial speech was acceptable in both cases of trial. In the case#2, the background traffic had no impact on quality of speech.

Conclusions

Persons, who assessed the quality of trial speech, noticed the echo effect in both cases of this trial. Such effect becomes when round-trip delay is more than 50 ms (the payload size of packets generated by WinSip application is 500 bytes, it introduce 62 ms delay by PCM coding process).

6.2.4.2 Trial of WINSIP application – assessing of speech quality using STD service

Description

The aim of this trial is to assess quality of speech. The trial conversation was realised by WinSip application. Traffic generated by WinSip application was served by STD service (TCL5 class). Speech quality was measured assuming the background traffic in TCL5 class. Background traffic flows were constant bit rate type.

Trial set-up

- Tested topology is shown in Figure 6-26. Two persons spoke using WinSip application. One of them was user of the PC1 computer while the second one used the PC3 computer. The quality of speech was assessing by user of the PC1. Two background traffic flows (BT1 and BT2 traffic) were loaded into the links of up-direction of the PC3 user. The HP BSTS measurement equipment from aq1605_2:eth 1 port to aq3640_3:eth0/1 port generated the BT1 traffic. The IW equipment from aq3640_2:eth0/2 port to aq7507_2:fast_eth1/0/1 port generated the BT2 traffic.

- Traffic parameters:

- WinSip application generated the following traffic (in up- as well as in down-direction): 16 Ethernet frames/sec, it means 71.4 kbps. TCL5 class (network service STD) served this traffic. The coded voice information is conveyed with RTP/UDP/IP protocols.

- Background traffic characteristics:

  - BT1: constant bit rate flow with traffic rate=3 Mbps, packet size=1000B

  - BT2: constant bit rate flow with traffic rate=10 Mbps, packet size=1000B

  Transport protocol UDP, traffic class TCL5 (network service STD).

- QoS objectives

- TCL5: Buffer size=64 packets.

- Test duration: 3 min.

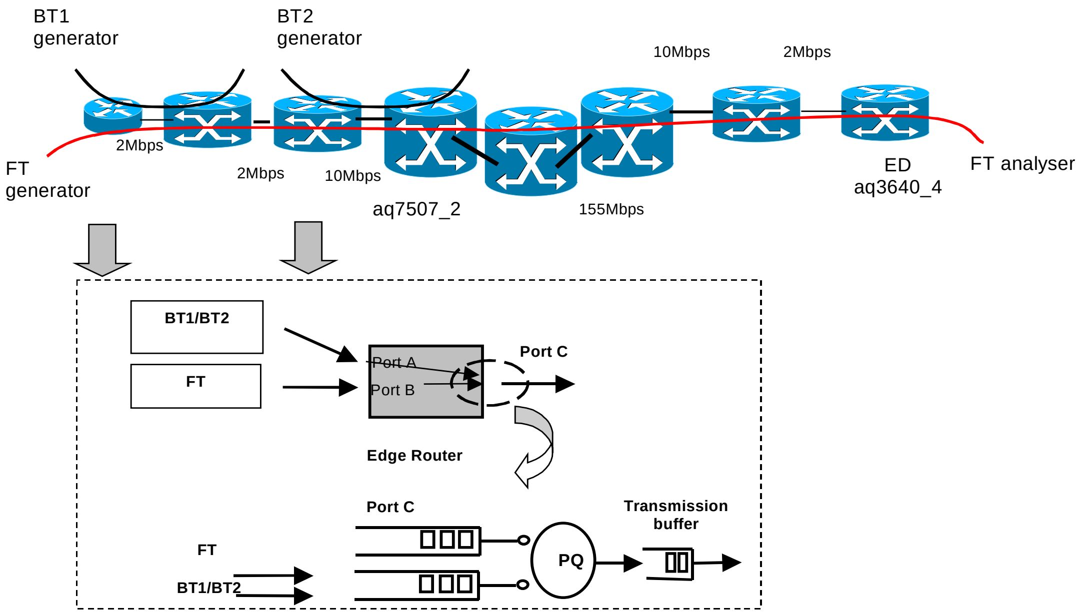

Figure 6-26. Trial topology – 11

Results

Quality of the trial speech was not acceptable.

Conclusions

The above verdict was expected, because of no guarantee of quality of service by the TCL5 class.

6.2.4.3 Trial of WINSIP application – assessing of speech quality using PCBR service (background traffic: ON/OFF type)

Description

This trial consists of two trial cases (case#1 and case#2). The aim of the case#1 was to assess quality of speech, which was realised by WinSip application. Traffic generated by WinSip application wass served by PCBR service (TCL1 class). The goal of the case#2 was to measure end-to-end delay values for artificial flows, which traffic pattern was consistent with traffic generated by WinSip application. Quality of speech and end-to-end delay were measured loading background traffic into the network. Background traffic flows were ON/OFF type, because of verification the impact of tx ring mechanism in the output port (see point 6.2.2 of this document).

Trial set-up

- Tested topology is shown in Figure 6-27. In case#1, two persons spoke using WinSip application. One of them was user of the PC1 computer while the second one used the PC3 computer. The quality of speech was assessing by user of the PC1. In the second case of trial (case#2), five background traffic flows (BT1, BT2, BT3, BT4, and BT5 traffic) were loaded into the links of up-direction of the PC3 user. The HP BSTS measurement equipment from aq1605_2:eth 1 port to aq3640_3:eth0/1 port generated the BT1 traffic. The IW equipment from aq3640_3:eth0/2 port to aq3640_2:eth0/2 port generated the BT2 traffic and from aq3640_2:eth0/1 port to aq7507_2:eth0/0/3 port generated BT3 traffic. RT measurement equipment from aq7507_2:POS1/1/0 port to aq7507_1:POS4/1/0 port generated BT4 traffic and from aq7507_1:fast_eth1/0/0 port to aq3640_1:fast_eth2/0 port generated BT5 traffic.

Case#1

- Traffic parameters:
- WinSip application generated the following traffic (in up- or down-direction): 16 Ethernet frames/sec, it means 71.4 kbps. TCL1 class (network service PCBR) served this traffic. The coded voice information is conveyed with RTP/UDP/IP protocols.
- Background traffic characteristics:
  - BT1: ON/OFF flow with parameters: ON period 100 ms (peak rate =3Mbps), OFF period 500 ms, packet size=1000B.
  - BT2: ON/OFF flow with parameters: ON period 100 ms (peak rate =3 Mbps), OFF period 500 ms, packet size=1000B.
  - BT3: ON/OFF flow with parameters: ON period 100 ms (peak rate =10 Mbps), OFF period 100 ms, packet size=1000B.
  - BT4: ON/OFF flow with parameters: ON period (peak rate 155 Mbps, 1000 packets), SR=100 Mbps.
  - BT5: ON/OFF flow with parameters: ON period (peak rate=15Mbps, 1000 packets), SR = 6Mbps.

  Transport protocol UDP, traffic class TCL5 (network service STD).

Case#2

- Traffic parameters:
- FT: TCL1 class (network service PCBR), flow with constant bit rate, transport protocol: UDP.
- Background traffic characteristics:
  - No BT1 (limited number of traffic generators)
  - BT2: ON/OFF flow with parameters: ON period 100 ms (peak rate =3 Mbps), OFF period 500 ms, packet size=1000B.

- BT3: ON/OFF flow with parameters: ON period 100 ms (peak rate =10 Mbps), OFF period 100 ms, packet size=1000B.
- BT4: ON/OFF flow with parameters: ON period (peak rate 155 Mbps, 1000 packets), SR=100 Mbps.
- BT5: ON/OFF flow with parameters: ON period – peak rate=15Mbps, SR = 6Mbps.

Transport protocol UDP, traffic class TCL5 (network service STD).

- QoS objectives
- TCL1: Buffer size=5 packets, AC limit (for link bandwidth: 2Mbps)=200kbps, target packet loss = 10^{-2} ⇒ ρ=0.685⇒ TCL1 target utilisation=137 kbps.
- Policing parameters: Single_Rate (PR=72 kbps, BSP=2000 B)
- Test duration: 3 min.

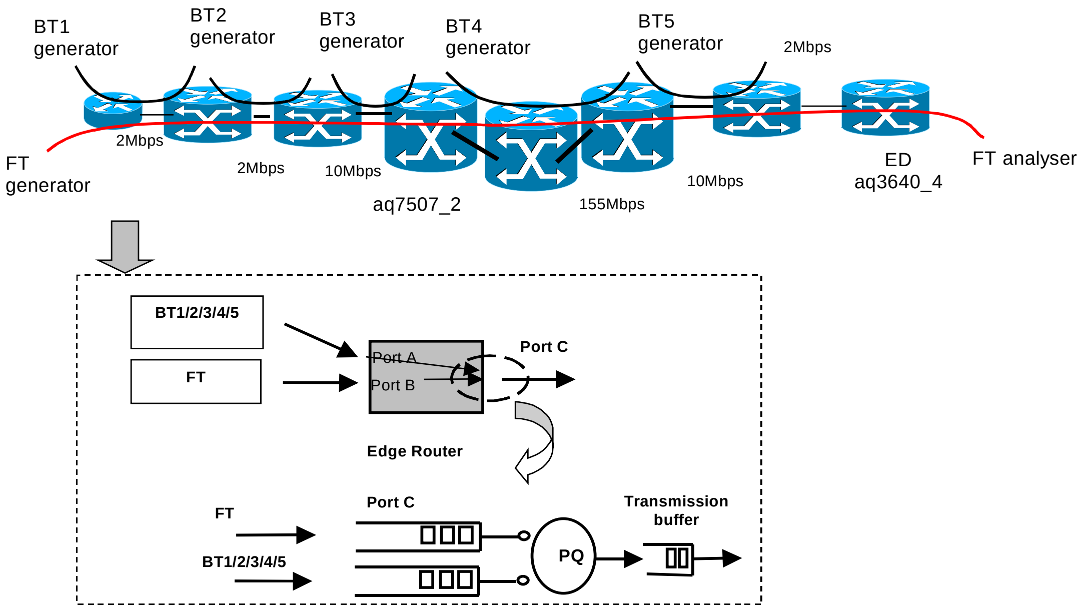

Figure 6-27. Trial topology – 12

Results

Case#1

Quality of the trial speech was acceptable in both trial cases. In this trial, the background traffic has no impact on quality of speech.

Case#2

Min. end-to-end delay: 23 ms

Max. end-to-end delay: 37 ms

Avg. end-to-end delay: 32 ms

Conclusions

In case#1 persons, who assessed the quality of trial speech, noticed the echo effect. Such effect becomes when round-trip delay is more than 50 ms (the payload size of packets generated by WinSip application is 500 bytes and it introduces 62 ms delay by PCM coding process).

In case#2, the minimum, maximum and average end-to-end packet delay for artificial flows values were measured. The values are less than target value (<<150ms). Let's notice that in this case it is no possibility to observe coding delay, as it is for voice applications.

6.2.5 Summary

The aim of first part of PCBR service trials was to identify limitations of edge and core routers, having an impact on quality of this service. Concerning the AQUILA scheduling algorithm the presence of additional buffering level (tx ring), after the scheduler's queues, with FIFO discipline can degrade the QoS parameters of traffic served by PCBR. In all trial cases tx ring introduces additional delay for PCBR packets. Maximum value of this additional delay is difficult to predict and depends on: router interface type as well as packet length of background traffic. The difference between the maximum and minimum (max-min column) end-to-end delay was measured for different packet sizes of background traffic. The largest value of delay introduced by tx ring was between 9 and 13 ms depending on background packet size and was obtained for 1605 CISCO router (interface 2 Mbps).

The objective of two next parts was to verify quality of PCBR service for artificial traffic patterns and for WinSip application. From these trials we can conclude that measurement results for PCBR service confirm assumptions made for this service.

6.3 Premium VBR network service

The PVBR service is proposed for real time applications, which generate traffic with variable bit rate, eg. video, teleconferencing. This service uses TCL 2 traffic class [see D1301] for carrying packets by the network. The QoS parameters of the Premium VBR service should guarantee both low packet delay and packet loss ratio. More precisely, loosely assumed maximum values of the above parameters are [see D1301]:

- delay ≤150 ms
- packet loss ratio ≤10^{-4}

Additional assumptions are the following:

- Reservation style: p2p
- Traffic characteristics at the packet level are provided in the form of dual token bucket description (Dual_Token_Bucket).

Assumed values of traffic descriptors for a potential user of PVBR service are shown in Table 6-12 (see [D1301]).

Parameter	***Minimum admitted***	***Maximum admitted***	***Default***
PR	0	1 Mb/s	…
BSP	n.a	n.a	1024 B
SR	0	PR	?
BSS	M	----	...
m	40 B	256 B	40 B
M	n.a	n.a.	512 B

Table 6-12. Possible values of traffic descriptors

6.3.1 Trial setup

The main goal of the trial experiments was practical verification of expectations from PVBR service, defined in D1301 document. In presented trials, the assumptions for TCL2 class were validated. The following experiments were made: validation of packet loss ratio, end-to-end delay assuming artificial flows only and assessing of speech quality for NetMeeting application with artificial background flows. Additionally, values of traffic descriptors for NetMeeting application were verified.

6.3.1.1 Routers output ports architecture

The output port architecture of CISCO routers for the trials of PVBR service is depicted in Figure 6-28.

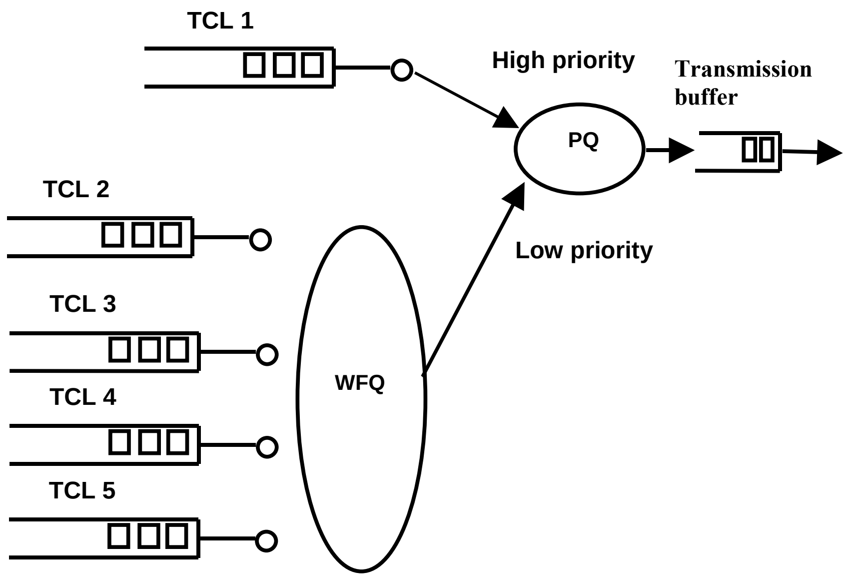

Figure 6-28. Router output ports architecture

The assumed values of dedicated bandwidth for each traffic class having 2 Mbps access link are presented in Table 6-13

Traffic class	**TCL1**	**TCL2**	**TCL3**	**TCL4**	**TCL5**
Dedicated bandwidth	200 kbps	300 kbps	600 kbps	100 kbps	800 kbps

Table 6-13. Bandwidth dedicated for each traffic class (for 2 Mbps access link)

Admission control rules for PVBR service used in presented trials are described in [D1301] document.

QoS objectives of PVBR service trials:

- TCL2: Buffer size=5 packets,
- AC limit=300kbps (for 2Mbps links),
- Target packet loss ratio=10^{-2}

In trial experiments, the value of target packet loss ratio (10^{-2}) was higher than the target value assumed for PVBR service in D1301 (10^{-4}). It was assumed to obtain more reliable results in shorter time.

6.3.1.2 Specification of worst case traffic patterns

To investigate all performances of PVBR service, the worst-case traffic patterns based on artificial flows are used. It is necessary because there are no possibilities to realise all test of this service in a real network since now. The following specification of worst case traffic patterns correspond to both individual and aggregated flows and are limited by the measurement tools available in the first trial.

Worst case traffic patterns for tested flow (foreground traffic - FT):

- Flow with variable bit rate – ON/OFF traffic pattern with constant bit rate in ON period and constant burst size;

Worst-case traffic patterns for aggregated flows submitted inside the tested traffic class/network service:

- Superposition of ON/OFF flows (e.g. MMDP – Markov Modulated Deterministic Process)

Traffic pattern for background traffic - BT

- Flows with constant bit rate sufficient to load the network resources dedicated to not-tested traffic class/network service.

6.3.2 QoS verification of PVBR service

In this part, the trials of QoS verification of PVBR service are presented. The following QoS parameters were measured: minimum, maximum and average end-to-end packet delay as well as packet loss ratio. Generally, one can distinguish between two groups of experiments. The first experiments were performed for artificial traffic patterns only while the second ones for NetMeeting application. The trials corresponding to the NetMeeting application take also into account the assessment of speech and video quality.

6.3.2.1 Measurements of end-to-end delay and packet loss ratio

Description

The aim of this trial was to verify the assumptions made for development of admission control algorithms for PVBR service. Packet loss ratio as well as minimum, maximum and average end-to-end delay were measured assuming superposition of ON/OFF flows as traffic scenario for PVBR service and constant bit rate background traffic.

Trial set-up

- Tested topology is shown in Figure 6-29. The Synthetic flow generator from PC3 to PC1 generated foreground traffic. The HP BSTS measurement equipment from aq1605_2:eth1 port to aq3640_3:eth0/2 port generated the background traffic flows and tested flow. The tested flow was used to measure end-to-end delay.

- Traffic parameters:
    - Foreground traffic (FT): traffic class TCL2 (network service PVBR), trace flow: superposition of ON/OFF flows, number of flows depends on trial case, parameters of one ON/OFF flow: PR=32 kbps, SR=16kbps, BSS=4000 B or 15000 B, packet size=500B, transport protocol UDP.
    - Background traffic (BT):
        - BT1:TCL1 class (network service PCBR): CBR flow with traffic rate=200kbps, packet size: 100B, transport protocol UDP.
        - BT2: TCL3 class (network service PMM): CBR flow with traffic rate=600kbps, packet size: 500B.
        - BT3: TCL4 class (network service PMC): CBR flow with traffic rate=100kbps, packet size: 500B.
        - BT4: TCL5 class (network service STD): CBR flow with traffic rate=1000kbps, packet size: 1000B.
- QoS objectives of TCL2 class (for 2 Mbps access link)
    - AC limit=300kbps, target packet loss = 10^{-2} , Effective bandwidth for each admitted flow=27 290 bps (PR=32 kbps, SR=16kbps) => number of admitted flows according to the AC algorithm = 10. $\sum_{i=1}^{10} Eff_i = 272.9kbps$.
- Test duration: 1h.

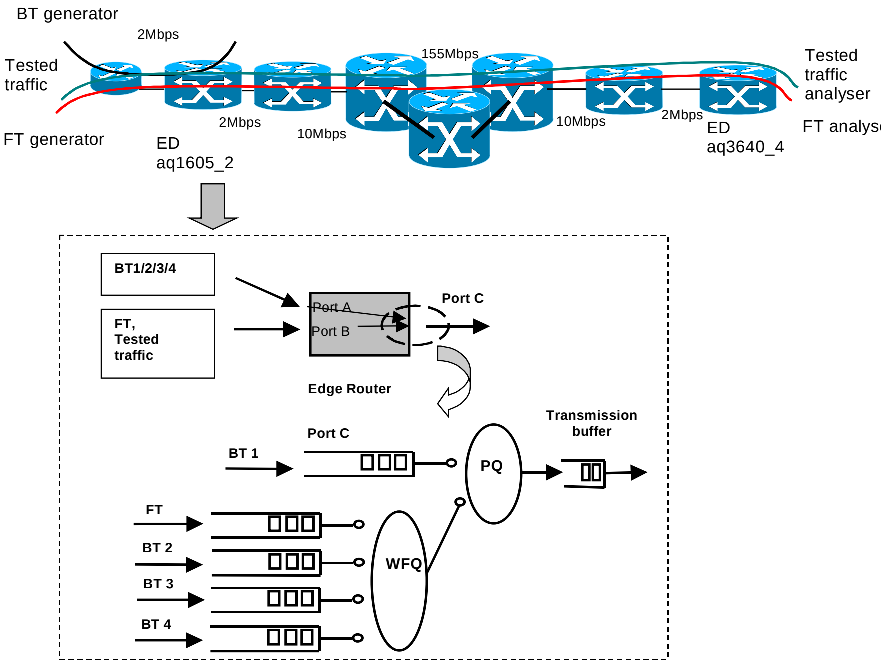

Figure 6-29. Trial topology -13

FT, average bit rate [kbps]	FT, peak bit rate [kbps]	Number of flows	Packet loss ratio
144	288	9	0
160	**320**	**10**	**$1*10^{-4}$**
192	384	12	$2*10^{-3}$

Table 6-14. Results from trial of packet loss ratio for different traffic rate (BSS=15000 B)

FT, average bit rate [kbps]	FT, maximum peak bit rate [kbps]	Number of flows	BSS [bytes]	Packet loss ratio
160	**320**	**10**	**4000**	**$7*10^{-5}$**
160	**320**	**10**	**15000**	**$1*10^{-4}$**

Table 6-15. Results from trial of packet loss ratio for different Burst Size (BSS)

FT, average bit rate [kbps]	FT, maximum peak bit rate [kbps]	Number of flows	BSS [bytes]	Min. Delay [ms]	Max. Delay [ms]	Avg. Delay [ms]
144	288	9	15000	10.1	47.7	22.9
160	**320**	**10**	**4000**	**9.7**	**76.7**	**24.4**
160	**320**	**10**	**15000**	**10.1**	**82.9**	**23.4**
192	384	12	15000	9.6	86.0	26.2

Table 6-16. Results from trial of end-to-end delay ratio for different traffic rate

Conclusions

One can conclude that the level of packet loss ratio is satisfying for each rate of foreground traffic. It is smaller than target packet loss ratio = 10^{-2}. Values of end-to-end delay are also smaller than target ≤ 150 ms. Let us remark that maximum measured value of end-to-end delay was 82.9 ms for flows admitted according to AC limit for TCL2 class. This value is rather large assuming background traffic in ingress router only. In fact, values of packet loss ratio do not depend on BSS value, as it was expected.

6.3.2.2 Measurements of end-to-end delay and packet loss ratio

Description

The aim of this trial was to verify the assumptions made for development of admission control algorithms for PVBR service. Packet loss ratio as well as minimum, maximum and average end-to-end delays were measured assuming the worst-case traffic scenario for PVBR service (superposition of 30 ON/OFF flows) and constant bit rate background traffic. In contrary to the trial presented before, in this case superposition of more ON/OFF sources were tested (for receiving better multiplexing gain).

Trial set-up

- Tested topology is shown in Figure 6-30. The Synthetic flow generator from PC3 to PC1 generated foreground traffic (superposition of ON/OFF sources). The HP BSTS measurement equipment from aq1605_2:eth1 port to aq3640_3:eth0/2 port generated the background traffic flows and tested flow. The test flow was used to measure end-to-end delay.

- Traffic parameters:

  - Foreground traffic (FT): traffic class TCL2 (network service PVBR), trace flow: superposition of ON/OFF flows, number of flows=30, parameters of one ON/OFF flow: PR=18.5 kbps, SR=5.6 kbps, BSS= 526B, packet size=256B, transport protocol UDP.

  - Test flow: 2 frames/s.

  - Background traffic (BT):

    - BT1:TCL1 class (network service PCBR): CBR flow with traffic rate=200kbps, packet size: 100B, transport protocol UDP.

    - BT2: TCL3 class (network service PMM): CBR flow with traffic rate=600kbps, packet size: 500B.

    - BT3: TCL4 class (network service PMC): CBR flow with traffic rate=100kbps, packet size: 500B.

  - BT4: TCL5 class (network service STD): CBR flow with traffic rate=1000kbps, packet size: 1000B.

- QoS objectives of TCL2 class (for 2 Mbps access link)
  - AC limit=300kbps, target packet loss = 10^{-2}, Effective bandwidth for each admitted flow=9.97 kbps (PR=18.5 kbps, SR=6.48 kbps) => number of admitted flows according to the AC algorithm = 30; $\sum_{i=1}^{30} Eff_i = 299.1kbps$

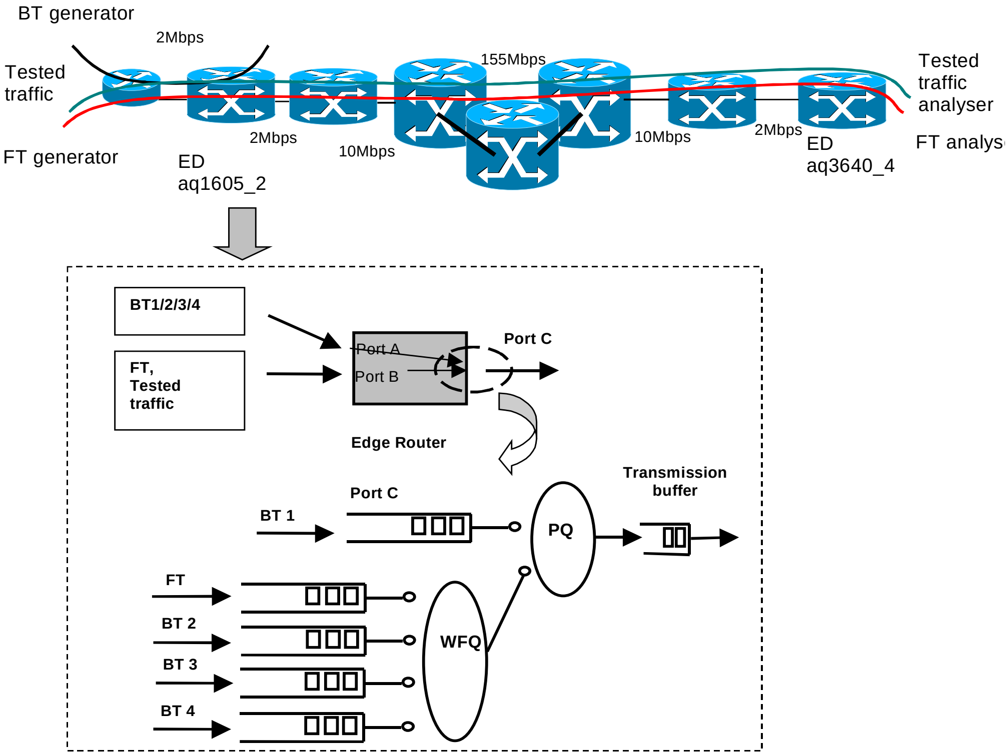

Figure 6-30. Trial topology – 14

FT, average bit rate [kbps]	FT, peak bit rate [kbps]	Number of flows	Min. Delay [ms]	Max. Delay [ms]	Avg. Delay [ms]	Packet loss ratio
194	555	30	15	44	26	10^{-5}

Table 6-17. End-to-end delay and packet loss ratio

Conclusions

One can conclude that the level of packet loss ratio is satisfying. It is smaller than target packet loss ratio = 10^{-2}. Value of end-to-end delay is also smaller than target ≤ 150 ms. In previous trial the value of maximum end-to-end delay was larger (86 ms) than the value received in this trial (44 ms), because larger size of packets (500 bytes) in foreground traffic was assumed.

6.3.3 Trials of NetMeeting application

NetMeeting application is a Windows-based conferencing tool that provides real-time communication over the Internet. NetMeeting supports audio, video, and data capabilities. More details about this application one can find in D2202 document. The simplified trials of this part provide the subjective speech assessment as well as end-to-end delay measurements using artificial foreground traffic. The assumed traffic patterns of artificial flows were consistent with values of traffic characteristic for VoIP CODEC used by NetMeeting application. Verification of traffic descriptors values for video is also provided.

6.3.3.1 NetMeeting application – verification of traffic descriptors values for video

The aim of this trial was to verify values of traffic descriptors (Dual_Token_Bucket parameters) for NetMeeting application using video and audio options. The video conferencing was realised between two persons. One of them was user of the PC1 computer while the second one used the PC3 computer. In this trial no background traffic were used. The values of traffic parameters were verified using policing mechanism (according to Dual_Token_Bucket) implemented in 1605 CISCO. The measured values, for different kinds of video quality, are presented in Table 6-18.

Session Scenario	Large window High quality video	Medium window Medium quality (1)	*Medium window Medium quality (2)*	Small window Low quality
PR	10 Mb/s	2 Mb/s	*270 kb/s*	380 kb/s
BSP	4000 bytes	2000 bytes	*10000 bytes*	2000 bytes
SR	800 kb/s	160 kb/s	*160 kb/s*	60 kb/s
BSS	8192 bytes	12000 bytes	*12000 bytes*	10000 bytes

Table 6-18. NetMeeting application - traffic description

As one can observe, the received values of parameters are higher than we can offer for PVBR service since now (300kbps).

For example for medium window and medium quality (2), we can admit one flow (effective bandwidth is equal 280.8 kbps for packet loss ratio= 10^{-2}), but in this case BSP must be 10000 bytes. The assumption of AC algorithm is that this value should be relatively small (about 2 packets only).

Due to the large values of traffic descriptors for video, for PVBR trials, only speech quality offered by NetMeeting application (audio option) was assessed.

6.3.3.2 Measurements of end-to-end delay and packet loss ratio

Description

The goal of this trial was to measure end-to-end delay values for artificial flows, which traffic pattern (superposition of 18 ON/OFF sources) was consistent with traffic generated by 18 NetMeeting applications using audio option only (Lernout&Hauspie SBC, 16kbps, 8kHz, 16Bit, Mono). Packet loss ratio as well as minimum, maximum and average end-to-end delays were measured.

Trial set-up

- Tested topology is shown in Figure 6-31. The Synthetic flow generator from PC3 to PC1 generated foreground traffic (trace flow: superposition of ON/OFF sources). The HP BSTS measurement equipment from aq1605_2:eth1 port to aq3640_3:eth0/2 port generated the background traffic flows (BT1, BT2, BT3, BT4) and tested flow. The test flow was used to measure end-to-end delay.

- Traffic parameters:

  - Foreground traffic (FT): traffic class TCL2 (network service PVBR), trace flow: superposition of ON/OFF flows, number of flows=18, parameters of one ON/OFF flow: PR=26.8 kbps (for data: PR=16kbps), SR=9.38 kbps, BSS= 762B, packet size=94B, transport protocol UDP.

  - Test flow: 2 frames/s.

  - Background traffic (BT):

    - BT1:TCL1 class (network service PCBR): CBR flow with traffic rate=200kbps, packet size: 100B, transport protocol UDP.

    - BT2: TCL3 class (network service PMM): CBR flow with traffic rate=600kbps, packet size: 500B.

    - BT3: TCL4 class (network service PMC): CBR flow with traffic rate=100kbps, packet size: 500B.

    - BT4: TCL5 class (network service STD): CBR flow with traffic rate=1000kbps, packet size: 1000B.

- QoS objectives of TCL2 class (for 2 Mbps access link)

AC limit=300kbps, target packet loss = 10^{-2}, Effective bandwidth for each admitted flow=16.55 kbps (PR=26.8 kbps, SR=9.38 kbps) => number of admitted flows according to the AC algorithm = 18. $\sum_{i=1}^{18} Eff_i = 298kbps$.

- Test duration: 1h.

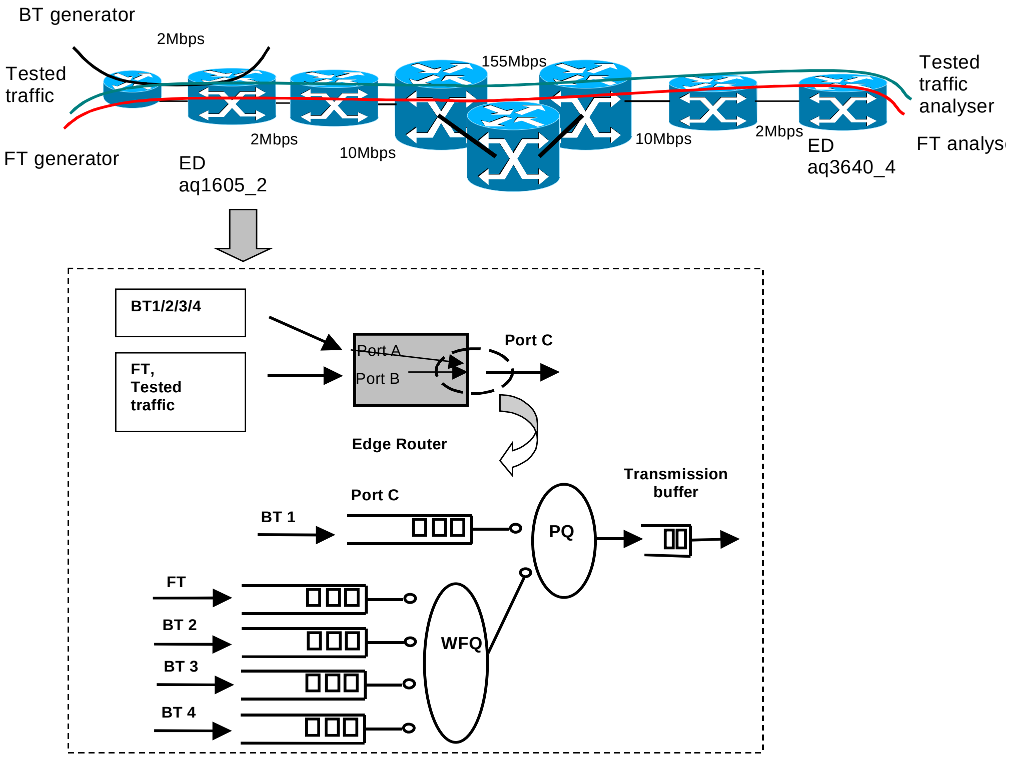

Figure 6-31. Trial topology - 15

FT, average bit rate [kbps]	FT, peak bit rate [kbps]	Number of flows	Min. Delay [ms]	Max. Delay [ms]	Avg. Delay [ms]	Packet loss ratio
168.8	482.4	18	11.6	39	24	10^{-4}

Table 6-19. End-to-end delay and packet loss ratio

Conclusions

One can conclude that the level of packet loss ratio is satisfying. It is smaller than target packet loss ratio = 10^{-2}. Value of maximum end-to-end delay is also smaller than the target value ≤ 150 ms.

6.3.3.3 NetMeeting application – assessing of speech quality

The aim of this trial was to assess quality of speech. The trial conversation was realised by NetMeeting application (using audio option only). Traffic generated by NetMeeting application was served by PVBR service (TCL2 class). Speech quality was measured assuming the background traffic in TCL1, 3, 4, 5 classes. Background traffic flows were constant bit rate type. In class TCL2 as background traffic superposition of ON/OFF sources was used. The values of traffic parameters for each ON/OFF source were consistent with characteristic of traffic generated by NetMeeting application.

Trial set-up

- Tested topology is shown in Figure 6-32. Two persons spoke using NetMeeting application. One of them was user of the PC1 computer while the second one used the PC3 computer. The quality of speech was assessing by user of the PC1. The Synthetic flow generator from PC4 to PC2 generated background traffic BG2 of TCL2 class. Five background traffic flows (BT1, BT2, BT3, BT4 and BT5 traffic) were loaded into the links of up-direction of the PC3 user. The HP BSTS measurement equipment from aq1605_2:eth 1 port to aq3640_3:eth0/1 port generated the BT1, BT3, BT4, BT5 traffic.

- Traffic parameters:

    - NetMeeting application generated the following traffic according to the Lernout&Hauspie SBC (16kbps, 8kHz, 16 bit, mono) voice codec with silence detection (in up- as well as in down-direction): it means that PR=26800 kbps (frame bit rate). TCL5 class (network service STD) served this traffic. The coded voice information is conveyed with RTP/UDP/IP protocols.

    - Foreground traffic (FT): traffic class TCL2 (network service PVBR), FT is generated by the NetMeeting application according to the Lernout&Hauspie SBC (16kbps, 8kHz, 16 bit, mono) voice codec (in up- as well as in down-direction): it means that PR=26800 kbps (frame bit rate). Effective bandwidth for this flow is equal = 16.55 kbps. The coded voice information is conveyed with RTP/UDP/IP protocols.

    - Background traffic (BT):

        - BT1:TCL1 class (network service PCBR): CBR flow with traffic rate=200kbps, packet size: 100B, transport protocol UDP.

        - BT2: TCL2 class (network service PVBR): trace flow: superposition of ON/OFF flows, number of flows: 17, traffic description of each ON/OFF flow: PR=26.8 kbps, SR=9.38 kbps, BSS=6097 B, packet size=94B, frame size=134B, transport protocol UDP.

        - BT3: TCL3 class (network service PMM): CBR flow with traffic rate=600kbps, packet size: 500B.

        - BT4: TCL4 class (network service PMC): CBR flow with traffic rate=100kbps, packet size: 500B.

- BT5: TCL5 class (network service STD): CBR flow with traffic rate=1000kbps, packet size: 1000B.

- QoS objectives of TCL2 class (for 2 Mbps access link)
  - AC limit=300kbps, target packet loss = 10^{-2}, Effective bandwidth for each admitted flow=16.55 kbps (PR=26.8 kbps, SR=9.38kbps) => number of admitted flows according to the AC algorithm = 17.
  - $\sum_{i=1}^{18} Eff_i = 298kbps$, where one source is generated by NetMeeting application and 17 sources are generated using superposition of ON/OFF sources(trace flow).

- Test duration: 1h.

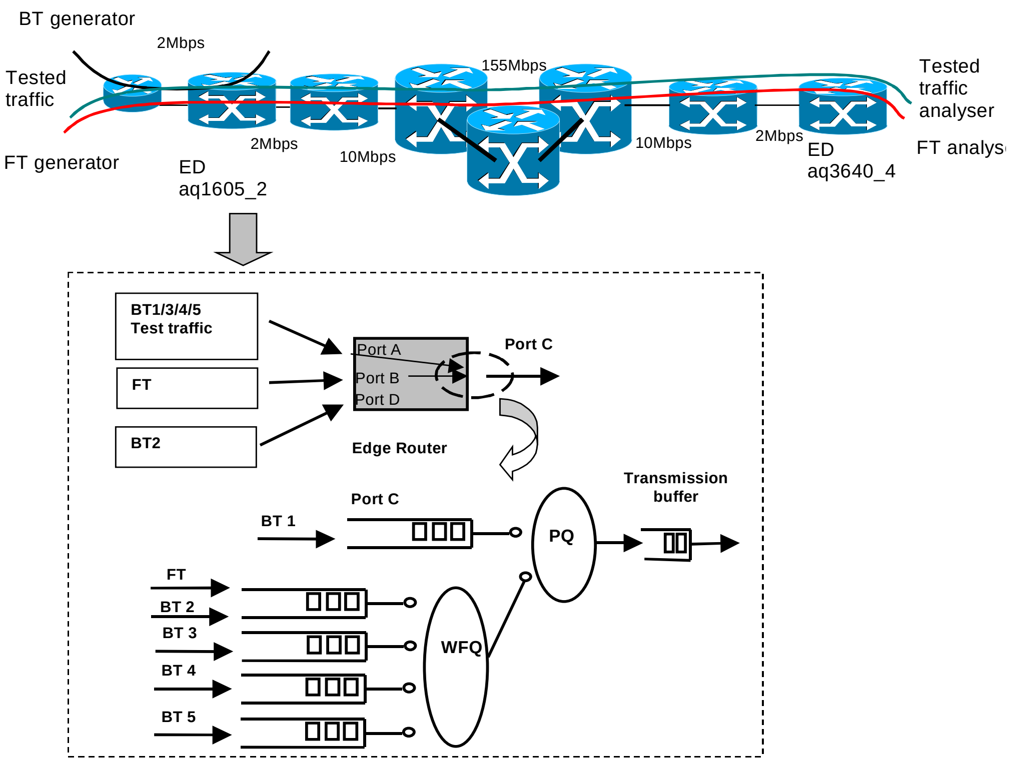

Figure 6-32. Trial topology - 16

Results

Quality of the trial speech was acceptable.

Conclusions

Persons, who assessed the quality of trial speech, do not notice any echo effect in this trial (packet size = 94 bytes) in contrary to trials of WinSip application (packet size=500 bytes).

6.3.4 Summary

The aim of the trial experiments of PVBR service was practical verification of expectations from this service. In the first part of trials packet loss ratio as well as end-to-end delay assuming artificial flows only were validate. In the next part, speech quality for NetMeeting application with artificial background flows was assessed. From obtained results, we can conclude that measurement results for PVBR service confirm assumptions made for this service.

The values of traffic descriptors for NetMeeting application using video option were also verified. Anyway, the range of bandwidth for PVBR service for 2Mbps access links is not enough to serve effectively video sent by NetMeeting application.

6.4 Premium MultiMedia network service

According to the specification in [D1301], Premium Multimedia service is targeted for low-quality video and file transfer applications. It is expected to carry a mixture of TCP and non-TCP traffic. PMM flows should be served with a guaranteed minimum throughput. Any excess bandwidth that might be available within PMM service should be divided among the competing flows.

PMM service is served by traffic class TCL3. Traffic descriptor type for PMM flows is Single_Token_Bucket. The flow is characterized by the following parameters:

parameter	*minimum admitted*	*maximum admitted*	*default*
SR	0	250 Kb/s	100 Kb/s
BSS	M	30 M	10 M
m	40 B	M	40 B
M	n.a	n.a.	1500 B

Table 6-20. Allowed values of traffic descriptor parameters

The QoS requirements for PMM service are: low P_{loss} for packets conforming to the traffic profile and no QoS guarantees for packets exceeding the traffic profile.

According to the deliverable [D1301], the new flow from TCL3 can only be admitted if the following conditions are satisfied:

$$SR_{new} + \sum_{k=1}^{N_3} SR_k \le r_i^3$$

and

$$(N_3 + 1) * M_3 < B_i^3 ,$$

where SR_{new} is the sustainable rate of new flow, the r_i^3 is AC limit, N_3 is the number flows and M_3 is the maximum packet size in the class TCL3.

6.4.1 Trial Setup

The aim of the measurements performed during the first trial is to verify the QoS affected by the flows served inside the Premium Multimedia network service. As the PMM service is intended for TCP controlled flows, the artificial greedy TCP sources will be used as measurement traffic generators. The Synthetic Flow Load Generator is a suitable application for emulating a greedy TCP controlled source. Multiple TCP streams will be generated using a multiplex option of the Synthetic flow generator.

Guaranteed portion of link bandwidth is provided for the PMM service by the WFQ scheduling discipline on the router output port. In order to investigate the behaviour of the PMM service under overloaded link conditions, background traffic must be submitted into all classes on the WFQ link. The background traffic in classes TCL1, TCL2 and TCL4 is a constant bit rate stream with a rate equal to the scheduled rate for a specific class. We assume that it is a worst-case traffic that would be allowed to the system by the admission control mechanism. The background traffic in STD traffic class is not subject to the admission control decision, so we assume that it may exceed its configured scheduling rate.

6.4.1.1 Router output port configuration

The assumed output port configuration of routers for the trials is shown in Figure 6-33. In this figure are depicted router elements, which are used in trials of PMM service.

Packets incoming to the output port are classified to appropriate queues.

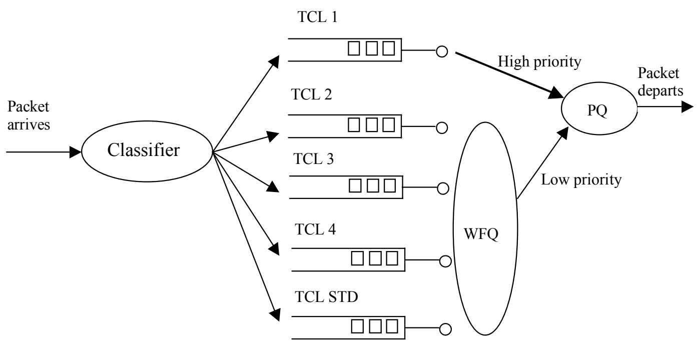

Figure 6-33. Routers output ports configuration

The scheduled bandwidth for the PMM class is equal to: 600kbit/s on a 2Mbit/s links, 3Mbit/s on a 10Mbit/s links and 46.5 Mbit/s on a 155Mbit/s links. The configuration of the WRED algorithm on a 2Mbit/s link is as follows: for “out-profile” packets the min_{th}=3, max_{th}=10, for “in-profile” packets min_{th}=10, max_{th}=15.

6.4.2 QoS verification for PMM service

6.4.2.1 Performance of single TCP flow

Description

The goal of this trial is to verify that the TCP flow served by the PMM sevice can adapt effectively to the available capacity on the link and its performance is not degraded below the capacity guaranteed for TCL3 class.

Trial setup

- Tested topology is shown in Figure 6-34.
- Traffic parameters:
- Foreground traffic: TCP controlled flow, generated from PC3 to PC1 using Synthetic flow generator. The generated flow is a 4Mbit/s constant bit rate stream with packet size equal to 1500B. Reservation was set-up for foreground traffic with parameters SR=250kbit/s, BSS=65kB.
- Background traffic: 4 constant bit rate streams generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP. Generated packets were marked with the appropriate DSCP code:
    - traffic class TCL1: 200 kbit/s, packet size 100B
    - traffic class TCL2: 300 kbit/s, packet size 500B
    - traffic class TCL4: 100 kbit/s, packet size 500B
    - traffic class TCL5: 0-1500 kbit/s, packet size 1000B

Rates of BG traffic in classes TCL2,4,5 correspond to the rates guaranteed for these classes by the WFQ scheduling discipline on the link between the Edge Device (aq1605_1) and the core network. Rate in the class TCL1 correspond to the assumed AC limit for this class. Therefore, we assume that the network load in TCLs 1,2,4 is equal to the maximum value allowed by the admission control mechanism.

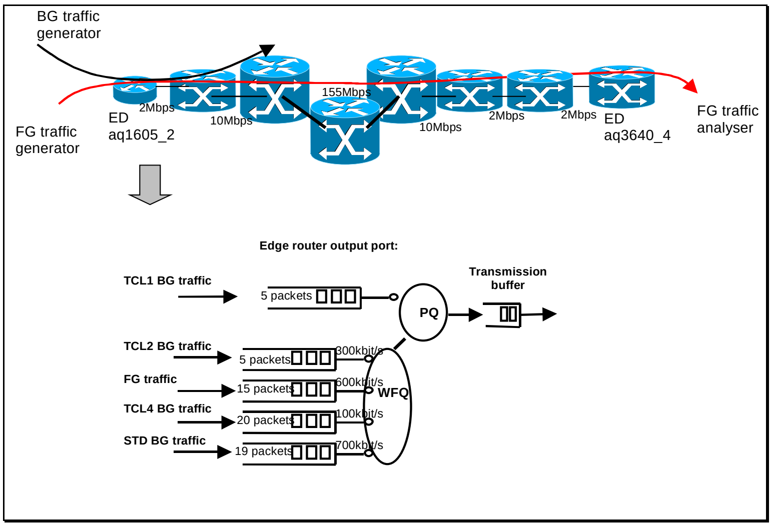

Figure 6-34. Trial topology - 17

Generated STD traffic rate [kbit/s]	Goodput of TCP flow in PMM service[kbit/s]	Measured STD traffic rate [kbit/s]	Total rate in all traffic classes [kbit/s]
0	1356	0	1956
500	891,5	500	1991,5
700	703,2	700	2003,2
800	625,85	776	2001,85
1000	615,04	774	1989,04
1200	605,88	774	1979,88
1400	621,7	776	1997,7
1500	619,461	774	1993,461

Table 6-21. Goodput of single TCP flow served by PMM

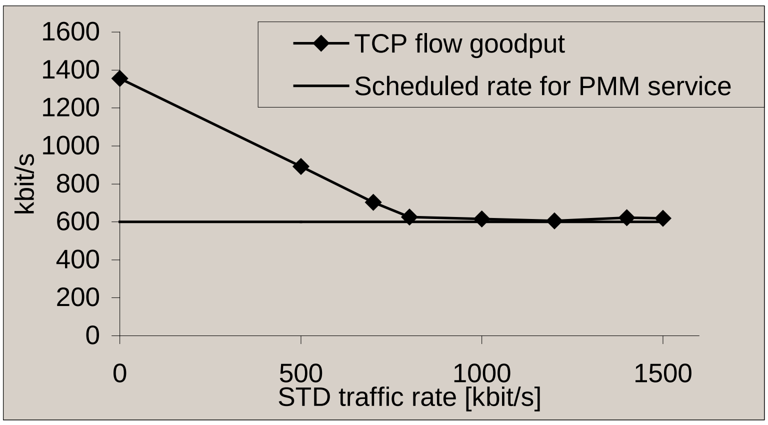

Figure 6-35. Goodput of single TCP flow served by PMM with presence of background traffic served as best effort

The bottleneck in the network is the 2Mbps link between routers aq1605_1 and aq3640_1. The scheduled bandwidth for TCL3 on this link is 600kbit/s. The results show that the TCP flow served by PMM service can adapt to the available link capacity. The sum of traffic rates in all classes is close to the bottleneck link capacity, which means that the link utilisation is high. In presence of uncontrolled background traffic served as best effort, significantly exceeding the rate configured for the STD service, the PMM flow obtains the bandwidth guaranteed for TCL3 class.

6.4.2.2 Performance of 4 TCP flows with the same reservation parameters

Description

The goal of this trial is to verify that multiple TCP flows achieve the QoS guaranteed for them in the Premium Multimedia service, and share the bandwidth available for them in a fair manner. The measured throughput of multiple TCP flows within the PMM service is compared with the requested value of SR parameter.

Trial setup

- Tested topology is shown in Figure 6-36.
- Traffic parameters:
- Foreground traffic: 4 greedy TCP controlled flows, generated using Synthetic flow generator. Reservation was set-up for each foreground flow with parameters SR=135kbit/s, BSS=15000B.
    - Flow 1 was generated between end-stations PC3 and PC1, destination port number 6000
    - Flow 2 was generated between end-stations PC3 and PC1, destination port number 6001
    - Flow 3 was generated between end-stations PC3 and PC1, destination port number 6002
    - Flow 4 was generated between end-stations PC3 and PC1, destination port number 6003

The sum of SRs of the reservations for the tested flows is equal to delta*AC_limit, so no more flows could be admitted by the admission control mechanism.

- Background traffic: 6 constant bit rate streams generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP,
    - traffic class TCL1: 200 kbit/s, packet size 100B
    - traffic class TCL2: 300 kbit/s, packet size 500B

- o traffic class TCL4: 100 kbit/s, packet size 500B
- o traffic class TCL5: 0-1200kbit/s, packet size 1000B

Rates of BG traffic in classes TCL2,4,5 correspond to the rates guaranteed for these classes by the WFQ scheduling discipline on the bottleneck link. Rate in the class TCL1 correspond to the assumed AC limit for this class.

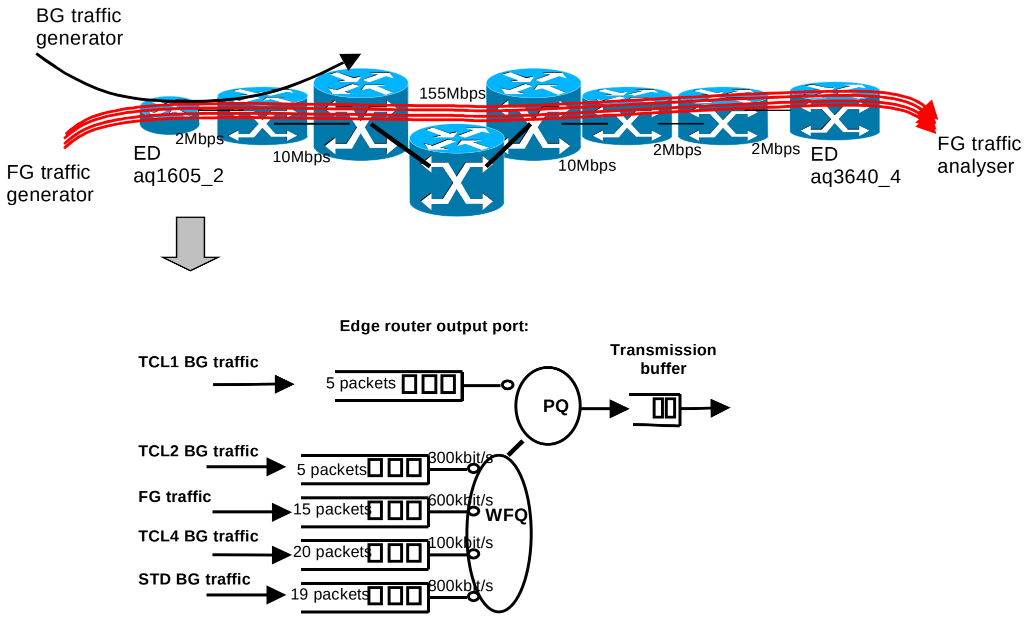

Figure 6-36. Trial topology - 18

STD BG traffic rate [kbit/s]	Flow1 goodput [kbit/s]	„In" stream throughput [kbit/s]	„Out" stream throughput [kbit/s]	„In" packet loss ratio	„Out" packet loss ratio
0	331,1	125,8	211,7	0,008	0,184
200	290,7	125,9	177,7	0,003	0,201
400	252,2	124,7	135,5	0,010	0,218
600	203,6	123,5	79,6	0,011	0,303
800	151,1	124,2	32,5	0,015	0,442
1000	146	125,2	26,7	0,014	0,500
1200	154,5	120,8	23,1	0,013	0,519

Table 6-22. TCP goodput and packet loss ratio of flow1 (Reservation parameters: SR=135kbit/s, BSS=10000B; measurement period =120s)

STD BG	Flow2 goodput	„In" stream	„Out" stream	„In" packet	„Out" packet

traffic rate [kbit/s]	[kbit/s]	throughput [kbit/s]	throughput [kbit/s]	loss ratio	loss ratio
0	328,2	126,4	236,1	0,005	0,167
200	294,7	125,0	173,1	0,009	0,196
400	234,1	121,1	121,5	0,007	0,250
600	195,6	124,9	78,5	0,009	0,302
800	149,1	122,6	32,9	0,017	0,448
1000	141,2	129,8	18,9	0,021	0,669
1200	136,5	118,9	23,7	0,011	0,513

Table 6-23. TCP goodput and packet loss ratio of flow2 (Reservation parameters: SR=135kbit/s, BSS=10000B; measurement period =120s)

STD BG traffic rate [kbit/s]	Flow3 goodput [kbit/s]	„In" stream throughput [kbit/s]	„Out" stream throughput [kbit/s]	„In" packet loss ratio	„Out" packet loss ratio
0	352,5	124,3	214,0	0,006	0,181
200	295	126,1	165,8	0,008	0,206
400	250,7	122,6	137,2	0,009	0,207
600	194,6	123,0	82,6	0,008	0,326
800	144,4	120,1	30,4	0,017	0,455
1000	154,3	130,0	36,8	0,011	0,445
1200	152,9	123,9	35,5	0,016	0,423

Table 6-24. TCP goodput and packet loss ratio of flow3 (Reservation parameters: SR=135kbit/s, BSS=10000B; measurement period =120s)

STD BG traffic rate [kbit/s]	Flow4 goodput [kbit/s]	„In" stream throughput [kbit/s]	„Out" stream throughput [kbit/s]	„In" packet loss ratio	„Out" packet loss ratio
0	339,2	125,0	224,5	0,008	0,178
200	282,7	125,6	183,3	0,011	0,171
400	237,4	123,7	121,9	0,008	0,241
600	192,7	124,4	76,3	0,015	0,315
800	156	124,7	38,6	0,005	0,430
1000	136,4	124,6	31,3	0,012	0,470
1200	136,3	126,2	34,6	0,013	0,438

Table 6-25. TCP goodput and packet loss ratio of flow4 (Reservation parameters: SR=135kbit/s, BSS=10000B; measurement period =120s)

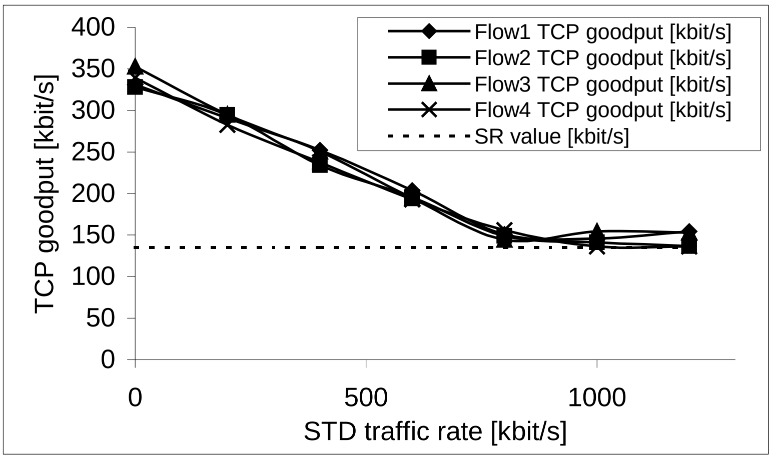

Figure 6-37. Goodput of 4 TCP flows in PMM service

The bottleneck in the network is the 2Mbps link between routers aq1605_1 and aq3640_1. The scheduled bandwidth for TCL3 on this link is 600kbit/s. The results show, that this capacity is shared between four TCP connections in a fair manner. Throughput of each admitted flow is not lower then the value of SR parameter in the reservation request. The sum of throughput of all 4 flows is a bit smaller then the rate guaranteed for TCL3 by the WFQ scheduling discipline on the bottleneck link.

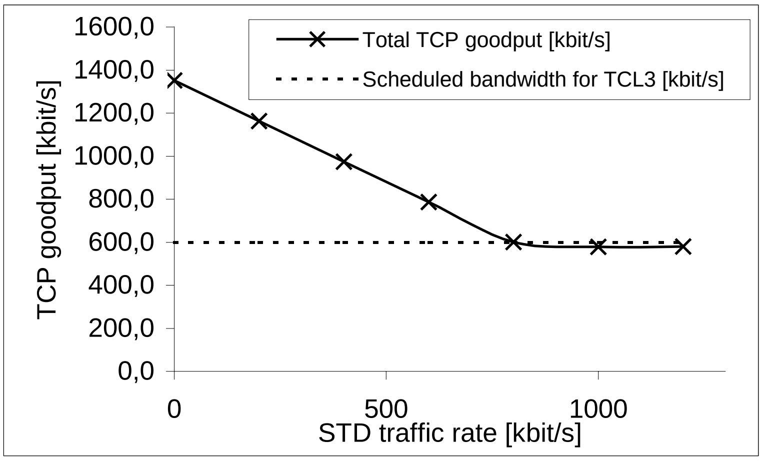

Figure 6-38. Total goodput of 4 TCP flows in PMM service

6.4.2.3 Performance of 4 TCP flows with different reservation parameters

Description

The goal of this trial is to verify the possibility to differentiate flows within the PMM service with respect to the value of SR parameter in the reservation request. The measured throughput of multiple TCP flows within the PMM service is compared with the requested value of SR parameter.

Trial setup

- Tested topology is shown in Figure 6-36.
- Traffic parameters:

Foreground traffic: 4 TCP controlled flows, generated using Synthetic flow generator. The generated flow is a 4Mbit/s constant bit rate stream with packet size equal to 1500B or 500B. Additionally, test packets were injected into the TCL3 class in order to measure packet delay.

  - Flow 1 was generated between end-stations PC3 and PC1, destination port number 6000. The reservation was set-up for this flow with parameters SR=135kbit/s, BSS=15000B
  - Flow 2 was generated between end-stations PC3 and PC1, destination port number 6001. The reservation was set-up for this flow with parameters SR=135kbit/s, BSS=15000B
  - Flow 3 was generated between end-stations PC3 and PC1, destination port number 6002. The reservation was set-up for this flow with parameters SR=70kbit/s, BSS=15000B
  - Flow 4 was generated between end-stations PC3 and PC1, destination port number 6003. The reservation was set-up for this flow with parameters SR=200kbit/s, BSS=15000B

The sum of SRs of the reservations for the tested flows is equal to delta*AC_limit, so no more flows could be admitted by the admission control mechanism.

- Background traffic: 6 constant bit rate streams generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP,
  - traffic class TCL1: 200 kbit/s, packet size 100B
  - traffic class TCL2: 300 kbit/s, packet size 500B
  - traffic class TCL4: 100 kbit/s, packet size 500B
  - traffic class TCL5: variable rate, packet size 1000B

Rates of BG traffic in classes TCL2,4,5 correspond to the rates guaranteed for these classes by the WFQ scheduling discipline on the bottleneck link. Rate in the class TCL1 correspond to the assumed AC limit for this class.

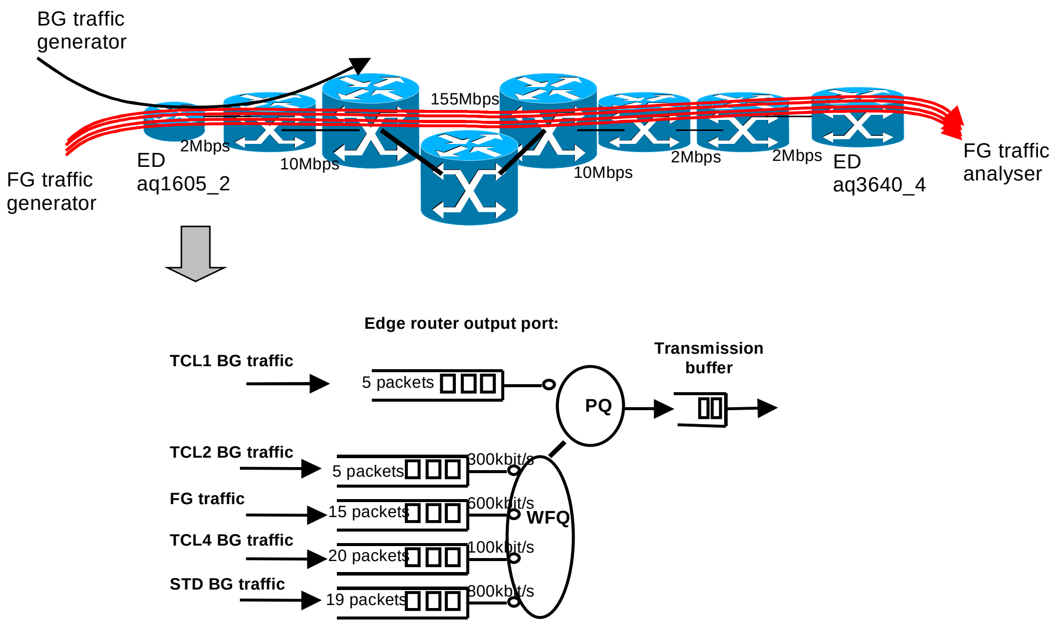

Figure 6-39. Trial topology - 19

STD BG traffic rate [kbit/s]	Flow1 goodput [kbit/s]	„In" stream throughput [kbit/s]	„Out" stream throughput [kbit/s]	„In" packet loss ratio	„Out" packet loss ratio
0	323,2	123,4	229,9	0,008	0,173
200	284,6	122,5	169,6	0,010	0,196
400	243,7	124,6	127,1	0,010	0,253
600	193,8	121,4	78,7	0,011	0,303
800	153,7	118,5	28,6	0,014	0,465
1000	143,8	118,6	22,3	0,018	0,547
1200	142,8	124,9	23,7	0,009	0,522

Table 6-26. TCP goodput and packet loss ratio of flow1 (Reservation parameters: SR=135kbit/s, BSS=10000B; measurement period =120s)

STD BG traffic rate [kbit/s]	Flow2 goodput [kbit/s]	„In" stream throughput [kbit/s]	„Out" stream throughput [kbit/s]	„In" packet loss ratio	„Out" packet loss ratio
0	342,8	125,6	211,4	0,008	0,169
200	268,5	124,7	152,2	0,013	0,230
400	243,7	124,2	123,4	0,002	0,251
600	204,7	125,8	87,1	0,008	0,286
800	140,5	122,3	37,4	0,017	0,428
1000	134,4	122,7	27,7	0,012	0,488
1200	138,6	121,4	23,9	0,017	0,538

Table 6-27. TCP goodput and packet loss ratio of flow2 (Reservation parameters: SR=135kbit/s, BSS=10000B; measurement period =120s)

STD BG traffic rate [kbit/s]	Flow3 goodput [kbit/s]	„In" stream throughput [kbit/s]	„Out" stream throughput [kbit/s]	„In" packet loss ratio	„Out" packet loss ratio
0	293,8	63,7	238,6	0,005	0,174
200	252	63,3	197,4	0,012	0,188
400	208,3	63,3	142,0	0,009	0,241
600	143,2	63,0	82,4	0,009	0,313
800	102,4	62,2	44,7	0,014	0,405
1000	93,2	63,0	35,9	0,014	0,457
1200	85,3	56,8	33,5	0,028	0,451

Table 6-28. TCP goodput and packet loss ratio of flow3 (Reservation parameters: SR=70kbit/s, BSS=10000B; measurement period =120s)

STD BG traffic rate [kbit/s]	Flow4 goodput [kbit/s]	„In" stream throughput [kbit/s]	„Out" stream throughput [kbit/s]	„In" packet loss ratio	„Out" packet loss ratio
0	382,4	194,0	197,2	0,010	0,169
200	349	194,8	163,4	0,004	0,181
400	288,6	189,7	107,7	0,012	0,235
600	242,2	189,9	58,5	0,012	0,297
800	199,5	180,4	25,7	0,013	0,385
1000	200,5	193,0	15,8	0,016	0,497
1200	206,8	195,3	18,7	0,012	0,465

Table 6-29. TCP goodput and packet loss ratio of flow4 (Reservation parameters: SR=200kbit/s, BSS=10000B; measurement period =120s)

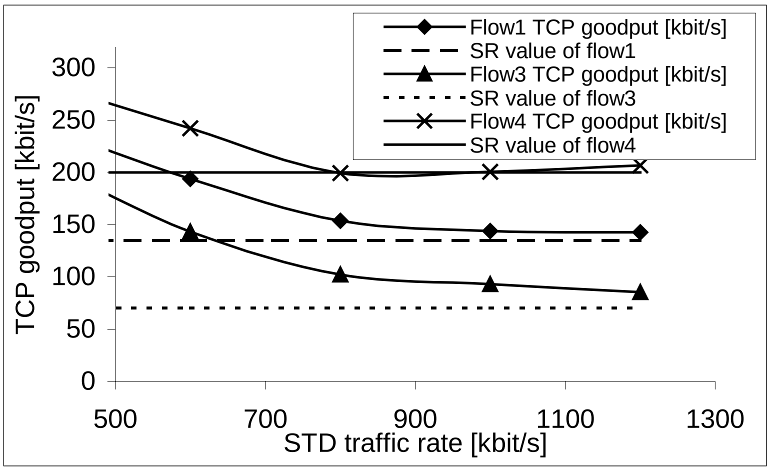

Figure 6-40. Goodput of TCP flows with different SR value

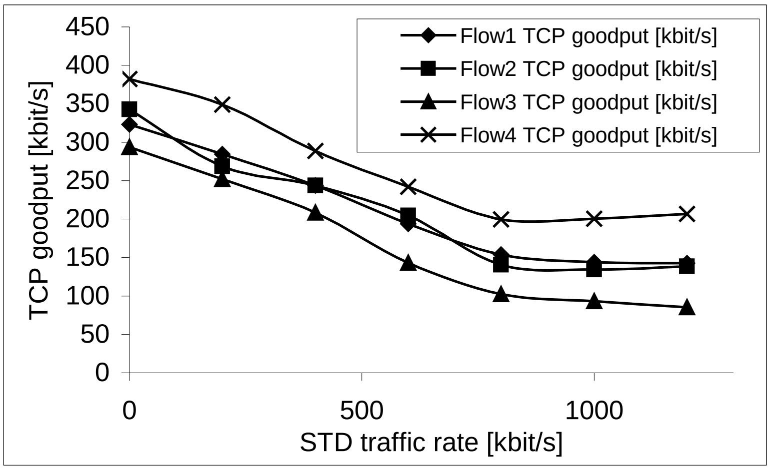

Figure 6-41. 4 flows with different SR within the PMM service

Below in the figure the proportion of packets marked as "in-profile" and "out-of-profile" contributing to the throughput of 2 considered TCP connections is shown. One can observe, that the amount of traffic submitted into the network above the traffic profile requested in the reservation phase is marked as "out-of-profile". In underload network conditions, the "out-of-prifile" traffic obtains the capacity unused by the other network services, but in time of network congestion, throughput of the TCP flow in PMM service is guaranteed roughly up to the requested SR value.

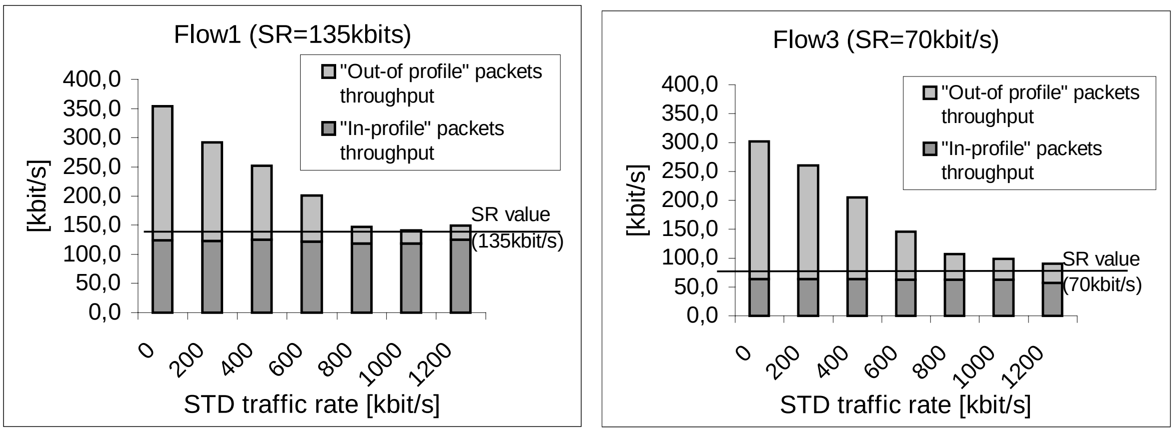

Figure 6-42. Throughput of "in-profile" and "out-of-profile" packet streams within flow 1 and flow3

The bottleneck in the network is the 2Mbps link between routers aq1605_1 and aq3640_1. The scheduled bandwidth for TCL3 on this link is 600kbit/s. The sum of throughput of all 4 flows is a bit smaller then the rate guaranteed for TCL3 by the WFQ scheduling discipline on the bottleneck link [see Figure 6-43]. The results show, that the throughput of TCP flow within the PMM service is not smaller then the value of SR parameter in the reservation request for this flow. Moreover, it is possible to differentiate flows within the PMM service with respect to the value of SR parameter. The target QoS, expressed in terms of minimal throughput, is met in presence of uncontrolled background traffic served within the STD network service.

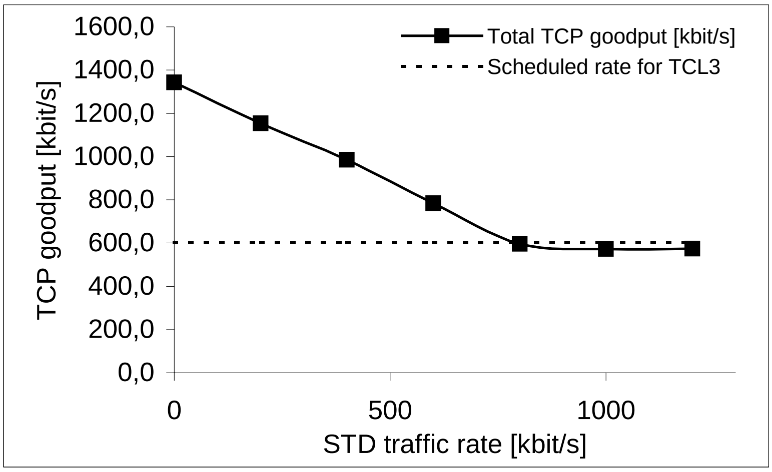

Figure 6-43. Total goodput of 4 TCP flows with different SR value in PMM service

Figure 6-44 shows measured values of one-way packet delay in PMM service. It should be noted, that in case of TCP controlled traffic the factor that is more significant from the traffic performance point of view is the RTT (round trip time) value.

STD BG trafficrate [kbit/s]	Minimum one-way packet delay [kbit/s]	Maximum one-way packet delay [kbit/s]	Average one-way packet delay [kbit/s]
0	55,4	165,4	103,4
200	61,5	161,4	116,6
400	65	199,4	134,7
600	77,7	266,1	160,2
800	55,4	319,4	200,2
1000	82,3	291,5	211,8
1200	133,7	264,4	215,9

Table 6-30. One-way delay of packets in PMM service with different background traffic rate

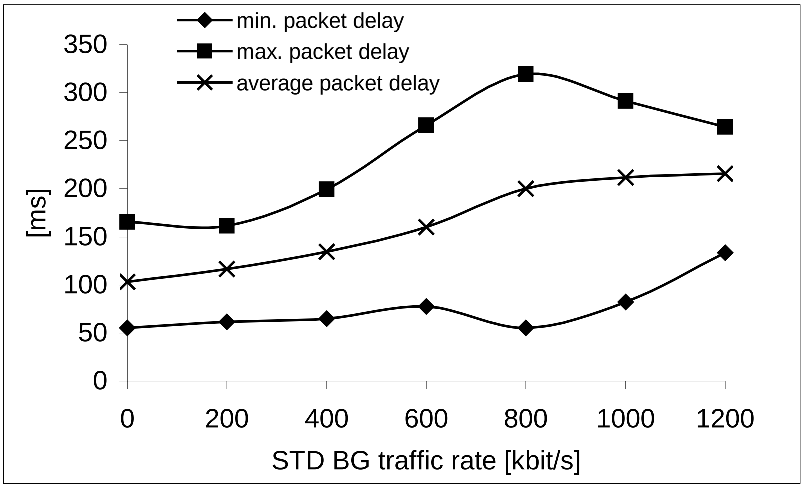

Figure 6-44. One way delay of packets in PMM service with different background traffic rate

6.4.2.4 Effectiveness of admission control algorithm for PMM service

Description

The goal of this trial is to verify the assumptions for the admission control function developed for the PMM service. Throughput measured for multiple TCP streams submitted into the PMM service is compared with the value of declared SR parameter. The purpose is to verify that target QoS guarantees are met when the number of TCP flows submitted into the network is defined by the admission control function.

Trial setup

- Tested topology is shown in Figure 6-45.
- Traffic parameters:

- Foreground traffic: n greedy TCP controlled flows, generated using Synthetic flow generator. Flows are generated between end-stations PC3 and PC1. Destination port number is increased in the generated flows from 6000 to 6000+n. The reservation was set-up for each flow with parameters SR=50kbit/s, BSS=15000B

- Background traffic: 6 constant bit rate streams generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP,

    - traffic class TCL1: 200 kbit/s, packet size 100B
    - traffic class TCL2: 300 kbit/s, packet size 500B
    - traffic class TCL4: 100 kbit/s, packet size 500B
    - traffic class TCL5: 1000 kbit/s, packet size 1000B

Rates of BG traffic in classes TCL2,4,5 correspond to the rates guaranteed for these classes by the WFQ scheduling discipline on the bottleneck link. The rate in class TCL1 corresponds to the assumed AC limit for this class.

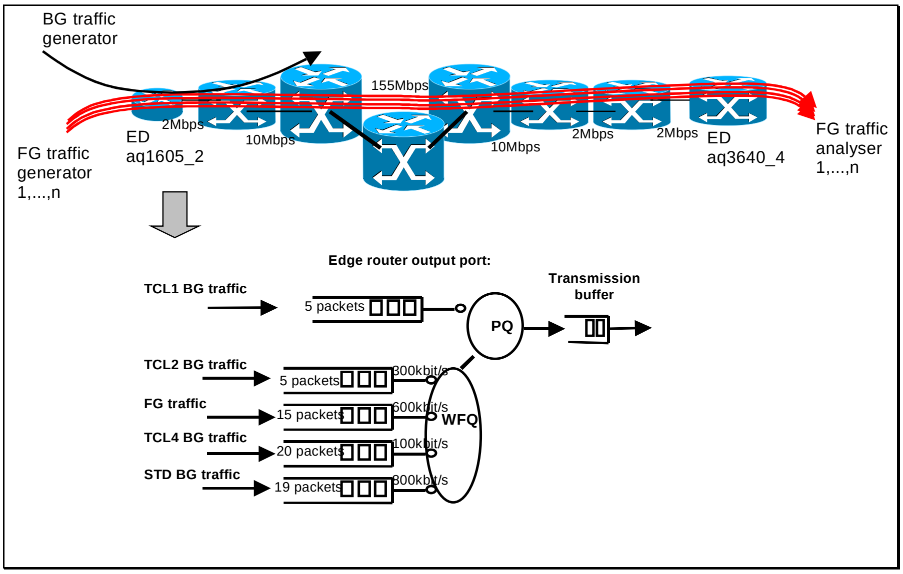

Figure 6-45. Trial topology - 20

n (number of TCP flows)	Goodput of n TCP lows [kbit/s].	Flow1 "In-profile" throughput [kbit/s]	Flow1 "Out-profile" throughput [kbit/s]	"In-profile" packets loss ratio	"Out-profile" packets loss ratio
1	567,3	48,18	528,03	0,000	0,028
5	128,4 / 107,8 / 110,4 / 118,5 / 106,2	47,69	64,53	0,018	0,313
8	71,6 / 67,7 / 74,1 / 73,5 / 73,6 / 69,2 / 77,4 / 67,2	47,60	27,35	0,020	0,506
10	49,1 / 55,9 / 59,9 / 60,6 / 59,4 / 54,1 / 56,0 / 55,3 / 56,4 / 64,7	47,01	14,41	0,026	0,632
11*	55,4 / 53,2 / 47,3 / 51,3 / 57,8 / 54,9 / 50,9 / 51,8 / 56,8 / 45,8 / 50,7	44,97	6,33	0,043	0,772
12*	46,5 / 44,2 / 47,1 / 48,7 / 49,2 / 50,6 / 45 / 50,7 / 47,7 / 49,0 / 48,0 / 51,4	46,04	7,11	0,039	0,759
13*	50,0 / 38,7 / 45,3 / 46,1 / 45,9 / 43,7 / 51,4 / 45,2 / 42,3 / 33,8 / 45,8 / 45,0 / 44,4	43,12	4,67	0,045	0,796

Table 6-31. Throughput and packet loss ratio as a function of number of admitted flows. *The limit for the number of flows, defined by the implemented AC algorithm was 10 flows. The flows exceeding this number were set-up manually, without using the AC function.

The scheduled rate for the class TCL3 on the 2Mbit/s link between the edge device and the core network is 600kbit/s. The Admission Control algorithm implemented in the ACA allows to admit flows until the sum of SR parameters in the reservation requests is smaller then delta*600kbit/s. The value of delta parameter is equal to 0,9, so the limit is 0,9*600kbit/s = 540 kbit/s. This allows admitting 10 flows with the value of the SR parameter equal to 50kbit/s.

One can observe that when the number of flows is below the limit defined by the AC algorithm, the measured goodput of each submitted flow is close then the value of SR in the reservation request. The flows share all the bandwidth available for TCL3. When the number of flows is above the limit defined by the AC, the flows do not obtain their guaranteed bandwidth share.

The packet loss ratio for "in-profile" packets as a function of the number of TCP flows served in PMM is depicted on Figure 6-46. The target packet loss ratio (10^{-3}) is not met. The observed packet loss ratio is significantly higher. This is caused mainly by the fact that out of profile packets are allowed to enter the network. The solution for that could be optimisation of the thresholds for in and out-of-profile packets in WRED algorithms.

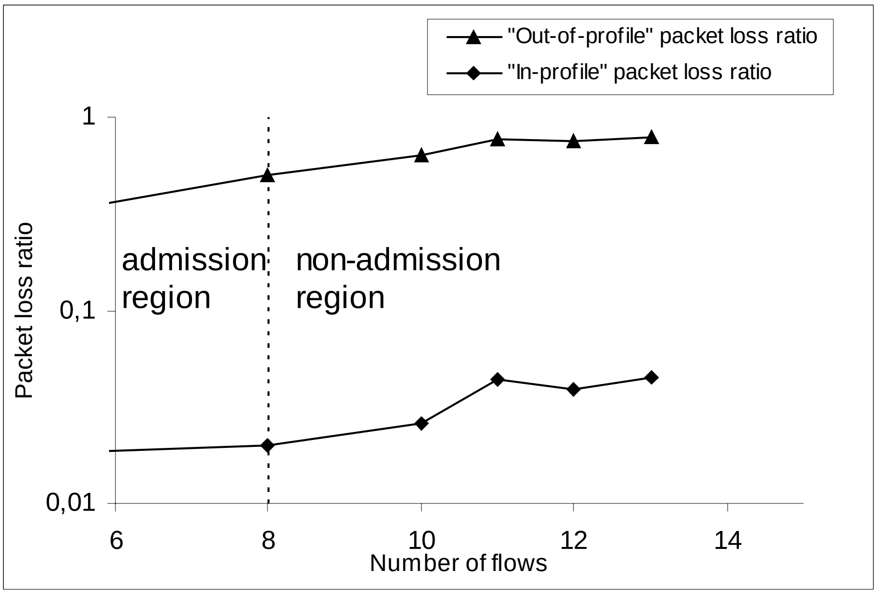

Figure 6-46. "In-profile" and "out-of-profile" packet loss ratio vs. number of TCP flows in PMM service

N (number of TCP flows)	Minimum on-way packet delay [ms]	Maximum one-way packet delay [ms]	Average on-way packet delay [ms]
1	51,1	172	107
5	121,6	339,3	213,2
8	126,8	333,2	215
10	115,4	389,4	227,3
11	125,3	404	252,5
12	176,6	381,4	252,9
13	188,1	476,4	271,3

Table 6-32. One-way delay of packets in PMM service as a function of number of admitted flows

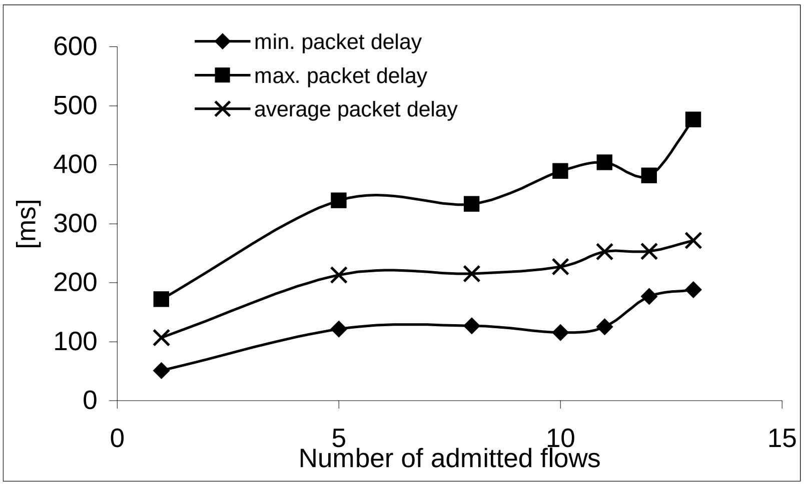

Figure 6-47. One-way delay of packets in PMM service depending on the number of admitted flows

6.4.3 Trials of RealPlayer application served by the PMM

The PMM service is suited for adaptive non-real time applications requiring minimum bandwidth guarantees. An example for such applications is the RealPlayer, which is a non-real time streaming media application. Although the RealPlayer uses UDP as the transport protocol, it incorporates a higher-level control protocol that has a capability to adapt the rate of transmitted data stream to the network conditions. The best video and audio quality is obtained when the rate of stream generated by the RealPlayer is equal to 225 kbps (240 kbps including the UDP/IP/Ethernet overhead).

The RealPlayer trials were performed in a testbed configuration shown in Figure 6-48. The RealServer was installed on PC4, while the RealPlayer was running on PC2.

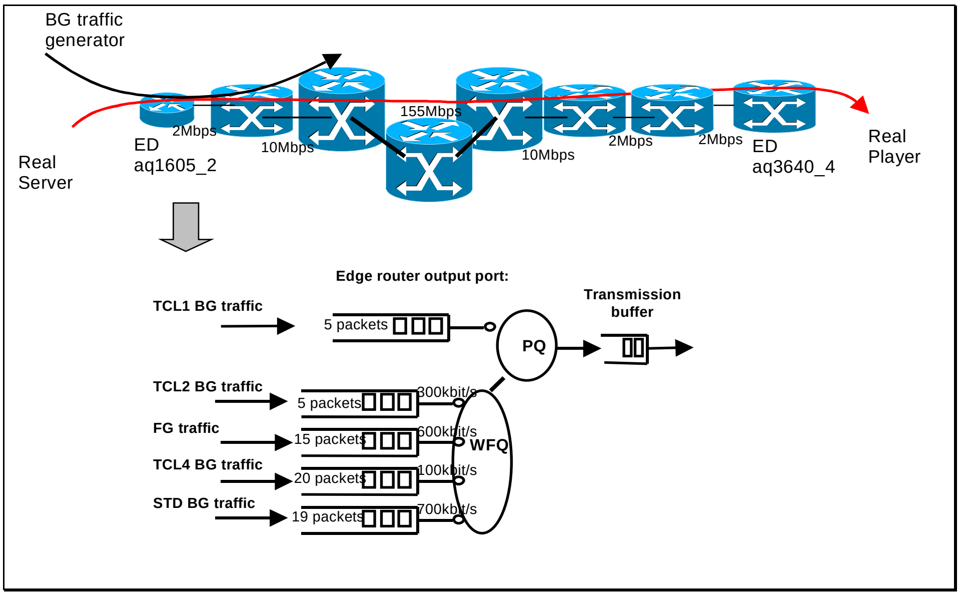

Figure 6-48. Trial topology – 21

6.4.3.1 Real Player application served by the PMM service

Description

The goal of this trial is to observe, how the RealPlayer application can take advantage of the QoS capabilities offered by the PMM service under overload link conditions. Quality of the video stream submitted into the PMM service is compared to the quality of the video stream submitted into the STD service.

The RealServer can use either UDP or TCP as the transport protocol for submitted media stream. In this trial UDP was used.

Trial setup

- Tested topology is shown in Figure 6-48.
- Traffic parameters:
- Case #1:
  - o Foreground traffic: Real Player (UDP) served by the STD service
  - o Background traffic: Constant bit rate UDP stream in STD service with rate equal to 1750 - 2200 kbit/s.
- Case #2:

- o Foreground traffic: Real Player (UDP) served by the PMM service. Reservation set with SR=248 (264), BSS=15000B.
- o Background traffic: 4 constant bit rate streams generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP, and 5 4CP sources generated using Synthetic flow generator from PC3 to PC1
  - traffic class TCL1: 200 kbit/s, packet size 100B
  - traffic class TCL2: 300 kbit/s, packet size 500B
  - traffic class TCL3: 4 greedy TCP sources, reservation set with SR=88 (80)kbit/s, BSS=15000B
  - traffic class TCL4: 100 kbit/s, packet size 500B
  - traffic class TCL5: 1250 kbit/s, packet size 500B

Rates of BG traffic in classes TCL2,4,5 correspond to the rates guaranteed for these classes by the WFQ scheduling discipline on the bottleneck link. The rate in class TCL1 corresponds to the assumed AC limit for this class. The sum of reservations in PMM class equals to the AC limit for this class (assuming delta=1).

BG traffic rate [kbit/s]	Total rate of generated traffic [kbit/s]	Rough assessment of RealPlayer quality
1750	2000	Good quality, no video and audio distortions. Rate of generated media stream was equal to 225kbit/s
1900	2150	Acceptable quality, some video and audio distortions. Rate of generated media stream was reduced to 150kbit/s
1950	2200	Acceptable quality, some video and audio distortions. Rate of generated media stream was reduced to 100kbit/s
2000	2250	Bad quality, severe audio and video distortions. Rate of generated media stream was reduced to 45kbit/s
2200	2450	Bad quality, not acceptable video and audio. Rate of generated media stream was reduced to 12kbit/s

Table 6-33. Case #1, RealPlayer in STD service in overload link conditions

SR values in reservation request	Total rate of generated traffic [kbit/s]	Throughput of 4 TCP flows in PMM service [kbit/s]	Rough assessment of Real Player quality
SR = 248kbit/s for RealPlayer SR = 88kbit/s for 4 TCP flows	2450	135.1 115.5 116.5 111.2	Acceptable quality, some distortions can be observed. Rate of generated media stream was reduced to 150kbit/s
SR = 264kbit/s for RealPlayer SR = 80kbit/s for 4 TCP flows	2450	94.3 119.1 93.4 89.5	Good quality, no video and audio distortions. Rate of generated media stream was equal to 225kbit/s

Table 6-34. Case #2, RealPlayer in PMM service in overload link conditions

Figure 6-49. Real Player application under overload link conditions served by the STD service (case #1, left), and served by the PMM service with SR = 248 kbit/s (case #2, right)

As one could expect, the quality of application served as best effort in overload link conditions (case #1) was not acceptable. In the beginning of the played video clip, packet losses caused severe degradation of the video and audio quality. After some time, the rate of generated media stream was decreased (at most to 45kbit/s). Then, packet losses were not observed, but perceivable subjective quality of the played video was not good due to the small rate of the recorded media stream.

The excess STD traffic did not degrade the quality of RealPlayer, when the application was served by the PMM (case #2, see Figure 6-49). Important observation is that the declared value of SR parameter must be a little higher then the rate of generated media stream. Otherwise, packet losses are observed and the quality of the application is degraded.

Note also, that throughput of additional TCP flows submitted into PMM service was not smaller than the declared SR value. The result confirms that the PMM service defined by AQUILA provides QoS guarantees suitable for adaptive non-real time applications. Both the tested application and the background TCP sessions obtained the expected bandwidth guarantees and were not affected by the traffic belonging to other Network Services.

6.4.3.2 Comparison of Real Player application using TCP and UDP protocol and served by the PMM service

Description

The goal of this trial is to observe how the RealPlayer application can take advantage of the QoS capabilities offered by the PMM service. Real Player can use UDP or TCP protocol to carry the application data. Transfer capabilities using these two protocols are compared.

Trial setup

- Tested topology is shown in Figure 6-48.
- Traffic parameters:
- Case #1:
    - Foreground traffic: Real Player using TCP protocol, served by the PMM service. Reservation was set-up with SR=248 kbit/s, BSS=15000B.
    - Background traffic: 4 constant bit rate streams generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP, and 4 TCP sources generated using Synthetic flow generator from PC3 to PC1
        - traffic class TCL1: 200 kbit/s, packet size 100B
        - traffic class TCL2: 300 kbit/s, packet size 500B
        - traffic class TCL3: 4 greedy TCP sources, reservation set with SR=88kbit/s, BSS=15000B
        - traffic class TCL4: 100 kbit/s, packet size 500B
        - traffic class TCL5: 800 kbit/s, packet size 500B

- Case #2:
    - Foreground traffic: Real Player using UDP protocol, served by the PMM service. Reservation was set-up with SR=248 kbit/s, BSS=15000B.
    - Background traffic: the same as in case #1
- Case #3:
    - Foreground traffic: Constant bit rate UDP stream, generated with the HP BSTS measurement equipment between ports aq1605_2:eth1 and aq3640_4:eth1/1, served by the PMM service. Reservation was set-up with SR=248 kbit/s, BSS=15000B.
    - Background traffic: the same as in case #1

Rates of BG traffic in classes TCL2,4,5 correspond to the rates guaranteed for these classes by the WFQ scheduling discipline on the bottleneck link. The rate in class TCL1 corresponds to the assumed AC limit for this class. The sum of reservations in PMM class equals to the AC limit for this class (assuming delta=1).

Quality was acceptable. The speed of data stream generated by the Server application was reduced to 150 kbit/s.
Throughput of TCP flows in PMM service (SR=88kbit/s) [kbit/s]: 99.0 / 100 / 113.9 / 101.8

Table 6-35. Case #1: Real Player using TCP (SR=248kbit/s)

Quality was bad. Packet losses caused significant degradation of video and audio quality. The speed of data stream generated by the Server application was reduced to 150 kbit/s.
Throughput of TCP flows in PMM service (SR=88kbit/s) [kbit/s]: 135.1 / 115.5 / 116.5 / 111.2

Table 6-36. Case #2: Real Player using UDP (SR=248kbit/s)

Packet loss ratio	Min latency [ms]	Max latency [ms]	Avg latency [ms]
0.96*10-2	9.6	281.8	130.4

Table 6-37. Case #3: Artificial source of UDP data stream (SR=248kbit/s)

6.5 Premium Mission Critical network service

According to the specification in [D1301], Premium Mission Critical service is targeted for low bandwidth, short lifetime, elastic application that require low packet loss rate. The typical application that might be served by this service are database transactions, networked games, supervisory applications etc.

The PMC service will use the TCL4 traffic class. Traffic descriptor type for PMM flows is Dual_Token_Bucket. The flow is characterised by the following parameters:

parameter	***minimum admitted***	***maximum admitted***	***Default***
PR	0	50 Kb/s	...
BSP	n.a.	n.a.	2048 B
SR	0	? Kb/s	PR
BSS	M	10 M	10 M
m	40 B	M	40 B
M	n.a	n.a.	1024 B

The QoS requirements for PMC service are: very low P_{loss} for packets conforming to the traffic profile and no QoS guarantees for packets exceeding the traffic profile.

According to the deliverable [D1301], the new flow characterised by PR, SR and BSS is accepted if the following condition is satisfied:

$$Eff(.) + \sum_i Eff(i) \le C$$

The effective bandwidth Eff(.) in this case is calculated by:

$$Eff(.) = \max\left\{ SR, \frac{PR \cdot T}{B/C + T} \right\}$$

where

$$T = \frac{BS}{PR - SR}$$

6.5.1 Trial setup

The objective of the following tests was to verify whether the PMC network service can provide assumed quality of service. As the PMC service is intended for TCP controlled flows, the artificial greedy and non-greedy TCP sources will be used as measurement traffic generators. The Synthetic Flow Load Generator is a suitable application for emulating a greedy TCP controlled source. Multiple TCP streams will be generated using a multiplex option of the Synthetic flow generator. Two characteristics were concerned in the measurements: goodput and throughput. The goodput corresponds to the useful number of bits transmitted on the application level while the throughput corresponds to the number of bits transmitted through the network (on the IP level). In fact the goodput parameter corresponds to the throughput decreased by the packets loss rate (expressed in bps).

Guaranteed portion of link bandwidth is provided for the PMC service by the WFQ scheduling discipline on the router output port. In order to investigate the behaviour of the PMC service under overloaded link conditions, background traffic must be submitted into all classes on the WFQ link. The background traffic in classes TCL1, TCL2 and TCL3 is a constant bit rate stream with a rate equal to the scheduled rate for a specific class. We assume that it is a worst-case traffic that would be allowed to the system by the admission control mechanism. The background traffic in STD traffic class is not subject to the admission control decision, so we assume that it may exceed its configured scheduling rate.

6.5.1.1 Router output port configuration

The assumed output port configuration of routers for the trials is shown in Figure 6-33. In this figure are depicted router elements, which are used in trials of PMC service.

Incoming packets to the output port are classified to appropriate queues.

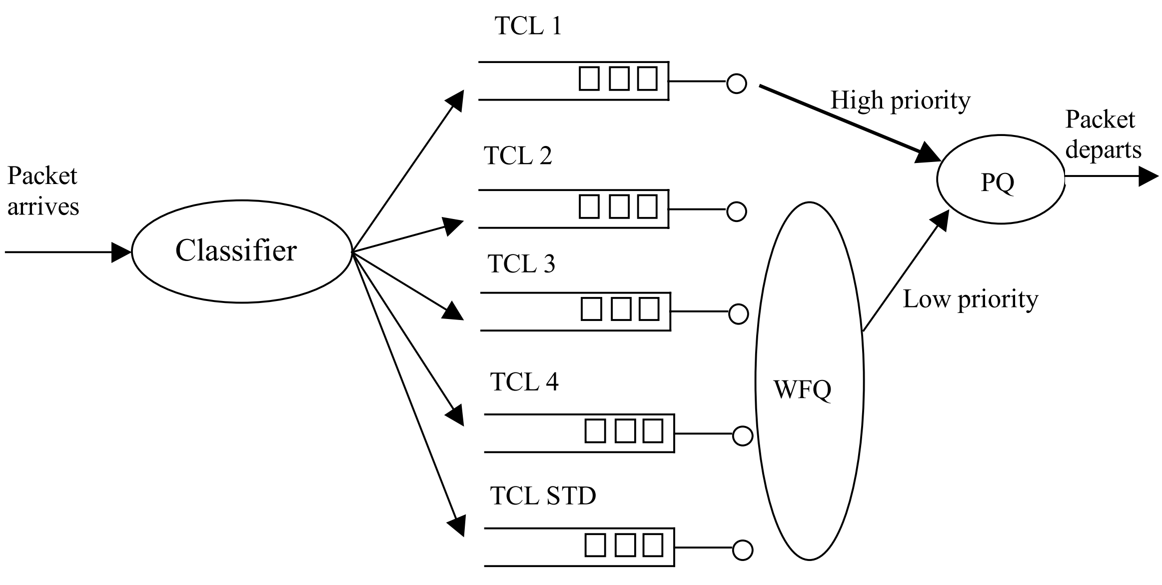

Figure 6-50. Routers output ports configuration

The scheduled bandwidth for the PMC class is equal to: 100kbit/s on a 2Mbit/s links, 500kbit/s on a 10Mbit/s links and 7.75Mbit/s on a 155Mbit/s links. The configuration of the WRED algorithm on a 2Mbit/s link is as follows: for “out-profile” packets the min_{th}=4, max_{th}=13, for “in-profile” packets min_{th}=13, max_{th}=20.

6.5.2 QoS verification for PMC service

6.5.2.1 Performance of 4 TCP flows with the same reservation parameters

Description

The objective of this trial is to measure the performance of multiple TCP flows served by the Premium Mission Critical service. All TCP flows have the same traffic descriptors and are served by the same network elements. The aim of the test is ti verify if the TCP flows share the available bandwidth in a fair manner. The goodput and loss rates for in and out of profile packets are measured. The obtained total goodput is compared with the requested values expressed by traffic descriptors.

Trial setup

- Tested topology is shown in Figure 6-36.
- Traffic parameters:
- Foreground traffic: 4 greedy TCP controlled flows, generated using Synthetic flow generatorset. Reservation was set-up for each foreground flow with parameters PR=32kbit/s, BSP=2000B, SR=16kbit/s, BSS=10000B. According to the AC algorithm for TCL4, the value of effective bandwidth of the foreground flows is equal to 24.3kbit/s
    - Flow 1 was generated between end-stations PC3 and PC1, destination port number 6000
    - Flow 2 was generated between end-stations PC3 and PC1, destination port number 6001
    - Flow 3 was generated between end-stations PC3 and PC1, destination port number 6002
    - Flow 4 was generated between end-stations PC3 and PC1, destination port number 6003

The sum of the effective bandwidth of the foreground flows is equal to 97,56 kbit/s, so no more flows could be admitted by the admission control mechanism.

- Background traffic: 4 constant bit rate streams generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP,
    - traffic class TCL1: 200 kbit/s, packet size 100B
    - traffic class TCL2: 300 kbit/s, packet size 500B
    - traffic class TCL3: 600 kbit/s, packet size 500B
    - traffic class TCL5: 0-1400kbit/s, packet size 1000B

Rates of BG traffic in classes TCL2,3,5 correspond to the rates guaranteed for these classes by the WFQ scheduling discipline on the bottleneck link. Rate in the class TCL1 correspond to the assumed AC limit for this class.

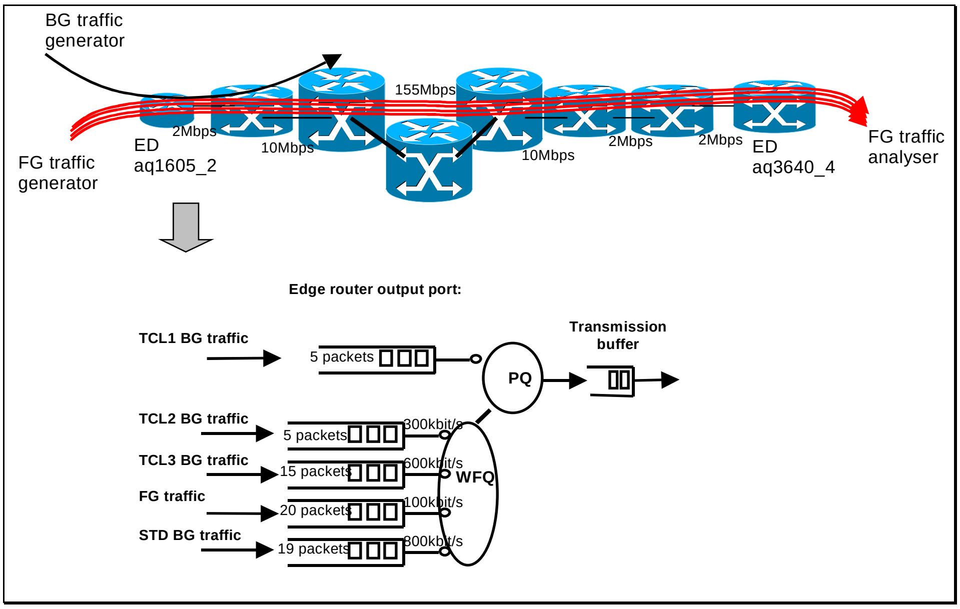

Figure 6-51. Trial topology - 22

STD generated rate [kbit/s]	Flow 1 goodhput [kbit/s]	Flow 2 goodhput [kbit/s]	Flow 3 poodhput [kbit/s]	Flow 4 goodhput [kbit/s]	Sum of TCP goodput [kbit/s]	"In" packets loss ratio	"Out" packets loss ratio
0	219,8	221	209,6	237,2	887,6	0,005	0,094
200	180,8	168,7	154,5	189	693	0,003	0,111
400	139,1	128,7	126,5	117,6	511,9	0,003	0,143
600	71,2	91,4	77,3	86,1	326	0,006	0,134
800	36,8	35	35,6	32,7	140,1	0,006	0,123
1000	27,8	23,2	21	29,6	101,6	0,006	0,222
1200	28,4	25,4	21	25	99,8	0,010	0,260
1400	24,6	23,5	27,6	25,3	101	0,009	0,293

Table 6-38. Results for multiply TCP flows (Reservation parameters: PR=32, SR=16, eff=24.3, measurement period = 120s)

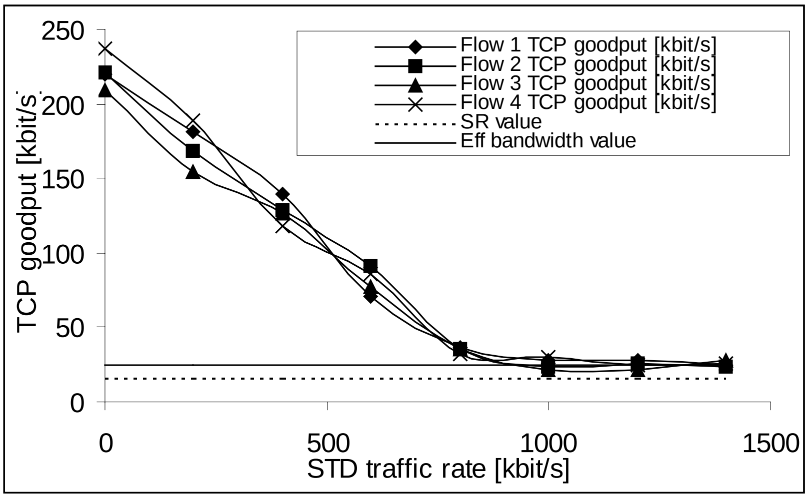

Figure 6-52. Goodput of 4 TCP flows with the same reservations

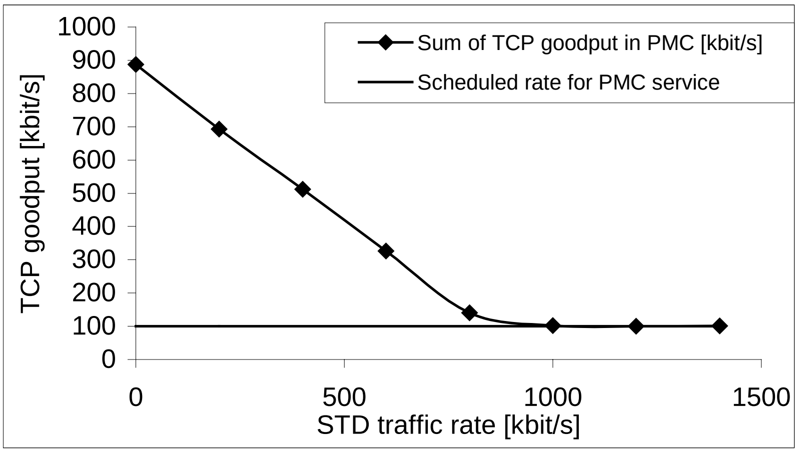

Figure 6-53. Total goodput of 4 TCP flows in PMC service

The measurement results obtained for multiply TCP connections with the same RTT are presented in Table 6-38. The Figure 6-52 shows the goodput characteristics of the TCP flows as a function of background traffic load. The bottleneck in the test network is the 2Mbps link between routers aq1605_1 and aq3640_1. The scheduled bandwidth for TCL4 on this link is 100kbit/s. The obtained results show, that this capacity is shared between four TCP connections in a fair manner. All TCP flows obtained equal share of the bottleneck capacity. The goodput of each admitted flow is not lower then the value of effective bandwidth calculated from the reservation request and link parameters. The sum of goodput of all 4 flows is not smaller then the rate guaranteed for TCL1 by the WFQ scheduling discipline on the bottleneck link.

The packet loss objective is not met. The measured packet loss rate for “in profile” packets is on the level of 10^{-2}-10^{-3} while the target packet loss is 10^{-6}. This is caused by the fact that the TCP flows are greedy. Although the PMC service was designed for non-greed y TCP connection in practice there is mechanism for detecting and eliminating such flows. Therefore if the TCP flows are greedy the packet loss objectives cannot be met.

6.5.2.2 Performance of 4 TCP flows with different reservation parameters

Description

The goal of this trial is to verify the possibility to differentiate flows within the PMC service with respect to the value of reservation request parameters. The goodput as well as throughput and packet loss rate for "in" and "out of profile" packets for individual flows were measured.

Trial setup

- Tested topology is shown in Figure 6-36.
- Traffic parameters:
- Foreground traffic: 4 greedy TCP controlled flows, generated using Synthetic flow generatorset.
    - Flow 1 was generated between end-stations PC3 and PC1, destination port number 6000. The reservation was set-up for this flow with parameters PR=32kbit/s, BSP=2000B, SR=16kbit/s, BSS=10000B
    - Flow 2 was generated between end-stations PC3 and PC1, destination port number 6001. The reservation was set-up for this flow with parameters PR=32kbit/s, BSP=2000B, SR=16kbit/s, BSS=10000B
    - Flow 3 was generated between end-stations PC3 and PC1, destination port number 6002. The reservation was set-up for this flow with parameters PR=24kbit/s, BSP=2000B, SR=8kbit/s, BSS=10000B
    - Flow 4 was generated between end-stations PC3 and PC1, destination port number 6003. The reservation was set-up for this flow with parameters PR=48kbit/s, BSP=2000B, SR=16kbit/s, BSS=10000B

The sum of the effective bandwidth of the foreground flows is equal to 96,62 kbit/s, so no more flows could be admitted by the admission control mechanism.

- Background traffic: 4 constant bit rate streams generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP,
    - traffic class TCL1: 200 kbit/s, packet size 100B
    - traffic class TCL2: 300 kbit/s, packet size 500B
    - traffic class TCL3: 600 kbit/s, packet size 500B
    - traffic class TCL5: 0-1400kbit/s, packet size 1000B

Rates of BG traffic in classes TCL2,3,5 correspond to the rates guaranteed for these classes by the WFQ scheduling discipline on the link between the Edge Device (aq1605_1) and the core network. The rate in class TCL1 corresponds to the assumed AC limit for this class. Therefore, we assume that the network load in TCLs 1,2,3 is equal to the maximum value allowed by the admission control mechanism.

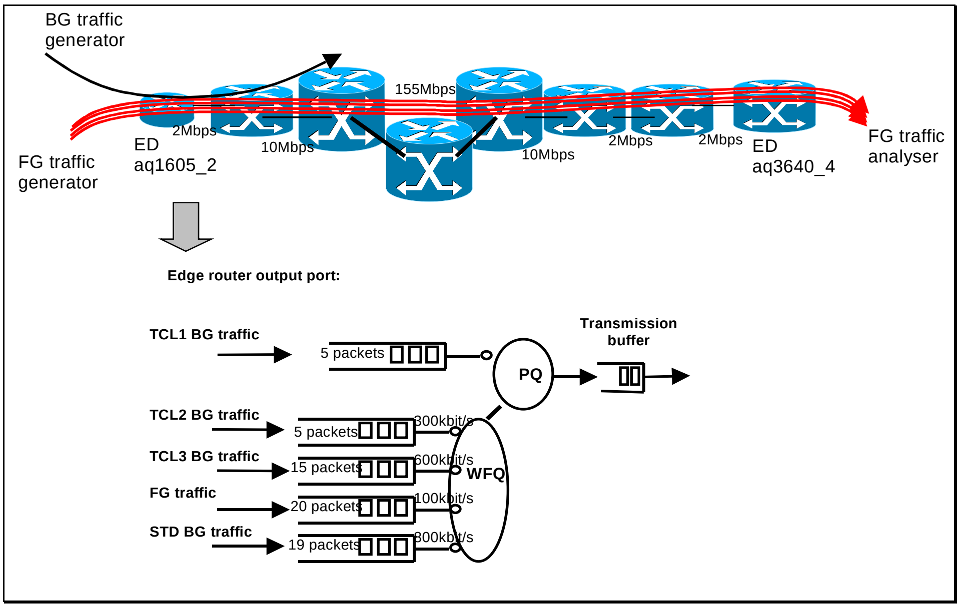

Figure 6-54 Trial topology - 23

STD traffic rate [kbit/s]	Flow 1 goodput [kbit/s]	„In" throughput [kbit/s]	„Out" throughput [kbit/s]	„In" packets loss ratio	„Out" packets loss ratio
0	226,7	16,2	211,3	0,006	0,096
200	182,1	16,3	185,1	0,000	0,074
400	135,3	16,2	125,4	0,012	0,115
600	87	16,5	76,2	0,006	0,124
800	40,5	16,2	27,4	0,000	0,213
1000	29,2	16,5	15,9	0,006	0,181
1200	24,5	16,8	12,1	0,000	0,220
1400	24,5	15,4	11,4	0,019	0,240

Table 6-39. Results for TCP flow 1 (reservation parameters PR=32, SR=16, eff=24,3kbit/s; measurement period = 120s)

STD traffic rate [kbit/s]	Flow 2 goodput [kbit/s]	„In" throughput [kbit/s]	„Out" throughput [kbit/s]	„In" packet loss ratio	„Out" packet loss ratio
0	221	16,1	218,1	0,006	0,093
200	195	16,2	170,4	0,000	0,093
400	132,2	16,2	121,9	0,000	0,114
600	83,4	16,4	72,6	0,000	0,131
800	38,7	16,7	28,3	0,000	0,142
1000	28	15,7	17,4	0,000	0,238
1200	25	15,9	11,4	0,018	0,188
1400	30,2	16,4	18,4	0,012	0,216

Table 6-40. Results for TCP flow 2 (reservation parameters PR=32, SR=16, eff=24,3kbit/s; measurement period = 120s)

STD traffic rate [kbit/s]	Flow 3 goodput [kbit/s]	„In" throughput [kbit/s]	„Out" throughput [kbit/s]	„In" packet loss ratio	„Out" packet loss ratio
0	202,8	8,3	199,9	0,000	0,100
200	154,3	8,3	151,5	0,000	0,108
400	116,2	8,4	125,1	0,000	0,111
600	71,8	8,7	81,7	0,000	0,140
800	33,2	9,2	25,8	0,000	0,167
1000	20,9	8,9	14,4	0,011	0,253
1200	21,1	9,1	20,1	0,011	0,176
1400	17,1	8,8	12,0	0,000	0,324

Table 6-41. Results TCP flow 3 (reservation parameters PR=24, SR=8, eff=18,2kbit/s; measurement period = 120s)

STD traffic rate [kbit/s]	Flow 4 goodput [kbit/s]	„In" throughput [kbit/s]	„Out" throughput [kbit/s]	„In" packet loss ratio	„Out" packet loss ratio
0	236,1	16,3	226,5	0,000	0,092
200	171,8	16,2	161,2	0,006	0,106
400	129,8	16,4	104,6	0,006	0,144
600	85,4	16,3	59,8	0,018	0,152
800	34,4	16,8	16,9	0,017	0,240
1000	29,5	16,6	15,0	0,012	0,189
1200	27,6	18,3	14,5	0,005	0,212
1400	30,4	17,9	17,6	0,000	0,177

Table 6-42. Results for TCP flow 4 (reservation parameters PR=48, SR=16, eff=29,5kbit/s; measurement period = 120s)

The trial results are presented in tables Table 6-39, Table 6-40, Table 6-41 and Table 6-42. The goodput, in profile throughput, out profile throughput, in profile loss rate and out profile loss rate for each TCP flow were measured. Similarly as in previous experiments the packet loss objectives are not met due to the fact that the TCP flows are greedy.

Figure 6-55 shows the goodput characteristics of tested TCP flows. When the rate of traffic that is submitted into STD network service is low, the flows in PMC service obtain all the available capacity. With the increase of background traffic the goodput of TCP flows decreases down to the capacity requested in the reservation. The bandwidth share of each TCP flow is proportional to the their effective bandwidth.

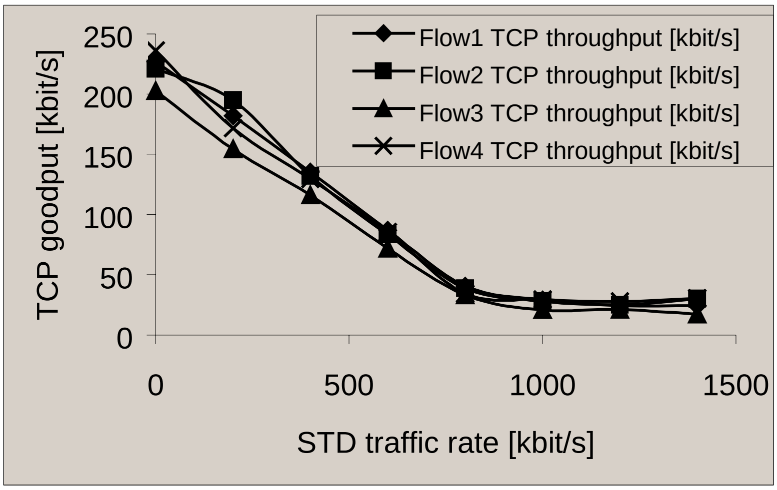

Figure 6-55. Goodput of 4 TCP flows with different reservations

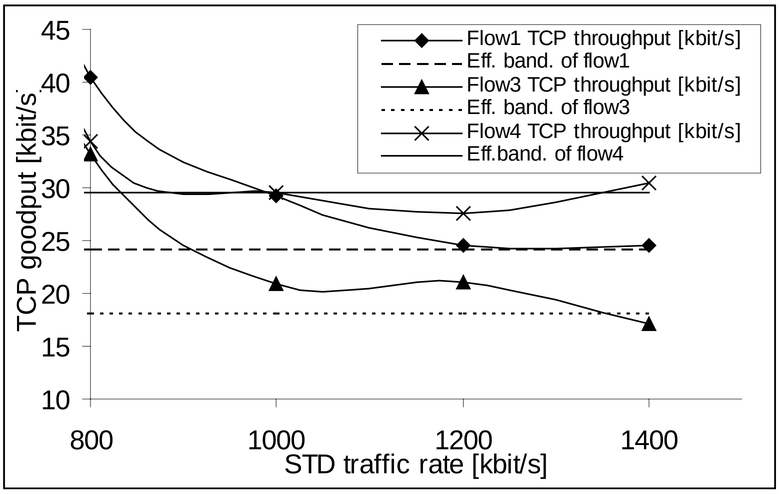

Figure 6-56. Comparison of goodput and effective bandwidth of 4 TCP flows with different reservations

6.5.2.3 Effectiveness of admission control algorithm for PMC service

Description

The goal of this trial is to verify the assumptions for the admission control function developed for the PMC service. Throughput measured for multiple TCP streams submitted into the PMC service is compared with the value of declared traffic descriptor parameters and calculated effective bandwidth value. The purpose is to verify that target QoS guarantees are met when the number of TCP flows submitted into the network is defined by the admission control function.

Trial setup

- Tested topology is shown in Figure 6-57.
- Traffic parameters:
- Foreground traffic: test flows are generated between end-stations PC3 and PC1. Destination port number is increased in the generated flows from 6000 to 6000+n. The reservation was set-up for each flow with parameters PR=16kbit/s, BSP=2000B, SR=8kbit/s, BSS=5000B. The calculated value of effective bandwidth of each flow is equal to 12,1kbit/s. Two types of foreground traffic was used in the experiments:
    - Case #1: n non-greedy TCP controlled flows, generated using Synthetic flow generator. The application level was modelled as Poisson stream with the mean rate equal to the SR parameter (8 kbps).
    - Case #2: n greedy TCP controlled flows, generated using Synthetic flow generator. The greedy source was modelled by setting the traffic generation rate at the application level higher then the PR parameter.
- Background traffic: 4 constant bit rate streams generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP,
    - traffic class TCL1: 200 kbit/s, packet size 100B
    - traffic class TCL2: 300 kbit/s, packet size 500B
    - traffic class TCL3: 600 kbit/s, packet size 500B
    - traffic class TCL5: 1000 kbit/s, packet size 1000B

Rates of BG traffic in classes TCL2,3,5 correspond to the rates guaranteed for these classes by the WFQ scheduling discipline on the bottleneck link. The rate in class TCL1 corresponds to the assumed AC limit for this class.

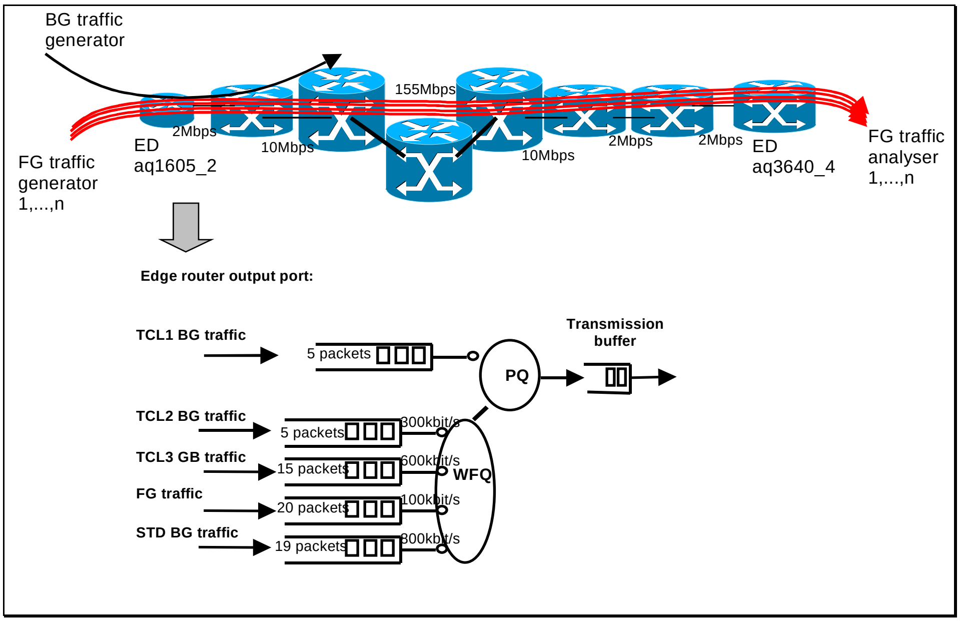

Figure 6-57. Trial topology - 24

n	Goodput of n TCP lows [kbit/s].	Aggregated "In" stream throughput [kbit/s]	Aggregated "Out" stream throughput [kbit/s]	"In" packets loss ratio	"Out" packets loss ratio	Packet latency min/max/avg [ms]
6	7,8 / 7,8 / 7,8 / 7,8 / 7,8 / 7,8	56505,24	7462,22	0,0000	0,0271	129 / 1987 / 766
7	7,8 / 7,8 / 7,8 / 7,8 / 7,8 / 7,8 / 7,8	62059,73	9006,58	0,0015	0,0759	294 / 1346 / 598
8	7,8 / 7,8 / 7,8 / 7,8 / 7,8 / 7,8 / 7,8 / 7,8	68159,29	10512,00	0,0027	0,1060	153 / 1613 / 651
9*	7,8 / 7,8 / 7,8 / 7,8 / 7,8 / 7,8 / 7,8 / 7,8 / 7,8	74985,60	13146,49	0,0038	0,2686	277 / 2469 / 1187
10*	7,8 / 7,8 / 7,8 / 7,8 / 7,8 / 7,8 / 7,8 / 7,8 / 7,8 / 7,8	78113,24	13509,87	0,0074	0,5294	104 / 2405 / 1047

Table 6-43. Admission control verification for non-greedy sources (reservation parameters PR=16, SR=8, eff=12,1kbit/s; measurement period = 15min)

The limit for the number of flows, defined by the implemented AC algorithm was 8 flows. The flows exceeding this number were set-up manually, without using the AC function.

n	Goodput of n TCP lows [kbit/s].	Aggregated "In" stream throughput [kbit/s]	Aggregated "Out" stream throughput [kbit/s]	"In" packets loss ratio	"Out" packets loss ratio	Packet latency min/max/avg [ms]
6	18,6 / 15,7 / 16,2 / 16,3 / 17,1	43125,16	61190,22	0,01	0,28	940 / 3991 / 2727
7	15,0 / 13,6 / 14,8 / 12,8 / 15,7 / 13,8 / 13,6	49380,44	55570,84	0,01	0,33	343 / 4062 / 1406
8	11,2 / 12,2 / 12,6 / 11,9 / 13,2 / 12,7 / 12,7 / 13,2	54973,87	50392,71	0,01	0,39	136 / 4167 / 1708
9*	11,6 / 10,2 / 12,6 / 10,0 / 10,9 / 11,4 / 12,0 / 10,4 / 10,1	60878,76	45097,78	0,01	0,44	566 / 4151 / 1948
10*	9,2 / 10,6 / 9,9 / 9,5 / 10,3 / 8,9 / 10,7 / 10,1 / 103, / 10,0	66913,42	39374,58	0,03	0,49	770 / 4147 / 1900

Table 6-44. Admission control verification for greedy sources (reservation parameters PR=16, SR=8, eff=12,1kbit/s; measurement period = 15min)

The limit for the number of flows, defined by the implemented AC algorithm was 8 flows. The flows exceeding this number were set-up manually, without using the AC function.

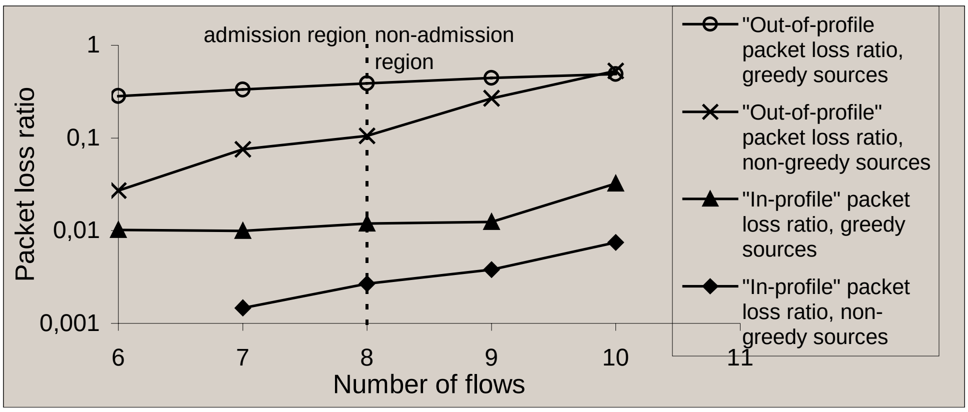

Figure 6-58. "In-profile" and "Out-of-profile" packet loss ratio vs. number of greedy and non-greedy TCP flows in PMC service

The obtained results show that the target packet loss ratio for in profile packets is not guaranteed for greedy as well as non-greedy sources. In case of greedy sources the packet loss rate is significantly higher what is caused by fact that large number of out of profile packets enters the network. Any way, even for non-greedy TCP sources with mean offered traffic 64 kbps (64 % of the admission limit) the packet loss rate is higher then the target rate (10^{-2} instead of 10^{-6}). In theory the admission control algorithm should guarantee no packet loss for in profile packets. But this would be the case if out of profiles packets are dropped or push-out buffer management scheme employed to give in profile packet priority in accessing the buffer. Even taking into account that certain number of out-of profile packet for non-greedy sources enters the network the packet loss rate should be on the level as given by the analysis of M/D/1/B queuing system. The observed packet loss ratio and packet delay suggests that the CBWFQ scheduler works differently than theoretical WFQ scheduler. Very large packet delay was observed on the level of seconds. The average delay for 8 non-greedy TCP sources (admission limit) is about 600 ms while the maximum delay is 1.6 sec. The large delay could be caused by higher service rate variability then in theoretical WFQ scheduler, larger periods of time between consecutive TCL4 packets are transmitted on the output link. During such events the TCL4 queue can build up causing larger delay and larger packet loss rate.

6.5.2.4 Impact of TCL4 scheduling rate on the packet delay in PMC service.

Description

The objective of this trial was to verify the effect observed in the previous experiment related to the increase of packet loss rate and packet delay observed in CBWFQ scheduler for queue with small weights.

Trial setup

- Tested topology is shown in Figure 6-59.
- Traffic parameters:
- Foreground traffic: n non-greedy TCP controlled flows, generated using Synthetic flow generator. Non-greedy application is emulated as a Poisson stream with mean rate equal to 8kbit/s. Flows are generated between end-stations PC3 and PC1. Destination port number is increased in the generated flows from 6000 to 6000+n. The reservation was set-up for each flow with parameters PR=16kbit/s, BSP=2000B, SR=8kbit/s, BSS=5000B. The number of sources is calculated using the AC formulas for TCL4. Additionally, test traffic with rate 1 packet/s was injected in order to measure packet delay in class TCL4.
- Background traffic: 4 constant bit rate streams generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP,
    - traffic class TCL1: 200 kbit/s, packet size 100B
    - traffic class TCL2: 300 kbit/s, packet size 500B
    - traffic class TCL3: 600 kbit/s, packet size 500B
    - traffic class TCL5: 1000 kbit/s, packet size 1000B

Rates of BG traffic in classes TCL2,3,5 correspond to the rates guaranteed for these classes by the WFQ scheduling discipline on the bottleneck link. The rate in class TCL1 corresponds to the assumed AC limit for this class.

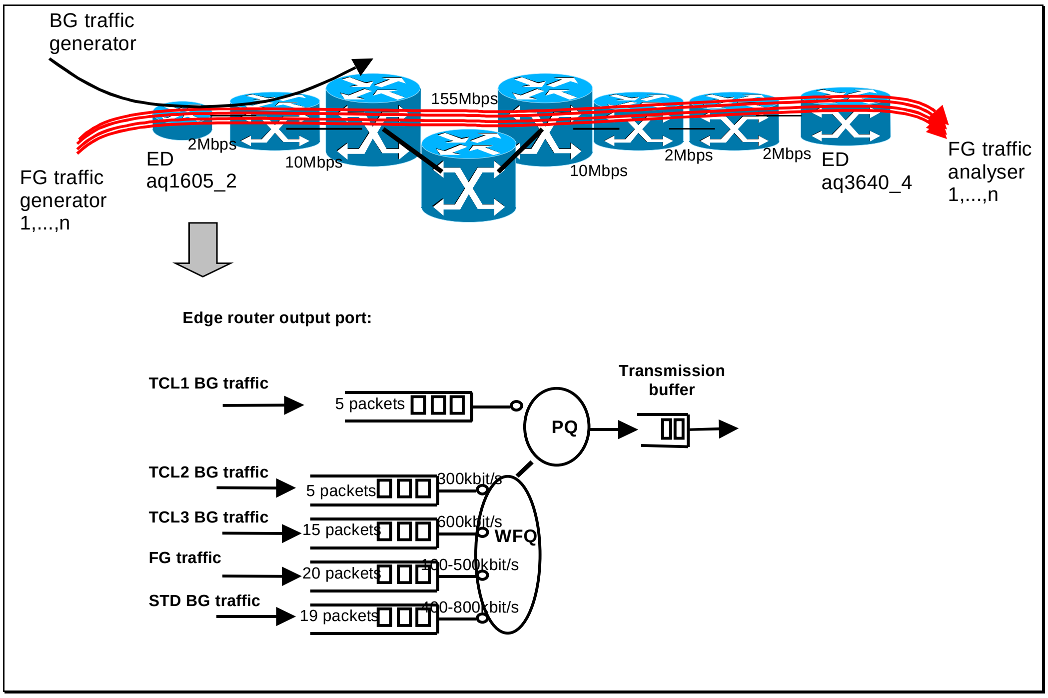

Figure 6-59. Trial topology - 25

The rate scheduled for TCL4 on the link is changed from 100 to 500 kbps during the experiment. On the other hand, the rate scheduled for STD service is decreased from 800 to 400kbps. When the amount of bandwidth assigned for PMC service is increased, the number of flows admitted into this service is also increased, according to the AC formulas for TCL4.

The trial results are shown in Table 6-45. The delay characteristics for TCL4 traffic as a function of the scheduling rate are presented on Figure 6-60. One may observe that the delay experienced by TCL4 traffic depends on the scheduling rate. Although the delay increases slightly faster when the scheduling rate drops below 300 kbps no dramatic increase was observed (at least for the measured range). The real reason for this effect is not clear. The most probable cause is some differences of the CISCO implementation of the WFQ algorithms or same architectural issues of CISCO routers.

Scheduled rate for STD service [kbit/s]	Scheduled rate for PMC service [kbit/s]	Number of admitted flows	Minimum one-way packet delay [ms]	Maximum one-way packet delay [ms]	Average one-way packet delay [ms]
800	100	4	166	1037	603
700	200	7	80,9	897	441
600	300	10	2,7	469	260,4
500	400	13	22,1	400,7	189,3
400	500	16	14,8	347	181,2

Table 6-45. One-way packet delay in PMC service as a function of TCL4 scheduling rate

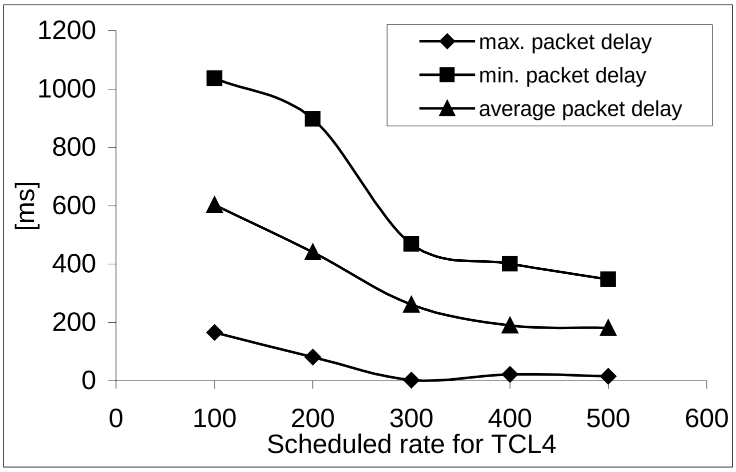

Figure 6-60. One-way packet delay in PMC service as a function of TCL4 scheduling rate

6.5.3 Trials of Unreal Tournament application - verification of traffic descriptors values

Unreal Tournament is an on-line game, where multiple client computers communicate with the game server. Details about this application one can find in D2202 document.

The aim of this trial was to verify values of traffic descriptors (Dual_Token_Bucket parameters) for Unreal Tournament application. Two persons played the game; one of them was user of the PC4 computer while the second one used the PC2 computer (see Figure 6-1). The person playing on PC2 roughly assessed the application quality (note, that the Unreal Tournament indicates network problems with the use of a flashing "sign" on the screen). The server was located on the PC4 computer. Background traffic was submitted on the 2Mbit/s link between the ingress edge router and the core network.

Two test cases were carried out: first, 3 greedy TCP sources were used as the background traffic in TCL4, then 3 non-greedy TCP sources were submitted. Non-greedy source generated Poisson traffic with mean rate 25kbit/s. In both cases, different reservation parameter values were set for the application traffic and for background TCP traffic. In all test cases, the sum of effective bandwidth of all reservations was not higher then the scheduled bandwidth for TCL4.

Reservation parameter values	Greedy TCP flows as background traffic in TCL4	Non-greedy TCP flows as background traffic in TCL4
Unreal Tournament: PR=24kbit/s, SR=16kbit/s, BSP=2000B, BSS=10000B TCP flows: PR=32kbit/s, SR=8kbit/s, BSP=2000B, BSS=10000B	Noticeable degradation of game quality	Noticeable degradation of game quality
Unreal Tournament: **PR=32kbit/s**, **SR=24kbit/s**, BSP=2000B, BSS=10000B TCP flows: PR=32kbit/s, SR=8kbit/s, BSP=2000B, BSS=10000B	Noticeable degradation of game quality	Good playing quality
Unreal Tournament: PR=40kbit/s, SR=32kbit/s, BSP=2000B, BSS=10000B TCP flows: PR=24kbit/s, SR=8kbit/s, BSP=2000B, BSS=10000B	Noticeable degradation of game quality	Good playing quality
Unreal Tournament: PR=48kbit/s, SR=40kbit/s, BSP=2000B, BSS=10000B TCP flows: PR=24kbit/s, SR=8kbit/s, BSP=2000B, BSS=10000B	Noticeable degradation of game quality	Good playing quality

Table 6-46. Unreal Tournament application - traffic description

One can observe that when the application traffic is mixed with greedy TCP sources, setting proper reservation parameters is very difficult. Although the traffic generated by the application did not exceed the traffic profile (no out-of-profile packets), the playing quality was affected. In case of non-greedy TCP sources mixed with Unreal Tournament traffic, setting the traffic descriptor values: PR=32kbit/s, SR=24kbit/s seems to be enough for acceptable playing quality.

6.6 Network services mixture

This section presents the results of the trial scenarios concerning the mix of AQUILA network services. The aim of the experiments was twofold:

- To demonstrate the need for service differentiation and rationale the AQUILA network services
- Test if the network services with different QoS objectives can effectively share the capacity of the link, scheduled by the WFQ algorithm.

6.6.1 Service differentiation

6.6.1.1 Differentiation of TCP and UDP traffic

Description

The objective of the test was to demonstrate the need for service differentiation for streaming and elating traffic. In the trial the performance parameters for UDP traffic mixed with TCP traffic were measured. Two cases were considered with and without service differentiation. In the case without service differentiation the TCP and UDP was served together by the same network resources. In the second case the PQ and WFQ schedulers were used to differentiate QoS for this traffic types. This trial aim to prove the need to provide separate network services for streaming and elastic traffic.

Trial setup

- Tested topology is shown in Figure 6-34.
- Traffic parameters:
    - n greedy TCP controlled flow, generated from PC3 to PC1 using Synthetic flow generator. The number of TCP flows was changed from 1 to 100 flows. The TCP packets were 1500 bytes long.
    - 1 UDP flow, generated from PC3 to PC1 using Synthetic flow generator. The UDP flows were constant bit rate streams. The traffic rate of UDP flow was set to 100, 200 and 500 kbps. The UDP packets were 100 bytes long.

Case #1

All scheduling mechanism on link between the Edge Device (aq1605_1) and the core network were disabled. The UDP and TCP traffic was served by FIFO queue.

Case #2

The priority queuing scheduler was enabled on link between the Edge Device (aq1605_1) and the core network. The UDP flows were served by higher priority queue.

Case #3

The WFQ scheduler was enabled on link between the Edge Device (aq1605_1) and the core network. The UDP and TCP flows were assigned to different queues. The service rates for queue dedicated for streaming traffic was set to 1 Mbps (50% of the link).

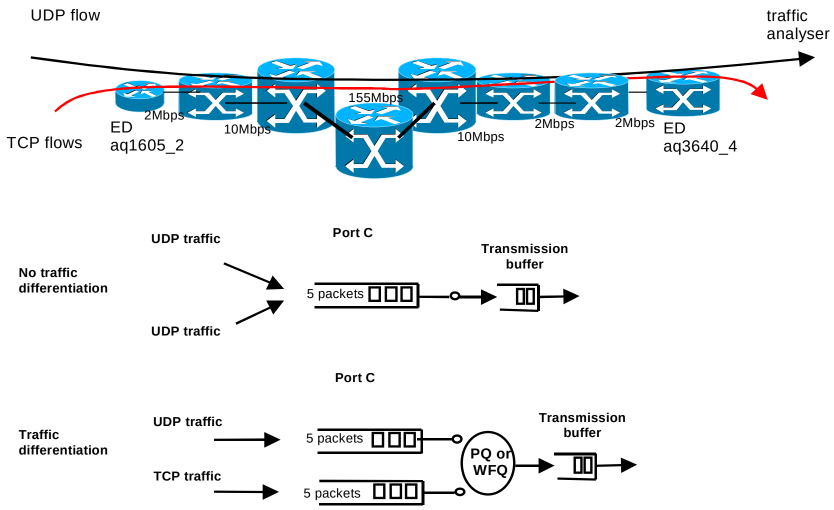

Figure 6-61. Trial topology - 26

The trial results for case #1 for different rates of UDP flow are presented in Table 6-47, Table 6-48, and Table 6-49. Results for 500 kbps UDP stream

respectively. For each UDP flow the min, max and average delay was measured as well as the packet loss rate. These measurements were repeated for different number of TCP connections (from 1 to 100 TCP connections). One may observe that as number of TCP connections increases the delay and packet loss experienced by UDP traffic increases. For higher number of TCP flows the increase rate for the delay and the packet loss ratio for UDP traffic decreases. This is caused by the fact that the total offered traffic rate (to the network) increases slower the number of TCP connections. Any way the delay and packet loss values are unacceptable for most of the streaming applications. This clearly proves that separate network services have to be defined for streaming and elastic traffic.

Number of TCP flows	Min Delay [ms]	Max Delay [ms]	Average Delay [ms]	Ploss ratio
1	1.2	12.8	9.4	0
4	1.2	30.7	10.2	0
10	1.3	43.4	10.7	0
20	1.3	91.5	16.9	0
50	185.2	445.8	317.7	0.111522
100	285.2	465.2	374.5	0.258862

Table 6-47. Results for 100 kbps UDP stream

Number of TCP flows	Min Delay [ms]	Max Delay [ms]	Average Delay [ms]	Ploss ratio
1	1.2	13	6.8	0
4	1.2	30.5	9.4	0
10	1.2	44.1	13.2	0
20	199.3	336.2	254.6	0.184889
50	267.5	483	357.6	0.457235
100	292.8	502.9	385.9	0.535273

Table 6-48. Results for 200 kbps UDP stream

Number of TCP flows	Min Delay [ms]	Max Delay [ms]	Average Delay [ms]	Ploss ratio
1	1.2	14.2	6.2	0
4	110.1	151.4	130.3	0.119696
10	130.4	207.7	170.1	0.270066
20	186.5	346.4	260.6	0.529283
50	268.9	484.4	366.3	0.703776
100	289.6	494.6	385.9	0.739759

Table 6-49. Results for 500 kbps UDP stream

Number of TCP flows	Min Delay [ms]	Max Delay [ms]	Average Delay [ms]	Ploss ratio
1	1.1	14.1	5.4	0
4	95.7	158.4	135.3	0.516089
10	133.3	213.6	173.7	0.567104
20	184.3	355.6	255.7	0.723836
50	280	480.7	369.1	0.73246
100	308	529.8	390.5	0.737891

Table 6-50. Results for 1000 kbps UDP stream

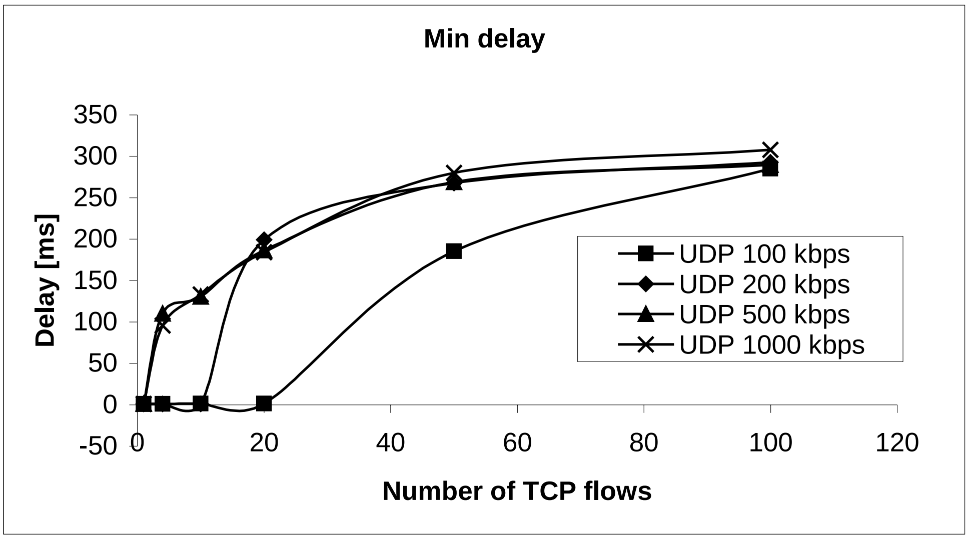

Figure 6-62. Min delay for UDP stream as a function of the number of TCP flows

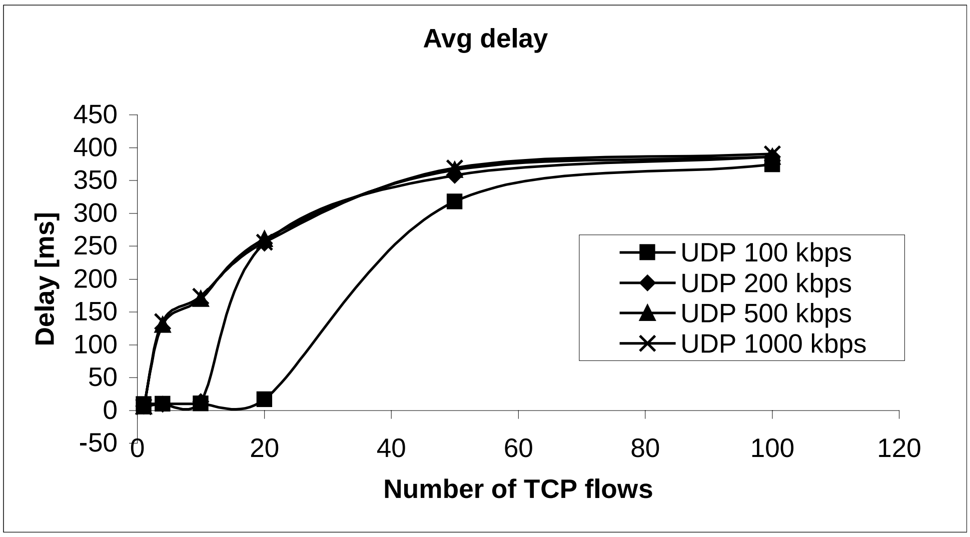

Figure 6-63. Average delay for UDP stream as a function of the number of TCP flows

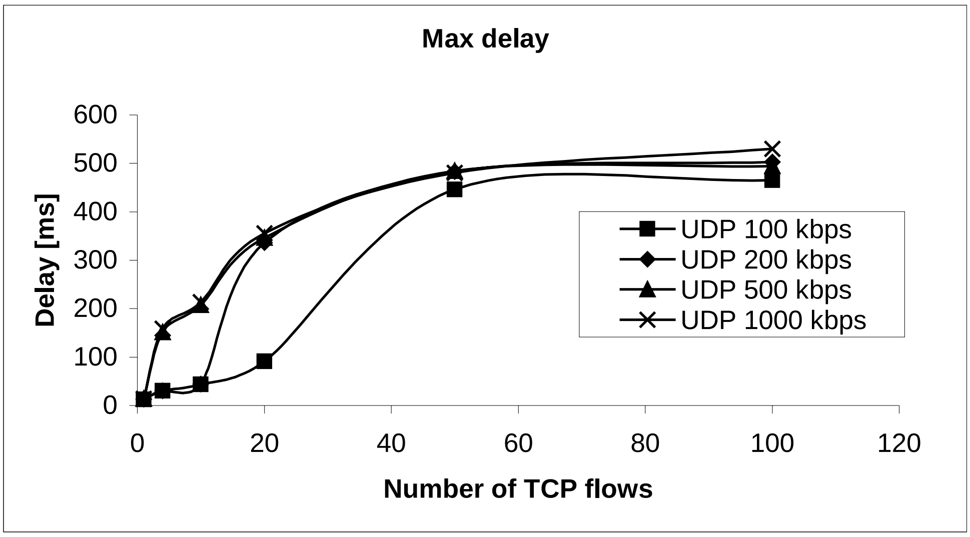

Figure 6-64. Max delay for UDP stream as a function of the number of TCP flows

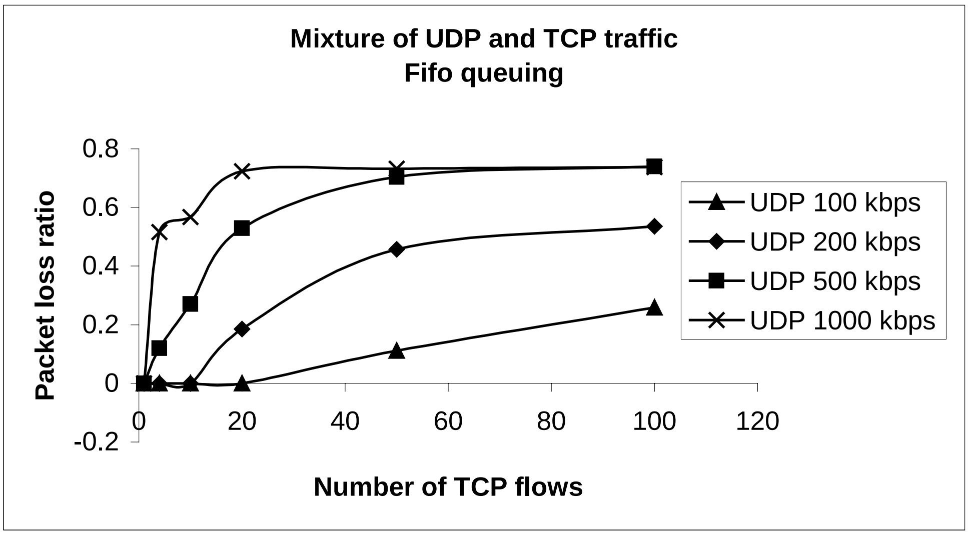

Figure 6-65. Packet loss rate for UDP stream as a function of the number of TCP flows

The trial results for case #2 (PQ scheduler) are presented on the Figure 6-66 and Figure 6-67 while the results for case #3 (WFQ scheduler) are presented on Figure 6-68 and Figure 6-69. The average packet delay for UDP traffic is between 5 and 10 ms and the maximum delay is about 14 ms. Similar results were obtained for PQ and WFQ scheduler. The delay for UDP traffic decreases as the offered rate of UDP increases. This effect is probably caused by Tx ring buffer. If the UDP rate increase the tx ring is more often filled by shorter packets what effectively decreases delay.

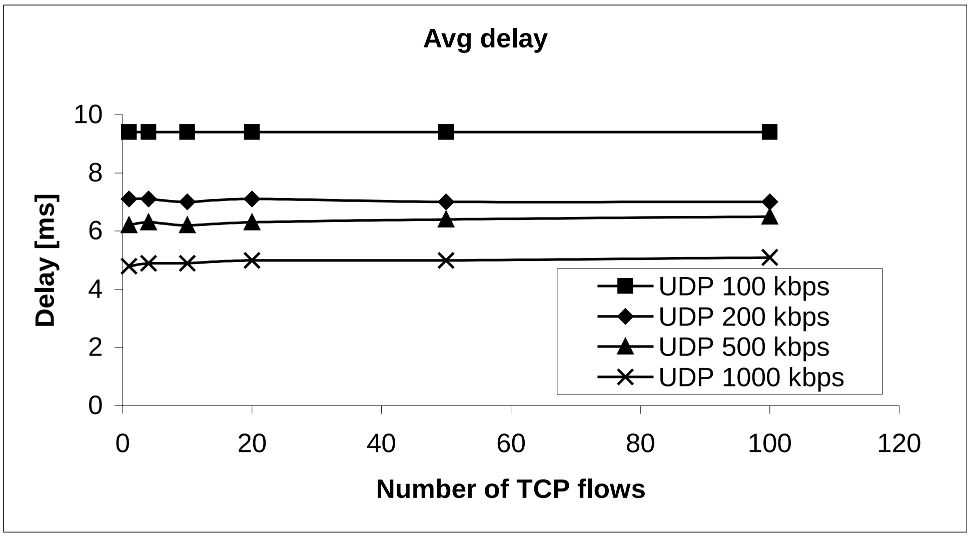

Figure 6-66. Average delay for UDP stream as a function of the number of TCP flows in case of PQ scheduler

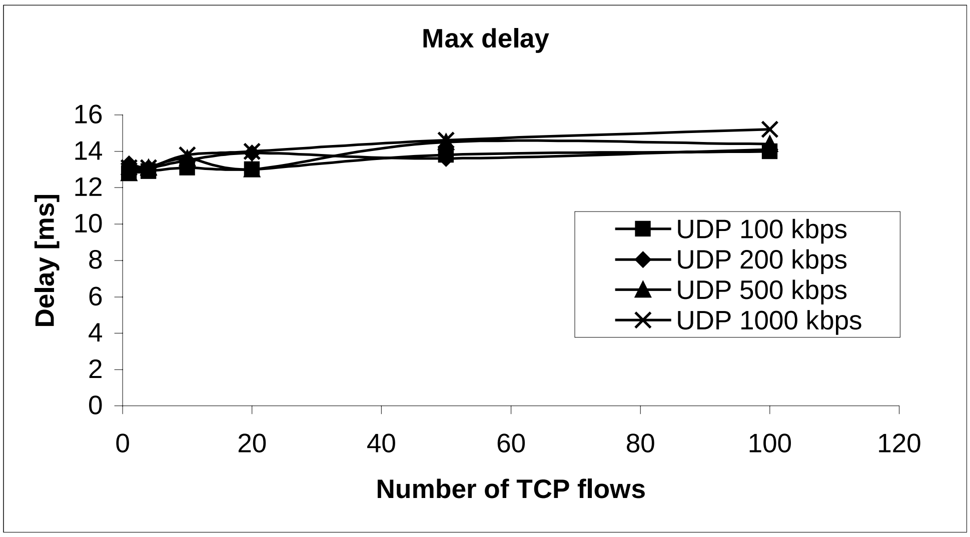

Figure 6-67. Maximum delay for UDP stream as a function of the number of TCP flows in case of PQ scheduler

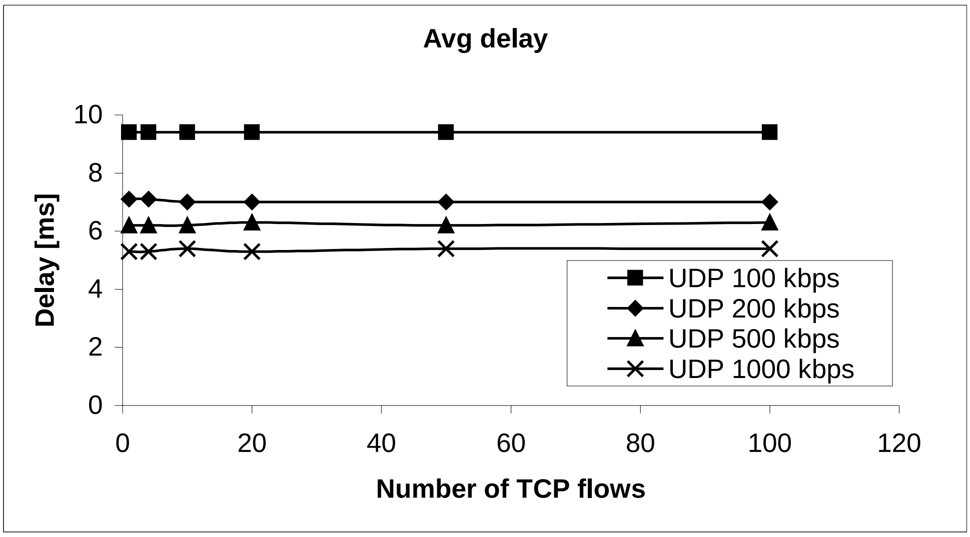

Figure 6-68. Average delay for UDP stream as a function of the number of TCP flows in case of WFQ scheduler

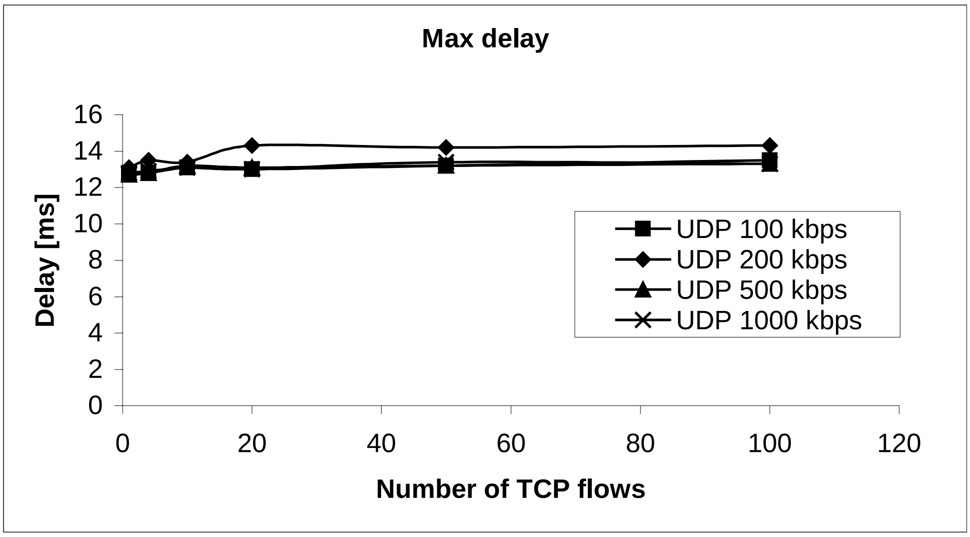

Figure 6-69. Maximum delay for UDP stream as a function of the number of TCP flows in case of WFQ scheduler

6.6.1.2 Influence of low priority traffic on PCBR service

Description

The aim of this trial was to measure the influence of low priority traffic on PCBR service in order to assess the possible level of quality of service differentiation between the PCBR and other network services (PVBR, PMM, PMC and STD). The foreground traffic was generated in PCBR and STD network services. The STD service was chosen because it dose not provide any control over the number of accepted flows and thus can have the greatest influence on the performance of PCBR service. The background traffic whose aim was to fill the rest of link capacity was generated in each service class independently. The measured parameters are packet loss ratio and delay of the flows submitted into PCBR and STD services. The performance of both network services is measured in different load conditions in the low priority service.

Trial setup

- Tested topology is shown in Figure 6-34.
- Traffic parameters:
- Foreground traffic:
  - traffic class TCL1: 64 kbit/s, packet size 100B, constant bit rate stream generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP
  - traffic class STD: 64 kbit/s, packet size 100B, constant bit rate stream generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP
- Background traffic:
  - traffic class TCL1: Poissonian traffic with mean rate = 100kbit/s, packet size 100B. The TCL1 stream is generated from PC3 to PC1 using the Synthetic flow generator.
  - traffic class TCL2: 300 kbit/s, packet size 500B, constant bit rate stream generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP
  - traffic class TCL3: 4 TCP controlled flows, generated from PC3 to PC1 using Synthetic flow generator. The generated flow is a 4Mbit/s constant bit rate stream with packet size equal to 1500B. Reservation was set-up for this flow in the PMM service with parameters SR=250kbit/s, BSS=65kB.
  - traffic class TCL4: 100 kbit/s, packet size 500B, constant bit rate stream generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP
  - traffic class TCL5: variable rate, packet size 1000B, constant bit rate stream generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP

Generated packets were marked with the appropriate DSCP code. Rates of BG traffic in classes TCL2,4 correspond to the rates guaranteed for these classes by the WFQ scheduling discipline on the link between the Edge Device (aq1605_1) and the core network. Therefore, we assume that the network load in TCLs 2,4 is equal to the maximum value allowed by the admission control mechanism.

The total rate of foreground and background streams in PCBR service is approximately equal to the maximum value admitted by the admission control function. In case of STD service, the flows submitted into the network are not subject to the AC decision, so the load in the STD service can be high.

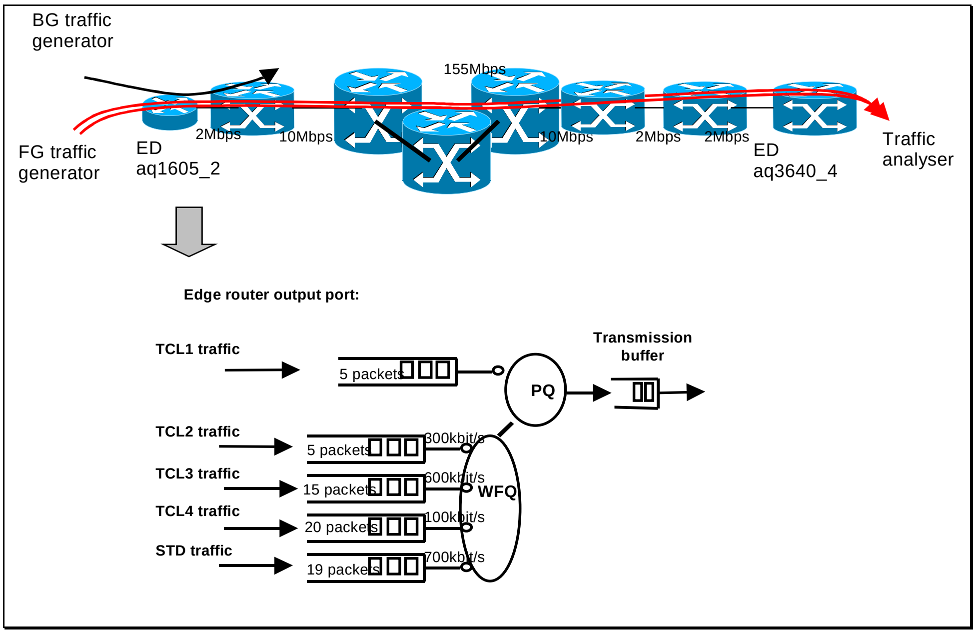

Figure 6-70. Trial topology - 27

BG STD rate [kbit/s]	FG flow in network service:	Throughput [kbit/s]	Loss ratio	Min latency [ms]	Max latency [ms]	Avg latency [ms]
700	PCBR	64	0	7,7	28,8	20,3
	STD	64	0	14,7	39,4	25,5
800	PCBR	64	0	8,4	28,1	20,1
	STD	59,6	0,059	122,2	195,5	153,8
1000	PCBR	64	0	8,2	27,0	20,4
	STD	47,0	0,103	125,9	208,3	160,7
1200	PCBR	64	0	8,5	29,1	20,7
	STD	30,8	0,171	129,6	219,2	177,3

Table 6-51. UDP traffic in PCBR and STD service

Two flows generated in the same way (UDP stream with rate 64kbit/s) were submitted into different networks services.

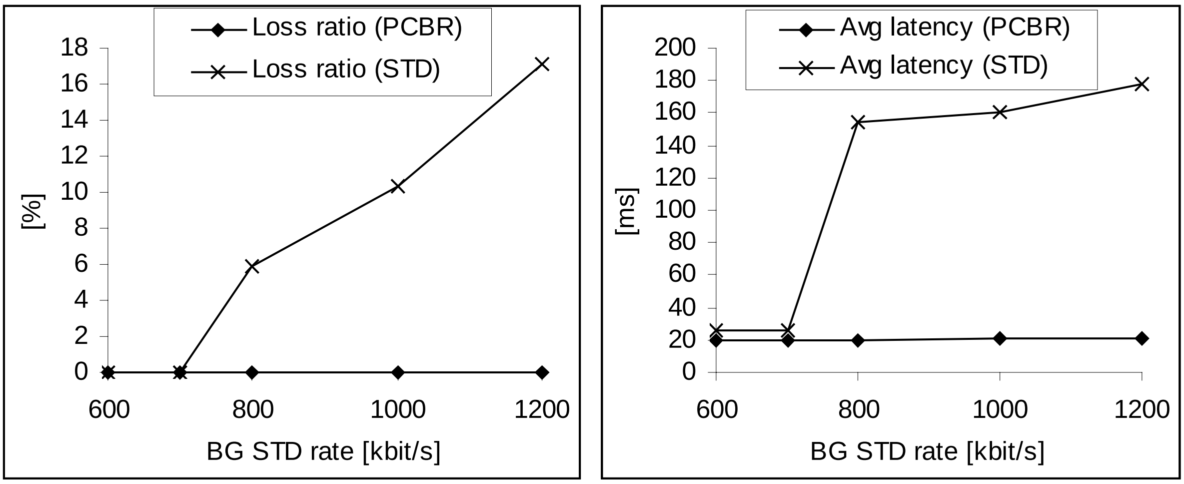

Figure 6-71. Comparison of QoS of flows in PCBR and STD service

The comparison of measured QoS parameters shows, that when the load in the STD network service is low, the performance of both services is similar. Anyway, the access to the STD service is not controlled by the AC function and the load in this service can be high. As one can expect, in the high load conditions the PCBR service can guarantee QoS for the flows admitted into the network..

6.6.2 Separation of Network Services

6.6.2.1 Separation of network services in overload traffic conditions

Description

The aim of the trial is to verify that the WFQ scheduling discipline on the link provides bandwidth guarantees assumed for each network service.

Trial setup

- Tested topology is shown in Figure 6-34.
- Traffic parameters:
- Test traffic: 5 constant bit rate streams generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP. Generated packets were marked with the appropriate DSCP code:
    - traffic class TCL1: 200 kbit/s, packet size 500B
    - traffic class TCL2: 800 kbit/s, packet size 500B
    - traffic class TCL3: 800 kbit/s, packet size 500B

- traffic class TCL4: 800 kbit/s, packet size 500B
- traffic class TCL5: 800 kbit/s, packet size 1000B

Traffic submitted into each traffic class served by the WFQ algorithm exceeds the scheduled rate for a given class on a 2Mbit/s link between the edge device aq1605_1 and the core network. In the overloaded traffic conditions each class should obtain the bandwidth guarantees according to the weights set in the WFQ algorithm.

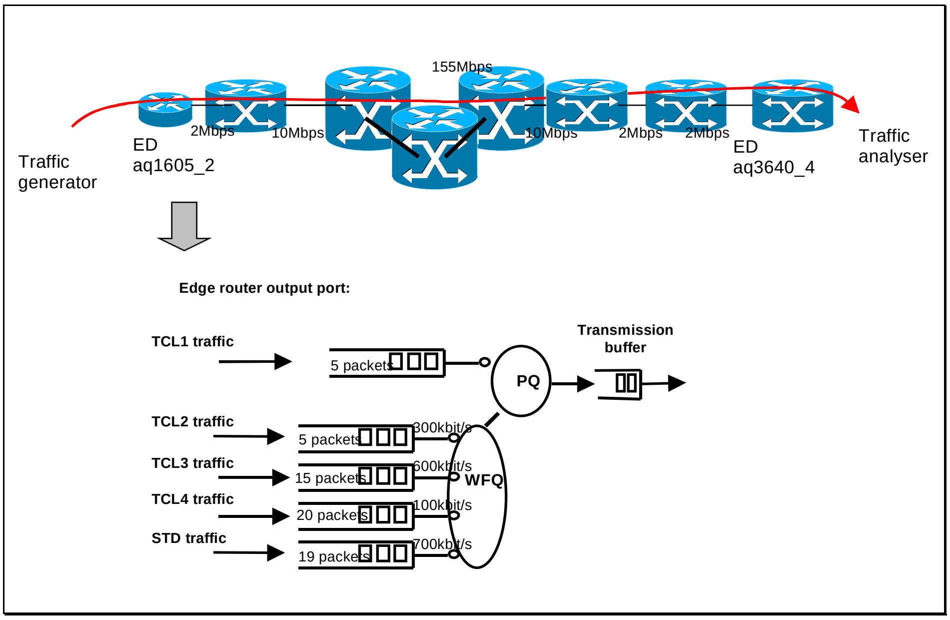

Figure 6-72. Trial topology - 28

TCL	Scheduled rate [kbit/s]	Measured rate [kbit/s]
1	-	200
2	300	328,7
3	600	654,1
4	100	109,4
STD	700	755,0

Table 6-52. Separation of network services

One can observe that the bandwidth guarantees in each traffic class are satisfied. Remark, that the sum of configured scheduled rates is equal to 1900 kbit/s, which is smaller then the link capacity (2000kbit/s). The classes served by the WFQ in a fair manner share this spare capacity.

6.6.2.2 Influence of the PCBR traffic on the QoS of the flows served inside the PMM service

Description

The aim of this trial is to measure how the high priority traffic can degrade the traffic served by the PMM network service. It is also shown; that the amount of traffic submitted into the PCBR service must be limited by the admission control function, otherwise the QoS objectives for the traffic classes served with the lower priority on the link are not met.

Trial setup

- Tested topology is shown in Figure 6-73
- Traffic parameters:
- Foreground traffic:
    - Poissonian traffic with variable mean rate. The TCL1 stream is generated from PC3 to PC1 using the Synthetic flow generator.
    - 4 TCP controlled flows, generated from PC3 to PC1 using the 'multiplex' option of the Synthetic flow generator. The generated flow is a 4Mbit/s constant bit rate stream with packet size equal to 1500B. Reservations was set-up for foreground traffic flows with parameters SR=250kbit/s, BSS=65kB.
- Background traffic: 3 constant bit rate streams generated using HP BSTS traffic generator from port aq1605_2:eth1 to port aq3640_4:eth1/1, transport protocol UDP. Generated packets were marked with the appropriate DSCP code:
    - traffic class TCL2: 300 kbit/s, packet size 500B
    - traffic class TCL4: 100 kbit/s, packet size 500B
    - traffic class TCL5: 700 kbit/s, packet size 1000B

Rates of BG traffic in classes TCL2,4,5 correspond to the rates guaranteed for these classes by the WFQ scheduling discipline on the link between the Edge Device (aq1605_1) and the core network. Therefore, we assume that the network load in TCLs 2,4 is equal to the maximum value allowed by the admission control mechanism.

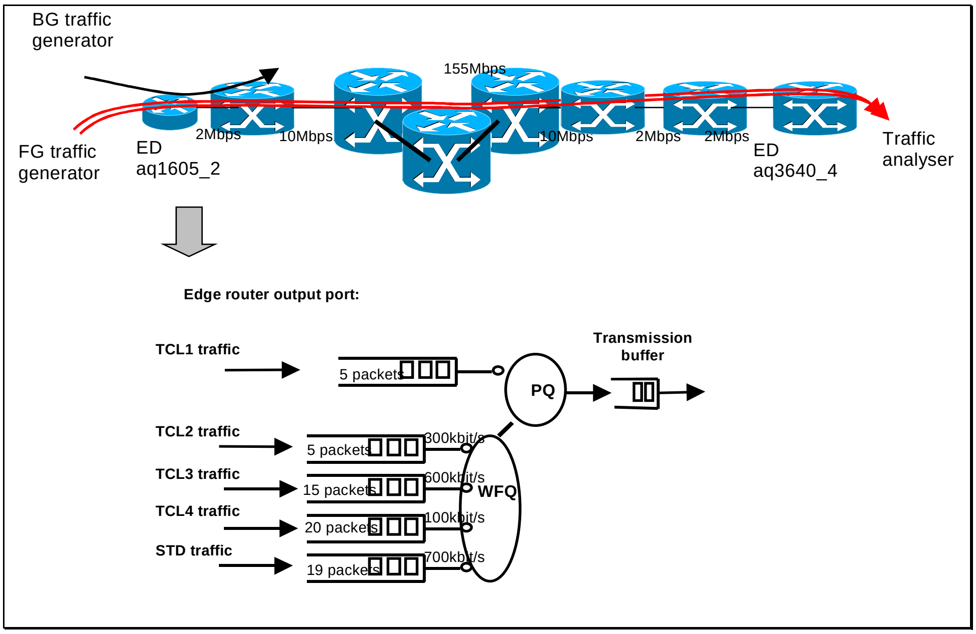

Figure 6-73.Trial topology - 29

Mean rate of generated PCBR traffic [kbit/s]	Measured throughput of PCBR traffic [kbit/s]	Throughput of PMM flow 1 (SR=135kbit/s) [kbit/s]	Throughput of PMM flow 2 (SR=135kbit/s) [kbit/s]	Throughput of PMM flow 3 (SR=135kbit/s) [kbit/s]	Throughput of PMM flow 4 (SR=135kbit/s) [kbit/s]
100	91,1	185,0	190,0	191,3	187,6
133	119,96	178,7	177,8	183,3	175,4
160	141,9	177,3	167,9	181,3	162,9
266	239,3	159,4	149,1	153,6	154,2
400	346,1	135,1	142,0	130,6	131,77

Table 6-53. Case#1, 4 PMM flows

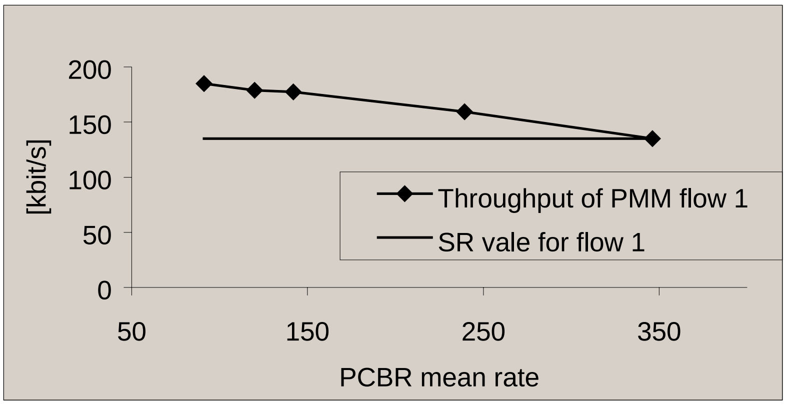

Figure 6-74. Impact of PCBR traffic on the throughput of PMM flow, delta=0.9

Traffic submitted into the PCBR service is served with higher priority on the link. Therefore, increasing the amount of traffic in the TCL1 class causes degradation of traffic served with the lower priority on the link. The admission control mechanism for the PCBR service assumes that the maximum utilisation within the TCL1 should not be higher then rho*AC_limit, which is 0.69*200kbit/s=138kbit/s.

Figure 6-74 shows how the performance of flow served inside the PMM service can be degraded by the increased traffic in PCBR service. One can observe, that the throughput achieved by the PMM flow is high above the requested SR value. Two factors have significant influence on the conservativeness of such approach:

- 100kbit/s of capacity of the link between the ingress edge device and the core network is not assigned to any network service
- Flows in PMM service are admitted until the total value of SR parameters of the incoming flows is not higher then delta*AC_limit, while the value of delta is 0.9.

The measurements presented below assume the value of delta = 1. This means, that one additional flow with the value of SR = 60kbit/s could be admitted.

Mean rate of generated PCBR traffic [kbit/s]	Measured throughput of PCBR traffic [kbit/s]	Throughput of PMM flow 1 (SR=135kbit/s) [kbit/s]	Throughput of PMM flow 2 (SR=135kbit/s) [kbit/s]	Throughput of PMM flow 3 (SR=135kbit/s) [kbit/s]	Throughput of PMM flow 4 (SR=135kbit/s) [kbit/s]	Throughput of PMM flow 4 (SR=60kbit/s) [kbit/s]
133	119,9	152,0	155,2	160,0	152,1	100,5
160	148,3	159,4	160,1	158,5	145,9	93,9
200	182,3	146,7	149,4	142,9	143,7	94,8
266	239,9	137,6	131,5	132,2	142,7	71,6
400	346,1	119,9	121,7	119,5	122,8	59,1

Table 6-54. Case#2, 5 PMM flows

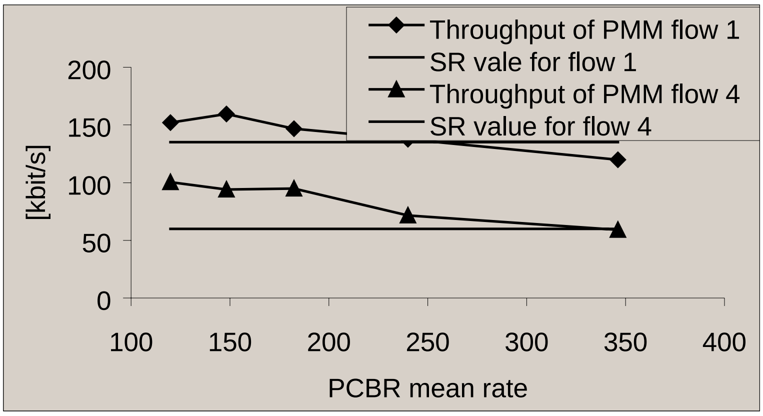

Figure 6-75. Impact of PCBR traffic on throughput of PMM flows, delta = 1

The results depicted on the Figure 6-75 show, that when the traffic submitted into the PCBR class is limited by the admission control function, the QoS guarantees for the flows served by the PMM service are met.

6.7 AC mechanism validation

The objective of this trial was to validate the correctness of the AC algorithm's implementation for particular traffic classes, i.e. for TCL1, TCL2, TCL3 and TCL4. Detailed description of assumed AC one can find in deliverable D1301. The tested flows were set-up/released between terminals PC1 and PC3 by using EAToolkit. In this trial, the following resource pool (admission control limits, and target QoS parameters) was established.

Traffic class	AC limits				Target Packet loss rate
	Max PR [kbps]	Max SR [kbps]	Buffer space	Bandwidth [kbps]	
TCL1	200	-	20 packets	200	10-4
TCL2	1000	PR	20000 bytes	300	10-4
TCL3	250	-	20000 bytes	600	10-4
TCL4	50	5	20000 bytes	100	10-4

Table 6-55. Values of AC limits and target packet loss rate

Details about validation process of AC algorithm's, including traffic characterisation as well as theoretical and measured maximum numbers of admitted flows, are described bellow.

6.7.1 Trials for TCL1 class

In this section, we concentrate on the validation of AC algorithm for TCL1 class. Let us recall that a new flow is accepted as long as the sum of peak rate of admitted flows does not exceed the maximum admissible rate value. This maximum admissible rate depends on both the volume of the bandwidth dedicated for the TCL1 class and the target utilisation factor ρ_1, calculated from the following equation:

$$\rho_1 = \frac{2B_i^1}{2B_i^1 - \ln(P_{loss})},$$

where: B_i^1 is the buffer space dedicated for class TCL1 and Ploss is target packet loss rate. Detailed description of AC rules for TCL1 class one can find in deliverable D1301.

For the purpose of validation of AC implementation, two trails were assumed, which differ in values of dedicated bandwidth and buffer size (different resource pools). For each trial case, a number of identical flows were submitted, and then the maximum number of accepted flows was measured.

Trial#1

In this trial, we assume that dedicated bandwidth is 200 kbps, buffer space is 20 packets and target packet loss rate is equal to 10^{-4}. From equation (1) we calculate the target utilisation factor ρ_1=0.81. Therefore, the maximum admissible rates equals 162 kbps. The maximum number of admitted flows (measured and theoretical calculated) is presented in below table.

Peak Rate of submitted flows [kbps]	**Trial#1**	
	No of admitted flows (measurements)	No of admitted flows (calculations)
163	0	0
162	1	1
64	2	2
32	5	5
16	10	10

Table 6-56. Maximum number of admitted flows in trial_case#1

Trial#2

In the second trial case, we assume that dedicated bandwidth is 250 kbps and buffer size is 10 packets. The value of packet loss rate is set as previous to 10^{-4}. Now, due to lower buffer size, the target utilisation factor is ρ_1=0.68. Therefore, the maximum admissible rate is equal to 171 kbps. The maximum number of admitted flows (measured and theoretical calculated) is presented in below table.

Peak Rate of submitted flows [kbps]	Trial#2	
	No of admitted flows (measurements)	No of admitted flows (calculations)
163	0	0
162	1	1
64	2	2
32	5	5
16	10	10

Table 6-57. Maximum number of admitted flows in trial_case#2

In both trial cases measured number of accepted flows is equal to value calculated theoretically. Therefore, one can conclude that the implementation of AC algorithms is consistent with specification given in deliverable D1301.

6.7.2 Trials for TCL2 class

This section contains results of validation the AC implementation for TCL2 class. The admission control algorithm for this class is based on definition of effective bandwidth. It means, that new flows are accepted as long as the sum of effective bandwidth of admitted flows does not exceed volume of dedicated capacity. The effective bandwidth, *Eff(.)* for the flows belonging to TCL2 class can be calculated as follows:

$$Eff(.) = \begin{cases} a \cdot AR(1 + 3z(1 - AR/PR)) \;\; if \;\; 3z \le \min(3, PR/AR) \\ a \cdot AR(1 + 3z^2(1 - AR/PR)) \;\; if \;\; 3 < 3z^2 \le PR/AR \\ a \cdot PR \;\; otherwise \end{cases}$$

$$a = 1 - \frac{\log_{10} P_{loss}}{50}, \quad z = \frac{-2\log_{10} P_{loss}}{R_i^2 / PR}$$

where: R_i^2 is the dedicated bandwidth for class TCL2 , AR denotes average rate and can be replaced by SR value.

In the trial cases four types of flows were submitted:

1. Type #1 is characterised by: PR=27.7 kbps, BSP=2000 bytes, SR=27.7 kbps, BSS=2000 bytes, M=1500 bytes
2. Type #2 is characterised by: PR=18 kbps, BSP=2000 bytes, SR=6 kbps, BSS=2000 bytes, M=1500 bytes
3. Type #3 is characterised by: PR=28 kbps, BSP=2000 bytes, SR=9 kbps, BSS=2000 bytes, M=1500 bytes
4. Type #4 is characterised by: PR=37 kbps, BSP=2000 bytes, SR=12 kbps, BSS=2000 bytes, M=1500 bytes

The results of trials for validation of AC implementation are gathered in the table below.

	No of type #1 flows	No of type #2 flows	No of type #3 flows	No of type #4 flows	Σ Eff(.) [kbps]	Result	Verdict
Trial#1	10	0	0	0	299.9	All flows were accepted	OK
Trial#2	11	0	0	0	329	One flow of type #1 was not accepted	OK
Trial#3	0	23	0	0		Five flows were not accepted	ERROR
Trial#4	0	0	12	0		Three flows were not accepted	ERROR
Trial#5	0	0	0	x		All flows were accepted	OK.

Table 6-58. Results of AC validation for TCL2 class

Table 6-58. Results of AC validation for TCL2 class say that in some cases the implementation of the AC fails.

6.7.3 Trials for TCL3 class

This section contains result for validation of AC algorithms for TCL3 class. The admission control rules for this class assumes that new flows are accepted as long as the sum of sustainable rate of admitted flows does not exceed maximum admissible rate and the sum of the maximum policed unit of admitted flows is lower then dedicated buffer space. The maximum admissible rate depends on the dedicated for this class bandwidth and target utilisation factor δ, which is set to 0.9 (this value is related with percentage of non-TCP controlled flows submitted to TCL3 class). In this trial we assumed that dedicated bandwidth is equal to 600 kbps, so that maximum admissible rate is 540 kbps and volume of buffer space is 20 000 bytes.

In the trial cases two types of flows were submitted:

1. Type #1 is characterised by: SR=250 kbps, BSS=2000 bytes, M=1500 bytes (this is maximum admissible flow)

2. Type#2 is characterised by: SR=20kbps, BSS=2000 bytes, M=1500 bytes

The results of trials for validation of AC implementation are gathered in the table below.

	No of type#1 flows	No of type#2 flows	Σ SR [kbps]	Σ M [bytes]	Result	Verdict
Trial #1	2	2	540	6000	All flows were accepted	OK
Trial #2	2	3	560	7500	One flow of type #2 was not accepted	OK
Trial #3	3	0	750	4500	One flow of type #1 was not accepted	OK
Trial #4	0	13	260	19500	All flows were accepted	OK
Trial #5	0	14	280	21000	One flow of type #2 was not accepted	OK

Table 6-59. Results of AC validation for TCL3 class

On the basis of performed trials, one can conclude that implementation of AC for TCL#3 is consistent with specification in deliverable D1301.

6.7.4 Trials for TCL4 class

In this section validation of AC implementation for TCL4 class is provided. Let us recall, admission control algorithm is based on definition of effective bandwidth. New flows are accepted as long as the sum of effective bandwidth of admitted flows does not exceed volume of capacity dedicated for this class. The effective bandwidth, *Eff(.)* for the flow of class TCL4 can be calculated as follows:

$$Eff(.) = \max\left\{SR, \frac{PR * T}{B_i^4 / R_i^4 + T}\right\} \qquad (3)$$

where *T= BSS/(PR-SR)*, R_i^4 is the dedicated capacity for TCL4 in ingress link, B_i^4 is buffer size dedicated for TCL4 traffic.

In this trial we assumed that dedicated capacity is 100000 bps, buffer space is 20000 bytes. Moreover, we assume that two types of traffic are submitted to the system, which are:

1. Type #1 is characterised by: PR=20 kbps, SR=10 kbps, BSS=5000 bytes, M=1500bytes, so the effective bandwidth equals to 14.286 kbps

2. Type #2 is characterised by: PR=40 kbps, SR=30 kbps, BSS=5000 bytes, M=1500 bytes, so the effective bandwidth equals to 28.572 kbps

The results of trials for validation of AC implementation are gathered in the table below.

	No of type#1 flows	No of type#2 flows	Σ Eff(.) [kbps]	Result	Verdict
Trial #1	7	0	100	All flows were accepted	OK
Trial #2	8	0	114	One flow of type #1 was not accepted	OK
Trial #3	1	3	100	All flows were accepted	OK
Trial #4	1	4	128	One flow of type #3 was not accepted	OK

Table 6-60. Results of AC validation for TCL4 class

On the basis of performed trials, one can conclude that implementation of AC for TCL#4 is consistent with specification in deliverable D1301.

6.7.5 Summary

Taking the received results into account we can say that implementations of admission control for traffic classes TCL1, TCL3, and TCL4 is consistent with specification D1301. In the case of TCL2 class some inconsistency is observed.

7 Annex B – RCL layer trial scenarios and results

7.1 Resource Pool mechanism

The aim of this trial scenario is to test the efficiency of the resource usage and the frequency of resource shifts. Sequences of reservation requests and releases without any actual sending of data suffice for this purpose.

7.1.1 Testing of the basic functionality

In order to check the functionality of the resource pools, an appropriate topology is necessary. At least a one level hierarchy should be used.

The minimum topology consists only of one RP having its resources shared among the two RPLs. This is used to test the basic functionality of the RP, i.e. how it shares resources among the RPLs, how it manages resource reservation requests and resource release requests generated by them.

The basic functionality is tested using a core with 3 edge devices. Traffic from ED1 and ED 2 passes the network through the core to ED3.

7.1.2 Description of the RCA Algorithm

In this section the algorithm for resource distribution and redistribution will be presented. Basis for this description is the document "An Adaptive Algorithm for Resource Management in a Differentiated Service Network" [D1201]. Due to the fact that this algorithm is implemented in the RCA, but until now not available in a public deliverable, we decided to describe it here in more detail.

7.1.2.1 Algorithm mechanism

The basic mechanism of the algorithm is to handle efficiently the cases when re-distribution of resources is needed. This is invoked when a Resource Pool Leaf (RPL), also called *child,* does not have enough resources to accommodate a new user request. According to the algorithm, the RPL will make a request for additional resources to its Root Pool (RP), also called *father*. The *child* makes a request determining the minimum additional resources needed to admit the request and an upper limit for the resources that can accept from its father. The *father* is responsible for deciding how many resources to give to its *child*, depending on the amount of resources requested, the upper limit defined by the *child* and the amount of its free resources. In case, the *father* does not have enough resources it will also make a resource request to its father RP (of the above level). This procedure can continue up to the root of the tree. The procedure of finding additional resources is bottom-up, i.e. from the leaves of the tree up to the root.

7.1.2.2 Initial Resource Distribution

The initial resource distribution to the nodes of the tree is defined via the QMTool (see Annex D). These initial resources may not reflect the actual traffic load of each sub-area, therefore, the RPs/RPLs should be able to adjust resource assignments to real traffic conditions, which are difficult to be forecasted and may change during time. During this top-down start-up procedure, each RP distributes its resources to its *child's* according to the initial amounts defined. Each RP and RPL is basically described by the following set of parameters:

Rmax	upper limit of resources that can be assigned to an RP/RPL
Rtot	current resource assignment to an RP/RPL
Rres	current reserved resources of an RP/RPL
Rfree	currently unused (free) resources of an RP/RPL
Rav	maximum resources that can be additionally assigned to an RP/RPL

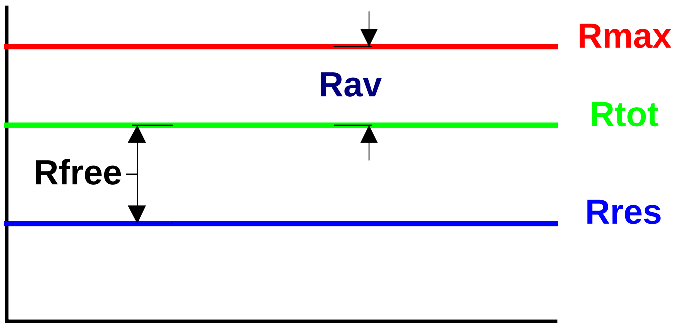

Figure 7-1. Initial Resource Distribution

The equations (1)-(6) describe the initial resource status of an RP/RPL as well as the relation of the resources of a father RP and its child's (f: father, c: child):

$$\text{Rmax} >= \text{Rtot} >= 0 \quad (1)$$
$$\text{Rfree} = \text{Rtot} - \text{Rres} \quad (2)$$
$$\text{Rav} = \text{Rmax} - \text{Rtot} \quad (3)$$
$$\text{Rfres} = \Sigma\ \text{Rctot} \quad (4)$$
$$\text{Rfmax} >= \text{Rcmax} \quad (5)$$
$$\Sigma\ \text{Rcmax} >= \text{Rfmax} \quad (6)$$

7.1.2.3 Resource Distribution

After the initialisation of the tree and the assignment of the initial set of resources, resource reservation requests according to the test specifications are established via the EAT, which forwards these requests to the ACA. Under the condition that the access to the network is verified, ACA hands over this request to the corresponding RPL for admission control.

A number of additional parameters must be defined, first:

Rreq	minimum resources requested from an RP/RPL
Rrecv	resources actually received from a child after a request for more resources to its father
Amax	number of max resource shifts; father RP increases the resources of its child by Amax * Rreq
Amin	number of min resource shifts; father RP increases the resources of its child by Amin * Rreq
Amed	number of resources shifts; father RP increases the resources of its child by Amed * Rreq *(Amax < Amed <Amin <= 1)
wL	a low limit for the free resources of the RP, wL < 1
wH	a high limit for the free resources of the RP, wH <1

As long as the RPL has enough resources to accept a reservation request, there is no need of redistribution of the resources. In case an RPL does not have efficient resources to accommodate an *Rreq* for a reservation it asks more resources from its father RP, which decides how much to give back (*Rrec*v). The same procedure can be repeated many times, up to the root of the tree. The father will give a multiple *(Amax/Amin/Ame*d) of the *Rreq* depending on the amount of its free resources *Rfre*e. The steps of the proposed algorithm executed by the RPL after a resource reservation request are depicted in below table:

Step	Pseudo-Code	Description
1	If (RRPLres + Rreq > RRPLmax) then reject the request endif	Reject request
2	If RRPLres + Rreq < RRPLtot then RRPLres = RRPLres + Rreq endif	Admit request, change reserved resources
3	Else if RRPLres + Rreq > RRPLtot then x = (RRPLres + Rreq) – RRPLtot	Calcuate resources (x) to ask from father
	RRPLav = RRPLmax – RRPLtot	Calculate RRPLav
	Rrecv = request(x, RRPLav)	Make a request to father
	If request accepted by father-RP then RRPLtot = RRPLtot + Rrecv RRPLres = RRPLres + Rreq endif	Admit request, change total and reserved resources

Table 7-1. Algorithm for Resource Requests

Figure 7-2 should support the above mentioned Pseudo-Code.

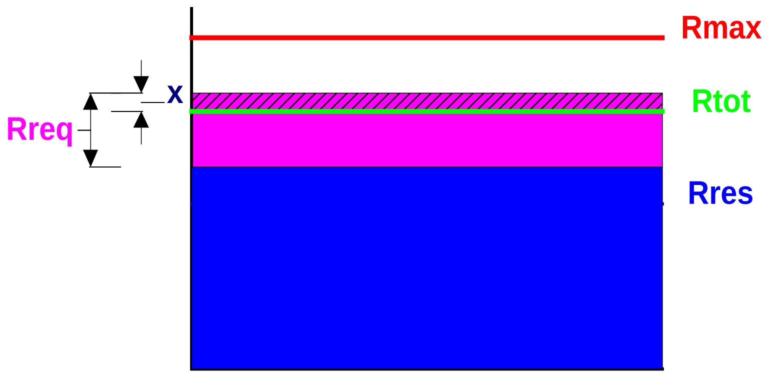

Figure 7-2. Resource Request

When the child RPL can not accommodate a request then a re-distribution of resources procedure starts. The function *request(x , R^{RPL}av)* asks the father for more resources and returns the actual resources given to the child. The upper limit of the resources that can be assigned to, is bounded by the *Rav* (*R^{c}av* in *request()* below). In case a father RP can not assign even the minimum amount of resources requested to its child, it calls the same request function to its corresponding father. The realisation of the function *request()* is given Table 7-2:

Step	Pseudo-Code	Description
1	If (Amax * x < wL * Rfree) Then Rrecv = min(Amax * x, Rcav) Rres = Rres + Rrecv Return Rrecv Endif	Admit request, change reserved resources or goto step (2)
2	Else If (Amed * x < wH * Rfree) Then Rrecv = min(Amed * x, Rcav) Rres = Rres + Rrecv Return Rrecv Endif	Admit request, change reserved resources or goto step (3)
3	Else If (Amin * x < Rfree) Then Rrecv = min(Amin * x, Rcav) Rres = Rres + Rrecv Return Rrecv Endif	Admit request, change reserved resources or goto step (4)
4	Else x' = (Rres + x) – Rtot R'recv = request(x', Rav) If request accepted by father Then Rtot = Rtot + R'recv; Rfree = Rtot – Rres; Goto step (1)	Ask resources from its father and goto step (1)
5	Else reject the request End	Reject the request

Table 7-2. Algorithm for Resource Request to the father

wL and *wH* define two limits for the free resources of an RP (see Figure 7-3). Depending on the amount of requested resources compared to these limits of the free resources, an appropriate multiple of the requested resources is given to the child RP.

Figure 7-3. Resources of the Root Pool

7.1.2.4 Resources Release

When initiating a release request at the RPL, the RPL deletes the reservation and checks whether or not it can release any unused resources to its father. In order to take such decision an additional set of variables are defined:

l	A low watermark, l < 1
Rrel	Requested resources to be released
R'rel	Resources to get released to the upper level
a	a < 1

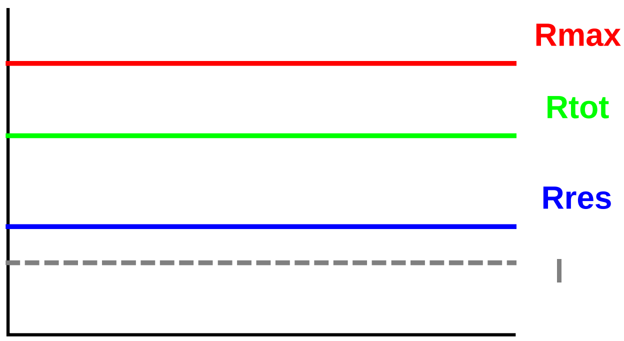

Figure 7-4. Variables for Resource Release

The low watermark, l, is used to check the current status of reserved resources of an RP/RPL. In case the reserved resources are below this watermark, this indicates that there are unused resources that should be freed. The amount of released resources should be calculated considering the trade-off between giving as much as possible and keeping resources for future use. The algorithm for deciding and calculating the resources to be released is explained in Table 7-3:

Step	Pseudo-Code	Description
1	R'res = Rres - Rrel	After the release
2	R'res = a * (R'tot + l * R'tot) R'tot = Rtot – R'rel	The new reserved resources must be between the R'tot and (l *

	From above: R'rel = Rtot – R'res / (a(1 + l))	R'tot)

Table 7-3. Algorithm for Resource Release

The value of *a*, determines indirectly the actual amount of resources released (see Figure 7-5).

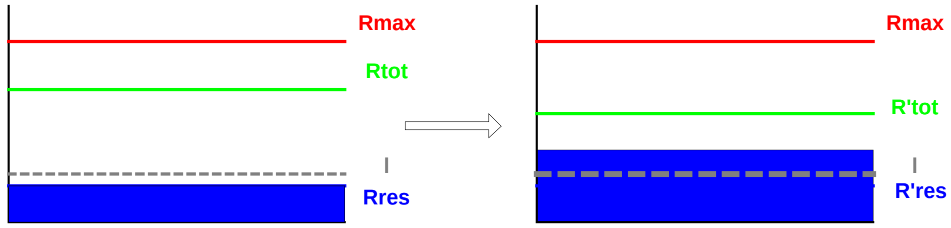

Figure 7-5. Resource Release (a = 0,5)

The adaptability of *Rtot* to the reserved resources, *Rres*, depends mainly on the values of *Amax, l.* The greater the value of *Amax* the less adaptive the algorithm becomes, since a greater amount of resources will be re-assigned to a child after a *request()* call. The value of l determines the limit which controls the release of resources, meaning that the greater its value is, the sooner unused resources will be released to the upper level.

7.1.3 RCA Trial scenarios aim

The aim of this test is, to validate the basic functionality of the RCA behaviour with forced resource shifts. Start-up configuration of the resource pool leafs is to set the values (PR and SR) of tot to zero. That means, at the beginning of the tests no resources are available at the RPLs.

7.1.4 Trial set-up

The objective of these trial scenarios is to show the resource pool reservation behaviour within the AQUILA network.

In order to check the functionality of the resource pools, an appropriate topology is necessary. In our case a one level hierarchy is used as depicted in the figure below.

At both edge devices, LeafVienna and LeafHelsinki, in all traffic classes reservation requests and releases for traffic leaving the AQUILA network through edge device LeafWarsaw are performed as described below.

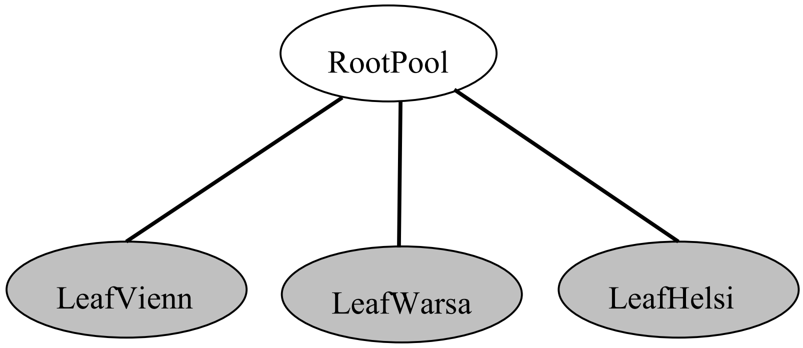

Figure 7-6. First Trial Resource Pool topology

The algorithm were examined under two basic cases:

- with zero initial resources in RPL (Rtot = 0),
- with certain initial resources, *Rtot*, in RPL.

The first condition can be preferred when there are no definite forecasts of the traffic load of the sub-areas of the network, so resources are distributed according to the demand. Only the root of the tree has initial *Rtot* values.

Promising trial results are available (see table 3-1), but some test still have to be continued in order to give a meaningful presentation.

7.2 RCL performance

The purpose of this trial was to evaluate the performance of the RCL. The RCL performance trial scenarios were divided into three groups:

- Signalling load where the signalling load between different AQUILA architecture components was measured. Signalling was tested with sender and third party based reservations and with high and low bandwidth access links.
- Set-up time measurements where the set-up time for making the reservation and releasing the reservation were measured.
- Measurement under error conditions where the purpose was to evaluate the behaviour of the resource control layer when one of the network components is down or otherwise working under error conditions. For example to see how the network is coping when RCA is rebooted.

7.2.1 Trial network

In the trial three level resource pool with for leaves was used. Topology is shown in Figure 7-7. Serial links were configured 4Mbit/s for high bandwidth tests and 512kbit/s for low bandwidth tests.

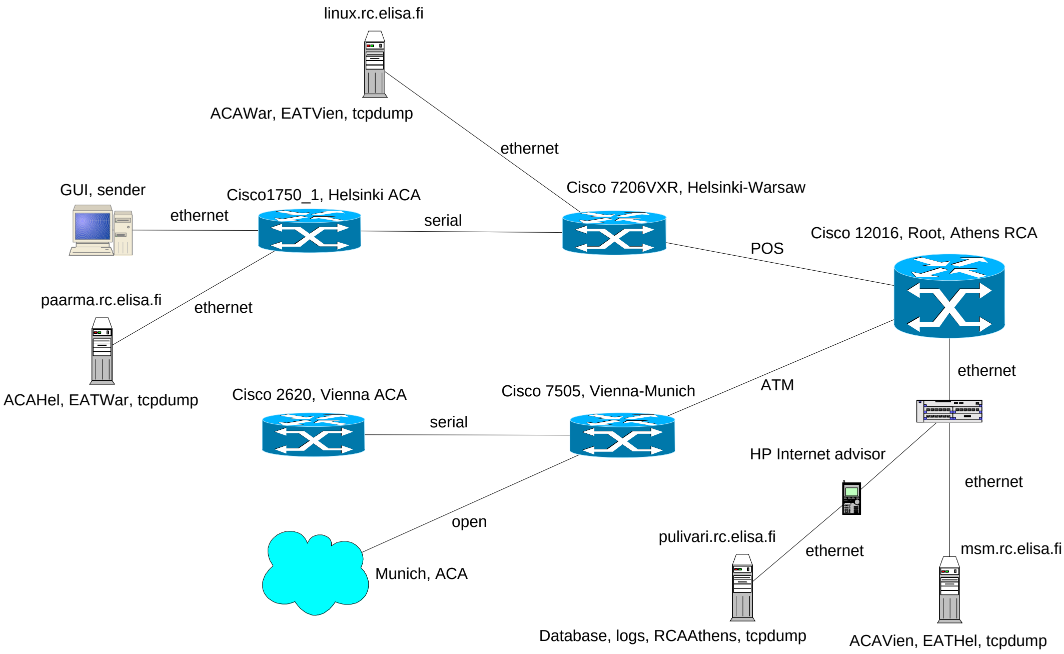

Figure 7-7. RCL performance testing topology

The RCL components were situated in the core and in the ingress edge devices. The measurements were done using TCPDump and a couple of AWK scripts. TCPDump was used to capture the data from the RCL components. TCPDump was configured to filter specified machines and known ports from the packets, so that only relevant data was captured. This method was used to monitor traffic between ACA and Edge Device, between ACA and Database and between RCA and Database.

However, communication between components that is done using CORBA methods was more difficult to measure. In this case, TCPDump was configured to filter out the known ports from the output. The TCPDump output was analysed, the different TCP connections were separated from the data using AWK scripts. Using the separated TCP connections, log information and HP Internet Advisor, the CORBA connections between each component were measured.

The RCA, database, TnameServ and TraceServer were running on an Ultra Enterprise 2 computer, running Solaris 8. The ACA.Vienna and EAT.Helsinki were running on an Ultra 5 computer, running Solaris 8. ACA.Helsinki and EAT.Vienna were running on an Ultra 5 computer, running Solaris 6. All the machines had the latest operating system patches installed.

7.2.2 Signalling load measurements

Signalling load measurements covered the message exchange between each AQUILA RCL component. The amount of traffic on terms of packet count, average packet size and total bytes transferred in signalling was measured.

Sender oriented and third party oriented reservation styles were tested with two different type traffic classes: PCBR and PVBR. PMM and PMC were not tested since from the signalling point of view all p2p reservations generate almost identical signalling load. Only difference is the amount of traffic specification information carried, where PCBR represents the Traffic Specification with least parameters and PVBR the Traffic Specification with most parameters transferred.

Signalling messages between following components were captured:

- EAT.Helsinki-GUI
- EAT.Helsinki-ACA.Helsinki
- ACA.Helsinki-Database
- ACA.Vienna-Database
- ACA.Helsinki-RCA
- ACA.Vienna-RCA
- ACA.Helsinki-ACA.Vienna
- ACA.Helsinki-Edge device (router)
- ACA.Vienna-Edge device (router)
- ACA.Helsinki-Trace server
- ACA.Vienna-Trace server
- EAT.Helsinki-Trace server
- RCA-database

When measuring the amount of signalling messages the presence of keep-alive connections between components was noticed. Since this adds up to signalling load we also measured the amount of traffic generated by keep-alive connections in order to find out how much these connections contribute to total signalling load. Also we measured the signalling load when starting up the whole system.

The results of the measurements are presented in tables. In the table, first three columns contain the number of packets, average size of an packet and total amount of data for the actual signalling load. The next two columns contain the amount of data and number of packets for keep-alive (KA) traffic. The last column contains the number of connections used in signalling. The keep-alive traffic is transmitted in ten second intervals, and the table lists the signalling amount in that time.

The values in the tables are illustrated graphically. Two charts are presented to show the contribution of keep-alive connections to the total amount of signalling. First is the chart for signalling during a ten seconds time interval, and then a chart for signalling during a two minute time interval.

7.2.2.1 RCL Initialisation

Table 7-4. RCL Initialisation

This measurement was done in order to find out the amount of signalling when starting up the whole system.

RCL Initialization	# of pkts	Avg. size	Data/bytes	KA/bytes	KA pkts	# of Conn.
EAT.Helsinki-GUI	0	0,00	0	N/A	N/A	6
EAT.Helsinki-ACA.Helsinki	0	0,00	0	0	0	2
ACA.Helsinki-Database	170	161,58	27469	N/A	N/A	2
ACA.Vienna-Database	170	161,14	27393	N/A	N/A	2
ACA.Helsinki-RCA	7	94,43	661	736	6	2
ACA.Vienna-RCA	7	94,43	661	736	6	2
ACA.Helsinki-ACA.Vienna	0	0,00	0	736	6	2
ACA.Helsinki-ED	2025	43,47	88028	N/A	N/A	2
ACA.Vienna-ED	2176	42,56	92617	N/A	N/A	0
RCA-Database	789	180,67	142546	N/A	N/A	2
ACA.Helsinki-Traceserver	418	164,82	68895	N/A	N/A	2
ACA.Vienna-Traceserver	409	164,03	67090	N/A	N/A	2
EAT.Helsinki-Traceserver	0	0,00	0	N/A	N/A	1

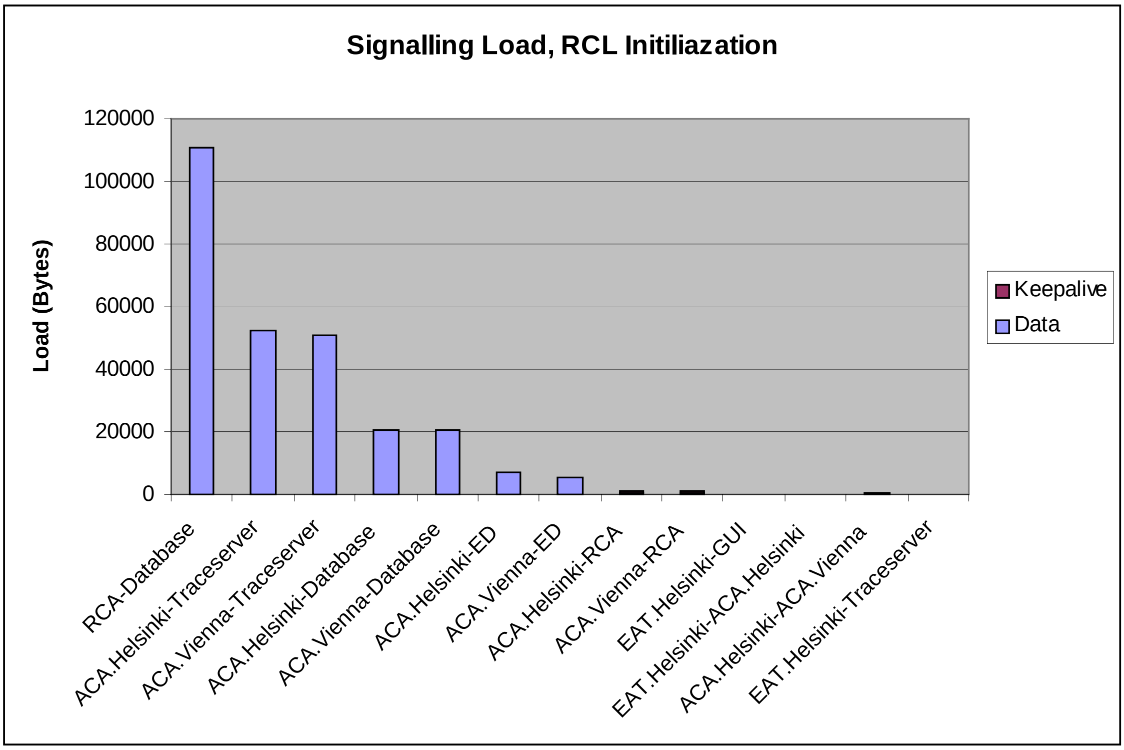

Figure 7-8. RCL Initialisation

7.2.2.2 Successful reservation and release, sender oriented

Single p2p sender oriented reservation was made using the EAT GUI. Signalling loads of PCBR and PVBR type reservations are presented in Table 7-5 and Table 7-6.

Signalling Load Measurment, PCBR successful reservation						
	# of pkts	Avg. size	Data/bytes	KA/bytes	KA pkts	# of Conn.
EAT.Helsinki-GUI	86	118,69	10207	N/A	N/A	6
EAT.Helsinki-ACA.Helsinki	22	123,27	2712	736	6	2
ACA.Helsinki-Database	112	172,93	19368	N/A	N/A	1
ACA.Vienna-Database	48	176,08	8452	N/A	N/A	1
ACA.Helsinki-RCA	0	0,00	0	736	6	2
ACA.Vienna-RCA	0	0,00	0	736	6	2
ACA.Helsinki-ACA.Vienna	11	116,82	1285	736	6	2
ACA.Helsinki-ED	615	44,52	27382	N/A	N/A	2
ACA.Vienna-ED	0	0,00	0	N/A	N/A	0
RCA-Database	0	0,00	0	N/A	N/A	0
ACA.Helsinki-Traceserver	181	175,61	31786	N/A	N/A	2
ACA.Vienna-Traceserver	88	167,78	14765	N/A	N/A	1
EAT.Helsinki-Traceserver	63	172,17	10847	N/A	N/A	1

Table 7-5. PCBR successful reservation

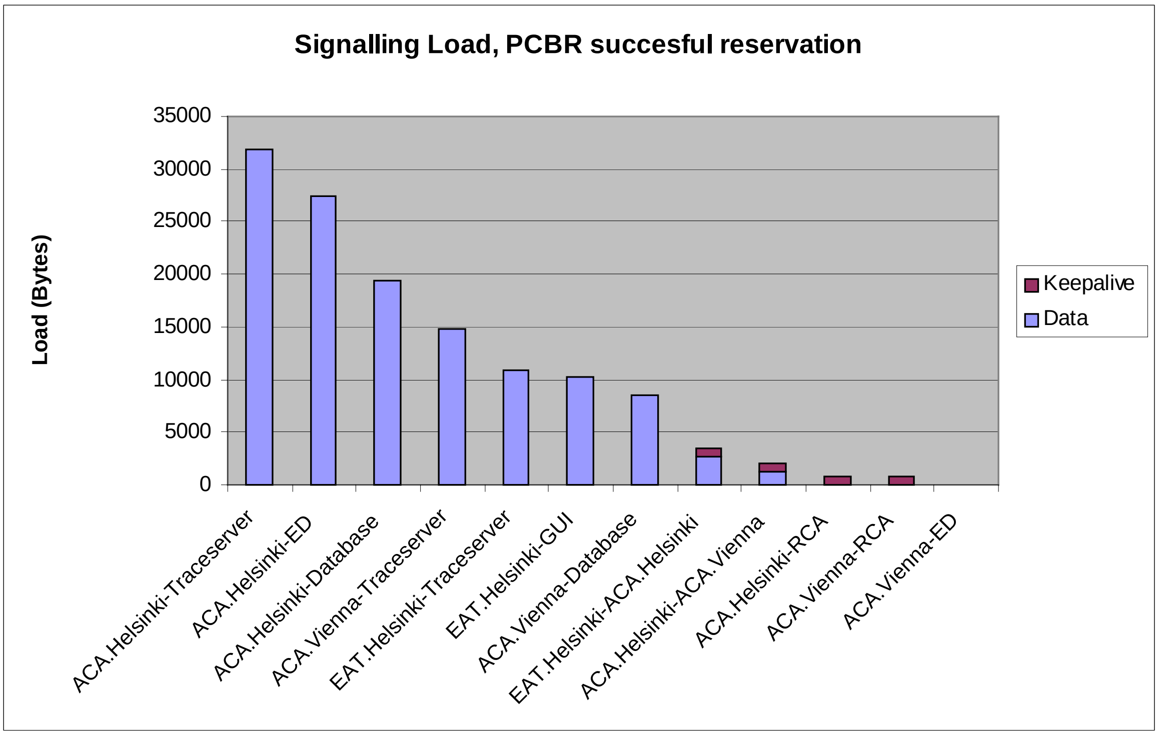

Figure 7-9. PCBR successful reservation (10sec)

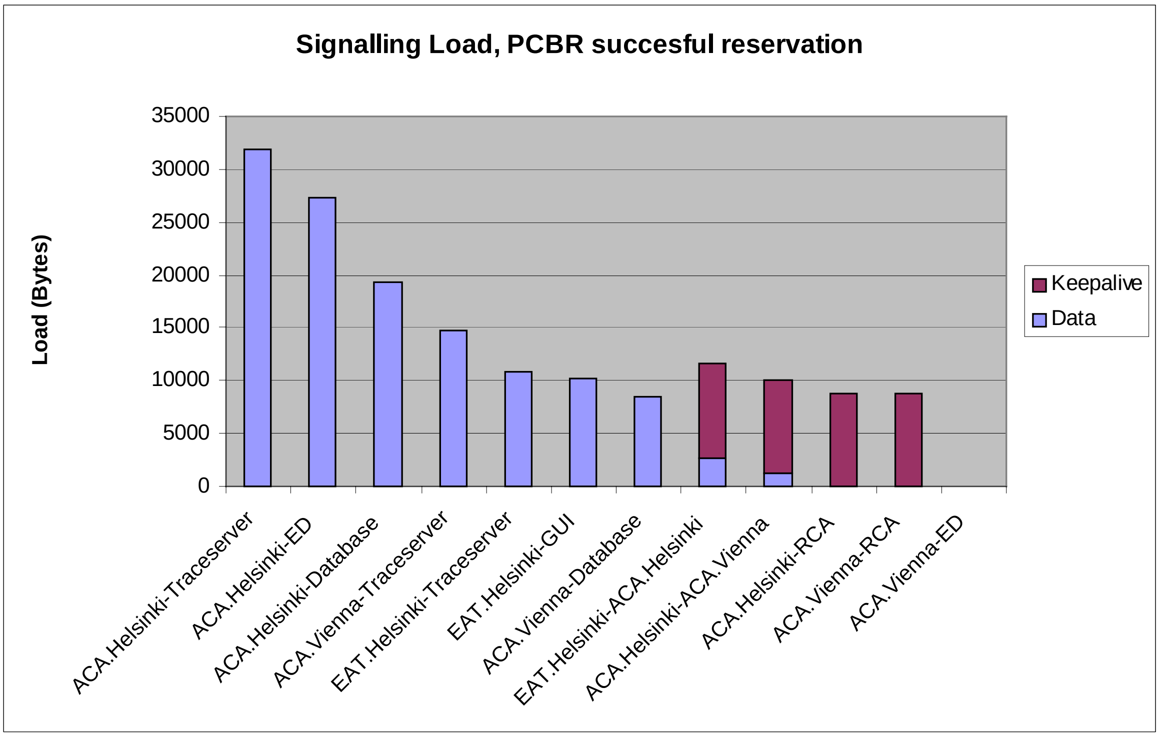

Figure 7-10. PCBR successful reservation (2min)

Signalling Load Measurment, PVBR succesful reservation						
	# of pkts	Avg. size	Data/bytes	KA/bytes	KA pkts	# of Conn.
EAT.Helsinki-GUI	74	120,97	8952	N/A	N/A	6
EAT.Helsinki-ACA.Helsinki	20	127,80	2556	736	6	2
ACA.Helsinki-Database	116	169,16	19622	N/A	N/A	1
ACA.Vienna-Database	51	168,08	8572	N/A	N/A	1
ACA.Helsinki-RCA	2	194,50	389	850	6	2
ACA.Vienna-RCA	2	194,50	389	850	6	2
ACA.Helsinki-ACA.Vienna	9	76,11	685	850	6	2
ACA.Helsinki-ED	251	44,75	11232	N/A	N/A	2
ACA.Vienna-ED	0	0,00	0	N/A	N/A	0
RCA-Database	0	0,00	0	N/A	N/A	0
ACA.Helsinki-Traceserver	171	162,65	27813	N/A	N/A	1
ACA.Vienna-Traceserver	94	163,51	15370	N/A	N/A	1
EAT.Helsinki-Traceserver	63	173,22	10913	N/A	N/A	1

Table 7-6. PVBR successful reservation

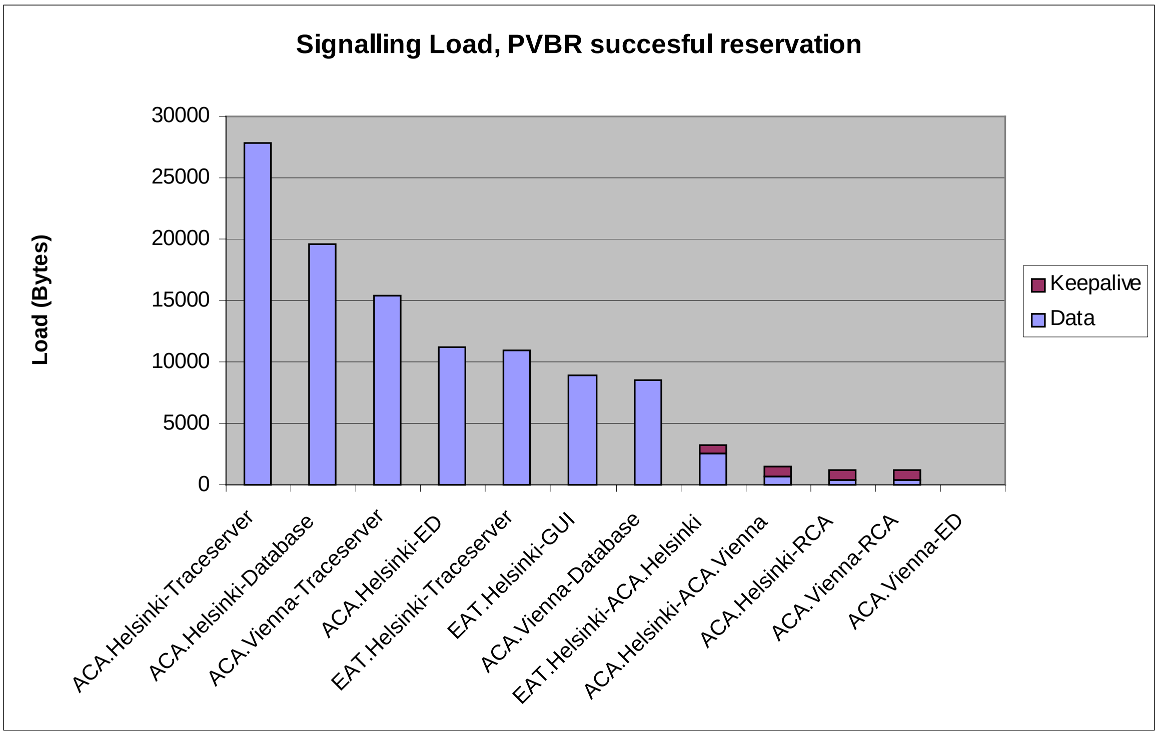

Figure 7-11. PVBR successful reservation (10sec)

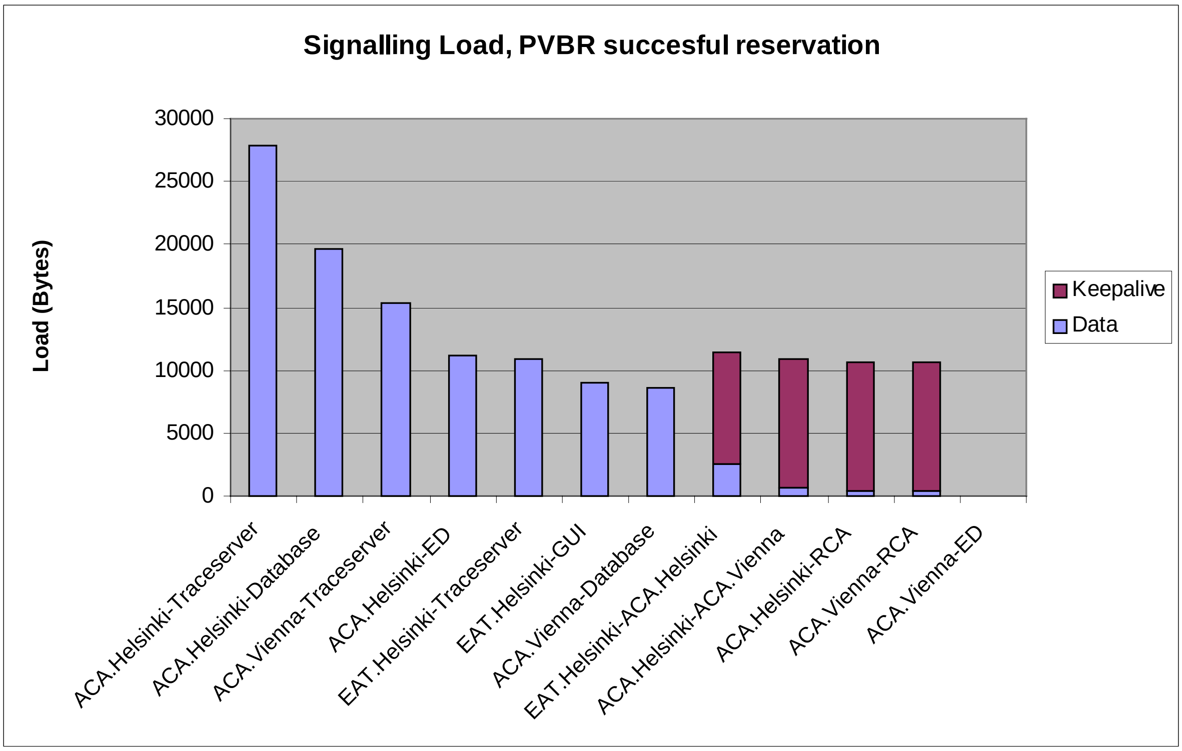

Figure 7-12. PVBR successful reservation (2min)

7.2.2.3 Successful reservation, third party oriented

Single p2p third party oriented reservation was made using the EAT GUI. Signalling load of PCBR type reservation is presented in Table 7-7.

Signalling Load Measurment, PCBR succesful 3rd party reservation	# of pkts	Avg. size	Data/Bytes	KA/bytes	KA pkts	# of Conn.
EAT.Warsaw-GUI	86	118,69	10207	N/A	N/A	6
EAT.Warsaw-ACA.Warsaw	22	123,27	2712	736	6	2
ACA.Helsinki-Database	48	176,08	8452	N/A	N/A	1
ACA.Vienna-Database	48	176,08	8452	N/A	N/A	1
ACA.Warsaw-Database	44	224,02	9857	N/A	N/A	1
ACA.Warsaw-ACA.Vienna	8	131,38	1051	736	6	2
ACA.Warsaw-ACA.Helsinki	8	131,38	1051	736	6	2
ACA.Helsinki-RCA	0	0,00	0	736	6	2
ACA.Warsaw-RCA	0	0,00	0	736	6	2
ACA.Vienna-RCA	0	0,00	0	736	6	2
ACA.Helsinki-ED	615	44,52	27382	N/A	N/A	2
ACA.Vienna-ED	0	0,00	0	N/A	N/A	0
ACA.Helsinki-Traceserver	103	169,15	17422	N/A	N/A	2
ACA.Vienna-Traceserver	88	167,94	14779	N/A	N/A	1
ACA.Warsaw-Traceserver	70	201,99	14139	N/A	N/A	1
EAT.Warsaw-Traceserver	62	174,31	10807	N/A	N/A	1

Table 7-7. PCBR successful 3rd party oriented reservation

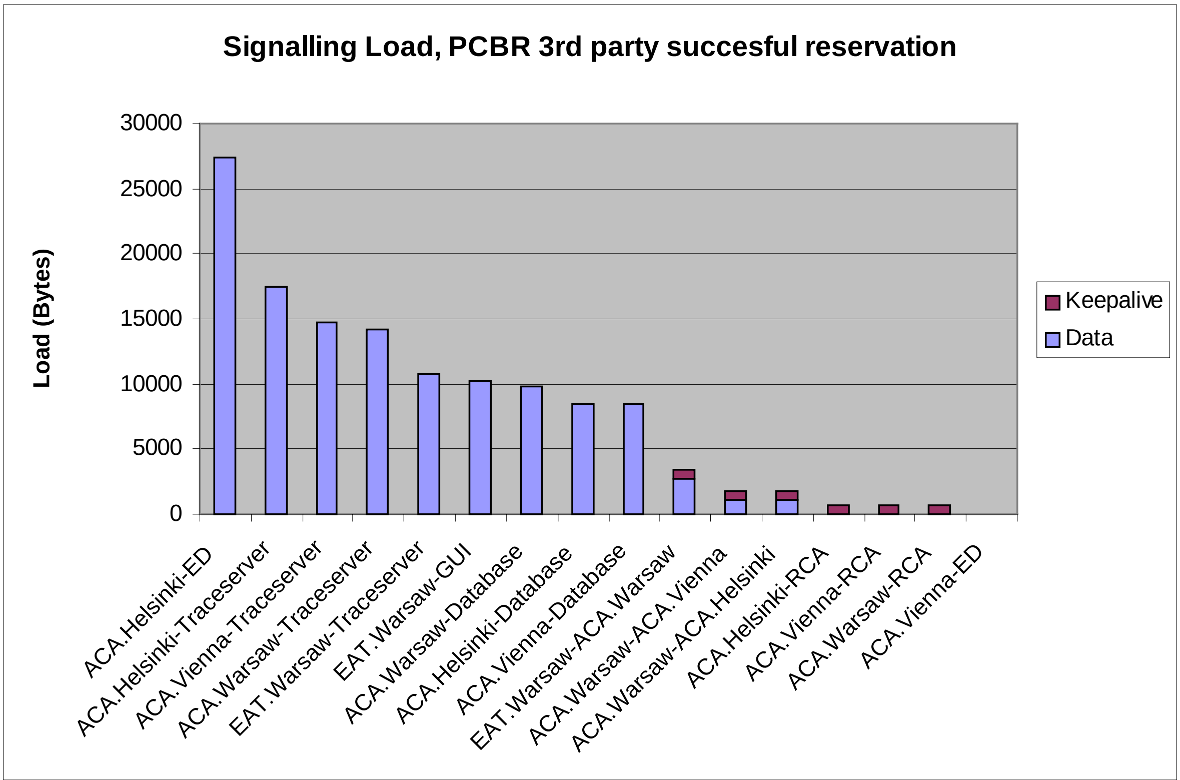

Figure 7-13. PCBR 3rd party oriented successful reservation

7.2.2.4 Successful reservation, sender oriented, low bandwidth

Single p2p sender based reservation was made using the EAT GUI. In this case the access links were configured for low bandwidth traffic, so ACAs didn't get any resources during the initialisation phase. ACAs requested resources from RCA when the reservation was made.

The only difference between high and low bandwidth access links signalling load was 409 bytes which was introduced by ACA getting the resources from RCA, since in low bandwidth case the initial resources of the ACAs were set to zero.

Signalling Load Measurment, PCBR lowbandwidth succesful reservation						
	# of pkts	Avg. size	Data/Bytes	KA/bytes	KA pkts	# of Conn.
EAT.Helsinki-GUI	86	118,69	10207	N/A	N/A	6
EAT.Helsinki-ACA.Helsinki	22	123,27	2712	736	6	2
ACA.Helsinki-Database	112	172,93	19368	N/A	N/A	1
ACA.Vienna-Database	48	176,08	8452	N/A	N/A	1
ACA.Helsinki-RCA	3	176,33	529	736	6	2
ACA.Vienna-RCA	3	176,33	529	736	6	2
ACA.Helsinki-ACA.Vienna	11	116,82	1285	736	6	2
ACA.Helsinki-ED	615	44,52	27382	N/A	N/A	2
ACA.Vienna-ED	0	0,00	0	N/A	N/A	0
RCA-Database	0	0,00	0	N/A	N/A	0
ACA.Helsinki-Traceserver	181	175,61	31786	N/A	N/A	2
ACA.Vienna-Traceserver	88	167,78	14765	N/A	N/A	1
EAT.Helsinki-Traceserver	63	172,17	10847	N/A	N/A	1

Table 7-8. PCBR lowbandwidth successful reservation

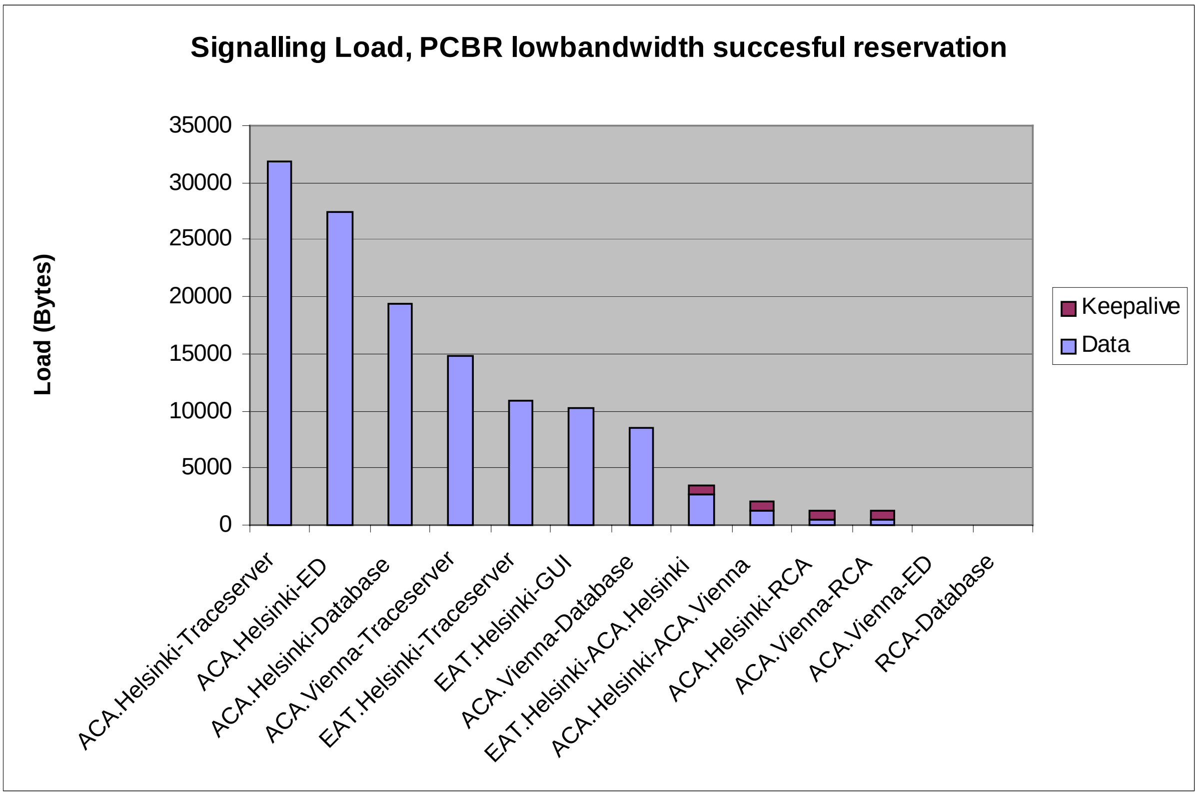

Figure 7-14. PCBR low bandwidth successful reservation

7.2.2.5 Unsuccessful reservation, single reservation

Single p2p sender oriented reservation, which exceeded the traffic capacity dedicated to its class was made. Signalling load of PCBR type reservation is presented in Table 7-9.

Signalling Load Measurment, PCBR unsuccesful reservation						
	# of pkts	Avg. size	Data/bytes	KA/bytes	KA pkts	# of Conn.
EAT.Helsinki-GUI	29	152,00	4408	N/A	N/A	2
EAT.Helsinki-ACA.Helsinki	4	205,50	822	736	6	2
ACA.Helsinki-Database	6	234,67	1408	N/A	N/A	1
ACA.Vienna-Database	0	0,00	0	N/A	N/A	1
ACA.Helsinki-RCA	0	0,00	0	736	6	2
ACA.Vienna-RCA	0	0,00	0	736	6	2
ACA.Helsinki-ACA.Vienna	3	220,67	662	736	6	2
ACA.Helsinki-ED	0	0,00	0	N/A	N/A	0
ACA.Vienna-ED	0	0,00	0	N/A	N/A	0
RCA-Database	0	0,00	0	N/A	N/A	0
ACA.Helsinki-Traceserver	15	199,73	2996	N/A	N/A	1
ACA.Vienna-Traceserver	0	0,00	0	N/A	N/A	1
EAT.Helsinki-Traceserver	17	175,88	2990	N/A	N/A	1

Table 7-9. PCBR unsuccessful reservation

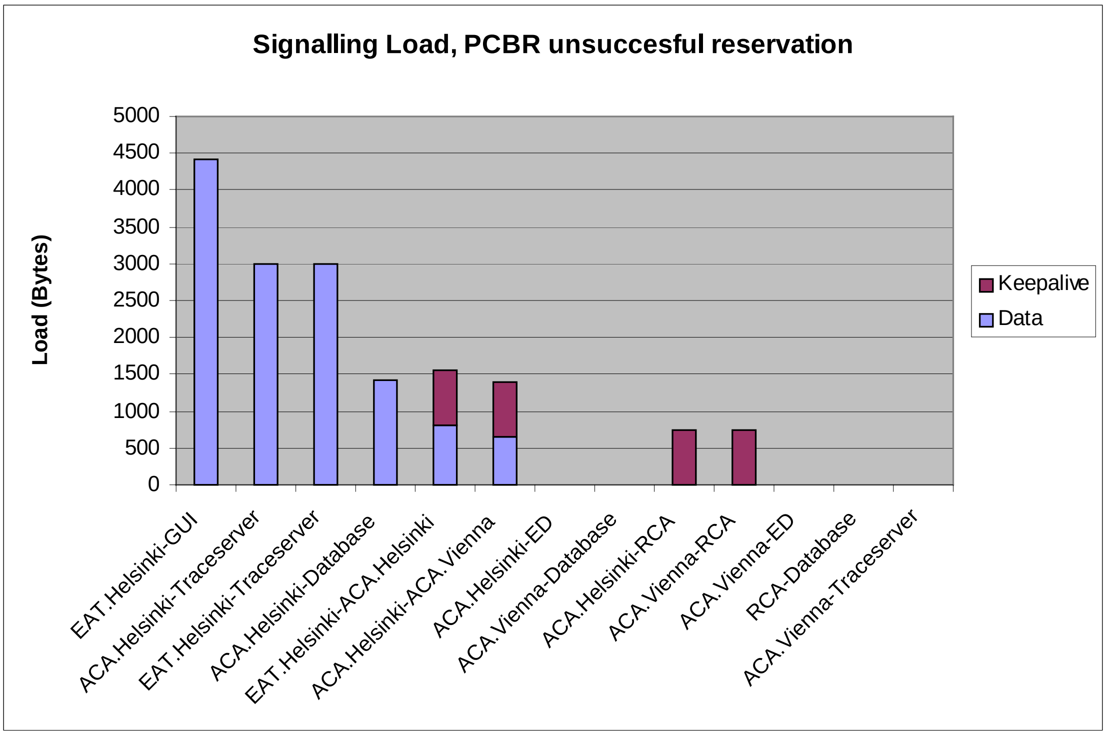

Figure 7-15. PCBR unsuccessful reservation (10sec)

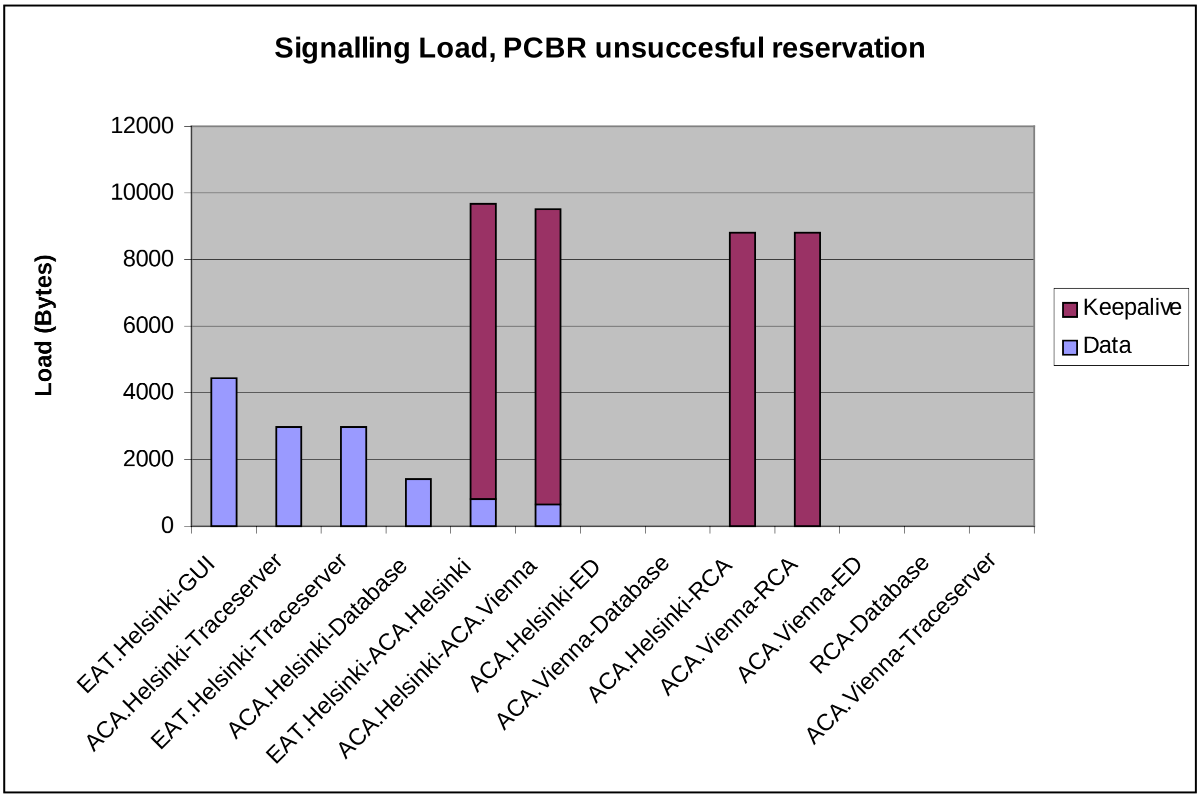

Figure 7-16. PCBR unsuccessful reservation (2min)

7.2.2.6 Unsuccessful reservation after too many reservations

Ten sender based PCBR reservations were made using the EAT GUI. Eleventh reservation exceeded the totTS value for the given link. This differs from the one unsuccessful reservation scenario quite much, since in 7.2.2.5 measurement the decision of rejecting the reservation is done based on PR parameter of the PCBR traffic class exceeding maximum value of PR. In this case the rejection was done because totTS parameter exceeded the maximum totTS value of TCL1.

Signalling Load Measurment, PCBR rejected reserv, too many reserv.						
	# of pkts	Avg. size	Data/Bytes	KA/bytes	KA pkts	# of Conn.
EAT.Helsinki-GUI	16	154,69	2475	N/A	N/A	1
EAT.Helsinki-ACA.Helsinki	4	192,50	770	736	6	2
ACA.Helsinki-Database	38	171,50	6517	N/A	N/A	1
ACA.Vienna-Database	0	0,00	0	N/A	N/A	1
ACA.Helsinki-ACA.Vienna	3	218,00	654	736	6	2
ACA.Helsinki-RCA	0	0,00	0	736	6	2
ACA.Vienna-RCA	0	0,00	0	736	6	2
ACA.Vienna-ED	0	0,00	0	N/A	N/A	0
ACA.Helsinki-ED	0	0,00	0		N/A	0
ACA.Helsinki-Traceserver	32	203,63	6516	N/A	N/A	1
ACA.Vienna-Traceserver	14	168,36	2357	N/A	N/A	1
EAT.Helsinki-Traceserver	11	174,27	1917	N/A	N/A	1

Table 7-10. PCBR rejected reservation, too many reservations

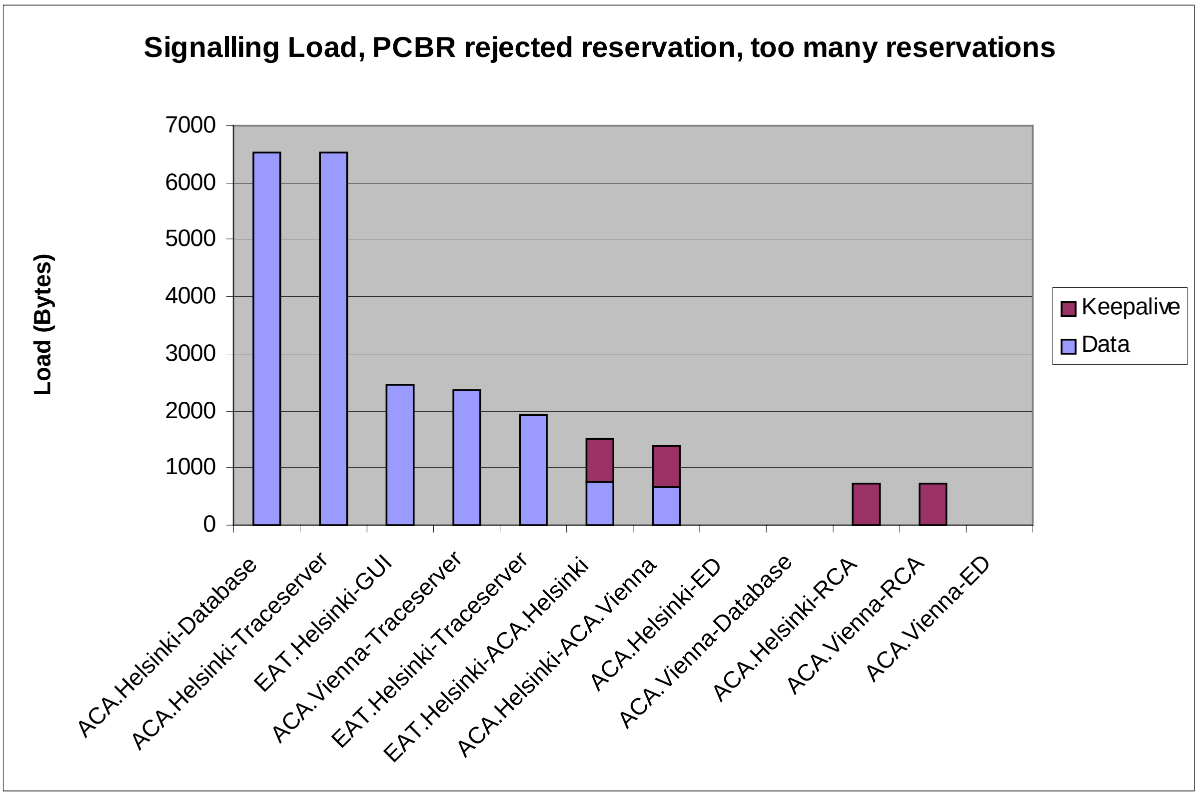

Figure 7-17. PCBR rejected reservation, too many reservations

7.2.3 Set-up time measurement

The overall set-up and release time of reservation was measured with and without logging information. The timestamps of the messages were collected from the EAT. Set-up times are shown in the following tables:

Set-up time measurements		
	Average Time (sec)	Standard Deviation
Login	0,298273	0,010090
Reservation	2,174727	0,427783
Release	2,390364	0,169170

Table 7-11. Set-up times

7.2.4 Measurements under error conditions

These measurements were intended for evaluation of the amount of signalling messages when there is a failure in one of the network components. The measurement was carried out by shutting down one network element at a time and observing its impact to the whole system in terms of signalling messages. Then the element was restarted and the signalling load was monitored again.

Point to point sender oriented PCBR reservation was used in all test scenarios and the impact of the shutdown of the following components was measured:

- RCA shutdown and start-up
- Ingress router reboot
- Database shutdown and start-up

The actual signalling load was not measured since we noticed that the signalling was quite like in normal cases except that between the component that was down, so detailed presentation of signalling in each case is not useful.

7.2.4.1 RCA failure

One p2p PCBR sender oriented reservation was done and the RCA was shutdown after that. Nothing happened, since the ACAs only communicate with RCA in the start-up phase in this high bandwidth access link case, where the bandwidth between access links is statically provisioned and no over-provisioning is made. ACA-components tried to make new alive-manager connections to the RCA to replace the lost ones, but otherwise the network was not affected and no extra signalling was noticed.

When RCA was up and running, the connections to the ACA components were not restored. RCA recovery time from failure was the normal initialisation time, which was about 14 seconds.

7.2.4.2 Router failure

One p2p PCBR sender oriented reservation was active. After the reservation was complete, the ingress router was rebooted. Following ingress router shutdown ACA.Helsinki stopped responding to alive-manager requests. EAT.Helsinki and ACA.Vienna noticed the loss of alive-manager connection. EAT.Vienna discarded the reservation and destroyed the user. ACA.Vienna released the reservation at the egress end of the connection.

The signalling was no different from the normal release reservation signalling except that the signalling between ACA.Helsinki and ingress router was missing, due to the router being down. After the router was online again, ACA.Helsinki released the reservation, and the signalling to the router was the same as in the normal case.

The recovery time from the failure was about 3 minutes 28 seconds, but most of this time was consumed by the router starting up. The actual recovery time of ACA and EAT was about six seconds after ACA.Helsinki could connect to the router.

7.2.4.3 Database shutdown

Two types of scenarios were tested. First p2p sender based PCBR reservation was on when the database was shutdown and in second there was no reservation done when database was shutdown.

When reservation was made and database went down the reservation was dropped by normal release reservation signalling except that the database was not updated and releasing the traffic class in resource pools failed. After re-start the system was down until all the components were rebooted in normal sequence RCA first and then others.

When no reservation was on nothing happened. When trying to make reservation while database was down there obviously was no way to make the reservation. Again starting the database won’t remedy the situation, but the whole system has to be rebooted as in the other case.

This case seemed to be the most hazardous, since no recovery mechanism from database failure was noticed.

8 Annex C - Measurement Tools

8.1 Deployment in the trials

The general structure of the AQUILA measurement architecture is illustrated in the following figure:

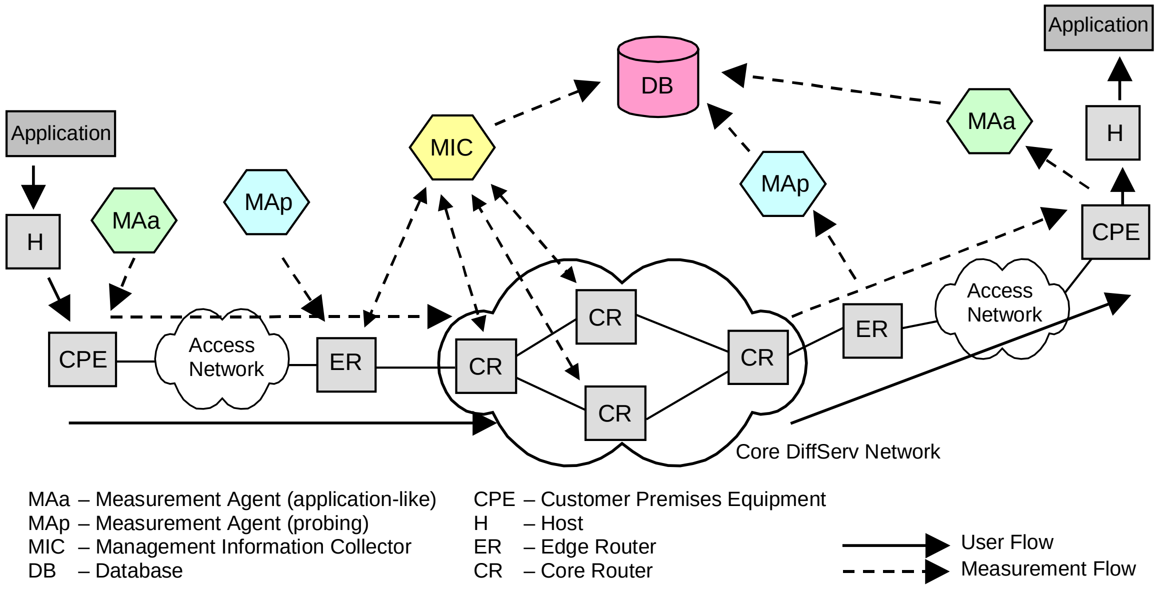

Figure 8-1: AQUILA measurement architecture (general)

Application-like flow generators (MAa) allow reproducible tests with "real" applications. It is intended to implement also emerging applications like VoIP, A/V streaming and online games. The results show the achievable QoS for certain services.

Active network probing (MAp, here connected to an edge router) allows a constant monitoring of the whole network concerning the network QoS parameters. All NS (traffic classes) should be monitored in parallel.

Router QoS monitoring (MIC) supplies additional information about queue lengths, packet drop counters and others of the network elements along the transmission path by reading the according management information bases (MIBs).

From the implementation point of view, the AQUILA measurement system consists of two main parts, the measurement server and measurement clients. The measurement server is situated in the core of the network, while the measurement clients are distributed in the network leafs. For one-way delay measurements, the clients are equipped with GPS hardware for time synchronisation.

8.1.1 Trial Site #1 – Warsaw

In the trial site in Warsaw 4 PC's were equipped with GPS cards needed for the synchronisation of the PC clocks. Because it was necessary to run the different measurement agents (synthetic flow generation, active network probing and the QoS monitoring agent) on one machine (even at the same time), the generation of the needed timestamps via direct accessing the GPS hardware was not feasible. Therefore it was necessary to install an NTP-server on every PC with a measurement agent. The following figure shows the installation of the measurement tools at the Warsaw trial site:

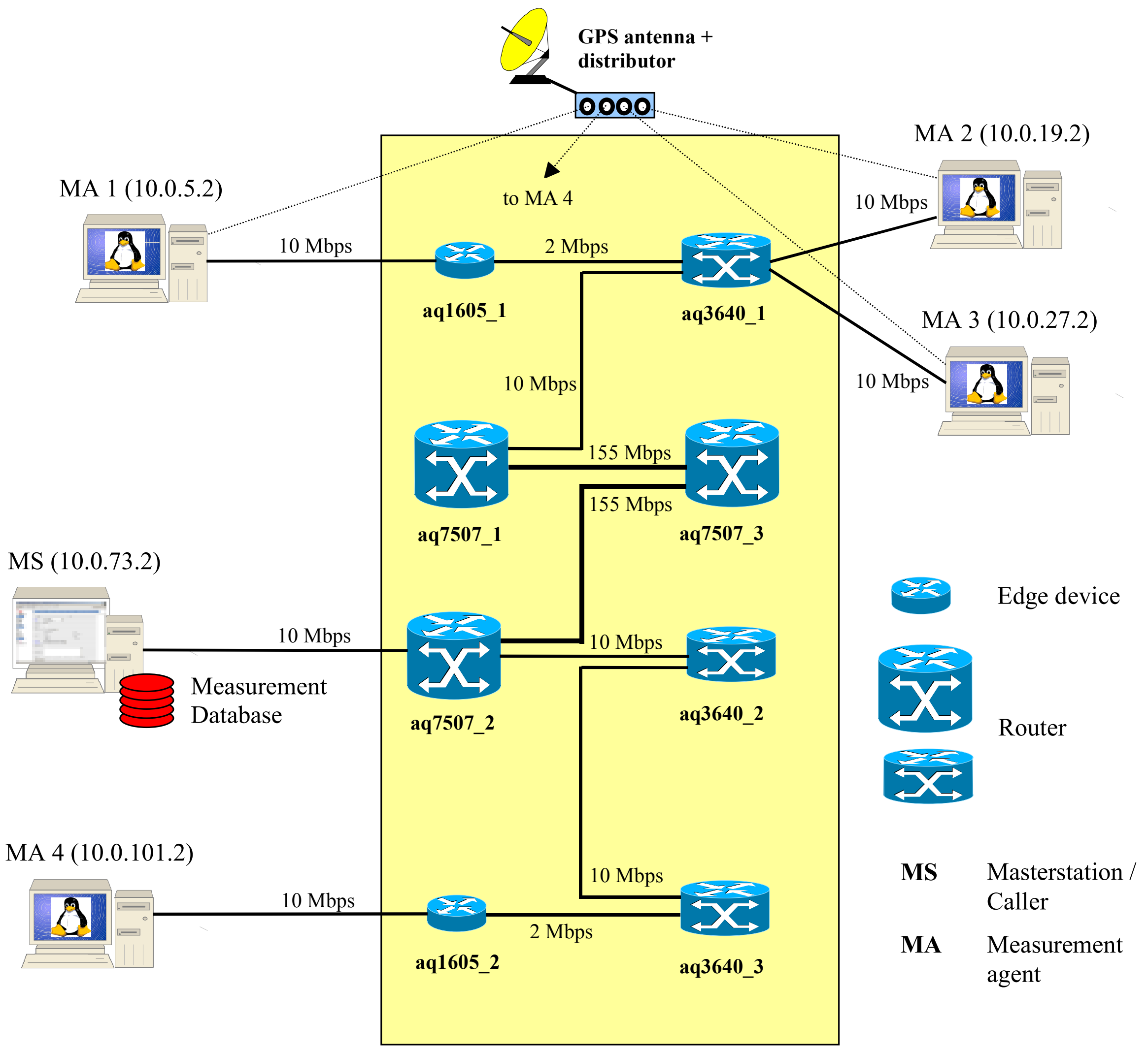

Figure 8-2: AQUILA measurement architecture (Warsaw)

The integration of the measurement tools at Warsaw was performed by the tool developers on site.

8.1.2 Trial Site #2 – Vienna

The Vienna trial site deals with performance tests of the Resource Pools. Therefore the AQUILA measurement tools were not actively used for the tests. Anyway the measurement server and clients were set up in view of the second trial. Problems occurred during the integration in Warsaw were taken into account at the Vienna trial site. The following figure shows the placement of the measurement equipment in the Vienna trial site topology:

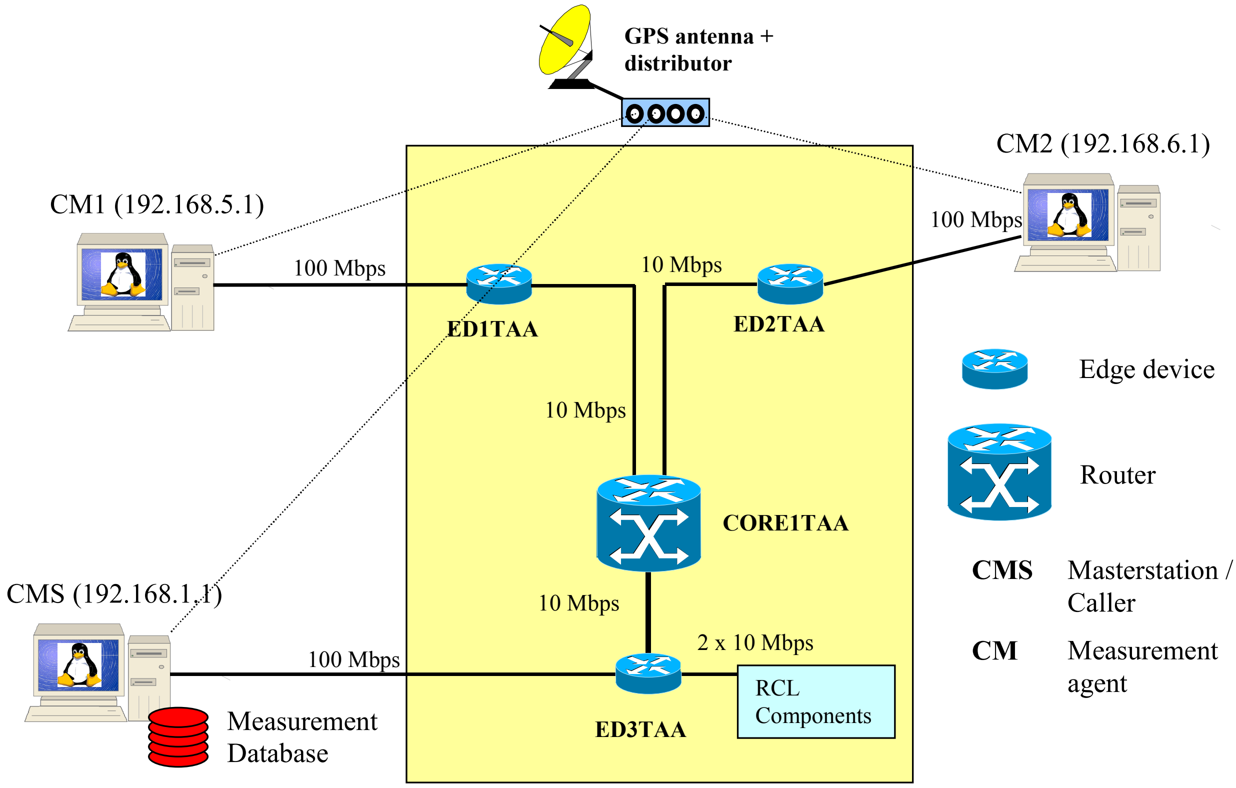

Figure 8-3: AQUILA measurement architecture (Vienna)

The integration of the measurement tools at Vienna was performed by the tool developers remotely.

8.1.3 Trial Site #3 – Helsinki

The Helsinki trial site deals with the RCL Signalling performance issues. Therefore the AQUILA measurement tools were not actively used for the tests. The measurement server and clients are set up for the second trial. Currently no GPS equipment has been installed.

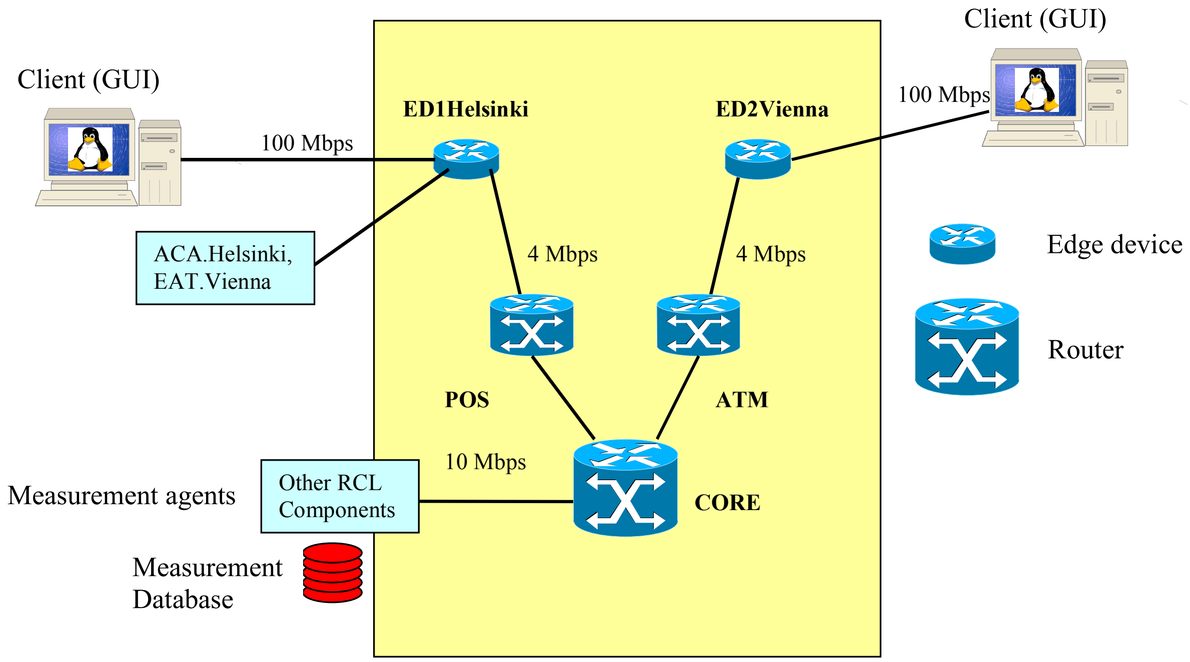

Figure 8-4: AQUILA measurement architecture (Helsinki)

The integration of the measurement tools at Helsinki was performed by the site operator using the provided installation instructions.

8.2 Evaluation of the Current Status

8.2.1 Measurement Database

The current version of the measurement database implements some enhancements in comparison to the database described in [D2301]. The database now also supports **AQUILA reservation requests**, **geographical information** about the hops and the possibility to **store the receiving DSCP of each measurement packet**.

8.2.2 Synthetic Flow Generator

As described in [D2301] the synthetic flow generator is used to generate application-like flows between two measurement clients. The synthetic flow load generation is implemented on Linux. The measurement scenarios are distributed from a centralised management station ("CMCaller") to the measurement clients, which implement the load generators and measurement end-points. For the first trial the load generators are able to generate CBR flows, exponential distributed flows, uniform distributed flows and flows from trace-files. Due to the support of trace-files the load generators are highly flexible. The variable parameters of the load generators are packet size[1] and the inter-arrival time[2] between the packets. UDP, TCP and TCP-no-delay (i.e. TCP with the Nagle-algorithm disabled) are supported as transport protocols. Port numbers are chosen randomly or determined by the user.

The measured parameters are one-way delay, goodput, packet loss and delay variation of the flow. For one-way delay the usage of GPS-equipment from *Meinberg* is supported.

In order to support the router QoS monitoring functionality, the path is discovered automatically (if the option is selected) by means of the UNIX-command “traceroute”.

Within the trials the synthetic flow generation was used to generate foreground traffic to measure the goodput and delay for the different network service in dependence of the background traffic.

8.2.3 Active Network Probing

The measurement agents run on Linux PC’s. They are controlled by the master station. The tool measures the current status of a network by sending probes to another measurement agent. The receiver sends the results to the master station. The measurement agent can also be used as a load generator for background traffic. Every agent can send and receive flows with different characteristics.

These characteristics are:

- Protocol: UDP, TCP, TCP no delay
- Packet length: 25 - 64k byte
- Send distribution: constant, exponential, uniform
- Send interval
- ToS byte

For each measurement flow the receiver calculates

- one way delay
- delay variation

---

[1] 30 Byte – 64kByte. Fragmentation of UDP-Packets is not allowed.

[2] In the current version the inter-arrival time between two packets can be 0 or a multiple of 10ms. Using a special configured Linux kernel, multiples of 1ms can be reached. The 1 to 10ms interval should not be used for e.g. CBR streams, as the sender will become the bottleneck then.

- packet loss
- throughput

Some problems occurred during the integration meeting concerning the GPS clock device driver:

The active network probing tool as well as the synthetic flow load generator use the *Meinberg* GPS clock for time-stamping. In the AQUILA testbeds the two measurement tools run on the same PC at the same time. But the device driver of the *Meinberg* GPS card can only be loaded by one of the tools. So both tools have to use the PC clock for the time-stamping. For that the PC clock must be synchronised by an NTP server (NTP: network time protocol).

Communication between master station and measurement agent:

If the measurement agent is generating high load, it is difficult to communicate with the agent. This problem will be solved by a redesign of parts of the measurement agents and the master.

8.2.4 Router QoS Monitoring

The current version of Router QoS Monitoring tool can retrieve router QoS information via CLI connection to the router. The QoS information includes dropped packets in each traffic class in the core routers, mean queue length in the core routers, dropped packets for each flow in the edge routers and CPU utilisation. Also any other value that can be shown from the GUI can be fetched and saved to the database.

8.2.5 GUI

8.2.5.1 Configuration GUI

The aim of the Configuration GUI is a user-friendly possibility to control the measurement tools. To get a running measurement system some options and control fields for the measurement system must be filled in by the user. It must be easy to configure the system via this interface. The interface must guide through the configuration and verify whether all inputs are consistent. The options and parameters must be written to the database. On the other hand information from the measurement system, which is taken from the database, must be displayed by the GUI.

In the current version every parameter of the measurement system can be controlled via the GUI. The following parts are implemented:

User administration: New users can be created, modified and deleted. The GUI differentiates between “normal” users and “administrators”. Identification is necessary to work with the GUI. Some changes can only be done by “administrators”. Normal Users can only work with their data.

Measurement components ("hops"), can be selected, modified and deleted. To make it easier for the user there is also a "copy"-function which allows it to make copies of existing hop selections with almost identical options and parameters.

Every parameter that is necessary to start a measurement can be written to the database via special menus in the GUI. The menus are separated in functional groups. In every group the users can create, delete, modify or copy the parameters.

Also every group gives an overview (All ...) of the existing parameters in the database. Fields can be sorted by the field header. Filters are implemented, whenever necessary.

Via other menus the users can start or stop tests or flows. At least every relevant information of the measurement system (e.g. the status of the hops or the eventlog) is displayed in a separate menu.

Users can navigate through the GUI with a taskbar on the left side and on the top.

The GUI was installed at the testbeds in Warsaw, Vienna and Helsinki. At the meetings ideas for a new version of the interface were presented to the members. Some experience with older versions was discussed. As a result of this discussions:

- The "copy"-function was implemented as a feedback from the meeting in Salzburg.
- The menu description, where the users get detailed information about the input fields, was implemented as a feedback of the meeting in Warsaw
- The unit of the parameters is shown wherever a unit is necessary.

While developing and working with the GUI in Vienna and Warsaw a lot of bugs were fixed. As an example the packets weren't delete from the database when deleting the results.

Because of different versions of the software and functional changes in the database structure not every testbed has the newest version of the GUI. This will be changed as soon as possible.

8.2.5.2 Display of Results

The results of the measurement tools are visualised with the web based user interface. For aggregated data, the current output is limited to text. Graphical visualisations are calculated from the raw data. The raw measurement data is also provided in a comma-separated-value format to allow post-processing of the measurement data with mathematics and statistics tools. Provided raw data is:

- Packet number within the flow
- Send time / receive time of packet
- One-way delay / IPDV (IP packet delay variation) per packet

- Packet length / packet state per packet
- Packet loss

For each measurement flow the following graphs can be immediately produced with the graphical user interface out of the raw data:

- One-way delay
- Mean of one-way delay
- Delay variation
- Packet size
- Throughput per packet / per flow

As x-axis the send-time or the packet number can be chosen.

For the passive measurements the results of the measured monitoring parameters (see [D2301] for details) are displayed by selecting the hops and the specific access-list number (which is the according CISCO-implementation for different queues).

The axes of the graphs are scaled automatically but can be modified by the user.

Additionally for one-way delay statistical functions like histogram and the auto correlation function are supported.

Each user only gets the results from his own tests.

8.3 Future Enhancements

8.3.1 Load Generators

For the active network probing tool we plan to implement the send distributions "trace file" and "power-tail".

Also the synthetic flow generator will implement more sophisticated load generators to get real application-like flows.

The measurement database currently supports only unidirectional flows, i.e. request-response scenarios like WWW-Traffic are only limited possible. Possible enhancements will be investigated.

8.3.2 GPS Co-ordinates

With a new function in the GPS device driver it will be possible to get the co-ordinates of a measurement agent. This function allows the graphical display of the measurements agent's physical location.

8.3.3 "Light version" of Active Network Probing

Due to the feedback from the trial site in Warsaw, it is planned to implement a light version of the master station, that doesn't need a database, web server and the web based GUI. This mini-master will be able to control up to 10 measurement agents and a fully meshed network of (configurable) measurement flows between these stations. The measurement results (one way delay, delay variation) will be displayed online. With this tool it will be much easier to set up a small measurement scenario and get the results via online monitoring.

8.3.4 GUI - User Friendliness

As a discussion whether the GUI is user friendly and intuitive, the design of the taskbar will be changed with the next version. Aims are an intuitive handling of the interface. This means a quick possibility to change between the menus. This means also better navigation through the necessary configuration of a measurement scenario. The description of the input field (help function) will be integrated near to the fields. There will be a quick start functionality, which allows configuring and starting a measurement in one step without switching between different configuration menus.

Performance problems with long HTML-tables will be solved. When the new version is ready and available to all partners a further discussion will be necessary about the implemented changes and about necessary enhancements for the future.

8.3.5 GUI - Online Monitoring

The GUI for the display of measurement results will be enhanced with an online monitoring function. This provides the possibility to monitor long-term flows even during running. The monitoring will be based on the aggregated results of the active measurement flows and the information gathered from router monitoring. While the active network probing tool already provides this data, the synthetic flow generator has to be enhanced to support this functionality.

8.3.6 Improving Poissonian Traffic Source

The Poissonian traffic source in the synthetic flow generator currently implemented has limitations in the inter-arrival times of consecutive packets. When generating such flows the exponential distribution of inter-arrival times should converge to zero. In the current implementation the shortest gap (> 0) between two consecutive packets is depending on the Linux kernel granularity (default value is 10 ms, using a different kernel configuration this value can become lower). To support shorter inter-arrivals the implementation will be enhanced.

9 Annex D - specification of network configuration

The configuration of the scheduler is constant during the runtime of the RCL. The configuration of the scheduler for low and high bandwidth links. For high Bandwidth links the traffic is divided into five different classes.

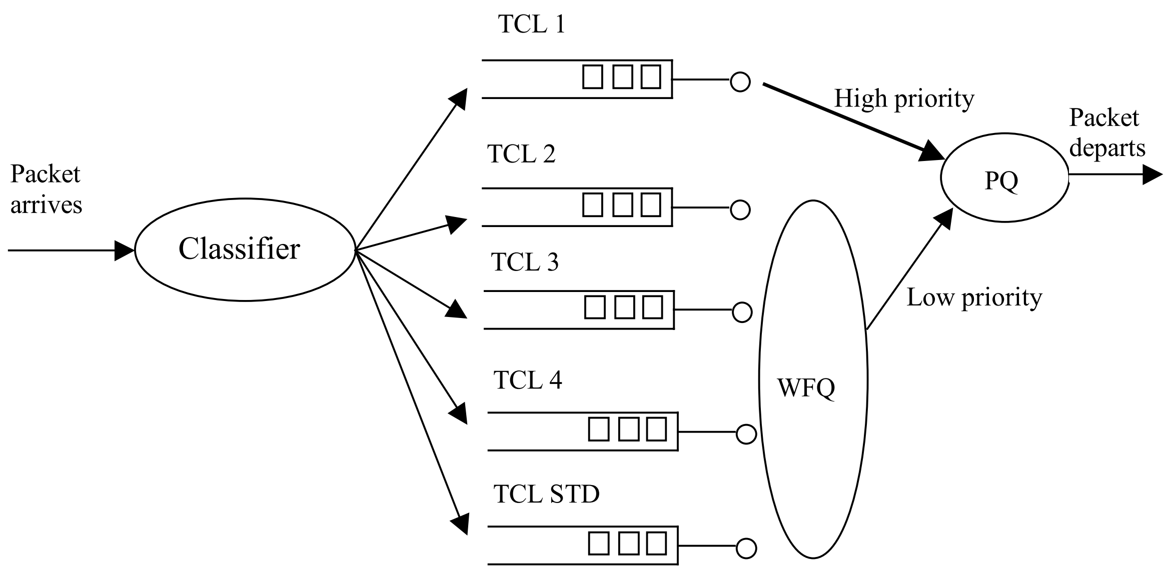

Figure 9-1. Design of the router output port for high bandwidth links

For the calculation of the weights for each Traffic Class the following parameters are used:

- C

  Link capacity

- w^s ($s = 2,3,4,5$)

  WFQ's scheduling weight for TCL *s* on a generic link *v* (the index *v* is omitted for ease of reading).

- z^s ($s = 2,3,4,5$)

  the provisioned rate (for a specific link *v*, *v* is omitted).

- g

  concerning the first trial it is suggested to set $g \in [1.5, 2]$.

9.1 Provisioning for trial in Warsaw

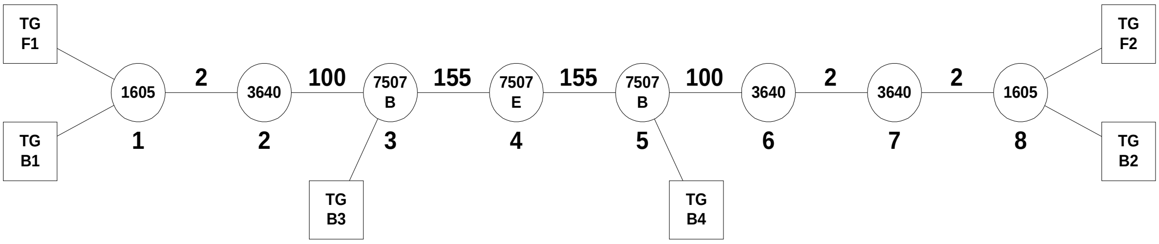

Figure 9-2. Network topology

There are 8 routers (node 1 to 8) and some attached traffic generators(TG F1 to TG B4). Numbers above links are link capacities in Mbps.

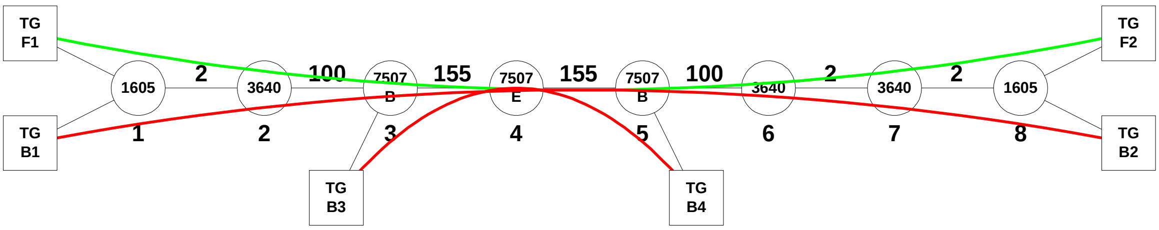

Figure 9-3. Network topology with traffic streams

Three traffic streams (coloured lines) are used. One foreground traffic stream between TG F1 and TG F2. Two background traffic streams between TG B1 and TG B2 resp. TG B3 and TG B4.

TCL s	PCBR	PVBR	PMM	PMC	BE
z^s/C	0,10	0,15	0,30	0,05	0,40
g	1,5				
w^s		0,25	0,30	0,05	0,40

9.2 Provisioning for trial in Vienna

ED1, ED2, ED3

TCL s	PCBR	PVBR	PMM	PMC	BE	Sum
z_s	1	1,5	0,4	0,2	6,9	10
z_s/C	0,10	0,15	0,04	0,02	0,69	1
g	1,5	1,5				
w_s	0,150000	0,225000	0,033333	0,016667	0,575000	1,000000
w_s in kbps	1500,00	2250	333	167	5750	10000,00

9.3 Provisioning for trial in Helsinki

In Helsinki both, low and high bandwidth links are investigated. The configuration of the core router is independent of the link configuration. For low bandwidth links the traffic is divided in 3 classes.

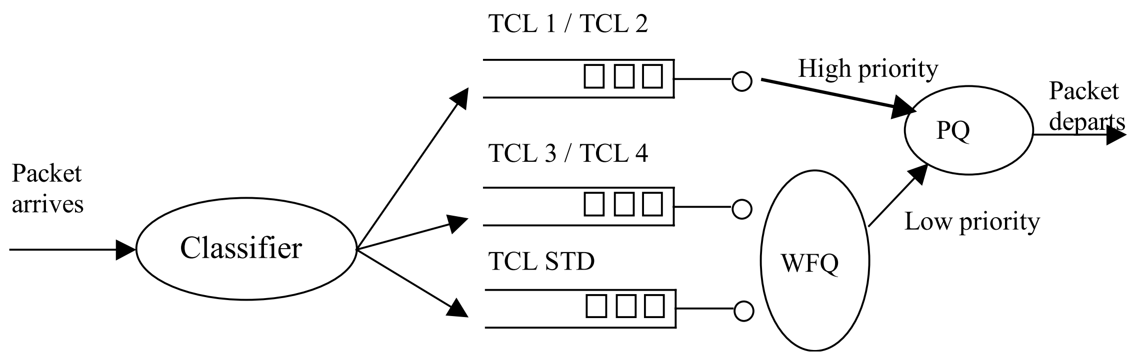

Figure 9-4. Design of the router output port for low bandwidth links

Low bandwidth links:

ED1, ED2 (1750, 2620)						
TCL s	PCBR/PVBR		PMM/PMC		BE	Sum
z_s in Kbps	307,2		358,4		51,2	512
z_s/C	0,60		0,70		0,10	1,4
g						
w_s	0,600000		0,875000		0,125000	1,600000
w_s in kbps	307,20		448		64	819,2

High bandwidth links:

ED1, ED2 (1750, 2620)						
TCL s	PCBR	PVBR	PMM	PMC	BE	Sum
z_s in Kbps	600	800	1600	600	400	4000
z_s/C	0,15	0,20	0,40	0,15	0,10	1
g	1,5	1,5				
w_s	0,225000	0,352941	0,398190	0,149321	0,099548	1,225000
w_s in kbps	900,000	1411,765	1592,760	597,285	398,190	4900

Core router:

CR						
TCL s	PCBR	PVBR	PMM	PMC	BE	Sum
z_s in Kbps	23250	31000	62000	23250	15500	155000
z_s/C	0,15	0,20	0,40	0,15	0,10	1
g	1,5	1,5				
w_s	0,225000	0,352941	0,398190	0,149321	0,099548	1,225000
w_s in kbps	34875,000	54705,882	61719,457	23144,796	15429,864	189875

9.4 Specification of network configuration for network services trials (Warsaw)

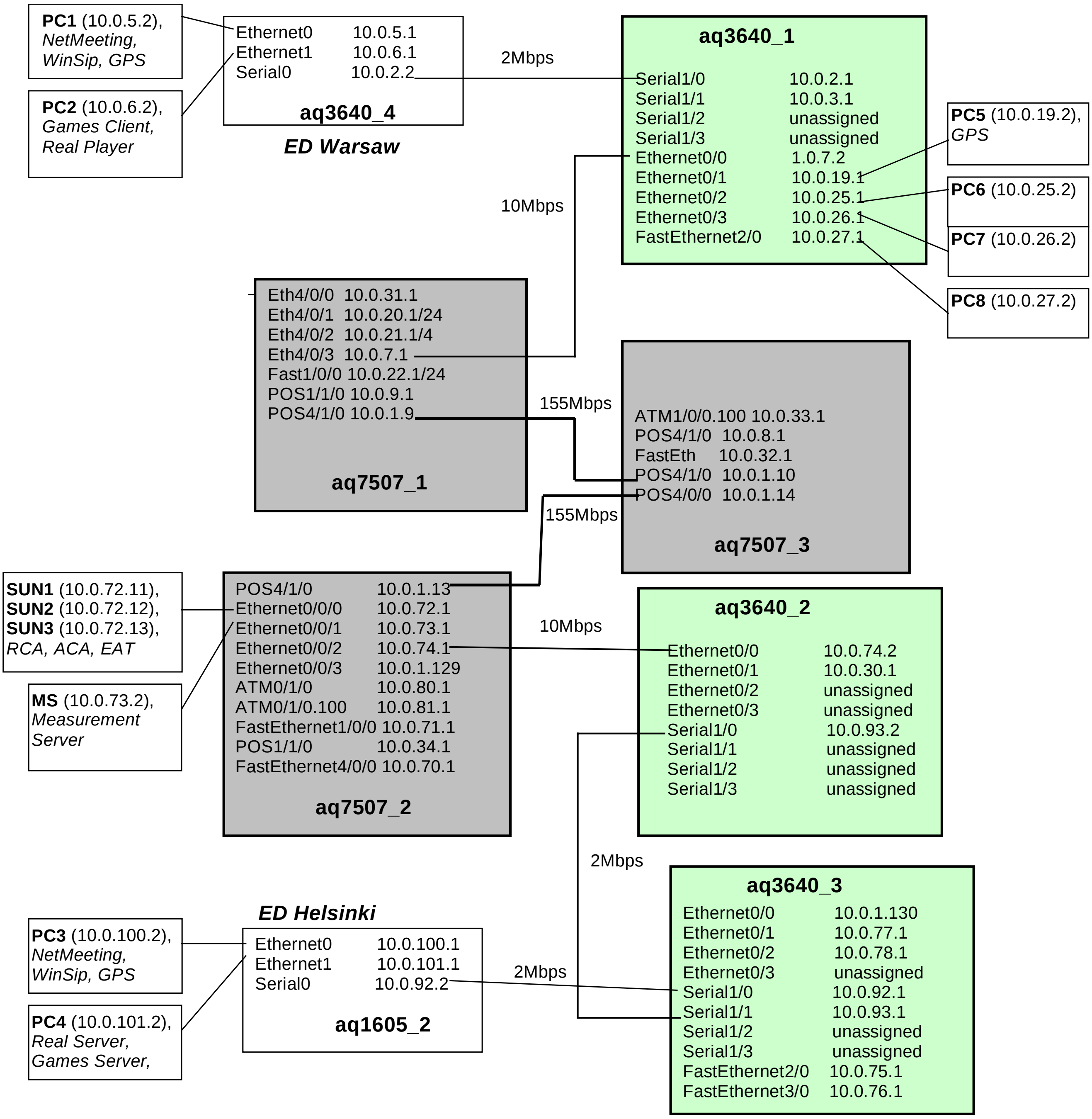

Figure 9-5. Topology of the trial network

The topology and addressing information of the trial network is depicted in Figure 9-5. The network setup (connections between routers) was not changed during the trials of AQUILA network services. Anyway, in some trial scenarios the connections between end-stations (PCs) and routers were changed. In particular, in some cases the measurement equipment (HP BSTS and IW95000 traffic generators/analysers) were connected to the edge devices instead of the PCs.

The following routers were used in the trial network:

- CISCO 7507 (3 routers). These routers constitute the high-speed core of the AQUILA network. The connections between the core routers are 155Mbit/s Packet over Sonet links.

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 (4 routers). One of the 3640 routers is used as the Edge Device (ED Warsaw). The rest of them are used as the core routers. The connections used in this part of the core network are 10Mbit/s Ethernet or 2Mbit/s serial links.

IOS software release	IOS (tm) 3600 Software (C3640-IS-M), Version 12.1(2), RELEASE 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

- CISCO 1605 (1 router). This router is the Edge Device (ED Helsinki). It is connected with a 2Mbit/s serial link to the core network.

IOS software release	Cisco Internetwork Operating System Software IOS (tm) 1600 Software (C1600-SY-M), Version 12.1(5), RELEASE SOFTWARE (fc1) c1600-sy-mz.121-5.bin
Router processor	Cisco 1605 (68360) processor (revision C) with 12288K/4096K bytes of memory.

The end-stations used in the trials were equipped with Pentium III – 700Mhz processors. The operating systems installed on the PCs were Linux Suse 6.4 and Windows NT 4.0. The PC1 and PC3 were running Windows 2000 system instead of WinNT.

Below, the configuration of CBWFQ scheduler on the router ports is presented.

- 2Mbit/s links between routers aq3640_1 and aq3640_4, aq1605_1 and aq 3640_3, aq3640_3 and aq3640_2:

```
access-list 100 permit ip any any dscp cs6
access-list 101 permit ip any any dscp cs5
access-list 102 permit ip any any dscp cs4
access-list 102 permit ip any any dscp cs3
ACCESS-LIST 103 PERMIT IP ANY ANY DSCP CS2
access-list 103 permit ip any any dscp cs1

class-map TCL3
  match access-group 102
class-map TCL2
  match access-group 101
class-map TCL1
  match access-group 100
class-map TCL4
  match access-group 103

policy-map aquila2
  class TCL1
    priority 2000
  class TCL2
   bandwidth 300
   queue-limit 5
  class TCL3
   bandwidth 600
   random-detect
   random-detect precedence 3   3     10    16
   random-detect precedence 4   10    15    166
  class TCL4
```

```
   bandwidth 100
   random-detect
   random-detect precedence 1   4    13    16
   random-detect precedence 2   13   20    166
  class class-default
   bandwidth 700
   queue-limit 19
```

- 10Mbit/s links between routers aq3640_2 and aq7507_2, aq7507_1 and aq3640_1:

```
class-map match-all class2
class-map match-all TCL3
  match ip dscp 24 32
CLASS-MAP MATCH-ALL TCL2
  match ip dscp 40
class-map match-all TCL1
  match ip dscp 48
class-map match-all TCL4
  match ip dscp 8 16
!
!
policy-map aquila
  class TCL2
    bandwidth percent 15
    queue-limit 100
  class TCL3
    random-detect
    random-detect precedence 3 10 20 10
    random-detect precedence 4 30 40 10
    bandwidth percent 30
    queue-limit 100
  class TCL4
    random-detect
    random-detect precedence 1 10 20 10
    random-detect precedence 2 25 35 10
    bandwidth percent 5
    queue-limit 100
  class TCL1
    priority percent 10
  class class-default
    random-detect
```

- 155Mbits links between routers aq7507_1 and aq7507_3, aq7507_3 and aq7507_2:

```
class-map match-all class2
class-map match-all TCL3
  match ip dscp 24 32
CLASS-MAP MATCH-ALL TCL2
  match ip dscp 40
class-map match-all TCL1
  match ip dscp 48
```

```
class-map match-all TCL4
  match ip dscp 8 16
!
!
policy-map aquila
  class TCL2
    bandwidth percent 15
    queue-limit 100
  class TCL3
    random-detect
    random-detect precedence 3 10 20 10
    random-detect precedence 4 30 40 10
    bandwidth percent 30
 QUEUE-LIMIT 100
  class TCL4
    random-detect
    random-detect precedence 1 10 20 10
    random-detect precedence 2 25 35 10
    bandwidth percent 5
    queue-limit 100
  class TCL1
    priority percent 10
  class class-default
    random-detect
```

Resource Pool configuration

In the network services trials, a simple resource pool configuration with the resource pool root and two resource pool leaves was used (see

Figure 9-8). The resource pool leaves correspond to the edge devices ED Warsaw and ED Helsinki.

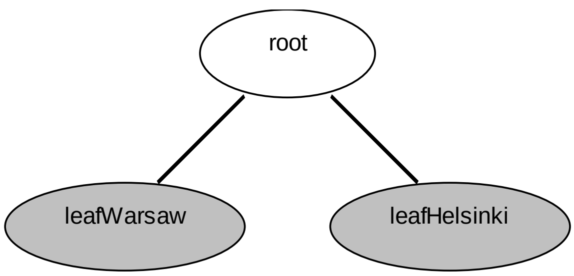

Figure 9-6. Resource pool configuration in Network Services trials

The resource share configuration is as follows (similar in both RP leaves, for ingress and egress reservations):

TclD	**TCL1**		**MAX**	**TOT**
LowW	0.5	*PR*	200000	200000
WHigh	0.8	*BSP*	512	512
B	1.0	*SR*	0	0
C	1.0	*BSS*	0	0
Amax	5.0	*m*	40	40
Amed	3.0	*M*	0	0
Amin	1.0	*EAR*	0	0
Rho	0.8	*PR1*	0	0
Buffer	20	*PR2*	0	0
Rate	10000			
linkL	2000000			

TclD	**TCL2**		**MAX**	**TOT**
LowW	0.5	*PR*	300000	300000
WHigh	0.8	*BSP*	1024	1024
B	1.0	*SR*	0	0
C	1.0	*BSS*	0	0
Amax	5.0	*m*	40	40
Amed	3.0	*M*	0	0
Amin	1.0	*EAR*	0	0
Rho	0.8	*PR1*	0	0
Buffer	20000	*PR2*	0	0
Rate	10000			
linkL	2000000			

TclD	**TCL3**		**MAX**	**TOT**
LowW	0.5	*PR*	600000	600000
WHigh	0.8	*BSP*	5000	5000
B	1.0	*SR*	600000	600000
C	1.0	*BSS*	5000	5000
Amax	5.0	*m*	50	50
Amed	3.0	*M*	640	640
Amin	1.0	*EAR*	0	0
Rho	0.8	*PR1*	0	0
Buffer	20000	*PR2*	0	0
Rate	10000			
linkL	2000000			

TclD	**TCL4**		**MAX**	**TOT**
LowW	0.5	*PR*	100000	100000
WHigh	0.8	*BSP*	2048	2048
B	1.0	*SR*	0	0
C	1.0	*BSS*	0	0
Amax	5.0	*m*	40	40
Amed	3.0	*M*	0	0
Amin	1.0	*EAR*	0	0
Rho	0.8	*PR1*	0	0
Buffer	20000	*PR2*	0	0
Rate	10000			
linkL	2000000			

9.5 Specification of network configuration for resource pool mechanism trials (Vienna)

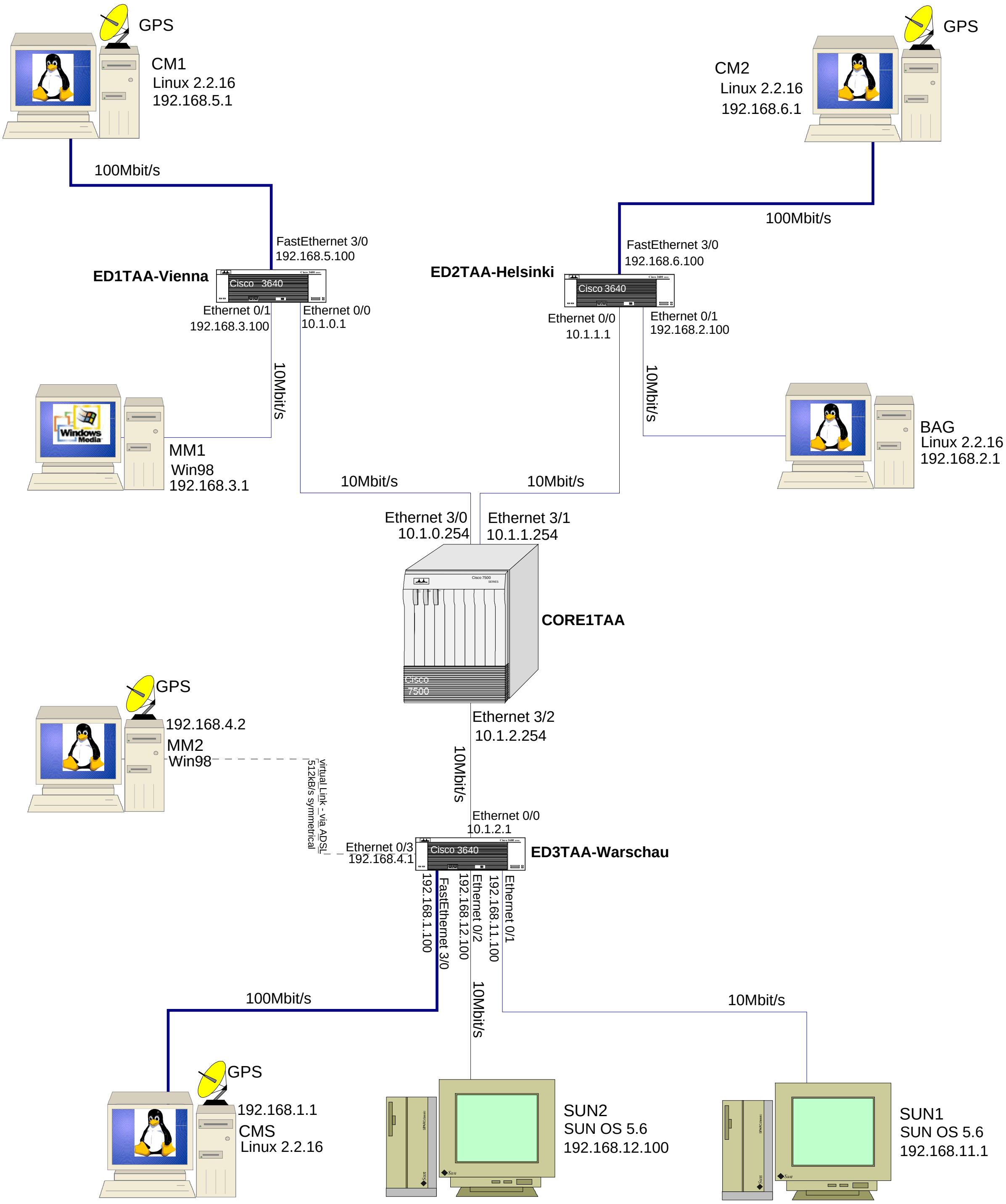

Figure 9-7. Topology of the trial network

The topology and addressing information of the trial network is depicted in Figure 9-7. Topology of the trial network. The network setup (connections between routers) was not changed during the trials of AQUILA network services. Anyway, in some trial scenarios the connections between end-stations (PCs) and routers were changed. The following routers were used in the trial network:

- CISCO 7500 (1 router). This router constitutes the core of the AQUILA network.

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 RSP1 (R4700) processor with 65536K/2072K bytes of memory. R4700 CPU at 100Mhz, Implementation 33, Rev 1.0
Interface processors	1 EIP controller (4 Ethernet)

- CISCO 3640 (4 routers). All of the 3640 routers are used as Edge Devices (ED Helsinki, ED Vienna and ED Warsaw). They are all connected to the Core Router vie 10Mbit/s Ethernet links.

IOS software release	IOS (tm) 3600 Software (C3640-IS-M), Version 12.1(2)T, RELEASE SOFTWARE (fc1) c3640-is-mz.121-2.T.bin
Router processor	cisco 3640 (R4700) processor (revision 0x00) with 44032K/5120K bytes of memory. R4700 CPU at 100Mhz, Implementation 33, Rev 1.0

The end-stations used in the trials were equipped with AMD T800 Socket A processors. The operating systems installed on the PCs were Linux Suse 7.0, Windows 2000 and Windows 98. Below, the configuration of CBWFQ scheduler on the router ports is presented.

- Edge Devices

```
class-map TCL3
  match ip dscp 24  32
class-map TCL2
  match ip dscp 40
class-map TCL1
  match ip dscp 48
class-map TCL4
  match ip dscp 8  16
!
```

```
!
policy-map aquila10
  class TCL1
    priority 1500
  class TCL2
   bandwidth 2250
  class TCL3
   bandwidth 333
   random-detect
   random-detect precedence 3   10    20    10
   random-detect precedence 4   30    40    10
  class TCL4
   bandwidth 166
   random-detect
   random-detect precedence 1   10    20    10
   random-detect precedence 2   25    35    10
  class class-default
   bandwidth 5750
   random-detect
!
!
policy-map aquila100
  class TCL1
    priority 15000
  class TCL2
   bandwidth 22500
  class TCL3
   bandwidth 3333
   random-detect
   random-detect precedence 3   10    20    10
   random-detect precedence 4   30    40    10
  class TCL4
   bandwidth 1666
   random-detect
   random-detect precedence 1   10    20    10
   random-detect precedence 2   25    35    10
  class class-default
   bandwidth 57500
   random-detect
```

- Core Router

```
class-map match-all TCL3
  match ip dscp 24 32
class-map match-all TCL2
  match ip dscp 40
class-map match-all TCL1
  match ip dscp 48
class-map match-all TCL4
  match ip dscp 8 16
```

```
!
!
policy-map aquila10
  class TCL1
    priority 1075
  class TCL2
    bandwidth 993
    queue-limit 64
  class TCL3
    bandwidth 1268
    queue-limit 64
    random-detect
    random-detect precedence 3 10 20 10
    random-detect precedence 4 30 40 10
  class TCL4
    bandwidth 1374
    queue-limit 64
    random-detect
    random-detect precedence 1 10 20 10
    random-detect precedence 2 25 35 10
  class class-default
    random-detect
!
policy-map aquila20
  class TCL1
    priority 833
  class TCL2
    bandwidth 833
    queue-limit 64
  class TCL3
    bandwidth 2083
    queue-limit 64
    random-detect
    random-detect precedence 3 10 20 10
    random-detect precedence 4 30 40 10
  class TCL4
    bandwidth 1041
    queue-limit 64
    random-detect
    random-detect precedence 1 10 20 10
    random-detect precedence 2 25 35 10
  class class-default
    random-detect
```

Resource Pool configuration

In the network services trials, a simple resource pool configuration with the resource pool root and three resource pool leaves was used (see

Figure 9-8). The resource pool leaves correspond to the edge devices: ED Vienna, ED Warsaw and ED Helsinki.

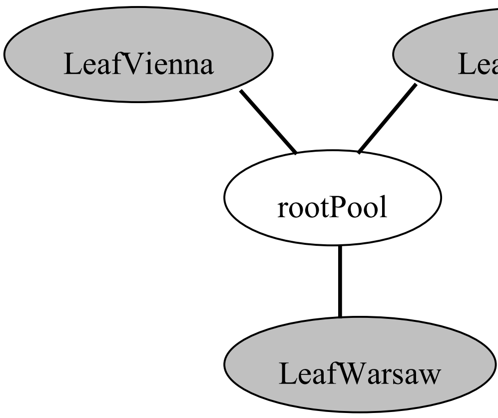

Figure 9-8. Resource pool configuration in Resource pool trials

Root Resource Pool configuration

TCL1 (ingress, egress)				
	MAX	**TOT**	**Other**	
PR	2000000	500000	*LowW*	0.5
BSP	256	256	*WHigh*	0.8
SR	0	0	*B*	1.0
BSS	0	0	*C*	1.0
m	40	40	*Amax*	5.0
M	256	256	*Amed*	3.0
EAR	0	0	*Amin*	1.0
PR1	0	0	*Rho*	0.8
PR2	0	0	*Buffer*	20000
			Rate	0
			linkL	10000000
TCL2 (ingress, egress)				

	MAX	TOT	Other	
PR	5000000	1500000	*LowW*	0.5
BSP	1024	1024	*WHigh*	0.8
SR	4000000	1000000	*B*	1.0
BSS	5120	5120	*C*	1.0
m	40	40	*Amax*	5.0
M	512	512	*Amed*	3.0
EAR	0	0	*Amin*	1.0
PR1	0	0	*Rho*	0.8
PR2	0	0	*Buffer*	20000
			Rate	9614
			linkL	100000000

TCL3 (ingress, egress)				
	MAX	**TOT**	**Other**	
PR	0	0	*LowW*	0.5
BSP	0	0	*WHigh*	0.8
SR	2000000	400000	*B*	1.0
BSS	30000	30000	*C*	1.0
m	40	40	*Amax*	5.0
M	512	512	*Amed*	3.0
EAR	0	0	*Amin*	1.0
PR1	0	0	*Rho*	0.8
PR2	0	0	*Buffer*	20000
			Rate	0
			linkL	10000000

TCL4 (ingress, egress)				
	MAX	**TOT**	**Other**	
PR	1000000	200000	*LowW*	0.5
BSP	1024	1024	*WHigh*	0.8
SR	800000	100000	*B*	1.0
BSS	5120	5120	*C*	1.0
m	40	40	*Amax*	5.0
M	1024	1024	*Amed*	3.0
EAR	0	0	*Amin*	1.0
PR1	0	0	*Rho*	0.8
PR2	0	0	*Buffer*	20000
			Rate	9614
			linkL	10000000

Leaf Resource Pool configuration (the same values are used for each leaf)

The following configuration represents the trial scenarios where max = tot (PR and SR)

TCL1 (ingress, egress)				
	MAX	**TOT**	**Other**	
PR	500000	0	*LowW*	0.5
BSP	256	0	*WHigh*	0.8
SR	0	0	*B*	1.0
BSS	0	0	*C*	1.0
m	40	40	*Amax*	5.0
M	256	256	*Amed*	3.0
EAR	0	0	*Amin*	1.0
PR1	0	0	*Rho*	0.8
PR2	0	0	*Buffer*	20000
			Rate	0
			linkL	10000000

TCL2 (ingress, egress)				
	MAX	**TOT**	**Other**	
PR	1500000	0	*LowW*	0.5
BSP	1024	0	*WHigh*	0.8
SR	1000000	0	*B*	1.0
BSS	5120	0	*C*	1.0
m	40	40	*Amax*	5.0
M	512	512	*Amed*	3.0
EAR	0	0	*Amin*	1.0
PR1	0	0	*Rho*	0.8
PR2	0	0	*Buffer*	20000
			Rate	9614
			linkL	100000000

TCL3 (ingress, egress)				
	MAX	**TOT**	**Other**	
PR	0	0	*LowW*	0.5
BSP	0	0	*WHigh*	0.8
SR	400000	0	*B*	1.0
BSS	10240	0	*C*	1.0
m	40	40	*Amax*	5.0
M	512	512	*Amed*	3.0
EAR	0	0	*Amin*	1.0
PR1	0	0	*Rho*	0.8
PR2	0	0	*Buffer*	20000
			Rate	0
			linkL	10000000

TCL4 (ingress, egress)				
	MAX	**TOT**	**Other**	
PR	200000	0	*LowW*	0.5
BSP	1024	0	*WHigh*	0.8
SR	100000	0	*B*	1.0
BSS	5120	0	*C*	1.0
m	40	40	*Amax*	5.0
M	1024	1024	*Amed*	3.0
EAR	0	0	*Amin*	1.0
PR1	0	0	*Rho*	0.8
PR2	0	0	*Buffer*	20000
			Rate	9614
			linkL	10000000