Evaluation of the AQUILA Architecture: Trial Results for Signalling Performance, Network Services and User Acceptance*

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Abstract. A set of five practically manageable Network Services is proposed for the IP QoS AQUILA architecture and implemented in a prototype network. QoS capabilities of routers in conjunction with Admission Control (AC) and Resource Pool (RP) allow for an efficient handling of traffic requiring different packet transfer characteristics. The paper presents the trial results illustrating the effectiveness of the AQUILA network for providing a well-differentiated Network Services set. Performed tests cover both, technical parameters such as per Network Service behaviour, signalling performance and user acceptance referring to application behaviour using the entire AQUILA architecture.

1 Introduction

Both, business and private end-users are looking for reliable and provable network applications with focus on cheap and easy accessible service offers. From the point of a network operator or Internet service provider, Quality of Service (QoS) is a business opportunity. An important prerequisite for QoS offers towards the customer is a technique for precise specification of Network Services and their support at network level using Traffic Classes (TC).

Within the AQUILA project [2], a modular Resource Control Layer (RCL) is defined to cover both, intra- and inter-domain issues. A Resource Pool (RP) approach accompanied with appropriate Admission Control (AC) mechanisms guarantees scalability. Multiple trials were carried out to evaluate the architecture and its parts.

The paper is organised as follows. In chapter 2, AQUILA architecture and Network Services are described. Traffic handling mechanisms at packet and flow levels are presented in chapter 3. The obtained trial results are discussed in chapter 4. The results correspond to Resource Control performance and evaluation of AQUILA

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Network Services. Chapter 5 contains a summary of the paper and main trial achievements.

2 AQUILA Architecture and Network Services

This chapter provides an overview of QoS IP architecture developed by AQUILA project with special focus on offered Network Services.

2.1 Architecture for Intra- and Inter-domain

AQUILA architecture covers intra- and inter-domain parts as depicted on Fig. 1. Intra-domain part relies on the Resource Control Layer (RCL) that acts as distributed bandwidth broker, controlling and providing the resources of the underlying DiffServ network. RCL contains three main components, that are:

- the *Resource Control Agent (RCA)* which is responsible for the control and management of overall resources of the domain;
- the *Admission Control Agent (ACA)* manages the local resources of one edge or border router. An ACA communicates with other ACAs for allocating the resources.
- the *End-user Application Toolkit (EAT)* is a kind of middleware between end-user application and the network. EAT requests appropriate network resources for setting the connection.

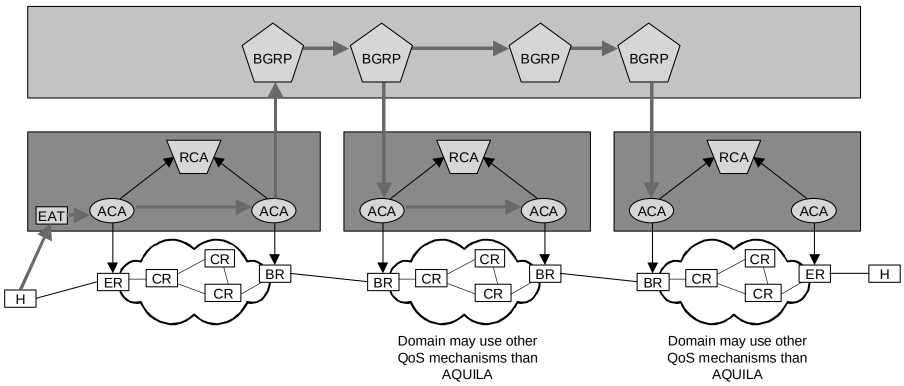

Fig. 1. AQUILA intra- and inter-domain Resource Control Layer architectures with associated message flows. H : Host, ER : Edge Router, CR : Core Router, BR : Border Router, BGRP : Border Gateway Reservation Protocol.

The objective of ACA is to control the volume of traffic injected into the network and in this way to avoid network congestion. This approach is necessary for providing QoS guarantees in the network. Additionally, overall resources of the domain are represented in the form of resource pools which is suitable for effective management by RCA [2]. The resource pools is a mechanism for achieving dynamic resource allocation in a domain.

Since, the initial distribution of resources is based on assumed provisioning rules, those resources may be again more effectively redistributed based on observations of network traffic load. The exemplary interactions between the RPs entities of the tree are depicted on Fig. 2.

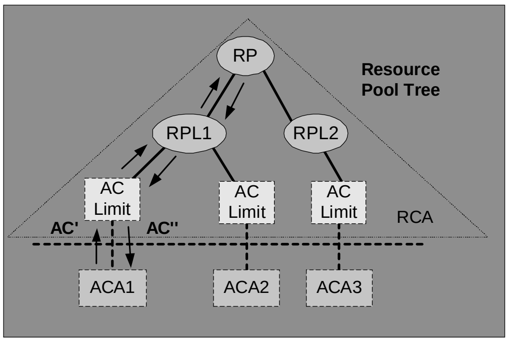

Fig. 2. Interactions between ACA and RCA.

When a new resource request can not be admitted because the current assigned AC limit is fully allocated for running connections, the ACA will request (AC') additional resources from the RCA. If the RP does not have enough resources to accommodate the request, then additional resources are requested from the RP of the level above. Each RP runs the same algorithm, which is executed whenever resources should be redistributed. The actual amount of assigned resources (AC'') from a RP is based on its spare resources. The request for additional resources may be propagated up to the root of the tree, as depicted on Fig. 2. Moreover, in case resources are not used by an ACA, they are released to the upper level RP.

In inter-domain architecture, the enhanced BGRP (Border Gateway Reservation Protocol) protocol [12, 2] for making reservations across borders is applied. Fig. 1 depicts a network consists of source, transit and destination domains. For such a scenario, the associated RCL components for intra-domain resource management, BGRP agents for inter-domain resource control as well as the interactions between the components are shown.

2.2 Network Services

The AQUILA project [2] defined four manageable premium transport options (beside best effort) for IP traffic, as listed in Table 1. They are named Network Services. The Network Service characteristics could be defined by the network operator. The idea of these services is to provide a few specific offerings to the customer, which are easy to understand, suitable for specific groups of applications, and maintainable in large networks [4].

Table 1. Network Services as defined within the AQUILA framework.

Service	Goals/Focus
PCBR: Premium Constant Bit Rate	designed to serve constant bit rate traffic e.g. voice trunks and virtual leased lines
PVBR: Premium Variable Bit Rate	designed to provide effective transfer of streaming variable bit rate traffic e.g. video-conference and video
PMM: Premium Multi-Media	designed to support TCP (or TCP like) applications of greedy type e.g. ftp or adaptive non-real time streaming video, that require some minimum bandwidth
PMC: Premium Mission Critical	designed to support TCP (or TCP like) applications of non-greedy type e.g. online games or home-banking
STD: Standard	designed to carry best effort traffic

Fig. 3 describes the relations between the different entities and the role played by the Network Services. The operator of a DiffServ aware network needs a formalism in order to express technically what can be provided to its customers. The AQUILA consortium defined a generic Service Level Specification (SLS), capturing all the possible service offerings that can be provided over a DiffServ network.

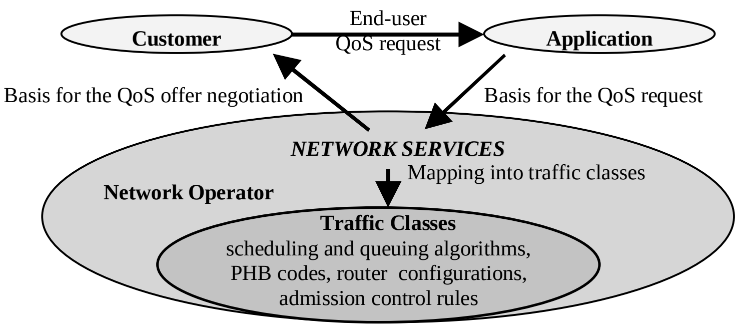

Fig. 3. Network Services as intermediate between application's/user's request and Traffic Classes.

3 Traffic Handling Mechanisms at Packet and Flow Levels

3.1 Mechanisms at Packet Level

To achieve QoS prerequisites at network level, the key issues are appropriate router configurations beside appropriate network design (network topology or link dimensioning) and traffic engineering (routing, network load assessment) [1]. The proposed solution aims to produce reliable differentiated network QoS, known as Traffic Classes (TC).

At the router ingress classification, marking/colouring and policing/profiling are performed. Interface selection and queue selection lead to a realisation of the handling defined by the TC, where queue dimensioning and drop policies influence the packet handling. AQUILA uses five TCs, mirroring a face to face mapping of the five Network Services. While the PCBR, PVBR and STD TCs are tail dropped, PMM and PMC make use of Weighted Random Early Detection (WRED). Scheduling among multiple queues influences the traffic merging. The TC for PCBR is prioritised, Priority Queuing (PQ) against the other four, which are handled with Weighted Fair Queuing (WFQ) with appropriate weights. Fig. 4 illustrates the packet flow through a routing entity. The decision made for the handling of selected packets is indicated by and stored in the precedence bits of the Type of Service (ToS) byte of the IP header.

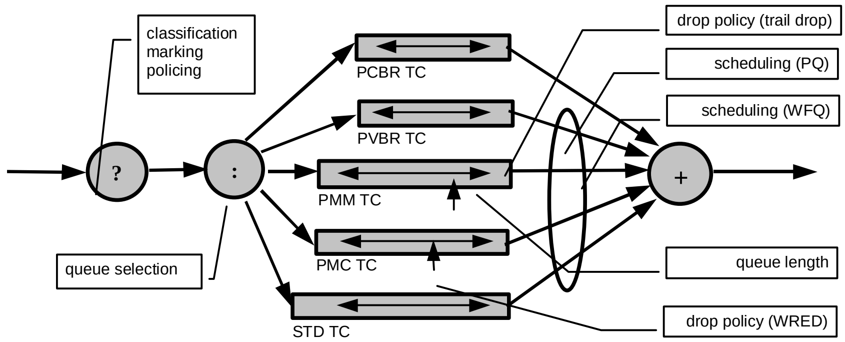

Fig. 4. Parameter setting points within a QoS sensitive router entity. After checking various selectors (?) the queue selection decision (:) is made. Packets of parallel queues have to be merged (+) before sending them onto the next link.

3.2 Admission Control

Admission Control (AC) operates on the flow level and prevents the network against congestion by limiting the volume of submitted traffic. The decision of new flow acceptance/rejection is based on the flow traffic declaration and the current network load. New flow is only accepted when the QoS requirements for both the considered flow and the flows in progress are met. In AQUILA, adequate AC rules govern the volume of the traffic submitted to each TC. Different AC are implemented since the QoS objectives as well as the handled traffic profiles are different for each TC. For achieving maximum link utilisation profit, the bandwidth of the link is not strictly partitioned between TCs but could be dynamically allocated to each TC according to the demands (leading to full available link). For this purpose, additional rules (named joint AC) are implemented and situated on the top of AC associated to particular TCs [7].

3.2.1 Admission Control for PCBR and PVBR Traffic Classes

The PCBR and PVBR TCs are designed to carry streaming type of traffic. The QoS objectives provided by these TCs are defined in terms of low packet loss ratio as well as low packet delay and jitter. For achieving this, the REM (Rate Envelope Multiplexing) scheme is assumed with appropriate AC algorithms. A short buffer (for a few packets) is applied for absorbing packets arriving to the router output port from different sources at the same time.

The PCBR TC handles constant bit rate flows, so the users characterise the submitted traffic by the parameters of single token bucket mechanism: peak bit rate (PR) and bucket size. The DBAC (Declaration Based Admission Control) method is applied, i.e. decision on admitting or rejecting the new flow is taken only on the basis of the submitted traffic descriptors. There is assumed, that so called negligible jitter property [8] is valid, so the aggregation of a large number of CBR flows is modelled as a Poisson stream. Therefore, the maximum allowed utilisation in PCBR TC is calculated from the analysis of M/D/1/B system, taking into account the available buffer size and the target loss ratio. Details of the algorithm can be found in [1, 7].

The traffic submitted to the PVBR TC is of variable bit rate type. In the DBAC approach, additionally to the PR a user declares the value of sustained bit rate (SR), which usually is greater than the mean bit rate. Anyway, providing a priori the proper value for the SR parameter is rather difficult. Therefore, the MBAC (Measurement Based Admission Control) approach is also investigated in AQUILA. The applied Hoeffding bound algorithm (see details in [3, 11]) takes into account the measured mean bit rate of aggregate traffic in the PVBR TC, instead of user declarations of SR.

3.2.2 Admission Control for PMM and PMC Traffic Classes

The PMM TC was designed to provide throughput guarantees for TCP connections of greedy type. The guaranteed throughput per TCP connection should not be below the requested rate value. For the PMM TC two alternative AC algorithms are implemented. Each of them operates per TCP flow and is of declaration based type. They assume that a user, before establishing TCP connection, submits its request to the network. The traffic contract specifies the target requested bit rate (RR). Furthermore, on the basis of the RR and information about round trip time (RTT) of the TCP connection, the user declarations are mapped into the form of single token bucket parameters, rate (SR) and bucket size (BSS), constituting input parameters for the AC decision. The first of the two proposed AC is based on the token bucket marking (TBM); the second one enables an ideal TCP behaviour by setting an appropriate value for the advertised window size. The details of the algorithms are presented in [7, 9] and [3, 4].

The PMC TC is designed for handling non-greedy TCP traffic with no packet losses as QoS objective. The potential applications for using PMC are e.g. transaction oriented applications and www applications. In this case, a flow is characterised by parameters of dual token bucket mechanism, similarly as for PVBR TC. The proposed AC algorithm assumes that a demand is expressed in the form of the effective bandwidth value calculated for the RSM (Rate Sharing Multiplexing) scheme. The details of the AC rules for this TC are described in [1] and [7].

4 Trial Results

In this chapter the results from the trials are presented and discussed. They correspond to the RCL performance and evaluation of Network Services, including tests with real users. The trials were performed in the three trial sides Helsinki, Vienna and Warsaw.

4.1 Resource Control Performance

The aim of Resource Control performance measurements was to evaluate the reservation set-up and release times as well as the volume of signalling load in the inter-domain scenario. These parameters determine the scalability factor of AQUILA architecture.

4.1.1 Reservation Times

The reservation times were measured assuming network connections through three neighbouring domains (like in Fig. 1). No information about reservation transactions was recorded to the system log file to minimise additional delays. Twenty PCBR reservations were set-up and released. After one reservation was released, another reservation was immediately set-up. The timestamps were measured with a reservation generator which counted the time between sending the request to EAT and receiving the acknowledgement of the established reservation. The obtained results are presented in Table 2.

Table 2. Results of reservation processing times.

Reservation	Set-up Time [s]		Release Time [s]	
	Average	Deviation	Average	Deviation
Initial	25.8	14.1	0.849	0.22
Subsequent	1.452	0.1	0.506	0.03

One can observe the significant difference between initial and subsequent reservation set-up. This difference was caused by the initial telnet connection to the router, requesting resources from RCA and first time initialisation of reservation related Java classes.

Initial reservations can be considered as a particular case and subsequent reservations as the standard case. Test results show that the average times for subsequent reservations were 1.45 seconds for reservation set-up and 0.506 seconds for reservation release. Additionally, the effect of requested network service on reservation set-up and release times was measured. The measurement was performed for both declaration and measurement based admission control schemes. The results show that either AC schemes or network services have no significant impact on reservation set-up and release times.

It was also measured if the number of the ongoing reservations has an impact to reservation set-up time. It was observed that the reservation set-up time did not change when the number of active reservations was increased.

4.1.2 Signalling Traffic

The amount of signalling traffic for reservation set-up was measured between RCL components. One reservation without existing sink-tree was made. In the intra-domain signalling the total amount of traffic was 64 kbytes for initial reservation and 50 kbytes for subsequent reservation. The largest component in both cases was router configuration (47% and 60 % respectively). Router contribution overhead is significant because of router telnet implementation inefficiencies.

For inter-domain reservations, additional signalling between BGRP agent and RCL components is necessary. When consecutive reservation joins the sink-tree, there is no additional signalling between BGRP agents.

4.2 Evaluation of Network Services

This section presents the measurement results illustrating the effectiveness of AQUILA Network Services, as introduced in chapter 2. The trials were mainly oriented on trial validation whether the assumed QoS objectives for particular Network Service were met under the allowed worst case traffic network conditions. All tests were carried out in intra-domain scenarios.

4.2.1 PCBR Service

The capabilities of PCBR service were measured assuming the test-bed network configuration as depicted on Fig. 5 with single bottleneck on the ingress link, 10 Mbps link connecting er1 and cr1. The packets of the foreground traffic submitted to PCBR service (emitted from PC1, with PC4 as the destination) were generated as Poisson stream, modelling a large number of CBR flows. The measured parameters were the PCBR packet loss ratio (P_{loss}) and packet delay characteristics. Furthermore, for getting more realistic traffic conditions in the network, traffic of lower priority services was also emitted (generated from PC2, with PC5 as the destination).

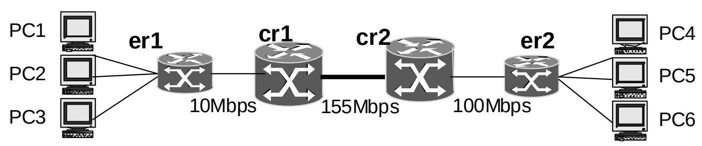

Fig. 5. Network configuration for testing PCBR and PVBR services. er : edge router, cr : core router.

In the experiments, the volume of bandwidth allocated for PCBR service, B_1, on the ingress link was changed from 1 to 10 Mbps. The mean bit rate of PCBR stream was equal to $B_1 * \rho$, where $\rho = 0.58$ that corresponds to the buffer size of 5 packets and target $P_{loss} = 10^{-4}$ [1]. The traffic submitted as a background load to the STD service was also of Poisson type. The mean rate of this traffic was tuned to give the total offered load to the system equal to 120 % of the link capacity. In this way, the overload conditions on the link er1-cr1 were modelled.

Table 3.. PCBR service: the measured packet loss ratio (P_{loss}), one-way delay and delay variation (IPDV) vs. the bandwidth available for PCBR service.

B_1 [Mbps]	PCBR traffic load [Mbps]	Lower priority background traffic load [Mbps]	P_{loss} of PCBR stream	Delay [ms]			IPDV [ms]	
				min	max	avg	avg	max
1	0.58	11.42	0	0.60	19.76	4.70	0.70	17.74
5	2.90	9.10	0	0.60	22.87	3.89	1.08	18.41
7	4.06	7.94	0	0.59	22.23	3.71	1.10	19.96
9	5.22	6.78	$4.5*10^{-5}$	0.59	24.59	3.6	1.09	22.26
10	5.80	6.20	$9.0*10^{-5}$	0.59	19.32	3.57	1.09	14.96

The measured parameter values are shown in Table 3. One can observe that capabilities of PCBR service for all considered traffic scenarios are satisfied, even in the overload conditions on the bottleneck. The P_{loss} is below the target value 10^{-4} and the packet transfer characteristics are acceptable.

4.2.2 PVBR Service

Trial validation of PVBR service with MBAC AC was carried out similarly as for PCBR service, assuming topology from Fig. 5. As previously, the experiments were focused on measurements of P_{loss} and packet delay characteristics. The submitted PVBR traffic (generated from PC1, with PC4 as the destination) was modelled by a superposition of the maximum number of PVBR flows, N_{PVBR}, allowed by the AC. The QoS requirements for PVBR traffic are represented by packet loss ratio (P_{loss}) assumed at 10^{-4} level [7].

Table 4. PVBR service: the measured packet loss ratio (P_{loss}), one-way delay and delay variation (IPDV), vs. volume of PCBR and PVBR traffic.

B_1 [Mbps]	PCBR traffic load [Mbps]	B_2 [Mbps]	N_{PVBR}	PVBR traffic load [Mbps]	P_{loss} of PVBR stream	Delay [ms]			IPDV [ms]	
						min	Max	avg	avg	max
0	0	8.945	23	3.45	$1.26*10^{-4}$	2.84	17.50	3.95	0.49	12.99
0	0	4.238	7	1.05	$1.30*10^{-4}$	2.95	17.37	4.01	0.52	13.04
4	2.32	5.243	10	1.50	$1.36*10^{-4}$	2.87	23.34	4.16	0.70	19.13
4	2.32	2.658	3	0.45	$1.00*10^{-4}$	2.23	14.88	4.15	0.63	11.44
7	4.06	2.658	3	0.45	$1.18*10^{-4}$	2.43	21.70	4.41	1.00	17.86

The flows were of ON-OFF type with the following parameters: peak bit rate 0.5 Mbps and mean bit rate 0.15 Mbps. The volume of bandwidth B_2 allocated for PVBR service was changing from 2.658 to 8.945 Mbps. The remaining bandwidth was allocated for PCBR service (B_1), according to the joint AC rules [7]. The background traffic submitted to PCBR service (generated from PC2, with PC5 as the destination) was of Poisson type with mean bit rate equal to $B_1*\rho$, ρ=0.58. In addition, constant bit rate traffic was submitted to STD service (generated from PC3, with PC6 as destination). The rate of this traffic was tuned to produce permanent congestion conditions on the bottleneck 10 Mbps link.

The measured parameters associated to PVBR traffic service are collected in Table 4. They say that the measured P_{loss} are close to assumed target value (10^{-4}) as well as the packet delays are acceptable. This allows us to conclude that the impact of higher priority PCBR traffic on PVBR service is effectively regulated by the applied AC rules.

4.2.3 PMM Service

The PMM service was designed to guarantee the throughput per TCP connection, which should not be below the requested rate. Since two alternative AC methods for PMM has been implemented, two groups of tests were performed: (1) for AC based on TBM and (2) for AC based on advertised window setting. The measured parameter was the TCP throughput. The obtained results were compared with the declared requested rate values.

The assumed trial topology for PMM is depicted on Fig. 6. This topology consists of 2 CISCO edge routers connected by 2 Mbps link (bottleneck link). The PC stations 1/2/3/4 are connected to the er1 router while PC 5/6 and PC 8 to the er2. The PC stations from 1 to 4 play role of TCP senders while the PC stations from 5 to 8 are the TCP receivers. In this configuration the maximum number of running TCP connections was 4.

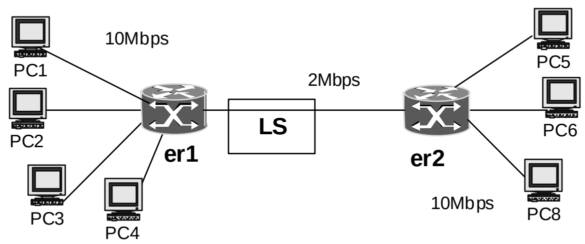

Fig. 6. Trial topology for PMM and PMC services. er: edge router, LS: Link Simulator.

In the investigated network scenario, an additional transmission delay on the bottleneck link by the Link Simulator (LS) was also introduced. In this way, the effectiveness of the PMM service for more realistic RTT values was verified. For all tests, the minimum round trip time RTT^{min} was 108 ms, including additional one-way transmission delay equal to 50 ms on 2 Mbps link. The MTU was 1500 bytes and TCP MSS (Maximum Segment Size) was set to 1448 bytes.

The foreground traffic was produced by the number of consecutive TCP flows generated by single TCP greedy source. Particular TCP flow started after the previous one was finished (the consecutive TCP flows started each 8 minutes). A volume of data generated by TCP source corresponding to single flow was fixed to 10 Mbytes. The background traffic was generated by parallel running greedy TCP flows. The number of these flows, including foreground flow, was admitted according to the joint

AC rules (in this case no additional flow could be admitted by ACA). The bandwidth B_3 allocated for PMM was equal to 2 Mbps. In addition, for AC algorithm based on TBM, parameter ρ_{PMM} was equal to 0.75 and T=202 ms, according to the recommendation from [9].

For both proposed AC algorithms two trial cases were performed: (1) assuming homogenous TCP flows with the same requested rate values, and (2) assuming heterogeneous TCP flows differing in the requested rates.

For homogenous TCP flows trial, two investigated AC approaches met the expectations and they guaranteed that the measured TCP throughput was above the requested rate. For the AC based on TBM the difference between the measured TCP throughput and the requested rate was hard to predict and depended on the number of running TCP flows. One could observe that in some cases this difference was significant. For the AC based on advertised window setting the measured TCP throughput, according to the expectations, was between the requested rate and the sustained rate, but rather closed to the requested rate. The reason that the measured TCP throughput was greater than the requested rate was mainly due to the error resulting from the assumed analytical approximation of average RTT, see [9]. The obtained results for the discussed case one can find in [6].

Table 5. Throughput characteristics for AC based on TBM. The parameters are: RR : Requested Rate, SR/BSS : token bucket parameters, Throughput : measured TCP throughput with a confidence interval of 95 %.

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

Table 6. Throughput characteristics for AC based on advertised window setting. Parameters description like Table 5 and W^{req} : advertised window size.

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

For heterogeneous TCP flows trial the AC algorithm based on TBM did not meet the expectations (see Table 5). In some cases the measured TCP throughput was below the requested rate. In addition, one can observe that by using this algorithm the TCP flows shared available bandwidth rather to the fair share than according to the requested rates. This was observed especially for more than 3 admitted flows.

For heterogeneous TCP flows trial, the AC algorithm based on advertised window setting met the expectations (see Table 6). Similarly to the homogenous case, again the measured TCP throughput was between the requested rate and the sustained rate, but rather closed to the requested rate.

Summarising, the results referring to the TCP throughput say that for the case with homogenous flows both considered AC approaches work properly, for different number of admitted flows. However, this conclusion can not be extended to the case with heterogeneous TCP flows, where only the AC based on advertised window setting meets requirements. The main reason that the AC based on TBM failed in this case was that the assumed maximum buffer size (25 packets) was shorter than required from theoretical studies, see [9]. This was caused by the limitation of the routers used in trial (maximum buffer size for PQWFQ scheduler was only 64 packets for all network services).

4.2.4 PMC Service

The PMC service was designed to guarantee very low packet losses and low delay for non-greedy traffic usually controlled by TCP protocol. The trial was performed assuming that PMC service was separated from other network services. During the trial the packet loss ratio was measured. By assuring low packet loss ratio one can expect the low transaction delay by avoiding packet retransmission.

The trial topology is depicted on Fig. 6. In this case, no additional transmission delay by the Link Simulator (LS) was introduced. The PMC foreground and background traffic was sent between terminals PC2-PC6 and PC1-PC5, respectively. Since PMC requires relatively large room, the almost whole router output port buffer space was dedicated for PMC services (60 packets). Moreover, the buffer management mechanism WRED was applied with parameters fixed according to [7].

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

In the trial the packet loss rate was measured after 100 measurement cycles. Each measurement cycle begun with simultaneous starting up of a given number of TCP flows and ended after completing all transfers. During single TCP connection a predefined amount of data was transferred corresponding to a typical size of www pages. The number of simultaneous running flows was determined by defined AC algorithm for PMC service [7]. The trial was performed under the minimum possible RTT value with negligible propagation delay. This condition constitutes the worst case for the PMC traffic.

The obtained results for heterogeneous case are shown in Table 7. In the presented case, two different types of flows were simultaneously submitted into the system. The number of admitted flows (4 flows) was determined by available bandwidth B_4 equals 2 Mbps. More trial cases for PMC service one can find in [6].

Table 7. PMC service: packet loss ratio (P_{loss}) characteristics for heterogeneous case. PR, SR, BSS : dual token bucket parameters.

Flows	#1/#2	#3/#4
Amount of transferred data per flow [bytes]	36200	73848
PR [Mbps]	10	10
BSS [bytes]	15000	30000
SR [kbps]	340	170
P_{loss}	0	0

Taking into account the obtained results for both homogenous and heterogeneous cases one can conclude that PMC service is able to guarantee low packet losses (in the performed tests no losses were observed). Moreover the AC algorithm designed for PMC service properly determines the maximum number of admitted flows.

4.3 Real User Trial for PCBR Service

In this section, the results of the real user listening-opinion trial with VoIP application as well as trial with using the NetQual software are presented.

4.3.1 Listening-opinion Trial

The listening-opinion trial aims at assessing QoS perceived by real users and expressed by their subjective opinion. This assessment was done by measurements of logatom (non-sense words) articulation, which gives statistical information about voice transfer quality. In other words, the probability of successful speech transfer on the basis of the perceived phonetic speech elements was calculated.

The calculated parameters were:

$$W_{n,k} = \frac{P_{n,k}}{T_k} * 100\,[\%] \quad \textbf{(a)} \qquad W_L = \frac{1}{N * K} \sum_{n=1}^{N} \sum_{k=1}^{K} W_{n,k}\ [\%] \quad \textbf{(b)} \qquad (\mathbf{1})$$

where: $W_{n,k}$: logatom articulation measured during listening logatoms from k-th test list by n-th listener, $P_{n,k}$: the number of correctly received logatoms from k-th test list by n-th listener, T_k : the number of read logatoms from k-th test list, W_L : average logatom articulation, N: the listener number, K : the number of read test list;

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

where S is the mean square deviation, which is used for calculating of logatom articulation dispersion.

The real user trial topology in Warsaw is depicted on Fig. 5. Foreground VoIP connection was established between PC1 and PC4, while background traffic was generated between PC2 – PC5 and PC3 – PC6.

The trial was repeated under different traffic conditions. In the scenario #1 (reference scenario) only single VoIP connection (tested connection) was established in the network. For the scenario #2, both tested VoIP connection as well as background traffic were handled by AQUILA Network Services (including STD). In this case foreground traffic (VoIP flow) was generated into PCBR, while background traffic to both PCBR (Poisson stream with mean rate 5.136Mbps) and to STD (Poisson stream with mean rate 6.8 Mbps) services. As a consequence the total offered traffic to the access link (between er1 and cr1 routers) was equal to 1.2 times link capacity and produced overload condition. Finally, in the scenario #3, comparing to the scenario #2, tested VoIP traffic was served by STD.

Trial procedure was the following. Five listeners and speaker, who tested VoIP application, were situated in acoustic separate rooms. The speaker was reading the prepared logatom lists, while listeners wrote down the received logatoms. The voice quality was estimated on the basis of the probability of correctly received logatoms. Before starting the experiment, the listeners passed the training with the speaker, by listening to the selected logatom lists. Then for the scenario #1, #2 and #3 listeners were listening to three logatom lists (100 logatoms each). Furthermore, for each scenario the logatom articulation ($W_{n,k}$) was calculated according to the formula (3a). Finally, average logatom articulation (W_L) and mean square deviation (S) were counted according to the formulas (3b) and (4). In addition, on the basis of W_L, the MOS (Mean Opinion Score) index was evaluated, in approximate way, according to the conversion rate given by the Polish standard, see Table 8.

Table 8. Average logatom articulation (W_L) and mean square deviation (S) calculated under different traffic conditions.

Trial scenarios	Average logatom articulation (W_L)	Mean square deviation (S)	MOS
Scenario #1: reference	74.1 %	7.1 %	4.0
Scenario #2: VoIP using PCBR	71.9 %	9.8 %	3.8
Scenario #3: VoIP using STD	46.1 %	9.6 %	1.9

On the basis of the obtained results one can conclude as follows. Measured W_L for both scenarios #1 and #2 was similar and on acceptable level for IP network (for a telephone network, with 64 kbps voice channel – MOS is 4.4 , with 16 kbps voice channel – MOS is 4.2). Results obtained in the scenario #3 were much worse comparing to the scenario #2 and evaluated quality was on unacceptable level.

In the Vienna test-bed similar intra-domain trials with German logatoms were performed, which also approved the presented results.

4.3.2 Trial with NetQual

In order to compare the real user trial measurements, which resulted by the perceived speech quality of the users further tests were performed using NetQual [10]. NetQual system enables the execution of sample wave files, which are recommended by the ETSI and used for MOS verification tests.

Therefore, a sample wave files was injected into the network on one side and recorded on the other side. Then the reference sample (reference, indicated by the white line) file and the recorded (coded, represented by the black line) file were compared and analysed by NetQual to get statistical values. Fig. 7 shows a scenario with a 100 % loaded network and a sample wave file injected in STD whereas Fig. 8 represents the same loaded network using PCBR for the sample wave file. The x-axes shows the time in seconds whereas the y-axes illustrates the signal level in dB. In Fig. 8 the similarity of the signals hardly exists, which indicates that the reference signal was highly distorted during the transmission. As a consequence, every voice conversation is impossible. On the other hand, in Fig. 8 both signals are nearly similar, which represents good quality and a MOS value of about 3.

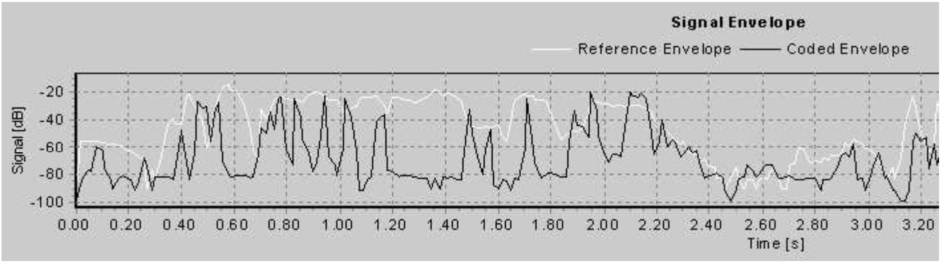

Fig. 7. Signal envelopes for STD service and 100 % background traffic.

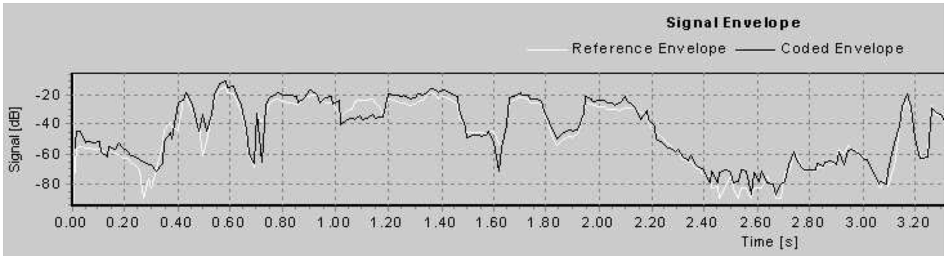

Fig. 8. Signal envelopes for PCBR service and 100 % background traffic.

Concluding, the obtained results in both trial sides confirm the expectations that VoIP needs a prioritised service in IP networks. The PCBR service in AQUILA supports VoIP in a very good way even in extremely congested traffic conditions.

5 Summary

A pilot implementation of the AQUILA solution has been evaluated during project trials. The main objectives of the trials were evaluation of the proposed Network Services for intra- and inter-domain scenarios, real user trials for different applications (voice, video and audio streaming, interactive games) as well as the trials of Resource Control performance. In this paper only selected part of the trials is presented.

The focus was set on Resource Control performance for inter-domain network topology and Network Services evaluation for intra-domain (single domain) including real user trials for the PCBR service. Main achievements of the presented trials are the following:

1. The trial confirmed that the assumed QoS objectives for PCBR, PVBR and PMC are met. It means that Admission Control mechanisms for these Network Services fulfil their role according to the expectations. *Four premium Network Services cover a wide range of applications.*
2. The results for PMM service were presented for two alternative AC algorithms. Only one of them based on advertised window setting met the QoS objectives for

homogenous and heterogeneous case. The second one based on TBM worked properly for homogenous case only. *There is a strong need for AC to produce QoS on a DiffServ aware network.*

3. The RCL performance tests show that set-up and release times for subsequent reservations are acceptable. It was also observed that AC scheme, traffic class and number of ongoing reservations have no significant impact on reservation processing times. *QoS add-ons should be manageable, scalable and well performing.*
4. The presented results from real user trials for PCBR service show that QoS perceived by real users expressed by their subjective opinion is on acceptable level taking into account obtained logatom articulation and MOS index values. *Beside all technical support user acceptance is the main focus which has to be supported by understandable operator offers.*

Detailed description of all trials performed during second phase of the AQUILA project one can find in [6].

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