

On handling streaming and elastic traffic in IP based AQUILA network: measurement results

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Abstract. The paper presents trial experiments with IP QoS network services (NS) defined and implemented in the AQUILA pilot installation. The AQUILA NSs (Premium CBR, Premium VBR, Premium Multimedia and Premium Mission Critical) provide a framework for supporting a variety of applications generating both streaming and elastic traffic. The measurement experiments confirm that AQUILA architecture differentiates the QoS offered to these NSs. The presented numerical results were obtained in the test network installed in the Polish Telecom (Warsaw) consisting of 8 Cisco routers.

Keywords: IP QoS, measurements

1 Introduction

The paper presents trial experiments with IP QoS network performed in the frame of IST AQUILA¹ project. The AQUILA network [6] is based on the Differentiated Services (DiffServ) architecture concept [1],[2], which allows us for defining a set of different network services (NS). Each NS should be dedicated for handling appropriate traffic profile (streaming or elastic) with assumed QoS guarantees. The main innovations of AQUILA include the definition of NSs with the specification of adequate traffic control mechanisms (e.g. classifiers, policers, schedulers, buffer management algorithms and admission control rules). The purpose of the reported trial experiments was to verify the concept of AQUILA architecture and

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

to check the correctness of NSs definition with associated traffic control mechanisms. The conclusions learnt from the experiments should provide an input to the next phase of designing and specification of AQUILA network.

The trial experiments presented in this paper confirm the assumptions have been made for definition of particular NSs in AQUILA network. Special focus is directed on showing differentiation between NSs serving streaming and elastic traffic.

The paper is organized as follows. In chapter 2 the basic concepts of AQUILA network are briefly outlined. The chapter 3 introduces us to the AQUILA test-bed used in the trial experiments. The trial results are presented in chapter 4. Finally, the chapter 5 concludes and summarizes the paper.

2 AQUILA network and service architecture

The AQUILA network architecture distinguishes two types of network elements (similarly as in DiffServ): the edge devices (ED) and core routers (CR). The EDs connect end users to the network and implement all per flow oriented traffic control functions e.g. traffic policing, marking etc. The CRs perform only packet forwarding according to the assigned Per Hop Behaviour (PHB). The CRs do not distinguish individual flows rather they operate on behaviour aggregates (the collections of packet that belongs to the same traffic class).

In AQUILA architecture (see Figure 1), additional layer, named Resource Control Layer (RCL), was added on the top of DiffServ enabled network.

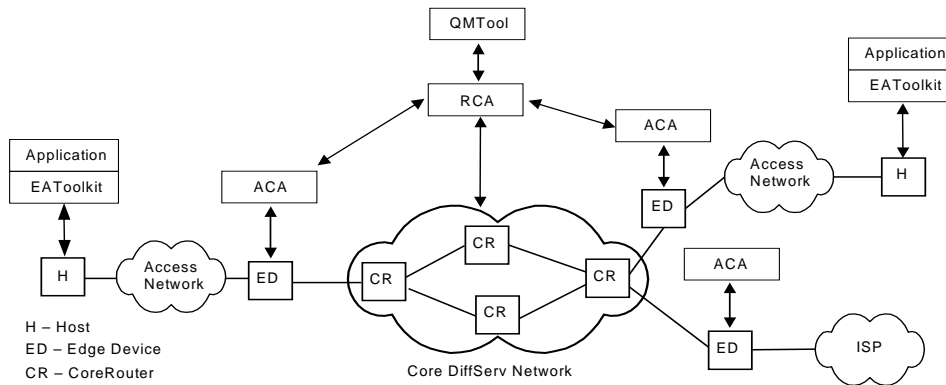


Figure 1 General AQUILA Network Architecture.

This layer is responsible for controlling and managing network resources (the RCL represents the control plane while the DiffServ network represents data pane of the AQUILA network). The RCL is subdivided into two sub-layers implemented by software-based components i.e. Resource Control Agent (RCA) and Admission Control Agents (ACA). The ACA agent is responsible for performing admission control, while the RCA manages the resource provisioning and distribution (or redistribution) between ACA agents.

For providing QoS differentiation to users traffic a set of four NSs was defined and implemented [7], [14]. The particular NSs differ with respect to QoS objectives, traffic characterization and supported traffic type (streaming or elastic). Each NS is designed for effective transmission of traffic produced by applications with similar QoS requirements (e.g. voice, video or data applications). The NSs are mapped into a set of Traffic Classes (TCL) that define appropriate traffic handling rules for meeting NS objectives, i.e. traffic conditioning mechanisms, admission control algorithms and PHB rules.

The following QoS NSs were defined in AQUILA: Premium CBR (PCBR), Premium VBR (PVBR), Premium Multimedia (PMM) and Premium Mission Critical (PMC) in addition to standard best effort Internet service. The first two services are for streaming traffic while the other are for elastic traffic.

The PCBR is intended for applications that require constant bit rate (CBR traffic) with very low packet transfer delay and packet losses e.g. voice applications. The user traffic in this case is characterized by peak bit rate, only. The next NS (PVBR) is designed for applications requiring variable bit rate (VBR traffic). This service provides similar QoS guarantees as PCBR. Typical application of this NS is video transmission. The user traffic is characterized by sustainable and peak bit rates.

The remaining NSs are intended for elastic traffic i.e. TCP-controlled. The PMM service uses single rate characterization (sustainable bit rate). This service allows for much higher burst tolerances comparing to PCBR. Therefore, the PMM service can be seen as a special case of VBR service with the peak bit rate equal to the link bit rate. This service is mainly intended for long life greedy TCP connections. On the contrary, the PMC service is designed for short life non-greedy TCP connections. In this service, the user traffic is characterized, similarly as in case of PVBR service, by the peak and sustainable bit rates.

The AQUILA NSs are mapped to appropriate traffic classes TCL (currently one NS is mapped to one traffic class). Depending on the TCL, the traffic conditioning (policing) is performed by single or dual token bucket algorithm. The TCL1 class (employed by PCBR service) uses single token bucket algorithm (peak bit rate) while the TCL2 (used by PVBR service) uses dual token algorithm (peak and sustained bit rates). In both cases the excess traffic is dropped (only conforming packets are allowed to enter the network). In case of TCL3 traffic class (used by PMM) the user traffic is characterized by single token bucket algorithm while in TCL4 (used by PMC) by dual token bucket. In both cases the excess traffic is marked as “out of the profile” and entered to the network.

After passing conditioning block, the packets are buffered in separate queues according to the traffic class they belong (the conditioning is done only in the ED). The TCL 1 and TCL 2 queues use simple drop tail queue management mechanism while TCL 3 and TCL2, since they are designed for elastic traffic, employ the WRED (Weighted Random Early Discard) algorithm to tailor the access of “in profile” and “out of profile” packets to the output link. The TCL 1 queue has non-preemptive priority over the other queues in the access to the output link (Priority Queuing scheduler - PQ). The remaining four queues (including the queue for best effort traffic) are served by WFQ (Weighted Fair Queuing) scheduler. The AQUILA scheduling algorithm is an equivalent of CBWFQ (Class Based WFQ) scheduler available on CISCO routers.

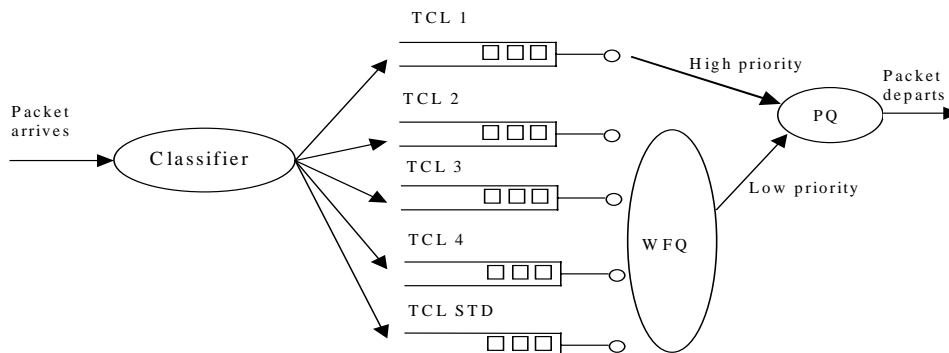


Figure 2 Routers output port architecture.

3 Description of the AQUILA testbed

The experiments were carried out in the AQUILA test-bed (see Figure 3), installed in the Polish Telecom in Warsaw.

The test-bed network consisted of 8 CISCO routers (of different types) connected in the form of the chain to emulate large number of hops. The end terminals were connected to the edge routers by Ethernet ports. The access links between the ED and the first CR had capacity of 2 Mbps. The core routers were connected by higher capacity links (10 and 155 Mbps). The following types of routers were installed in the test-bed: two edge routers - 1605 (aq1605_2) and 3640 (aq3640_4), 6 core routers - 3640 (aq3640_1, aq3640_2, aq3640_3,) and 7507 (aq7507_1, aq7507_2, aq7507_3). The core and edge routers were configured according to the AQUILA architecture design. The AQUILA software was installed on 3 workstations. Each workstation was used for different type of RCL components (ACA, RCA, EAT).

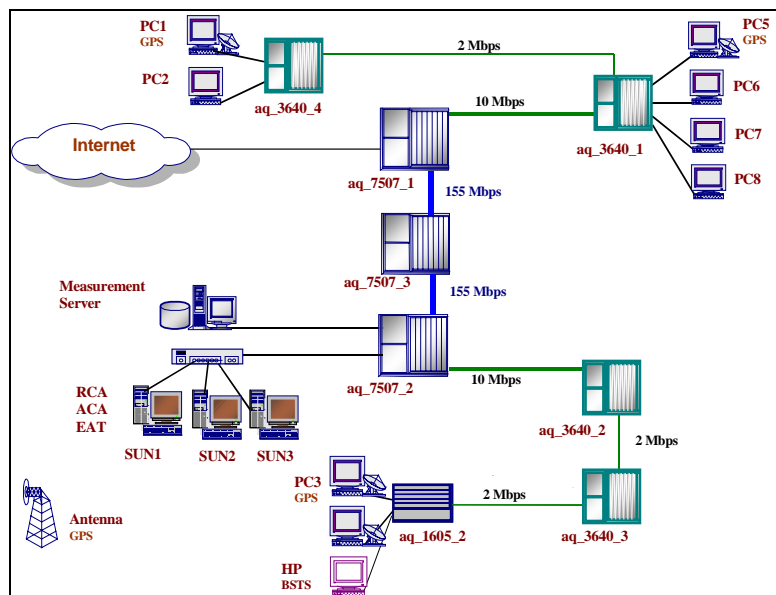


Figure 3 AQUILA test-bed configuration. PC1-8 – terminals, SUN1-3 – SUN Work Stations with implemented RCA, ACA and EAT modules, aq_1605, aq_3640, aq_7507 – CISCO routers.

4 Measurement results

4.1 Separation of streaming and elastic flows

The first set of experiments shows the rationale for defining separate NSs for traffic generated by streaming and elastic applications. The test traffic was generated between the end-stations PC4 and PC2 (see Figure 3) as the 200kbit/s constant bit rate stream controlled by UDP transport protocol. Additionally, a number of greedy TCP connections was established between the end-stations PC3 and PC1. Notice that the 2Mbps link connecting ED router to the core is the bottleneck link in the considered topology.

Two test cases were taken into account. First, the FIFO scheduling discipline was set-up in the ED. As a consequence, traffic produced by UDP and TCP connections was handled inside ED in the same way. In the second case, the PQ scheduler was selected in ED and UDP traffic was served in isolation from TCP

traffic. The highest priority was assigned for UDP traffic because of its QoS requirements. Note that it is not reasonable to assign the highest priority for greedy TCP traffic since it can lead to bandwidth starvation for the lower priority traffic. In both tested scenarios, the performances of transferring the UDP traffic were checked by measurements of the one-way packet delay and packet loss ratio QoS parameters.

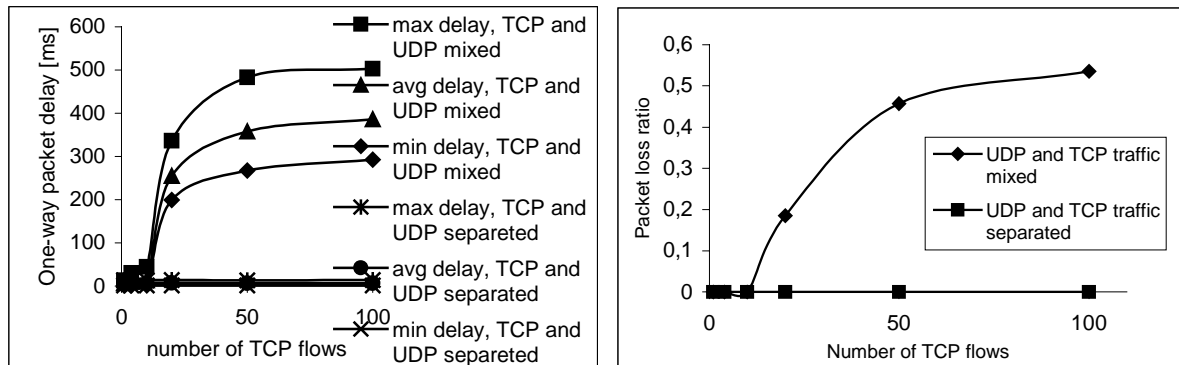


Figure 4 One-way delay and packet loss ratio of UDP packets mixed with TCP traffic and separated from TCP traffic.

The obtained results are shown on Figure 4. One can observe, that when TCP and UDP traffic is mixed together, the one-way delay and packet loss ratio of the UDP packets strongly depend on the number of active TCP connections competing for the bottleneck link capacity. This is the case now observed in IP networks, where the number of TCP connections is not limited by any admission control mechanism. When 100 TCP connections were set up in the network, the aggressive TCP congestion control scheme caused that the buffer in ED associated with the bottleneck link was heavily overloaded. Therefore, the delays experienced by tested UDP packets was about 500ms. The observed values of packet loss ratio were also considerably high (up to 50%).

This non desirable effect can be eliminated when UDP packets are served in the network in isolation, with highest assigned priority. In this case, no packet losses were observed and the maximum packet delay was close to 12ms, regardless the number of active TCP connections. This result confirms that streaming and elastic traffic should be separated in the network, otherwise the QoS guarantees for streaming traffic are hard to satisfy. In AQUILA, this requirement is met by appropriate definitions of PCBR and PVBR services for streaming traffic and PMM and PMC services for elastic traffic.

4.2 Premium CBR service

The carried out experiments corresponding to PCBR service were aimed for measuring effectiveness of CBR flows transmission. For the test scenario was assumed that the QoS parameters of carrying traffic were measured under the maximum submitted traffic allowed by the admission control of the TCL1 class. The test traffic was modelled by a Poisson stream with constant packet lengths. Notice that such traffic represents the worst case of the superposition of large number of CBR streams. To take into account the impact of other classes on the TCL1 packets (residual transmission time of low priority packets) the background traffic was also added to the STD class. The background traffic filled the rest of link capacity not dedicated to TCL1.

In the following experiments, 200 kbps of the access link capacity was reserved for TCL1. Furthermore, the TCL1 queues in the routers were set to 5 packets to guarantee low packet delay. The performance of TCL1 was validated assuming target packet loss ratio (Ploss) equal 10^{-2} . According to the

specified admission control algorithm, the maximum admissible load in this case (acc. to the M/D/1 system analysis [4]) is $r=0.685$, what is equivalent to 137 kbps.

The foreground traffic was transmitted between PC1 and PC3 terminals (see Figure 3) while the background traffic was generated only to the access link. The background traffic was created as a mix of packets with different lengths: 7% with 44 bytes, 21% with 256 bytes and 72% with 1280 bytes. Both foreground and background traffic was transmitted using UDP protocol.

The characteristic of packet loss rate as a function of the TCL1 traffic volume is presented on Figure 5.

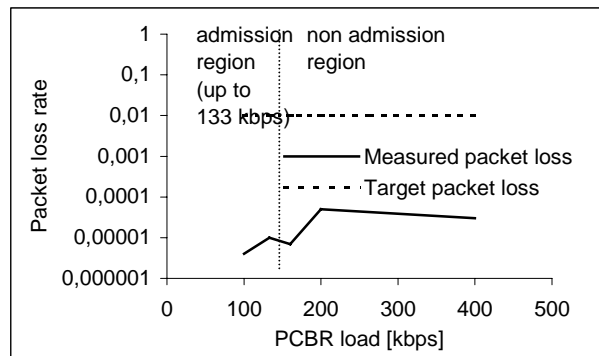


Figure 5 Packet loss rate vs. TCL 1 traffic load.

One can observe that the measured value of packet loss rate are in the range of 10^{-5} and they are significantly below the assumed target value 10^{-2} even for the load above the admission region (133 kbps). This is rather expected result since the TCL1 traffic is served with higher priority with the effective service rate of 2 Mbps (instead of 200 kbps as was assumed for the admission control algorithm). Anyway, increasing TCL1 traffic significantly above the assumed limit (133 kbps) can degrade the quality experienced by packets carried in low priority classes (e.g. TCL2). The recommended admissible load of TCL1 traffic is approximately 10 % of total link capacity.

The characteristics of one-way packet delay as a function of TCL1 packet length are depicted of Figure 6. These curves were measured assuming that Poisson traffic with the rate equal to 133 kbps (up to admission limit) was submitted to TCL1. The background traffic of ON/OFF type was submitted independently to each intermediate link (see Figure 4), with the peak bit rate equal to the appropriate link rate. The maximum observed delay was below 50 ms. This value is acceptable for most voice applications, that tolerate delay in the order of 150 ms (with codec and packetization delay).

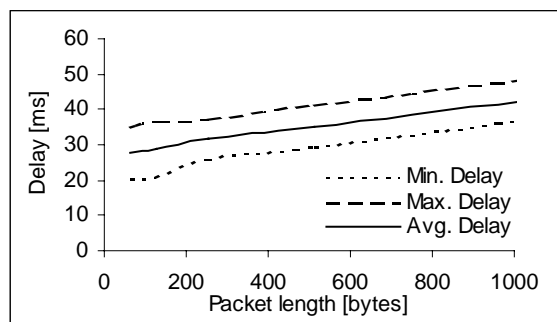


Figure 6 One-way delay vs. TCL 1 packet length.

4.3 Premium VBR service

The PVBR service was designed for real time applications producing variable bit rate traffic. The QoS objectives for this service are low packet transfer delay (≤ 150 ms) and low packet loss ratio ($\leq 10^{-4}$). In the followed experiments, the target packet loss ratio was fixed to 10^{-2} . The presented measurement experiments correspond to validation of packet loss ratio as well as end-to-end delay measured for artificial flows. Traffic served by TCL2 was generated between PC3 and PC1 while traffic served by TCL1, TCL3, TCL4, and TCL5 was generated between HP BSTS and aq_3640_3 router. The bandwidth dedicated for TCL2 class (on 2 Mbps access link) was 300 kbps. The following bandwidths were allocated to the other traffic class: TCL1: 200 kbps, TCL3: 600 kbps, TCL4: 100 kbps, and TCL5: 800 kbps. Output buffer in ED dedicated for TCL2 was assumed to be 5 packets long. The aggregated traffic of TCL2 class was assumed to be superposition of ON/OFF sources and was modelled by Markov Modulated Deterministic Process (foreground traffic). Flows of constant bit rate sufficient to load the network resources dedicated to the other traffic classes were used as background traffic flows.

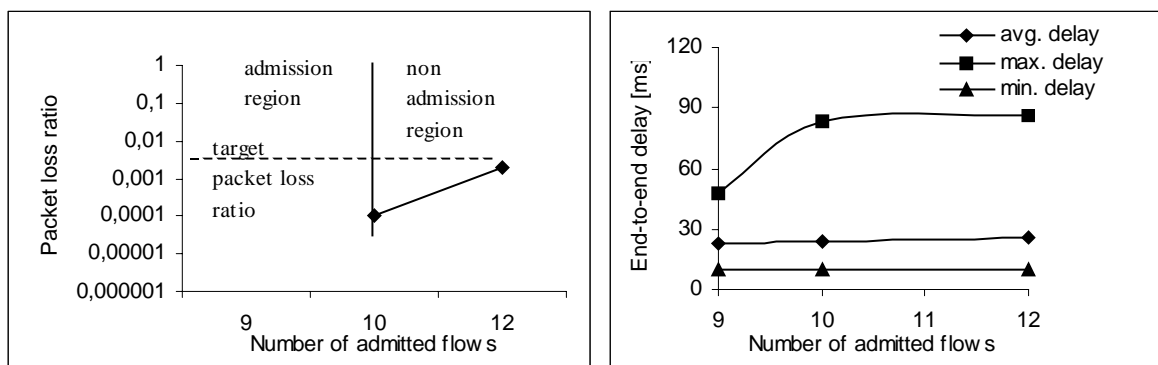


Figure 7 Packet loss ratio vs. number of admitted flows.

In the first experiment the packet loss ratio and the end-to-end packet delay were obtained as a function of the number of admitted flows (see Figure 7). In this case each ON/OFF flow was described by the following parameters: PBR=32 kbps, SBR=16 kbps BSS=15000 bytes, packet size=500 bytes. Effective bandwidth for each flow was equal to 27.29 kbps. Number of admitted flows, according to the AC algorithm, was 10. Values of traffic descriptors used in the following experiments correspond to the traffic generated by a voice applications.

The second experiment was done for the superposition of 30 ON/OFF flows served by TCL2 (to achieve greater multiplexing gain). Each ON/OFF flow was characterised by: PBR=18.5 kbps, SBR=5.6 kbps, BSS=526 bytes, and packet size=256 bytes. Effective bandwidth of each flow was 9.97 kbps. The sum of the peak bit rates of 30 flows was 555 kbps while the sum of the effective bandwidths over all flows was 299.1 kbps. The obtained results are presented in the table bellow. The measured values of QoS parameters satisfy requirements and objective of TCL2. The values of packet loss ratio ($10^{-5} - 10^{-3}$) are smaller than the assumed target value (10^{-2}).

Table 1

The measured values of QoS parameters

Min. Delay [ms]	Max. Delay [ms]	Avg. Delay [ms]	Packet loss ratio
15	44	26	10^{-5}

Some trials were also carried out with real video application (e.g. NetMeeting). Unfortunately, it appeared that it is very difficult to tune traffic descriptors for real application, like NetMeeting. This suggest that traffic declarations should be limited to the peak rate while admission control should get additional information about carried traffic from measurements.

4.4 Premium MultiMedia

The PMM service was mainly designed for effective support of greedy TCP-controlled flows. The objective of this service is to guarantee a minimum throughput to the TCP flows. The measurement results presented below were obtained assuming that the traffic generated by a number of TCP greedy sources (between PC1 and PC3) was submitted to the TCL3 class while the CBR background traffic was submitted to other NSs with the maximum possible rates (according to the assigned capacity for given service). In this way the capacity available for the TCP connections was limited to the capacity allocated to TCL3 class. In the considered case this capacity was equal to 600 kbps with target utilisation factor set to 0.9 (this parameter represents target utilisation for “in-profile” packets) what gives 540 kbps of available capacity for setting up flows. Notice that the “out-of-profile” packets in case of TCL3 (and also TCL4) are not dropped. Consequently, the considered greedy TCP flows can achieve higher rate than requested by the SBR parameters.

The goodput characteristics of 4 TCP flows, with different declared SBR values, as a function of best effort traffic volume are depicted on Figure 8. The assigned SBR values were as follows: 135, 135, 70 and 200 kbps. One can observe that the available capacity for PMM service is effectively used by the considered TCP connections. When the background traffic exceeds a certain threshold (in this case 800 kbps) the available capacity for TCL3 is limited to assumed AC limit (600 kbps). This capacity is shared by TCP flows roughly in proportion to their declared SBR rates. For example, the connections with SBR=200 gets 206 kbps while the connection with SBR=70 gets only 85 kbps.

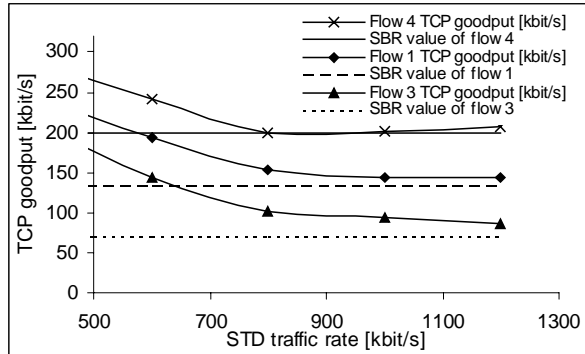


Figure 8 TCP goodput in PMM service vs. STD traffic rate.

Figure 9 shows the proportion of packets, marked as “in-profile” and “out-of-profile”, contributing to the throughput of 2 exemplary TCP connections. The traffic submitted into the network in excess of the traffic profile requested in the reservation is marked as “out-of-profile”. In the underload network conditions, the “out-of-profile” traffic obtains the capacity unused by the other NSs, but in time of network congestion, throughput of the TCP flow in PMM service is guaranteed roughly up to the requested SBR value.

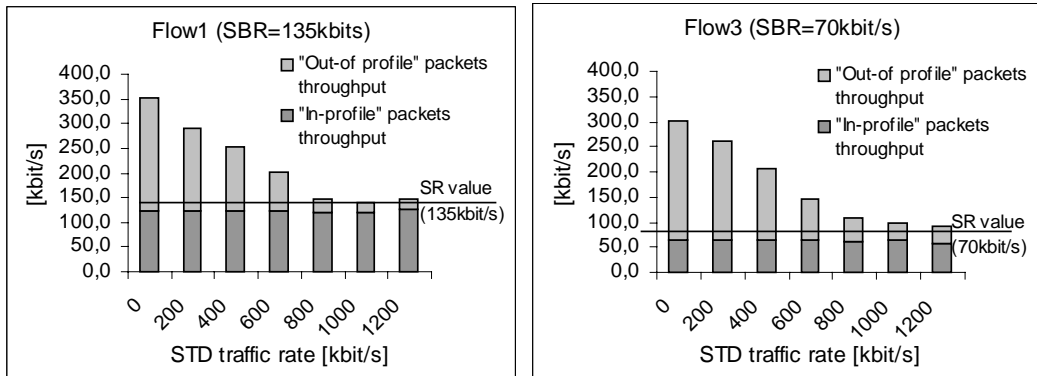


Figure 9 Throughput of “in-profile” and “out-of-profile” packet streams within flow 1 and flow3.

By applying the WRED mechanism, one can expect that the “in-profile” packet will obtain better service, than “out of profile” packets. In AQUILA, WRED mechanism controls the access of “in-profile” and “out-of-profile” packets to the TCL3 buffer. When the average queue size exceeds a predefined threshold, incoming packets can be dropped with a certain probability. By setting different threshold values for “in” and “out” packets, one can differentiate the loss ratio of packets marked as “in” and “out of profile”. The Figure 10 shows the received packet loss characteristic for “in” and “out” packets as a function of number of TCP connections. As it was expected, the packets conforming to the assumed traffic profile are delivered by the network with a significantly higher probability than the non-conforming packets.

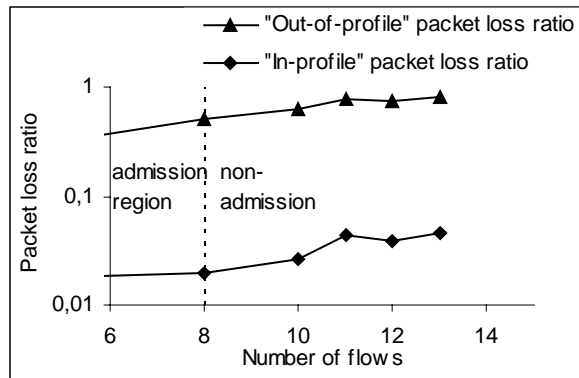


Figure 10 “In-profile” and “out-of-profile” packet loss ratio vs. number of TCP flows in PMM service.

Note that the proper configuration of WRED mechanism is crucial for flow differentiation inside the TCL3 class with respect to the guaranteed throughput. Since there is high probability that the “out of profile” packets will be lost during network congestion, the TCP source sending “out-of-profile” traffic will likely be forced to decrease its sending rate. On the other hand, when the source transmits only conforming traffic, its packet loss rate will be much lower than in the previous case. This TCP source will not be forced to decrease its sending rate. Consequently, the average throughput of each PMM flow will be close to the SBR declaration.

4.5 Premium MissionCritical service

The PMC service was designed for short-lived non-greedy TCP flows, typically generated by transaction-oriented applications, e.g. database queries. The objective of this service is to provide high guarantee of packet delivery (low packet loss rate and relatively low packet transfer delay). In the following experiment, the test traffic was produced non-greedy TCP flows, transmitted between end-stations PC3 and PC1 (additionally for comparison this experiment was repeated with greedy TCP flows). Similarly as in the PMM service tests, the background traffic of CBR type was submitted to other NSs with the maximum possible rate. The capacity available for the tested TCL4 class was equal to 100 kbit/s.

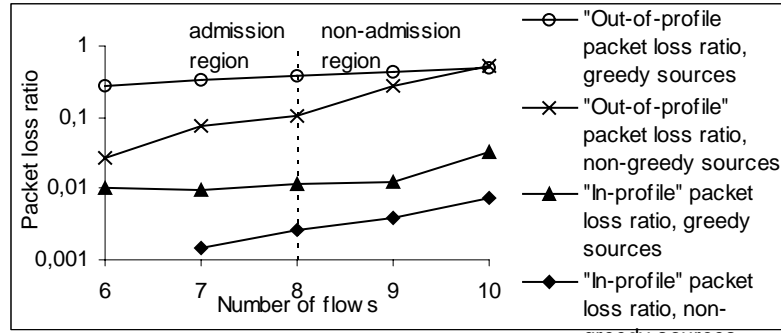


Figure 11 “In-profile” and “Out-of-profile” packet loss ratio vs. number of greedy and non-greedy TCP flows in PMC service.

Figure 11 shows characteristic of packet loss ratio for “in-profile” and “out-of-profile” traffic as a function of number of running TCP connections (greedy or non-greedy). As one could expect, in case of greedy TCP sources the packet loss ratio is significantly higher for both “in” and “out” packets. On the other hand, the observed packet loss ratio for non-greedy TCP flows is greater than the target value (fixed to 10^{-6}). Therefore, some modifications of queue management algorithm are required.

5 Conclusions

The measurement experiments presented in the paper confirm that IP network with appropriate traffic handling mechanisms is capable to offer QoS guarantees with dynamic reservation scheme. The experiments carried out in AQUILA trial demonstrated the need for separation of streaming and elastic traffic. Currently, AQUILA project defines 4 QoS NSs with different QoS objectives. Such approach allows for efficient support of wide range of applications with different requirements. The obtained measurement results confirm that this solution can be implemented in practice, and that the AQUILA NSs generally provide the assumed QoS guarantees.

To guarantee QoS objectives appropriate AC algorithms should be employed. AQUILA project shows that the declaration based AC algorithms could guarantee the QoS requirements on the per flow basis in the IP network based on the DiffServ architecture. On the other hand, AQUILA AC algorithms assume the worst-case traffic patterns that are rarely met in practice. This sometimes can lead to low network resource utilisation. Future work focus on adding some measurements in the resource control algorithm for improving network utilisation.

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