Distributed Measurement and Monitoring in IP Networks
(CMToolset for AQUILA DiffServ)

Ulrich Hofmann[1]
Dept. of Telecommunications, Salzburg Polytechnical University
A-5020 Salzburg, Austria
ulrich.hofmann@fh-sbg.ac.at

Ilka Milouchewa[1]
Salzburg Research
A-5020 Salzburg, Austria
ilka.milouchewa@salzburgresearch.at

ABSTRACT

The following paper is focussed on the CM Toolset distributed measurement toolkit and its use in AQUILA European IST project for scalable end-to-end QoS based networking. CM Toolset is integrated in AQUILA intra-domain QoS measurement architecture including QoS database and distributed measurement agents, traffic flow generation and active probing tools as well as router performance monitoring.
QoS analysis for single and aggregated traffic flows as well as measurement based admission control strategies using CM Toolset are discussed. Intra-domain QoS monitoring scenarios including CM Toolset as measurement architecture for AQUILA DiffServ core network environment are overviewed.
CM Toolset measurement concepts are compared with current measurement architectures and research.
Perspectives for extension of CM Toolset measurement architecture for inter-domain QoS monitoring are outlined.

Keywords: Distributed measurement architecture, Intra- / Inter-domain QoS monitoring, Measurement based Admission Control

1. INTRODUCTION

A lot of Internet architectures with specific Service Level Agreements (SLAs) and Quality of Service (QoS) specifications are proposed and experimentally exploited in different European IST projects – AQUILA, TEQUILA, CADENUS, QOSIPS.
Intra-domain QoS monitoring using dedicated measurement facilities to study the domain specific provision of defined SLAs, QoS and network service specifications is required for research, development and operation of such QoS based architectures.
In order to study the QoS provision in the context of resource and admission control of QoS based architectures, different toolkits based on passive and active measurement facilities are used [1]. Measurement tools are aimed to provide end-to-end QoS and traffic analysis as well as verification of the QoS provision according the specific SLAs of the architecture.
The following paper is focussed on design concepts of Distributed Measurement Architecture (DMA) based on CM Toolset used for scalable intra-domain QoS monitoring in the framework of AQUILA project. AQUILA DMA consists of QoS measurement tools and methodologies for passive and active QoS monitoring including distributed agents, QoS database, management stations for QoS aggregation and correlation, generation and emulation of application traffic classes.
The primary focus is CM Toolset designed for QoS analysis of emulated multimedia traffic flows and its interaction with other tools building integrated measurement architecture.
Passive and active tool interaction for intra-domain QoS monitoring of AQUILA traffic classes is based on time continuous measurement and analysis of related QoS metrics with appropriate storage in an integrated QoS data base.
Measurement based admission control strategies for multimedia traffic flows in the context of AQUILA scalable QoS based architecture are outlined.
Scenarios for intra-domain QoS analysis in the specific environment of the AQUILA QoS using the integrated measurement architecture are shown.
The distributed measurement concepts of CM Toolset architecture are compared with the current state-of-the-art of research and measurement architectures.
In conclusion, the experiences with the CM toolkit in the intra-domain QoS monitoring are summarised. Further work on the development of advanced measurement architecture for inter-domain QoS monitoring is proposed. Differences between intra- and inter- domain QoS monitoring are shown. Requirements for inter-domain measurement infrastructure are overviewed.

2. DISTRIBUTED MEASUREMENT ARCHITECTURE – INTEGRATION OF TOOLS

AQUILA is a scalable architecture for end-to-end QoS provision in Internet which goal is the implementation of network services, resource reservation and admission control mechanisms for QoS based applications using DiffServ networking environment.
AQUILA network services are seen as products for which customers have to establish contracts, so called Service Level Agreements (SLAs). The contract based on the selected network service depends on application QoS requirements, type of reservation requests, periods and scheduling of reservation time, etc. Different types of network services such as Premium CBR, Premium VBR, Premium MultiMedia, Premium Mission Critical are defined for mapping of AQUILA QoS based applications into traffic classes.
AQUILA admission control differentiates different types of traffic classes characterised with specific procedures for QoS mapping, parameter description, resource assignments, policing and processing of traffic flows and their aggregation [2]. Using traffic descriptions (such as single rate, dual token bucket, single token bucket, sliding window, etc), the reservation requests are computed, accepted or denied by admission control procedures.
The measurement tools in AQUILA are used to analyse the impact of domain specific network services and traffic classes on end-to-end QoS provision of applications. Measurement based QoS analysis of end-to-end behaviour of traffic classes includes active network probing, routing information collection and emulated traffic generation.

[1]The authors are partially funded by the IST project AQUILA

AQUILA measurement architecture is used for the following goals:

- QoS evaluation and validation of AQUILA network service and traffic class concept. This includes obtaining the realised quantitative values for QoS parameters of single and aggregated traffic flows consisting of real applications or emulation traffic using the network services and traffic classes defined in AQUILA. The effectiveness of AQUILA resource and admission control service provisioning is evaluated by the number and class of accepted flows, under- and over-provisioning of QoS for specific traffic class flows, effective bandwidth estimation and measurement based admission control strategies.

- Support network operation and resource control. This implies that the measurement QoS database and performance analysis capabilities are used immediately by the network operator to maintain and enhance the network operation ("online analysis"). The measurements are required to obtain performance information about networks paths (probing) and network elements (monitoring).

Figure 1 illustrates the concepts of AQUILA QoS based networking infrastructure and interactions of QoS processing components with the measurement architecture.
Distributed active and passive measurement tools are interacting via common QoS measurement database:

- **CM Toolset including distributed agents for QoS analysis of end-to-end single and aggregated flows**. Its purpose is the generation of synthetic traffic emulating typical end-to-end applications (e.g. VoIP, streaming audio, streaming video, WEB access, etc.). Passive measurements of traffic flows of AQUILA applications are used to obtain traces for traffic generation and to derive traffic models for specific application classes and map them to AQUILA traffic class concept (Premium CBR,... etc).

- **Active network probing agents** for obtaining path performance metrics (e.g. packet delay or packet loss as defined by IPPM [10], [22]) and performance metrics concerning intra-domain QoS monitoring of path reachability / connectivity. Performance characteristics of network paths describing QoS characteristics of traffic class forewarding are obtained and validated.

- **Router QoS monitoring** for passive collecting of QoS information characterising traffic classes and QoS of core and edge router, mapping of router QoS mechanisms. Its aim is optimisation of QoS based core routing system.

Integrated QoS measurement database is used for storage of intra-domain QoS metrics values of different layers as well as resource and admission control information for end-to-end QoS evaluation and validation. The integration of passive and active QoS measurements in the data base performed by different tools is based on the time stamping approach. The correlation of the measured QoS at different layers using specific tools is provided by their storage in the data base using common concept for recording measurements identified by the measurement scenario, timestamp of measurement and traffic flow identification.
QoS database can also be accessed directly by resource and admission control, which may use the stored QoS information for obtaining of actual QoS characteristics of applications and network connections and better distribution of resources within individual resource pools.
Figure 2 illustrates components of AQUILA DMA and their relationship to resource and admission control layer.

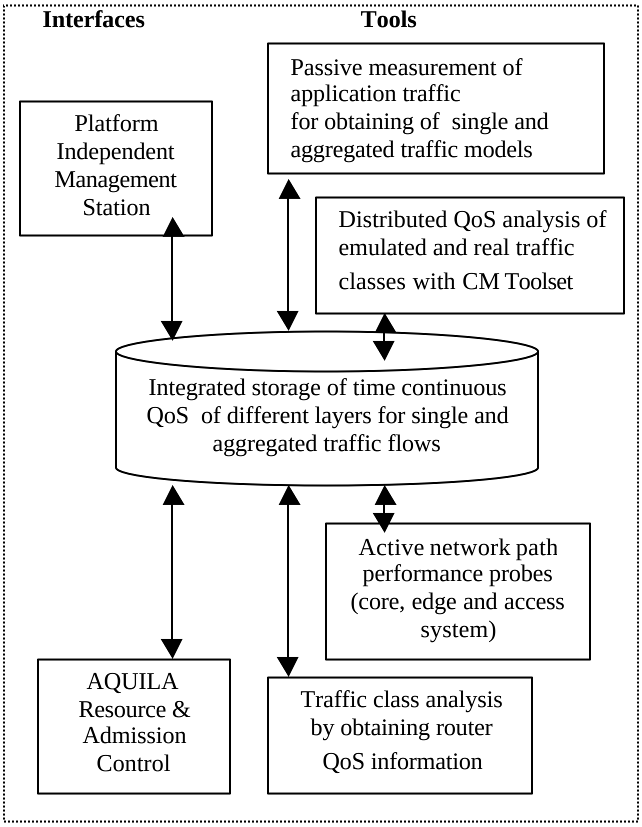

Fig. 2: AQUILA Integrated Measurement Architecture

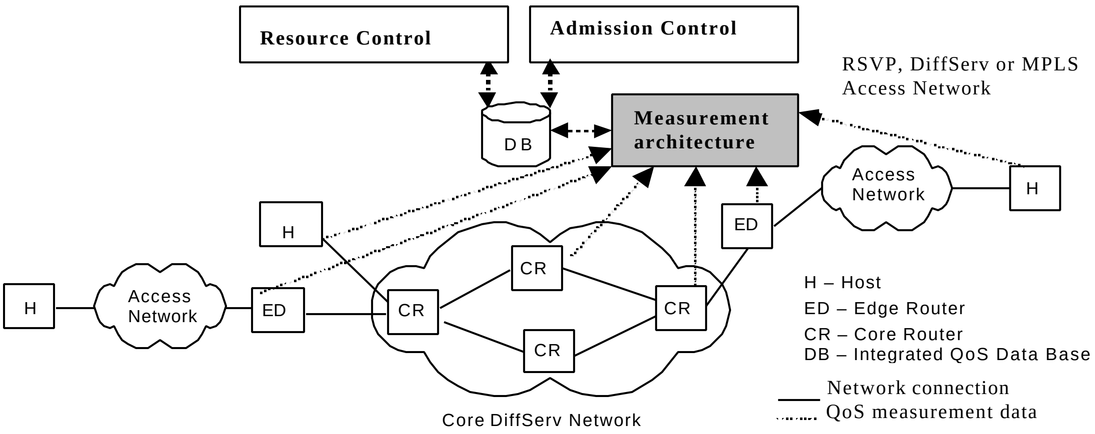

Fig. 1: AQUILA QoS networking infrastructure with integrated measurement architecture

The CM Toolset facilities are modular designed to reach the following goals:

- to emulate end-user applications and to characterise the mapping of their end-to-end QoS requirements into network services using performance metrics for generated single and aggregated flows.
- to maintain and store measurement information of different types (end-to-end performance, path metrics, network traffic, etc.) in order to be used for a mapping of the user end-to-end QoS to the network service requirements
- to offer online access to measurement information, e.g. to enhance the network operation by the use of path performance metrics in network elements.
- to provide time continuous performance analysis of measured end-to-end QoS with their mappings to traffic classes and resource reservations in order to enhance SLAs and to predict the performance of the network services.

CM Toolset uses options for selection of the measured QoS parameters of the flows and their management intervals. The interface to other tools for QoS monitoring of the DMA and to the QoS database is given by management intervals. The time interval for the online QoS monitoring is described by aggregation time. QoS measurement scenarios are specified for different kinds of QoS analysis and monitoring:

- Dynamic online QoS monitoring
- Result QoS analysis of traffic flow.

CM Toolset QoS monitoring results are stored per traffic flow in the integrated data base which allows comparison of the end-to-end traffic flow QoS with the flow QoS at specific router and network paths. On this way, dependencies between different intra-domain QoS measurements can be obtained, as for instance the impact of router packet loss and path throughput end-to-end delay. Using dedicated measurement scenarios, QoS of different traffic flows can be related and the impact of core and edge router OoS on the intre-domain QoS provision can be observed.
Fig. 3 shows the off-line analysis of the one-way-delay of udp-packets for an overloaded best effort channel (3 udp-flows, 1 tcp flow) between GPS-synchronised end systems [3]. The testbed consists of cisco routers and CM Toolset load generator.
Typical applications for VoIP service classes like PCBR [2] were emulated by on-off load generators.

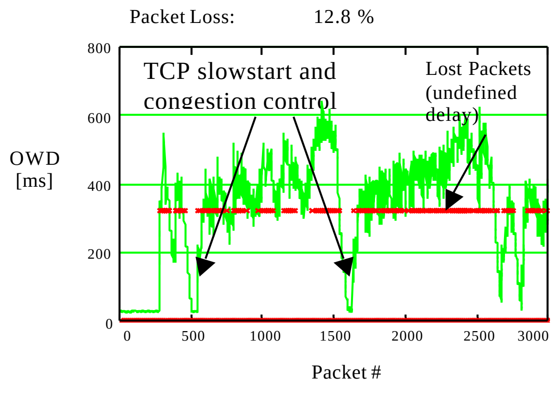

Fig. 3 : One Way Delay for udp multiplexed with tcp

The measured QoS in Fig.3 shows the need for differentiation (between the udp and tcp flows) and usage parameter control. The DiffServ usage parameter control classifies the incoming packets as “in-profile” or “out_of_profile”. AQUILA traffic measurement is extended with traffic class filtering to measure QoS values (loss, delay) for different packet types. The measured QoS were better than predicted by the models. This indicates, that the models are conservative and an adaptive measurement based admission control can be used for a fine tuning.

3. MEASUREMENT BASED ADMISSION CONTROL

The online processing of measured QoS data can be used to :

- get a better knowledge about the actual traffic profile of the (aggregated)flows
- calculate the delivered QoS in order to adapt the system parameters (add resources, reject new flows,...)

The measurements can be done directly by measuring the QoS values which are of interest. But the direct measurements are difficult for QoS paramaters which generate rare events, e.g. the packet loss process. Typical target values are $10^{-3}...10^{-7}$. Maintaining a loss rate of 10–7 with 95% confidence interval requires 154 million packets, in case of a
flow sending rate 3 Mbit/s it takes 616 000 s = 7 days.
Some authors propose to measure other values, e.g. buffer occupancy [4] which are correlated with the loss rate to get informations about the loss rate. Most of the models use the effective bandwidth formulas to estimate the loss probability and the number of flows, which can be admitted.

Using CM Toolset measurement tool, the following parameters can be used for online estimation of QoS values (loss, delay jitter := queuing delay):

- active probing flows
- router monitoring per time interval T
- loss statistics per aggregate
- mean load ρ

Fig.4 shows the general approach for measurement based admission control (MBAC).
An initial admission algorithm calculates the number of flows N, which can be admitted. The effective bandwidth formula for a large number of flows and a bufferless system is

$\mu_i + (-2 \log p)^{½} \sigma_i < C$; $p = P(\Sigma$actual rate $> C)$ (1)

where μ_i, σ_i are the means, variances of the flow rates. By measuring μ the maximum number of flows N can be adjusted.
In the given MBAC context:

(a) short term peaks (< 1s) are shaped by the smoothing curve (b)
(b) long term changes are monitored
(c) after crossing an threshold “target rate” from Eq. (1)
N:= N+1 for (b) < threshold
N:= N-1 for (b) > threshold
(d). flows leave the network ==> load decreases

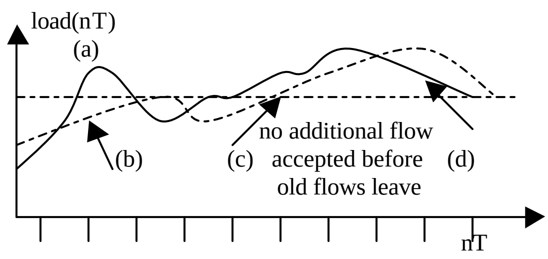

Fig.4 : Short and long term measurements

The short term peaks show the results of arriving bursty flows at the same time.
The smoothing/filtering of such performance degradations can be accepted, if the QoS must not be guaranteed per time slot T. Otherwise the smoothing algorithm must be more dynamically. On the other side the measurement interval T must be larger than the interval for short term rate fluctuations. Improved versions of MBAC include prediction models.
[5] gives an overview about the different MBAC algorithms with the following conclusions:

- all different MBAC algorithms have the same performance (the difference is smaller than the statistical uncertainty)

- MBAC solves the problem of long range dependency
- MBAC admit small flows to fill the link capacity; large flows and flows over long path are penalized
- the best way to use MBAC in operational networks should be to enable the operators to monitor the network performance in order to learn appropriate parameter setting (e.g. smoothing parameter)

AQUILA DMA concept offers these functions. The operator can install the different admission policies, the measurements, e.g. rate(nT), were stored in the QoS database. Then the operator starts the load generation facilities of CM Toolset which emulate the main applications in his network.
After the experiment the realised end-to-end QoS can be compared with the target and the consumed resources. Repeating these steps will result in a MBAC which is the best for this specific network.

4. USE OF CM TOOLSET FOR INTRA-DOMAIN QOS MONITORING

AQUILA intra-domain QoS analysis and monitoring is aimed at collection of QoS measurement information characterising QoS properties of traffic flows and their aggregation in different elements of the specific ISP (Internet Service Provider) architecture (i.e. core, ingress / egress edge router and access networks). QoS information measured at different layers and elements of the domain architecture is collected, aggregated and correlated in order to improve the mechanisms for provision of the specific SLAs, policies and network services of the domain.
The intra-domain QoS monitoring is dependent on the kind of application QoS, SLAs, policies, resource and admission control strategies defined for the specific domain. Aggregation of traffic flows is studied for the purpose of optimisation of admission control strategies and optimal core / ingress / eggress routing for the traffic classes defined in the domain.
Some key points of the intra-domain QoS monitoring are:

- Evaluation and validation of core routing system of the administrative domain, selection of core routing paths and router assignment for different kinds of traffic flows.
- Mapping of access network QoS mechanisms to ISP specific QoS based core networking and policies. In AQUILA, the core system QoS concept is based on the DiffServ QoS approach, however the accessing system can be based on different QoS mechanisms such as RSVP (requiring mapping of IntServ connection oriented QoS mechanisms to the DiffServ service classes), MPLS (strategies for MPLS label assignment to DiffServ classes).

To collect domain specific QoS information of single and aggregated traffic flows, the distributed active probing and end-to-end QoS measurement of CM Toolset is used in different scenarios (figure 5):

- **End-to-end QoS monitoring of traffic classes.** CM Toolset agents are installed at end-to-end systems connected directly or via access networks to the core network. The goal is to verify, whether the traffic classes, which are defined for specific network services are mapping optimal the end-to-end QoS requirements of applications. Obtained QoS metrics per traffic flow like throughput and end-to-end delay are compared with the target QoS parameters.
- **Core network path QoS optimisation.** The QoS properties of traffic flows are observed in the core DiffServ networks for the purpose of optimal routing of aggregated traffic and efficient resource assignment per traffic classes. CM Toolset distributed agents are installed at end-systems which are directly attached to core router. Core router passive QoS monitoring (workload and delay per traffic class) interacting with CM Toolset network active probing collects statistics for optimisation of resource and admission control within the core network.
- **Ingress / Eggress Router System QOS Monitoring.** The purpose is to evaluate and validate intra-domain admission control strategies in AQUILA at the ingress and egress routing system. This is done by stepwise increase of the number of traffic flows between the edge router and the core network considering different policies for selection of traffic classes. CM Toolset synthetic load generator is used to measure the performance metrics describing the QoS properties for each admitted flow and assigned traffic class. The different QoS values of traffic flows are correlated with QoS collected for ingress and egress router to optimise the edge / core OoS mapping. DiffServ networking using bandwidth broker for configuration of QoS parameter of egress / ingress router interacts with DMA to select the optimal QoS parameters of the core and edge routing system.

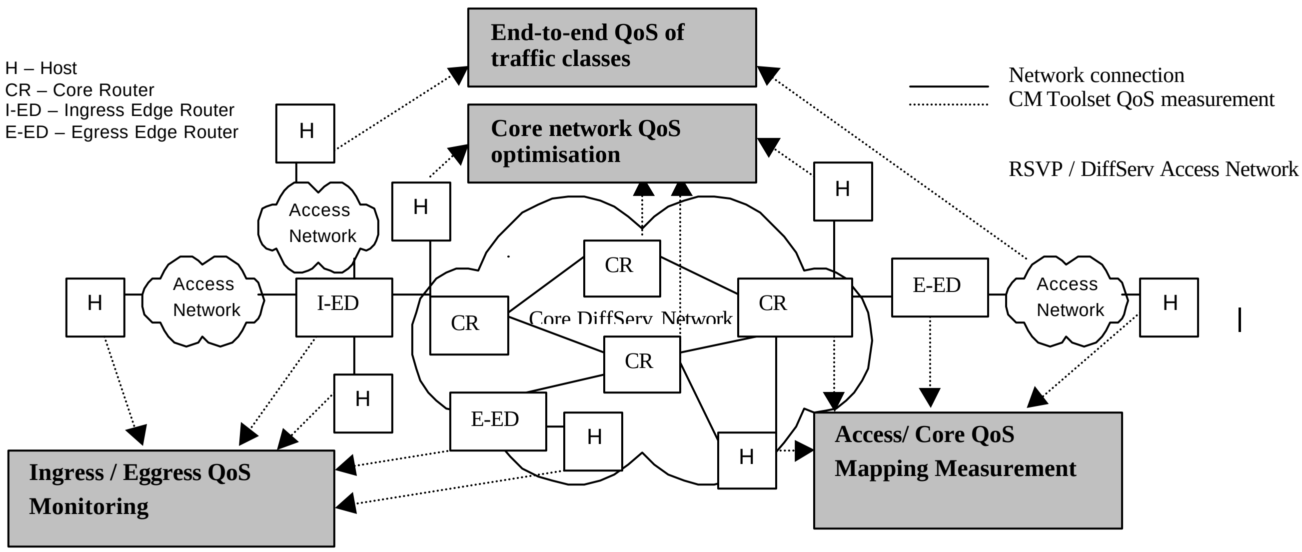

Fig. 5: Scenarios for intra-domain QoS monitoring using CM Toolset in AQUILA

- **Tuning of the QoS mapping between access and core networks.** There are different policies to map QoS of access networks to core QoS mechanisms which are specific for the traffic class. To validate DiffServ core network operation for different access network QoS concepts, CM Toolset agents are installed at hosts connected to access and core networks. In addition, core and access router QoS collection is used for a fine tuning of the network QoS provision and mapping for differentiated traffic classes.

5. RELATED RESEARCH AND DEVELOPMENT

Much work has already occurred within the ITU [13] and IETF IPPM working group, which have a direct bearing on the development of performance measurement methodology and metrics in the Internet addressed in RFCs [20], [25] [28], [22], [23] and Internet Drafts [10], [11], [12], [8].

Main interest of today developments on measurement architectures is focussed on network performance monitoring (especially path performance analysis) and scalable network wide area measurement infrastructure [1], [17], [15], [16], [26]. Some design considerations of CM Toolset are found in these measurement architectures and can be compared for further enhancements.

Surveyor [14] is based on network monitoring using active probes, provision of long-term performance data, measurement of unidirectional properties, usage of dedicated machines for accurate measurements and database. CM Toolset has similar concepts which are extended with features for integrated storage of QoS information for single and aggregated traffic flows in QoS database. The common QoS database is used also by other measurement tools of AQUILA DMA for storage of their specific measurements of flow QoS parameters.

The interpretation and analysis of collected data by Surveyor [14] and AMP [16] is done through post-analysis. These tools are primarily used for network research and planning where CM Toolset design due to time continuous storage of QoS information related to the specific traffic classes and QoS concepts defined for AQUILA is intended to support the actual network operation and research.

Some similarities of CM Toolset to NIMI [17] is the scheduling mechanism for the measurements to definite times and the scalability concept. The usage of the measurement systems is different. While NIMI is rather a command and control system for managing measurement tools, CM Toolset measurement architecture is designed to control specific measurement agents and interacts with other passive and active monitoring tools of AQUILA architecture using a common measurement database.

The automation of QoS performance analysis is another design approach of CM Toolset which is also found in network operation center discussed in [27]. This center is based on the concept of a common database management system (DBMS) with additional properties to automate performance analysis in real-time mode. The CM Toolset is based currently on the automation of QoS analysis for active measurements of single and aggregated traffic flows of different classes. Automation of integrated QoS analysis of passive and active QoS measurements of traffic flows performed by different tools of AQUILA DMA is work in progress.

CAIDA measurement environment [7], [1] uses the skitter tool [24] for integrated collection and evaluation of network path monitoring and management information. The network monitoring in CAIDA is combined with workload measurements and traffic flow matrices (tables which store how much traffic is flowing from a given source to a destination network). This approach is also considered in AQUILA measurement architecture considering the interactions of active and passive measurements. In AQUILA, the traffic measurement is extended with traffic class filtering.

The skitter tool [24] is not only used for gathering QoS analysis data in specific domain which is the main usage area of CM Toolset, but also for dynamic monitoring of reachability and connectivity. Further techniques for monitoring of reachability / connectivity are considered in [19] where synthesising wide area fault information and location of point of error by monitoring ICMP messages are proposed.

AQUILA performance monitoring methodology using active and passive measurements is similar to the NLANR Network Analysis Infrastructure – NAI [18]. NAI also combines active and passive measurements for the purpose of network path monitoring:

- active measurements with recording of metrics (Active Monitoring Project [18] and Internet Performance Measurement Protocol [9]),
- passive measurement where data being transmitted over a network path is captured and analysed,
- control flow monitoring (SNMP and router data collection).

Accuracy of measurement methodology is a topic, which is addressed by all kinds of measurement architectures. The assessment of performance metrics using passive and active measurements is discussed in [20]. This approach is also considered in AQUILA DMA using common QoS database for storing of related passive and active QoS measurement information of different tools for QoS aggregation.

6. CONCLUSIONS AND FURTHER RESEARCH TOWARDS INTER-DOMAIN QOS MONITORING

CM Toolset active measurement facilities for generation of emulated traffic flows of different classes combined with passive monitoring are used in AQUILA DMA for intra-domain QoS monitoring. As result QoS properties of emulated traffic flows and strategies for flow aggregation considering the QoS impact of the network components of AQUILA architecture are obtained and validated in the context of specific SLAs, domain policies and mapping of access, edge and core QoS mechanisms.

The intra-domain QoS monitoring differs from the tasks of inter-domain QoS monitoring of interconnected ISPs, which can be based on different SLAs, QoS provision mechanisms and policies.

The inter-domain QoS monitoring is emphasising on the macroscopic evaluation, collection, aggregation and validation of QoS information at ISP boundary (e.g. inter-domain QoS mapping, global ISP connectivity and topology).

An example of inter-domain QoS monitoring for interconnected DiffServ ISPs is the Qbone Internet2 network architecture [6].

The experiences in the intra-domain QoS monitoring with CM Toolset based on interaction of passive and active measurements using integrated database can be used for design of global measurement architecture for macroscopic monitoring of QoS in inter-domain context.

The work in progress for development of inter-domain QoS monitoring architecture is focused on:

- *Global inter-domain QoS measurement architecture.* Since the intra-domain signalling and QoS monitoring is specific dependent on the ISP network infrastructure, the global inter-domain QoS measurement architecture should be designed independent from the specific QoS mechanisms and tools used by each individual ISP for QoS monitoring. Inter-domain control agents will provide active and passive measurements at the ISP boundary.

- *Inter-domain measurement methodology for collection of QoS parameters at ISP ingress / egress border measurement points.* In the inter-domain measurement, all measurements are to be taken at or as close to inter- domain boundary, i.e. at ingress / egress routering system of the ISP. This allows evaluation and verification of the QoS properties of the traffic classes considering global QoS mappings and interconnections.

- *Integrated QoS, policy and accounting mapping using inter-domain QoS data base.* The measurement results will be stored in an integrated inter-domain data base and monitored by inter-domain management stations for QoS aggregation and correlation.. Since the intra-domain SLAs, policies and accounting of the ISP are based on specific QoS and SLAs, the integrated QoS measurement architecture will provide for mapping of common inter-domain QoS, policies and accounting strategies in an integrated data base. This will provide for a common information data base which compares the performance, policies and accounting mechanisms of the different ISPs. In addition, the information stored in the inter-domain data base could be used for verification of inter-domain QoS, policies and accounting mechanisms and their mapping to the specific intra-domain policies, accounting and QoS mechanisms.

- *Macroscopic aggregation of inter-domain QoS using ingress/egress border measurement points.* Inter-domain QoS monitoring must provide QoS information for inter-domain routing and accounting. For this purpose, the aggregation of performance metrics measured in different ISPs for provision of macroscopic QoS topology information base is required.

- *Macroscopic topology visualisation of inter-ISP connectivity* including mapping IP addresses to more useful analysis entities: autonomous systems (BGP routing granularity), countries, equipment (multiple IP addresses map to the same router, but without any mechanism to derive the mapping), and geographic location information (latitude / longitude coordinates).

- *Enhanced user interface for inter-domain QoS management* including QoS mapping data base, control protocol and agents for interoperation of ISPs with heterogeneous QoS and networking architectures. On this way, the different intra-domain QoS measurement facilities and SLSs are mapped in common inter-domain QoS view.

7. REFERENCES

[1] Cooperative Association for Internet Data Analysis (CAIDA). http://www.caida.org

[2] S. Salsano, Definition and usage of SLSs in AQUILA consortium Internet Draft, draft-aquila-sls-00.txt,11/2000

[3] U. Hofmann, Th. Pfeiffenberger, B. Hechenleitner, One Way Delay Measurement with CMToolset, Proc. 19th Int. IPCCC 2000 Conference,Pheonix, 41-47

[4] M.Siler, J.Walrand: On-Line Measurement of QoS for call admission control, Proc. 6th IWQoS, Napa 1998, 39-48

[5] L. Breslau, S. Jamin, S. Shenker, Comments on the Performance of MBAC algorithms, IEEE Journal on Selected Areas in Communications, 2000

[6] "Report from the First Internet2 Joint Applications / Engineering QoS Workshop", May 1998.

[7] K. Claffy: Internet measurement and data analysis: Topology, workload, performance and routing statistics. NAE 99 Workshop, 1999

[8] R. G. Cole, R. Dietz, C. Kalbfleisch, D. Romascano: A Framework for Sy nthetic Sources for Performance Monitoring. Internet Draft, June 2000

[9] IP Measurement Protocol (IPMP). September 1998. Http://watt.nlanr.net/AMP/IPMP/

[10] C. Demichelis, P. Chimento: Instantaneous Packet Delay Variation Metric for IPPM. Internet Draft, July 2000.

[11] R. Koodi, R. Ravikanth: One-way Loss Pattern Sample Metrics. Internet Draft, July 2000.

[12] V. Raisanen, G. Grotefeld: Network performance measu-rement for periodic streams.Internet Draft, July 2000

[13] ITU-T Recommendation I.380, Internet Protocol Data Communication Service-IP Packet Transfer and Availability Performance Parameters. Febr. 1999

[14] S. Kalidindi, M.J. Zekausus: Surveyor: An Infrastructure For Internet Performance Measurements. June 1999

[15] C. Labovitz, et al.: The Internet Performance and Analysis Project (IPMA). http://www.merit.edu/ipma/

[16] T. McGregor, H.-W. Braun: Balancing Cost and Utility In Active Monitoring: The AMP example. INET 2000

[17] The National Internet Measurement Infrastructure (NIMI) Web page, http://www.psc.edu/networking/nimi/

[18] NLANR's Active Measurement Program (AMP) web site. http://amp.nlanr.net

[19] K.Ohta, G.Mansfield, N.Kato, Y.Nemoto: Wide area fault detection by monitoring aggregated traffic.Passive & Active Measurement Workshop, New Zealand, April 2000

[20] V. Paxon, G. Almes, J. Mahdavi, M. Mathis: Framework For IP Performance Metrics. RFC 2330. February 1998.

[21] I.D.Graham,S.F.Donnelly,S.Martin,J.Martens, J.G.Cleary: Nonintrusive and Accurate Measurement ofUnidirectional Delay and Delay Variation on the Internet, Proc.INET '98

[22] G. Almes, S. Kalidindi, M. Zekauskas: A One-way Packet Loss Metric for IPPM. RFC 2680, Sept. 1999

[23] G. Almes, S. Kalidindi, M. Zekauskas: A Round-trip Delay Metric for IPPM. RFC 2681, September 1999.

[24] CAIDA's Skitter project web page. Http://www.caida.org/tools/measurement/skitter/

[25] J. Mahdavi and V. Paxson: IPPM Metrics for Measuring Connectivity. RFC 2678, Sept. 1999.

[26] RIPE Network Coordination Centre, Test Traffic Project. Http://www.ripe.net/test-traffic/index.html.

[27] H. Guy, R. Hatem: Statistics & Measurements: From Network Research to Network Operation. Workshop on Passive & Active Measurement, New Zealand, April 2000

[28] G. Almes, S. Kalidindi, M. Zekauskas: A One-way Delay Metric for IPPM. RFC 2679, Sept. 1999