INTERMON
Complex QoS/SLA analysis in large scale Internet environment

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Abstract. An advanced architecture for inter-domain QoS analysis, developed in the framework of European IST Project INTERMON[1], for automation of tasks in the area of inter-domain QoS/SLA monitoring, connectivity planning and traffic engineering is presented. The main focus of the INTERMON toolkit is the integration of tools covering different aspects of QoS analysis in large scale Internet environment such as inter-domain topology discovery, QoS and traffic measurement, traffic modelling, QoS prediction, load scenario simulation, pattern and traffic matrix analysis with common data base access. Policy based control is a design concept of the INTERMON technology allowing the flexible selection, configuration and usage of tools included in the architecture for supporting of inter-domain QoS engineering and planning task. The usage of the tools in scenario for complex QoS/SLA analysis in large scale inter-domain connections is discussed. Particular case for discovering of abnormal QoS behaviour (e.g. QoS outliers) is demonstrated using real measurements within a transatlantic trial (Austria, Brazil).

Keywords: QoS/SLA analysis, QoS outlier, pattern, data mining

1 Introduction

Analysis of QoS behaviour in a large scale Internet environment for the purpose of capacity planning and enhanced QoS provision is a complex task requiring new technologies based on automation of facilities for measurement, monitoring, visual data mining, modelling and simulation. Integration of

[1]The INTERMON project www.ist-intermon.org is partially found by EU IST 5th framework program

different data mining techniques (statistical and heuristic approaches) is needed in order to understand and model behaviour from data repositories considering different goals [1],[2],[3]. In order to process efficiently the large amounts of QoS measurement data bases ranging often in terabytes, access and interaction rules to control the interoperation and interfaces of different monitoring and analysis tools are important.

These challenges are considered in the development of the INTERMON architecture [4] discussed in this paper, which is aimed at the integration of different tools with a common data repository in order to support QoS analysis per traffic classes in an inter-domain environment. Special focus are access and interaction policies of integrated monitoring and analysis tools when solving concrete QoS analysis tasks.

Complex QoS/SLA analysis based on interaction of different INTERMON tools could be done for different goals:

- Reactive Monitoring (Fault Management) aimed to discover the cause of performance degradations (topology change, inter-domain routing failures, etc) when there is a customer QoS/SLA complain or proactive QoS measurement data showing abnormal QoS behaviour.
- Discovering spatial composition of end-to-end QoS on intra-/ and inter-domain level as well as QoS inference (network tomography approaches) based on proactive QoS and topology monitoring [16].
- QoS modelling and forecasting for different periods in order to plan and optimise the traffic and resources on inter-domain connections using data mining techniques and predictive QoS models, such as ARIMA [9].

Because the whole spectrum of INTERMON tool interactions as well as the resulting scenarios and cases are great enough, this paper is primary focussed to show a particular goal of QoS/SLA analysis aimed to discover abnormal QoS behaviour, e.g. QoS outliers.

Outliers are described by patterns; which do not appear to follow the characteristic distribution of the rest of the time series data [9]. They reflect QoS behaviour due to abnormal events, anomalies and exceptions. The usage of specific INTERMON tools, e.g. pattern analyser [12] interacting with proactive QoS monitoring is discussed in order to detect outliers.

This paper is organised as follows. Section 2 presents the INTERMON toolkit and the policy based concept of tool interactions. Section 3 demonstrates a scenario for QoS analysis based on usage of QoS data mining tools as well as practical results of inter-domain trial (Austria, Brazil). Section 4 concludes this paper.

2 INTERMON Toolkit and policy based configuration

2.1 Integrated tools for inter-domain QoS analysis

The INTERMON architecture is designed to combine different kinds of techniques for automated QoS analysis in large scale inter-domain environment based on monitoring. modelling and visualisation [4]. It integrates tools and technologies with common data base and user interfaces, using mechanisms for policy control interaction, to provide specific scenario in the area of inter-domain QoS analysis, planning and traffic engineering. Particular facilities and tools, integrated in INTERMON architecture are:

- Inter-domain route monitoring and quality analysis – InterRoute tool [14] used to discover the inter-domain route paths of the end-to-end connection considering common inter-domain routing repository and BGP-4 protocol data. BGP-4 messages are selected end evaluated to obtain the inter-domain route quality of particular end-to-end and intermediate connections .
- CM Toolset [16] for proactive end-to-end QoS monitoring and active tracing of connection topology on intra- and inter-domain level. In order to validate the QoS/SLA in the inter-domain environment, periodically or on demand the QoS of the inter-domain connection based on emulated QoS traffic is monitored. In addition, the topology of the connection could be traced to detect topology changes.
- Traffic measurement using IETF IPFIX traffic flow export concept [17].
- Border router monitoring tools collecting MIB information [4].
- Visual Data Mining (VDM) system for inter-domain QoS analysis aimed at automated processing, filtering, modelling and visualisation of different kind of QoS, traffic and topology data [18].
- Spatio-temporal QoS data mining and QoS pattern analysis for the area of network planning, anomaly detection and connectivity optimisation [7].
- Measurement based modelling including IP inter-domain delay analyser [4], ARIMA forecasting models [9] and Class Based Traffic models [20].
- Simulation tools for study QoS behaviour for different levels of abstractions hybrid packet [21], fluid [22], time series data [23] considering different traffic loads in inter-domain topologies. Connection topologies and inter-domain route qualities obtained from monitoring tools could be used to set parameters in simulation scenarios.

- Traffic matrix calculation and visualisation on different levels considering traffic aggregations on AS or end system connectivity level. [19] . The In/out traffic load per AS and end systems is obtained from IPFIX traffic flow measurements [17] in order to study the impact of particular flows.

The following picture describes the current state of the INTERMON architecture.

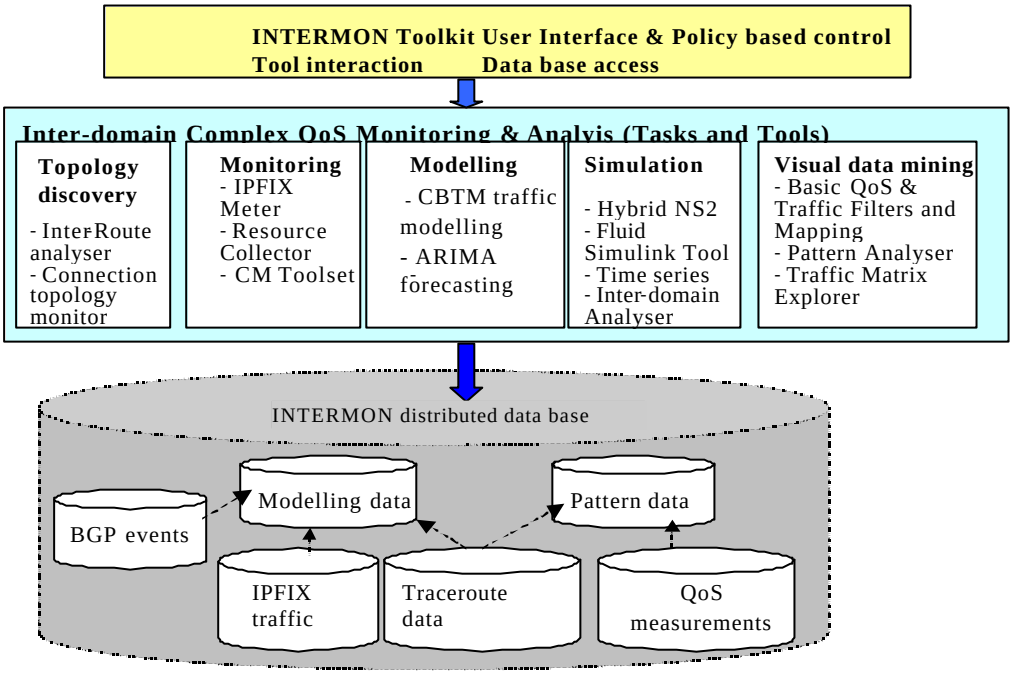

Fig.1. INTERMON toolkit

INTERMON architecture is designed for flexible integration of new tools and facilities using configurable user interface, XML based data exchange and policy controlled tool interaction [11]. INTERMON concept includes distributed data bases of different tools. There are operative data bases (like CM Toolset QoS and topology monitoring data base) and analysis data bases, such as QoS pattern data base and InterRoute data base for inter-domain topology study. Analysis data bases like QoS pattern data base are layered over QoS monitoring data base, in order to store only relevant QoS analysis data with possibilities to reference the whole QoS monitoring data on demand.

2.2 Policy based tool configuration for performing of specific scenario

Policy is defined as set of rules which describe the interaction of tools and data base to perform given task. Policies allow the users of the INTERMON toolkit

to specify the task they want it to exhibit, i.e. the concrete actions for inter-domain QoS analysis. For example, CM Toolset QoS monitoring tool have different options to generate artificial traffic for application emulation (VoIP; MPEG video, aggregated traffic) and measure the QoS dependent on the traffic class.
The access to the large scale distributed INTERMON data base could be also controlled over policies.

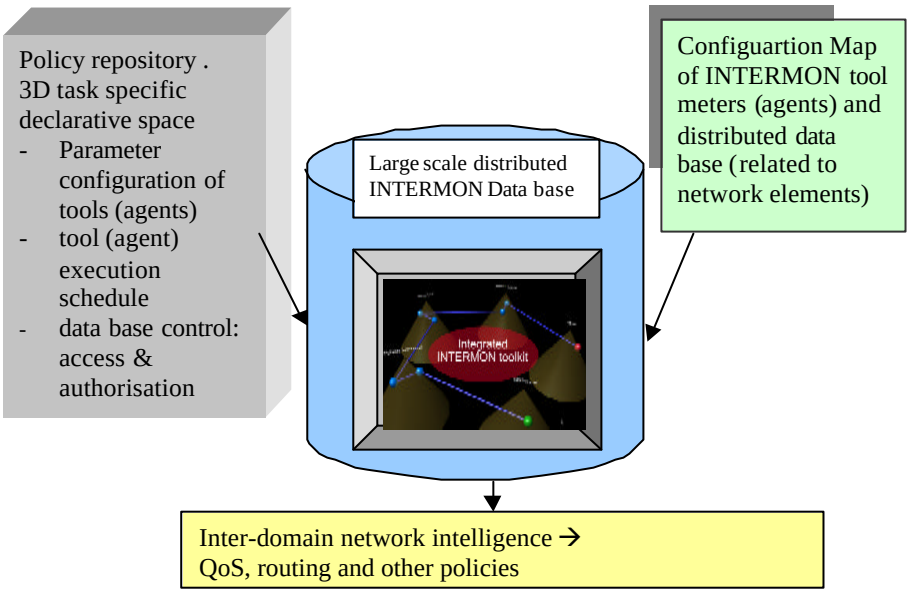

Fig. 2. Policy based tool and data control in INTERMON

Complex QoS analysis using INTERMON toolkit is based on interaction of QoS and topology monitoring as well as modelling and forecasting tools for performing of specific tasks.

3 Scenario for complex inter-domain QoS/SLA analysis

Complex QoS/SLA analysis in inter-domain environment is aimed to study, validate and optimise (offline) the network resource usage in order to fulfil the QoS/SLAs required by applications customers . It is required in different cases:

- when ISP needs to do inter-domain connectivity planning and optimisation, load balancing and troubleshooting considering abnormal behaviour

- when customers (for instance Virtual Private Networks or Application Service Provider) want to select optimal inter-domain resources (connections, routing path) for QoS/SLA
- when there is a need to compare different inter-domain connections and multihoming topologies in respect to optimise the QoS/SLA.

Our goal is to focus on a specific case of the complex QoS/SLA analysis aimed at study of extreme degradations in QoS behaviour, called outliers. QoS outliers in inter-domain environment can have different causes such as connection topology change [15], inter-domain route quality problems [14], DoS attacks [5], false configuration of BGP-4 inter-domain routing policy [13], route flap damping and oscillation [12], BGP-4 updates and their impact on traffic [8], BGP-4 convergence after failure [6].
INTERMON strategy is to integrate different tools is order to detect, study and obtain causes of outliers. Here, the approach for QoS outlier study is described using pattern discovery tools and proactive QoS monitoring is described.

3.1. Usage of INTERMON tools for complex QoS/SLA analysis considering outliers

There is a need to derive properties of inter-domain connections between source and destination such as extreme values (QoS outliers), typical behaviour of QoS values in specific periods (day, week,..), e.g. periodical patterns of QoS behaviour, etc. For this purpose, spatio-temporal QoS data mining and pattern analysing tool of INTERMON [7] based on automated detection, storage and processing of QoS patterns considering spatial (network topology) and temporal (time windows and periods) context could be used.
The network engineer derives pattern structure parameters (distance measures, extreme value calculation options) based on his experience (on route change, abnormal QoS values) and requested QoS/SLA. One particular focus are QoS patterns describing abnormal QoS behaviour important for fault management and QoS planning. Their study is based on specific periods and time windows as well as on spatial relationships of inter-domain connections. Multivariate QoS parameter analysis and spatial composition of QoS parameters could be considered for detection of dependencies of QoS outliers. Further focus are "dominant" spatial connections with outlier patterns.
In order to plan the inter-domain traffic and which connection this traffic should take, trends and forecasting of the QoS behavior is important. Prediction models (ARIMA, traffic based) integrated in INTERMON are aimed to find tendencies in QoS provision on different inter-domain connections in order to estimate load and adjust capacity [9].
QoS outliers detected by pattern analyser are eliminated from the forecasting process in order to provide more accurate prediction. Outlier patterns could be

also considered in reactive analysis to obtain dependencies of abnormal behaviour and events and their impact on QoS patterns. Examples for abnormal behaviour is topology change and route qualities/failure.
Figure 3 shows an INTERMON approach for complex inter-domain QoS analysis focussed to discover QoS outlier patterns and considering them in planning and management strategies.

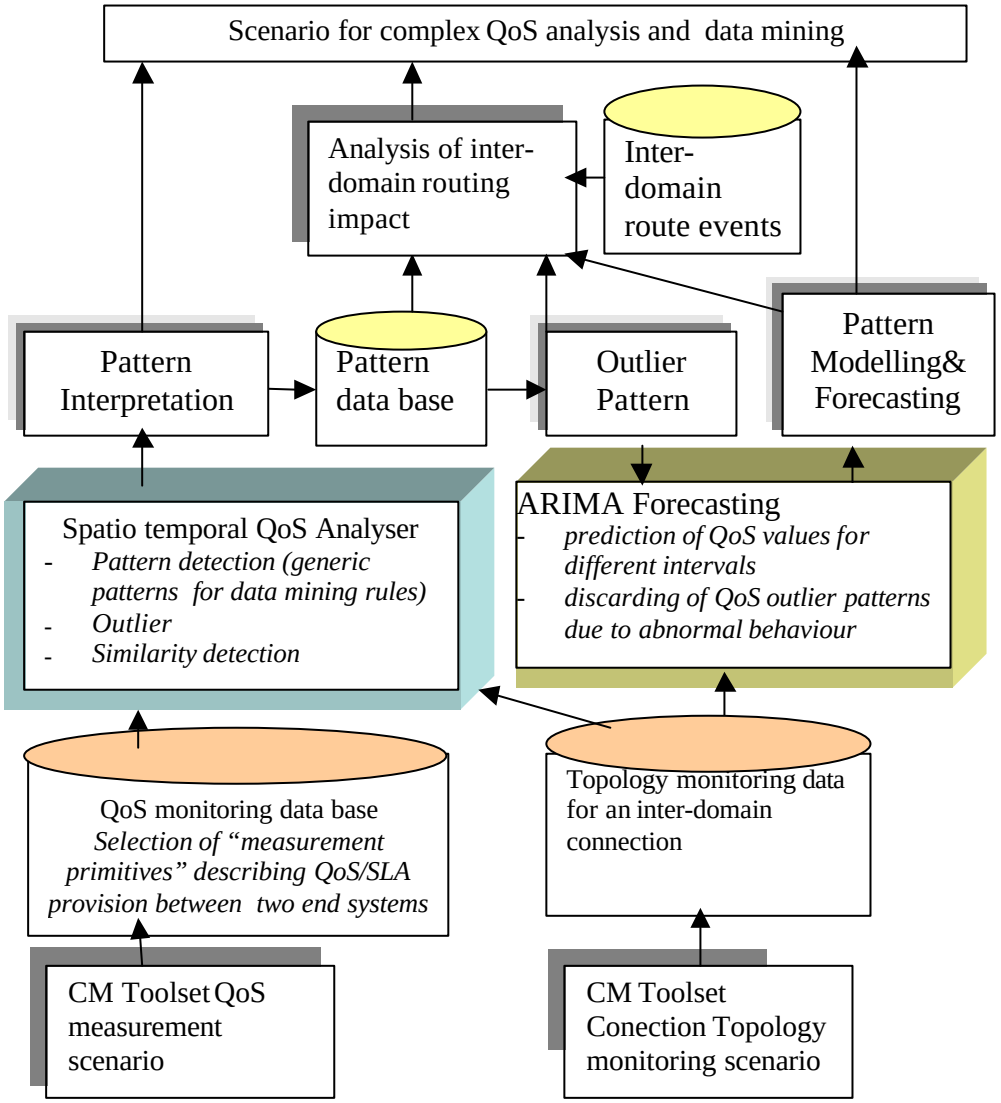

Fig. 3. Usage of INTERMON tools for complex QoS/SLA analysis considering outliers

As considered in the figure 3, there are different tools interacting using the outlier patterns discovered by the QoS pattern analyser and stored in a data base. The pattern data base is aimed to support the network engineer in the area of validation of QoS/SLA and detection of abnormal behaviour on inter-domain connections by archiving of "significant" patterns and their dependencies obtained by pattern matching algorithms.
The InterRoute tool uses outlier patterns from the data base to detect corresponding inter-domain routing behaviour (BGP-4 events). ARIMA provides forecasting eliminating detected patterns.

3.2 Usage of INTERMON tools in experimental inter-domain trial for complex QoS analysis

An experimental trial is established for complex QoS/SLA monitoring and analysis in large scale international inter-domain environment involving countries from Europe (Spain, Austria, Germany) and Latain America (Brazil). The purpose is proactive QoS and topology monitoring of selected important inter-domain paths for complex QoS/SLA analysis, e.g. to obtain understanding on typical QoS patterns and outliers in order to support inter-domain connectivity optimisation and capacity planning. The results are used to indicate significant fault events (inter-domain routing, topology changes, etc) and provide knowledge for operation and management in large scale inter-domain environment.
The following picture shows the inter-domain paths involved in the trial.

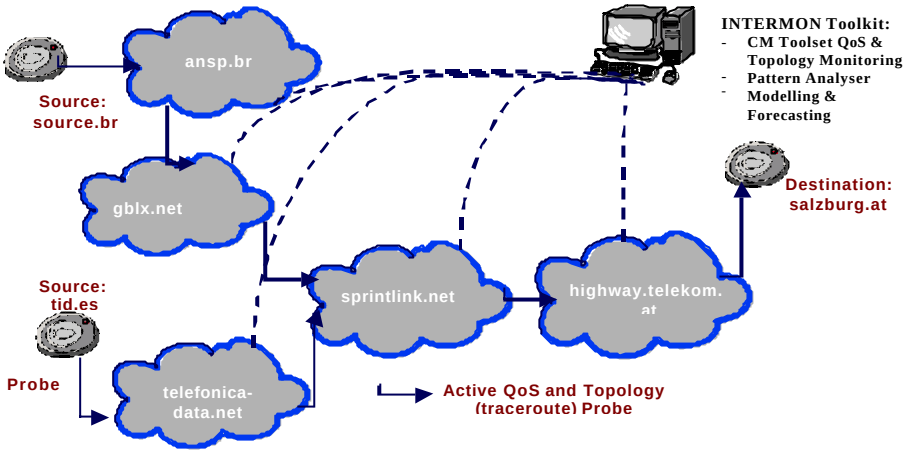

Fig. 4. Trial for complex inter-domain QoS analysis

CM Toolset agents are installed at the end systems for QoS and topology monitoring of the inter-domain connection [16]. The topology monitoring is based on tracing the route of the connection. The measurement results are stored in QoS and topology data base (cmbase) included in INTERMON architecture in order to be analysed with further tools of INTERMON toolkit. Spatio-temporal QoS Data Mining and QoS Pattern Analysis Tool [7] is used for deriving of significant patterns from measurements. These patterns are considered later by other INTERMON tools to provide more deeply understanding of inter-domain behaviour and to allow forecasting. For instance, derived outliers and periodical pattern behaviour is considered by InterRoute to show QoS and inter-domain routing dependencies.

3.3. Discussion of QoS parameter behaviour with special focus on outlier patterns

The quality of inter-domain connection from Brazil (Sao Paulo) to Austria (Salzburg) is the object of the study. The scenario for proactive QoS monitoring of this connection was based on sending every 5 minute of a 64 Byte packet and measuring QoS parameters per packet – end-to-end delay (mean, maximum, minimum) using GPS, packet loss, delay variation (mean, maximum), throughput.

The results have shown very unstable inter-domain connectivity. The measurement process was often broken. The QoS parameter measurements

obtained in time "portions" , have shown that the same inter-domain connection for some days or sequences of days has better end-to-end QoS characteristics (for instance, mean delay) than QoS characteristics in another days.
In figure 5 is shown that, the inter-domain connection for the time window starting at 31.07 has more worse performance for mean and minimum end-to-end delay (given in microseconds) than for the time window starting at 17.9. We have discovered that also for the other measured QoS parameters of inter-domain connection, the time window beginning on 17.09. behaves better.

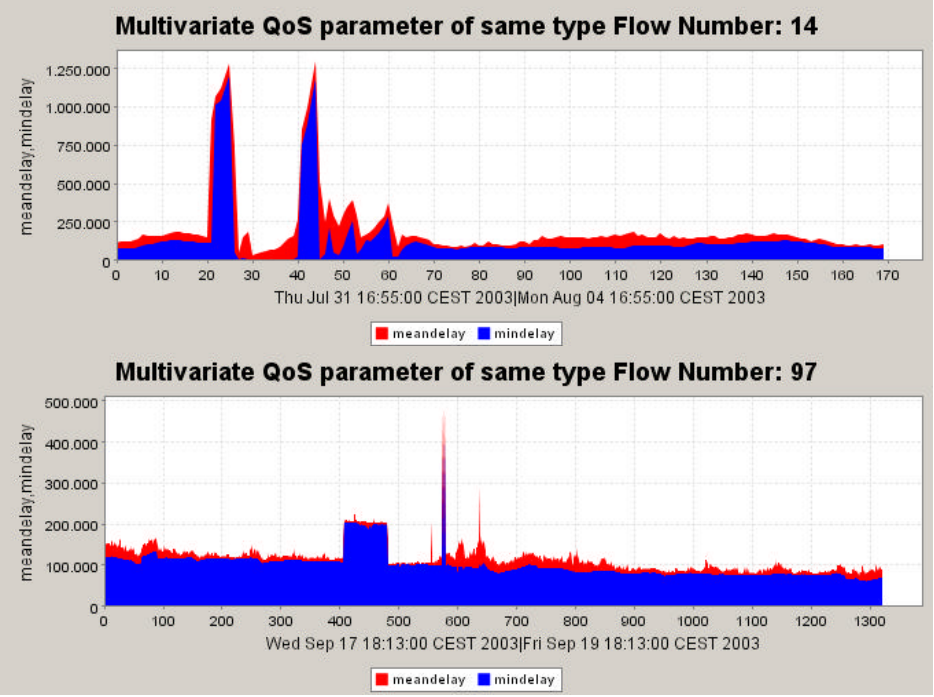

Fig.5 Different end-to-end QoS characteristics of the inter-domain connection for different time widows

More expressive, the differences in the end-to-end QoS parameter behaviour could be shown for the caused QoS outliers, e.g. significant extreme QoS values. The significant extreme value pattern could be calculated based on threshold values supplied by the network engineer, or based on multiple of standard deviation σ of QoS parameter values [9].

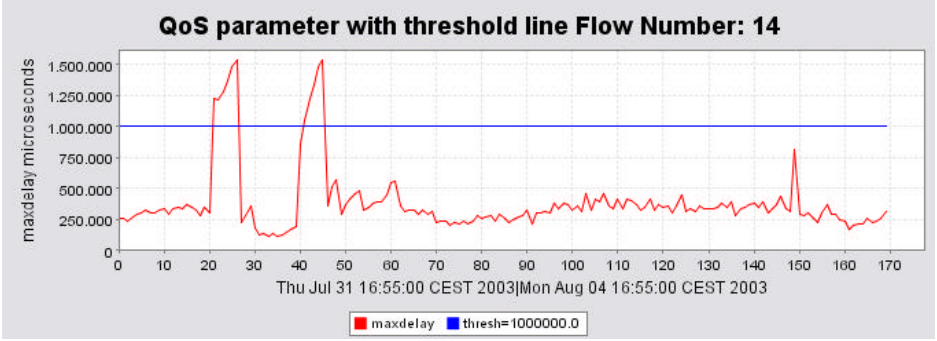

Fig.6 Threshold value selected for outlier

The QoS outlier patterns of the time window starting at 31.07. are more dominating on the performance than the outlier in the period starting at 17.9., who is lasting a very little time. There is also a different base for outlier calculation in the two windows due to the different overall performance of the end-to-end delay. The differences in the outlier patterns for the two periods are shown in figure 7:

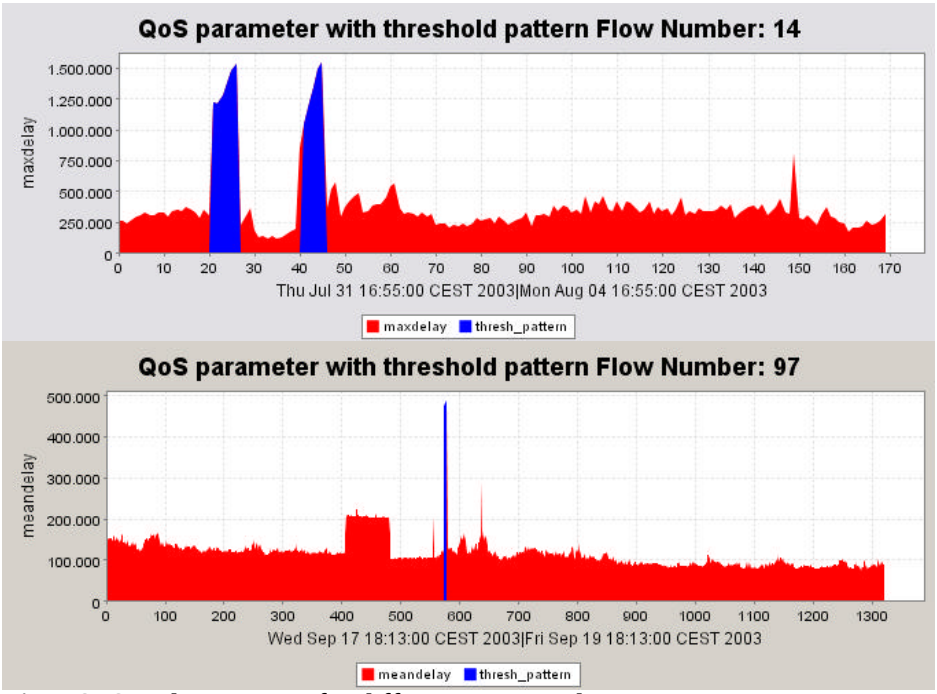

Fig.7 QoS outlier patterns for different time windows

The cause for the outliers on the inter-domain connections are probably inter-domain routing problems, which are studied with InterRoute tool [14].

4 Conclusion

This paper was focussed on complex QoS analysis in large scale inter-domain developed in the framework of INTERMON project integrating different techniques spatio-temporal QoS data mining, pattern analysis, modelling and forecasting of QoS data. Current usage of the described technology in the framework of INTERMON project is aimed at complex spatio-temporal QoS analysis obtained from real world QoS monitoring experiments to forecast future behaviour and detect patterns of interest to be specified and interpreted by operators and network analysts. Our further focus is aimed at development of policies and strategies for solving of specific tasks in the area of network management, QoS planning and network anomaly detection.

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