

# Dynamic monitoring architecture for spatio-temporal QoS and traffic mapping in inter-domain environment

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## Abstract

*This paper presents the INTERMON dynamic monitoring architecture for spatio-temporal QoS and traffic mapping in inter-domain environment considering inter-domain routing (BGP-4 protocol) behaviour.*

*The monitoring architecture is based on the collection of different types of time series data: QoS parameter time series data, border router traffic data and BGP-4 updates.*

*The different types of time series data are collected in the common data base with spatial relationships to network connections and topology elements (border router, end systems). The dynamic monitoring architecture allows for integrated topology, QoS and traffic monitoring based on spatio-temporal relationships of time series data of different types, collected in the common data base.*

*The paper describes the components of the architecture, together with their collection mechanisms. The MRCollector aimed to measure inter-domain border router traffic using SNMP data and QoS between border routers in order to provide information for inter-domain resource utilisation and capacity planning.*

*InterRoute is used to detect causes in the border router traffic behaviour by definition of heuristics based on BGP-updates to show inter-domain routing anomalies.*

*Active QoS measurement and pattern analysis based on traffic emulation aimed to store significant patterns to describe end-to-end QoS behaviour considering traffic and routing impact.*

*The coordinated usage of tools for inter-domain QoS dependency is shown based on scenarios for tool integrated in the dynamic QoS monitoring architecture.*

## 1. Introduction

Managing the inter-domain environment with the aim of end-to-end QoS measurement, and inter-domain traffic is complicated and requires consideration of BGP-4

behaviour [4]. Therefore the integration of tools measuring and discovering the inter-domain Internet behaviour from different points of view – border router traffic load, end-to-end QoS parameter and topology – is proposed in the framework of INTERMON [1]. This allows a new dimension in the understanding of complex QoS and traffic dependencies considering link failures, routing anomalies, peering configuration tuning etc.

The distributed nature of measurement and topology discovery tools as well as usage of specific data bases for information collection requires building of new kind of performance management architectures including monitoring and analysis (data-mining) components which are interacting using integrated data base access.

Generally, ISPs don't have a focused picture of the traffic passing through other domains and the management systems aren't adaptive to routing and traffic dynamics. Therefore different large scale, inter-domain scenarios should be considered in the policies for tool interaction in the integrated architecture. These include scenarios based on incomplete measurement data arising in the scope of network tomography, which should be focussed by appropriate mappings of topology, traffic and/or end-to-end QoS behaviour as functions of connectivity provided by the Internet and the time.

Examples for scenarios and tasks which could be provided by the dynamic integrated QoS monitoring toolkit are:

- Spatial traffic analysis, i.e. traffic comparison across multiple network links [7],
- Inferencing end-to-end connection traffic and QoS characteristics from internal (link) traffic and QoS measurements [16],[17],
- Inferencing of internal (link) distributions of traffic and QoS such as delay and loss from corresponding end-to-end connection measurements [18], [19], [20],[21]
- Congestion behaviour in spatio-temporal environment [5],

- Spatial and temporal monitoring of Denial of Service Attacks [14],
- Spatial QoS composition for and worst case delay guarantee [22] and QoS based routing [23]
- Assessment of QoS parameters of network connections for specific applications [26].

The demands for advanced management of integrated monitoring and topology discovery tools for study of QoS in inter-domain environment based on different scenarios considering impact of topology of traffic was the motivation for the INTERMON toolkit architecture [1]. The approach of the dynamic QoS monitoring of INTERMON is to automate the tool interactions needed to study dependencies based on different kinds of time series data (measured QoS parameters, border router traffic, BGP-4 updates) collected in an integrated data base. This allows the mapping of spatio-temporal relationships of different kind of multivariate time series data (traffic, QoS, BGP-4 message sequences) which facilitates the dependency analysis.

In this paper, particular design concepts of the dynamic QoS monitoring architecture of INTEMON are studied based on the spatio-temporal mapping of traffic, topology and end-to-end QoS. They are found to be essential for understanding of the integrated QoS/SLA monitoring and analysis in large scale interdomain scenarios in the Internet. Scenarios are discussed to illustrate the tool interaction for dependency study in inter-domain environment.

## 2. Dynamic QoS monitoring architecture for spatial and temporal mapping using time series data

### 2.1. Time series data analysis for performance study in inter-domain Internet environment

Time series data is characterized by data elements being a function of time.

A time series  $X$  is a sequence of observed data, ordered in time defined by

$$X = \{ x_t, t=1, \dots, N \}$$

where  $t$  is the time index and  $N$  is the number of observations.

Time series data can be represented using two variables, one for time and one for the measurement value at that time.

To describe QoS behaviour and impacts in the inter-domain environment, different types of discrete time series data could be used:

- QoS parameters
- Traffic volumes
- BGP-4 protocol updates.

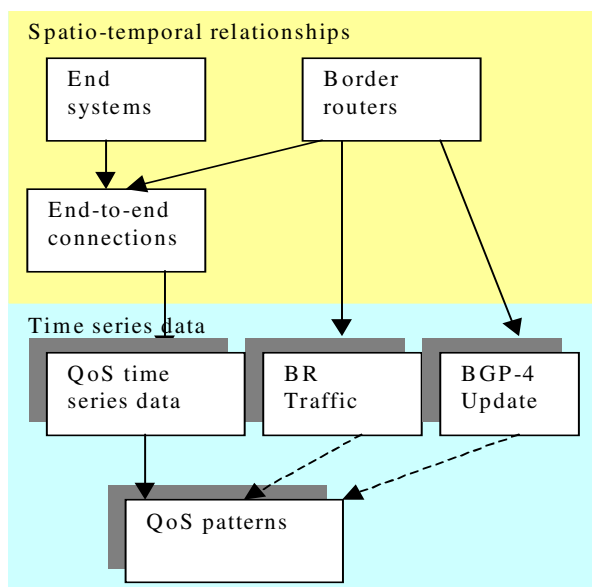
A time series is said to be discrete, when observations are taken at fixed times.

Time series data  $Q$  representing QoS parameter sequences and time series data  $T$  representing traffic volume measurements at border router are obtained usually by equally spaced monitoring interval, called time scale. The time scale depends on the goal of time series data analysis [2]:

- fine grained time scale for episode analysis (event, application QoS pattern, etc)
- more coarser time scale for planning and forecasting (for instance, usage of ARIMA modelling [3]).

Sequences of BGP-4 protocol updates (collected at border routers of autonomous systems) are examples for time series data which are not equally spaced.

Figure 1 shows the spatio-temporal framework for time series data analysis in inter-domain environment which builds the theoretical background of the dynamic QoS based monitoring architecture in INTERMON:



**Figure 1: Spatio-temporal analysis framework of time series data in inter-domain environment**

In order to obtain the dynamical impact of the monitored time series data in the spatio-temporal context, different approaches for time series data analysis could be applied.

[6] discusses the common approaches for time series data mining including:

- data adaptive (sorted coefficient, piecewise polynomial, singular value decomposition, symbolic, trees)
- non data adaptive (Wavelets, random mappings, spectral, piecewise aggregate approximation)

The Wavelets methods [7] were used for spatial traffic analysis, e.g. comparison of patterns across multiple networking links. Spectral time series analysis based on spatial and temporal mapping of Round Trip Time QoS parameter is proposed in [14].

Piecewise linear approximation as part of the piecewise polynomial techniques can be used to simplify the analysis based on accurate classification, clustering and relevance feedback [8]. Specifically, in the context of data mining, the piecewise linear representation [15] has been used to support:

- fast exact similarity search.
- novel distance measures for time series, including
- “fuzzy queries”
- weighted and multiresolution queries
- dynamic time warping and relevance feedback
- concurrent mining of text and time series
- clustering and classification algorithms
- change point detection.

In INTERMON, methods for piecewise linear representation of QoS parameter time series data were adopted to allow abstractions for QoS and traffic time series data sequences considering thresholds and “outliers” [10].

Patterns are generally defined as any recognisable regularity (structure) in the time series data sequence [24]. Pattern classes can be defined by filtering out all usable, interesting, frequent or periodic patterns, and disregard the rest.

Classes of patterns are defined by syntax and semantics descriptions [25]. The dynamic QoS monitoring architecture considers structures, e.g. patterns, to explain dependencies between different kinds of time series data (traffic, QoS, BGP-4 updates). Patterns are used in the dynamic QoS monitoring particularly for:

- Understanding of the structure of time series data sequences for specific periods by application of analysis methods [12] such as this of linear approximation,
- Classification of patterns based on applying of heuristics and pattern detection algorithms. Example for classes of patterns are basic patterns (increase, decrease, plain, outlier) for description of QoS parameter data [10], patterns based on heuristics for BGP-4 update sequences.
- Building of knowledge base of dependable patterns of different types (traffic, QoS, BGP-4 Updates)
- Event based analysis using temporal patterns as hidden structure in a time series data that is characteristic and predictive of event.

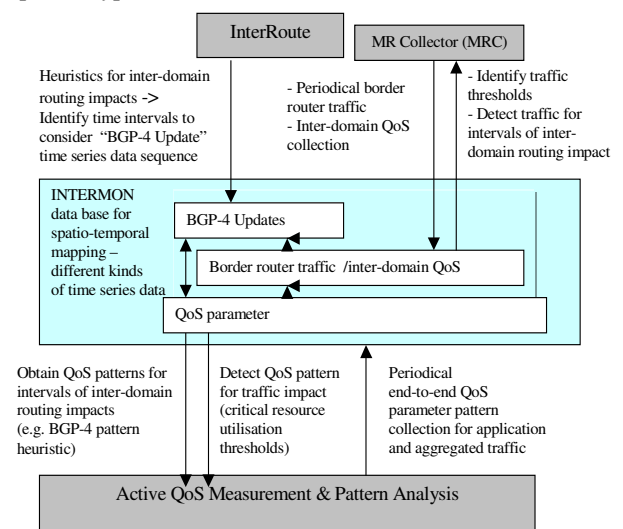
## 2.2. INTERMON dynamic QoS monitoring architecture

The INTERMON dynamic QoS monitoring architecture integrates tools which are interacting for spatio-temporal QoS and traffic analysis in inter-domain environments.

The focus of the dynamic QoS monitoring architecture as shown in INTERMON includes:

- Dynamic QoS monitoring to provide performance data to assess the properties of connections in inter-domain environment for QoS based communication considering the impact of BGP-4 protocol behaviour, inter-domain QoS and border router traffic based on time series data analysis
- Controlled interaction of end-to-end QoS monitoring and analysis with border router traffic collection and routing control using integrated data base
- Management of spatial and temporal mapping and dependencies of traffic, QoS and BGP-4 Updates as time series data related to spatio-temporal context.

Figure 2 shows the different tools included in the QoS monitoring architecture with specific tasks to monitor, manage and visualize context dependable time series data of specific type.



**Figure 2: Tool interaction for analysis of inter-domain dependencies**

The role of the tools in time series data collection and dependency study is briefly overviewed:

- **MRCollector**, provides easy-configuration features for generating both passive traffic measurements for border routers and active measurements between border routers to obtain inter-domain QoS parameter data.
- **InterRoute** analyses BGP-4 updates exchanged between border routers and detects causes for end-

to-end QoS and border router traffic behaviour based on heuristics describing specific BGP-4 Update sequences

- **End QoS measurement** is used to provide performance data in the time scales as required by the application traffic to obtain periodical QoS parameter patterns characterising end-to-end connections or patterns reflecting border router traffic over BGP-4 protocol impact.

The tool cooperation above explained could be utilized to compose a “QoS Dynamic Monitoring System”, making the procedures, to retrieve time intervals, for which impacts of topology and traffic could be identified in form of patterns of time series data.

The main interaction mechanisms considered in the architecture are based on:

- Inter-domain routing impact, i.e. detection of the time interval and the spatial context (i.e. end-to-end connection, border router) for which the monitored “BGP-4 Updates” sequences could be explained with specific heuristic of inter-domain routing impact (route change, misconfiguration, policy violation, etc).
- Inter-domain resource utilisation impact, e.g. border router traffic impact considering intervals with different traffic levels (traffic thresholds) impacting propagation delay and packet loss of end-to-end QoS.
- Inter-domain QoS impact on of end-to-end QoS considering the spatial composition of inter-domain QoS.

The following chapters discuss the main functions of the tools included in the dynamic QoS monitoring architecture focussing on scenarios for analysis of spatio-temporal dependencies of the different time series data collected by the tools.

### 3. MRCollector for study border router traffic impact on end-to-end QoS

#### 3.1. MRCollector role in integrated architecture

The MRCollector (MRC) management system is to achieve the deployment of a wide and efficient set of measurement from distributed starting points, e.g. border routers, in inter-domain environment, including

- traffic measurements at border router based on snmp statistics
- inter-domain QoS measurements, including scalable facilities allowing the configuration of large number of measures to different end-point, different AS crossing layers using different parameters.

MRCollector supports a transparent proxy-interface monitoring agent. The aim of the agent is to provide to Element Managers, Tool Managers and policy engines a flexible interface to perform different monitoring campaigns in a multi task environment with high reliability and efficiency. Therefore, the agent allows a full control of the measurement set over the time axis either with a remote procedure or operator manual setup.

MRC exposes three main branches of facilities to provide information for inter-domain resource utilization and capacity planning:

- Discover interface to retrieve node resources
- Configuration interface to set up measurement campaign.
- Collection interface to store measure data previously configured

Tool GUI allows user to interact with the three facilities mentioned above. The tool can manage measures, involving both the border router traffic, more specifically the resource belong to it using snmp statistics [9], and inter-domain QoS measurements starting from that border router toward all elements in the path.

The time series data collected by MRC are related over the network elements to the end-to-end QoS time series data and sequences of BGP-4 protocol messages. The time scale of the snmp statistics collection (5 minute) should be considered in the granularity of the time series data analysis [2].

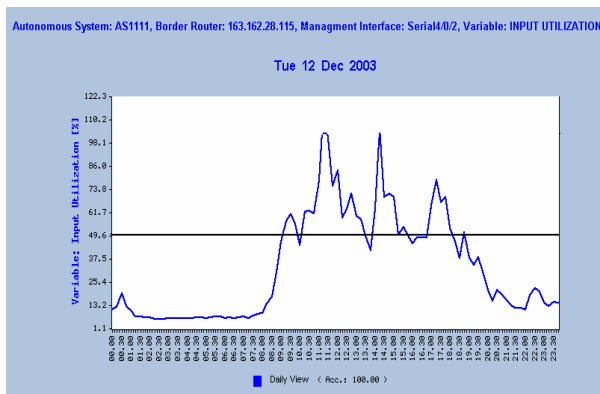
#### 3.2. Scenarios for dynamic monitoring considering inter-domain ttraffic and QoS impact

A full features implementation of SAA (Cisco Service Assurance Agent) is supported so that user can setup the following measurement scenarios:

- network element link resources monitoring and troubleshooting
- multi-layer performance metric analysis (TCP, HTTP, FTP, ICMP, UDP)
- multi-path analysis: e2e, access2end and border2end delay measurement
- VoIP traffic simulation and jitter analysis.

Its utilization in such a context is to understand QoS degradation starting from peer-to peer measures or node resource measures such as link utilization.

MRCollector can run on server co-located to border router in the path, more specifically, an MRCollector meter tool for each AS. The discovery interface provides user with node resources on which the user can start measures of link utilization, as below figure shows:



**Figure 3: Analysis of border router traffic impact on QoS provision using MRC**

The set threshold indicates a utilization limit of 50%, in order to retrieve a time period in which the router effectively works [2], in such a way MRCcollector can obtain the impact of the border router traffic on QoS provision.

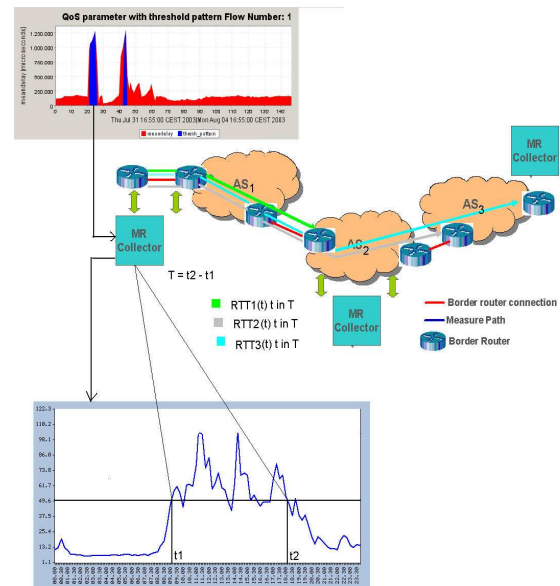
The end-to-end QoS monitoring and Pattern Analyzer provides to MRCcollector a critical threshold, e.g QoS parameter patterns describing outlier [3], to analyze in more detail in the spatio-temporal context.

MRCcollector obtains the related border router traffic patterns and inter-domain QoS, starting from provided critical thresholds found by end-to-end QoS monitoring. Two methodologies are carried out to extract time series data describing border router resources or inter-domain QoS related to end-to-end QoS time series data sequence:

1. Detection of Spatial element such as border routers impacting the end-to-end QoS, e.g. intermediate border router of the end-to-end connection.
2. Selection of the temporal period for corresponding border router traffic detection and inter-domain QoS measurement. This period is obtained from the critical threshold detected by the Pattern Analyzer.

Resuming, the above mentioned methodologies are used to perform a sort of spatial-temporal zoom-in.

In the identified spatio-temporal context, it is possible to start measure campaign to detect abnormal QoS behavior considering border router traffic and inter-domain QoS behaviour between border router of the end-to-end connection, as described in follow figure:



**Figure 4: Inter-domain traffic and QoS measurement campaign to detect causes for end-to-end QoS outlier**

The time series data describing inter-domain QoS in the spatial temporal context could be used for:

- Detection of spatio-temporal composition of end-to-end QoS considering intermediate inter-domain QoS time series data.
- Network tomography based on the inferencing of end-to-end QoS based on intermediate inter-domain QoS.

The benefit of MRC is the specification of traffic and QoS measurement scenarios with different levels of complexity, which could allow the study of causes considering heuristics for spatial network elements such as specific possible border routers, Internet exchanges, Autonomous systems and end users involved or impacted by the QoS degradation.

#### 4. InterRoute - automated detection of inter-domain routing impact

##### 4.1. Detection of BGP-4 message sequences belonging to border routers of end-to-end connection

InterRoute takes the view of the end-to-end path under study as seen from the intermediate border routers (BRs) and Autonomous Systems (ASs) of an end-to-end connection.

A heavy distillation process needed to obtain the routes involved in the end-to-end connection is explained in [4]. This results in a manageable set of border routes and “BGP-4 Updates” which explain the evolution of the

inter-domain routing impact as seen by the border routers of the intermediate ASs.

InterRoute collects to each BR involved in the scenario time series data of “BGP-4 Updates” described by:

- Time stamp of “BGP-4 Update”
- Type of update (Advertisement or withdrawal),
- prefix and BGP-4 attributes such as AS\_PATH, etc.

Patterns of “BGP4 Updates” are characterised by syntax and semantic to describe inter-domain routing impact.

InterRoute uses the “BGP-4 Update” patterns to :

- Derive a complete view of the topology of autonomous systems in the Internet that implement the end to end connection, including alternate paths which are programmed as backup routes and its evolution during the period under study.
- Detect spatio-temporal context by the “BGP-4 Update” pattern in which some inter-domain routing impact has happened. Heuristics are defined to assign semantic of the inter-domain routing impact to the particular “BGP-4 Update” pattern syntax.

#### 4.2. Detection of inter-domain routing impact described by “BGP-4 Update” patterns on traffic and QoS

Analysing the “BGP-4 Updates” at a given border router of the end-to-end connection in inter-domain environment, different kinds of inter-domain routing impact could be identified.

Heuristics are derived based on syntax and semantic of the “BGP-4 Updates” sequences, to identify the inter-domain routing impact on the

- end-to-end QoS
- intermediate border router traffic and
- inter-domain QoS involved in the spatial composition of the end-to-end QoS.

Based on spatio-temporal correspondence of the “BGP-4 Update” patterns to the border router traffic, end-to-end and intermediate QoS patterns, the impact of the inter-domain routing on QoS and traffic is detected.

The heuristics obtaining time series data sequences of “BGP-4 Updates” currently supported by the integrated QoS monitoring system are:

1. *Route flapping in absence of route dampening mechanisms*: Periodic series of advertisements and withdrawals of a specific prefix originated at one router.
2. *Route flapping in presence of route dampening mechanisms* When route dampening mechanisms are applied, a series of bursts of updates originated a one router can be observed.
3. *Severe human error (i.e. misconfiguration)* An advertisement and a withdraw originated at one router cause a severe degradation in end to end QoS parameters

4. *Manual trial-and-error approach to traffic engineering*: A series of advertisements for one prefix is detected. The BGP-4 attributes in the advertisements (i.e. the AS\_PATH) is changed using the 'as-path prepend' technique.

Figure 4 shows the detection and description of the pattern of the heuristics for “manual trial-and-error to traffic engineering operations”. The description is given in form of the syntax and semantic representation of sequences of “BGP-4 Updates” in the spatio-temporal context.



Figure 5: Example for “BGP-4 Update” Pattern describing the “manual trial-and-error to traffic engineering operations” heuristics

As it is seen in the figure, the traffic engineering operation which have been started at 15:15 has to be finally aborted at 15:32. With this temporal information, the integrated dynamic QoS monitoring system should extract the corresponding end-to-end QoS parameter patterns and border router traffic patterns which include the impact of the inter-domain routing described by the particular heuristic.

#### 5. Active end-to-end QoS measurement and pattern analysis of applications

Active QoS monitoring is used for emulation of application traffic and for end-to-end QoS parameter measurement in time scales required for the evaluation of the quality of applications. The active monitoring QoS is used for assessment of QoS parameter of connections in inter-domain environment considering specifics of applications which are used on the end-to-end connections. Monitoring interval or time scaling is important consideration for QoS analysis which depends on the application and its demands for fine granular measurement data to access quality demands [13]. Fine time scale granularity is required for instance in case of study of “congestion episodes” discussed in [2].

The QoS pattern analyser in connection with end-to-end QoS monitoring provides a set of functions for the capture, display, and analysis of time series of QoS

parameter considering required time intervals. The basic functionality includes the display of time series data, pattern detection from time series obtained by active monitoring, linear approximation of time series data.

The spatio-temporal dependency of QoS parameter data included in the QoS monitoring data base (cmbase) is based on the discovery of the topology of the end-to-end connections in inter-domain environment using active traceroute probing which is an optional facility of the active QoS monitoring tool or InterRoute for inter-domain topology discovery described in this paper.

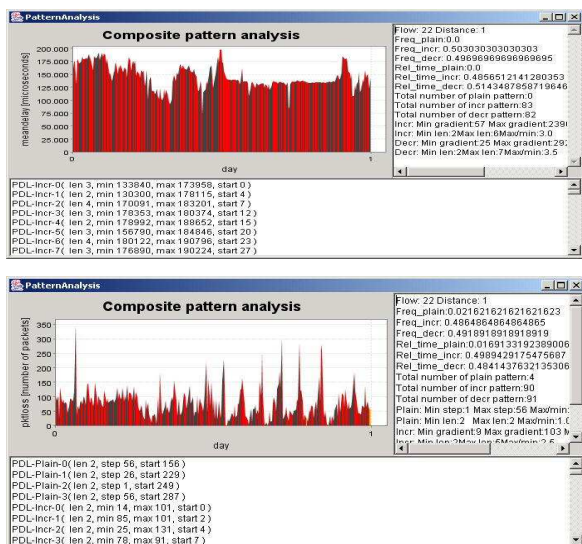
There are different pattern types which are detected and characterised to describe specific structures of QoS parameter behaviour :

- “outliers” (unexpected QoS values), given by the exceeding of some threshold values
- basic QoS parameter patterns (increase , decrease , plain) with structural descriptions including gradients, minimum ,maximum values and arithmetic mean.

The QoS parameter patterns could be obtained to describe:

- QoS parameter behaviour for specific period - a day, week, or month, which is useful for feedback in capacity planning and resource provision as well as for the tuning of application parameters according QoS parameter structure obtained for specific inter-domain connection
- Temporal QoS behaviour to describe behaviour in a specific time interval where some problem is encountered, as for instance to describe a QoS behaviour structure related to the BGP-4 heuristics, traffic or inter-domain QoS behaviour.

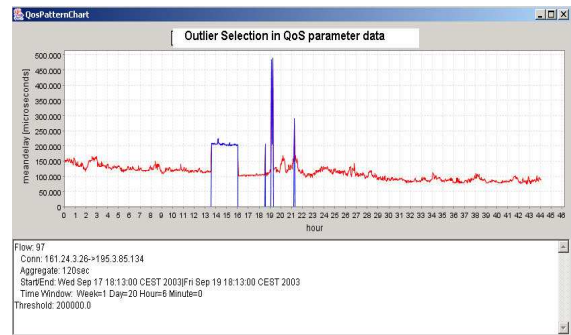
The following figure shows mean end-to-end delay and packet loss QoS structures obtained for daily periods on Transatlantic connection between Salzburg Brazil.



**Figure 6: Usage of patterns for description of QoS parameters in specific periods**

Obvious in the behaviour of the two QoS parameters is the “turbulent” structure which is due to inter-domain connection topology. The QoS patterns obtained for these inter-domain connections are measured in 1 sec interval to obtain fine grained patterns for assessment of congestion and topology impact.

In figure 6 other measurement results are shown in which QoS “outlier” patterns are extracted for further investigation. QoS “outlier” are detected based on selection of QoS parameter values exceeding some threshold provided by the experienced network engineer.



**Figure 7: Extraction of QoS “outlier” patterns**

The detected QoS “outlier” pattern could be compared with BGP-4 Update and border router traffic patterns to study the causes of the “outlier”.

**6. Conclusions and further work**

The interaction of tools for network topology discovery, analysis of traffic characteristics based on passive router measurements and active end-to-end QoS measurement is an important dynamic monitoring concept for more exact understanding of the QoS behaviour in Internet based on automation, which is still to be further explored in realistic scenarios. Considering our previous studies on inter-domain QoS dependencies using different independent tools and strategies [11], we could conclude that the policy based management of integrated QoS monitoring tools for provision of specific scenarios is powerful concept supporting on efficient way the work of the network engineer.

We believe that it will be easier to understand the QoS characteristics of inter-domain connections, the spatial impact of routing and router traffic causes and behaviour rules using patterns, e.g. time series data sequences with well defined structure of different types (QoS parameter data, router traffic, BGP-4 updates sequences), which are related spatially and temporally. Considering syntax and

semantic of related patterns describing different time series data, we hope to move toward a more precise study of system-wide effects in large scale Internet networks.

## 7. Acknowledgement

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