INTERMON architecture for complex QoS analysis in inter-domain environment based on discovery of topology and traffic impact

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Abstract

Quality of Service (QoS) analysis in inter-domain environment based on discovery of effects of topology and traffic on end-to-end QoS parameter is a feature of the advanced inter-domain QoS analysis architecture, developed in the framework of the European IST Project INTERMON (see [1]).

INTERMON is based on interaction and coordination of different kinds of tools - topology discovery, traffic monitoring, QoS measurement, modelling, simulation and visual data mining – with access to a common data base. Using tool and data base integration, INTERMON architecture supports the study of the QoS parameter behaviour dependent on the inter-domain topology changes, border router traffic and BGP-4 protocol patterns.

The paper describes the main concepts of INTERMON architecture focussing on flexible interaction mechanisms for automated processing of collected inter-domain topology, QoS and traffic monitoring data by modelling, simulation and visual data mining tools.

To show the application areas of the INTERMON architecture, scenarios considering their integration in management strategies for QoS analysis in inter-domain environment are discussed.

Particular usage of the architecture is illustrated based on an example scenario for study of topology and traffic effect on the end-to-end QoS parameters involving real world QoS measurements.

1. Introduction

There are different studies considering the QoS parameter dependencies in inter-domain environment, particularly focussed on:

- Effect of inter-domain routing and BGP-4 protocol behaviour on QoS parameter values (see [5], [6], [7] and [8]).

- QoS parameter behaviour dependent on the link failures (see [9]).

- Traffic and congestion impact on the QoS of applications (see [16]).

Such researches have shown that for better understanding of QoS behaviour in the inter-domain environment, complex QoS monitoring and modelling technologies are needed, including topology discovery and traffic monitoring tools for study of QoS dependencies.

Therefore, the novel idea of the INTERMON architecture ([1]) is the automated tool interaction and data base integration to support the complex QoS analysis in the inter-domain environment. Similar to the macroscopic global Internet QoS and topology analysis forced by CAIDA ([10] and [11]), INTERMON is aimed to integrate tools for efficient QoS data mining in inter-domain Internet environment considering traffic, topology changes, link failures and event behaviour.

“Data Mining is an extension of exploratory data analysis and has basically the same goals, the discovery of unknown and unanticipated structure in the data” [4]. In case of INTERMON, this means supporting the network engineer in the discovery of the impact of topology and traffic on the „unknown“ and „unanticipated“ structures, i.e. patterns [21], in the behaviour of end-to-end QoS parameters in inter-domain environments.

From data mining point of view, the goal of the INTERMON architecture [3] is to build a configurable measurement, modelling and simulation environment for spatio-temporal QoS analysis in inter-domain environments focussing of impacts of topology, BGP-4 protocol and traffic patterns. This involves methods, tools and algorithms for efficient and automated processing of large measurement databases considering following approaches:

- Dynamic QoS monitoring based on integrated topology discovery, QoS and traffic measurement tools with common data base access to provide information for solving of specific inter-domain QoS analysis tasks, as for instance in the area of spatio-temporal dependency detection [8] and network tomography [12].

- Pattern technology to describe QoS behaviour in more understandable structures, i.e. "patterns", for different kind of analysis (e.g. "linear approximation" of time series data [26] for capacity planning, "outliers" [25] for fault management) and to detect causes for QoS behaviour based on dependencies of multivariate time series data of QoS parameters, border router traffic, BGP-4 protocol updates and traceroute topology data records [3].
- Integration of modelling and simulation technologies with measurement and topology discovery tools using common databases leading to "automated measurement based modelling and simulation" ([13], [14], [15]) to provide "what if" analysis.

This paper will systematically explain the background for QoS analysis in INTERMON focussing on interaction on tools and databases to provide complex QoS analysis scenarios. Solving of management tasks in inter-domain environment using INTERMON architecture will be discussed. Scenario based on tool interactions will be demonstrated by practical measurements.

2. INTERMON architecture for complex QoS analysis in inter-domain environment

2.1 QoS analysis in inter-domain environment based on study of topology and traffic impact

INTERMON architecture contributes to end-to-end QoS analysis in inter-domain environment considering the effect of the inter-domain topology and traffic behaviour.

INTERMON was designed as integrated monitoring, modelling, visual data mining and simulation architecture for end-to-end QoS analysis based on large measurement data bases using combination of active QoS and passive traffic monitoring tools. For this purpose, the ideas of CAIDA Macroscopic Internet data collection and analysis project ([10] and [11]) integrating visualisation and automated analysis of measurement data by modelling tools were taken into consideration.

The initial objective of INTERMON QoS analysis was to study spatial composition of end-to-end QoS parameters in inter-domain environment considering the impact of border routers. The requirements to detect spatio-temporal dependencies of the end-to-end QoS parameters are leading to the design of integrated QoS database for end-to-end QoS parameter, inter-domain routing data (i.e. BGP-4 Updates related to the end-to-end connections) and border router traffic data. Combining the integrated measurement tools with appropriate modelling approaches could be used to solve different QoS analysis tasks for inferencing of performance data in inter-domain environments.

In INTERMON, the focus of end-to-end quality study considering inter-domain impact, is leading to the integration of active end-to-end QoS measurement and topology discovery technologies, e.g. CMToolset [18], with passive tools for inter-domain topology discovery based on BGP-4, such as InterRoute [12] and tools for traffic collection at border router, using MRCollector [1] and IPFIX traffic flow meter [19]. The purposes of the integrated tools detecting causes for QoS behaviour are:

- Topology discovery tools aimed at detection of the inter-domain routing impact on the end-to-end connection, topology changes, alternative topologies and inter-domain route quality (misconfiguration, policy violations, route flapping, etc.).
- Traffic measurement tools used at the border router to obtain the impact of the traffic load (resource utilisation) on the end-to-end QoS.

Particular aim is, that INTERMON technology should be able to support on efficient way the inter-domain QoS monitoring and analysis for Quality enabled applications like Voice over IP (VoIP). VoIP is a notion for a wide range of real time applications for transportation of voice data over Internet using different protocols and encoding schemes ([23]). Measurements done at different time scales are able to provide specific insight in performance as required by the application. For instance, quality of VoIP could be impacted by short-term congestion, which could be detected by fine-grained intervals (see [16]). This is addressed in INTERMON by usage of active QoS monitoring, emulating application behaviour and measuring QoS dependent on application demand, on this way capturing the possible impacts of traffic and topology on the QoS behaviour in the required time scales.

Summarising main QoS analysis approaches in INTERMON:

- Automated detection of impact of topology and traffic on the QoS parameters based on interaction of measurement, monitoring and topology discovery tools using common database to obtain spatio-temporal relationships of topology, traffic and QoS behaviour ([12]). This allows discovering dependencies of QoS parameter, traffic and topology using time series data.
- Modelling abstractions based on patterns allowing discovery of structures and dependencies of multivariate time series data (QoS parameter, traffic, topology) using heuristics and appropriate description techniques ("linear approximation"). Spatio-temporal QoS pattern analysis studying QoS patterns of end-to-end connections dependent

on "heuristics" for specific sequences of BGP-4 Updates and traffic patterns at intermediate border router is aimed to discover causes of the QoS behaviour.
- "Measurement" based simulation technologies using integration of inter-domain topology and traffic to study impact on QoS using "what if" analysis ([13], [14], [15]), i.e. usage of different simulation abstractions to study the behaviour of QoS parameters considering heuristics and patterns for inter-domain topology and traffic behaviour.

The approaches included in the INTERMON inter-domain QoS analysis are shown in the figure 1:

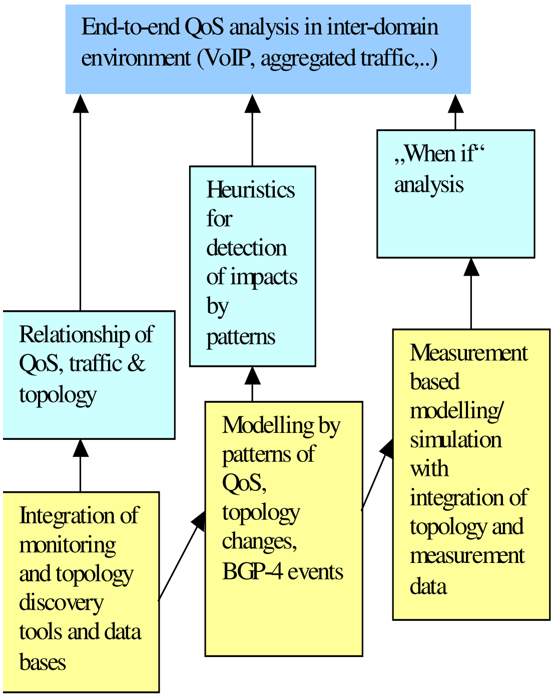


Figure 1: QoS analysis approaches in INTERMON

2.2 INTERMON integrated architecture

The main focus of INTERMON is the integration of tools supporting related tasks for QoS analysis in inter-domain environment including BGP-4 protocol behaviour and connection topology discovery, QoS and traffic monitoring, modelling, simulation, data mining and visualisation with common data base access.
The following picture shows the INTERMON toolkit architecture focussing on different functions required for QoS analysis in inter-domain environment and tools developed by INTERMON for their fulfilment:

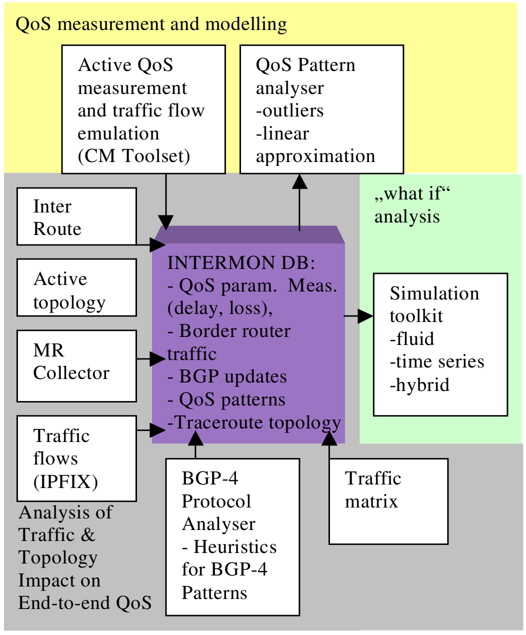


Figure 2: INTERMON integrated architecture for inter-domain QoS analysis

The technology based on INTERMON toolkit combines the automated collection of monitoring data (inter-domain topology, QoS, resources and traffic) with policies for their modelling, simulation and visual data mining, which are implemented in form of interaction mechanisms.
The role of the different tools included in the INTERMON architecture for understanding the QoS in inter-domain environment is briefly overviewed in the following table:

Function and Tool		Role in the analysis of inter-domain QoS
QoS Measur. & Analysis	**CM Toolset**	Active QoS parameter measurements by emulation of application traffic and storage of QoS parameters in a data base
	QoS Pattern analyse	Extraction of time series data sequences dependent on: - Events (topology changes, failures). - Periods (hour, day, week). - Usage of linear approximation for QoS parameter description by structure abstraction (increase, decrease, outlier, plain, etc).

Topology discovery & Analysis	**Inter-route**	- Filtering of BGP-4 protocol updates for border routers involved in the end-to-end connection from common inter-domain route data repositories. - Heuristics for detection of BGP-4 Update patterns impacting inter-domain QoS and traffic behaviour. - Calculation of alternative inter-domain routes for the end-to-end connection.
	Conn. Trace Route	Active topology detection of end-to-end connection for given time interval based on traceroute
Link config. & failure	**MR Collect**	Detection of border router configuration parameter (bandwidth) and failures of system
Traffic Measur. & Analysis	**IPFIX traffic**	Accounting of traffic flow classes of border router
	MR Collect	Border router traffic load measurement
	Traffic matrix	Volume (aggregated) traffic per source/destination Traffic flow class per source/destinations
Simulation („what if“) based on inter-domain topology and traffic	**Fluid**	Rate based simulation using differential equations considering inter-domain traffic and topology
	Hybrid	Packet based simulation with analytical QoS and traffic models derived from measurements
	Time series	Inter-domain time series data simulation technique

Table 1: INTERMON tools and their purpose in the system

3. Overview of Scenarios for complex QoS analysis in inter-domain environment using INTERMON

The INTERMON complex QoS analysis in inter-domain environment is aimed at enhancing the work in the area of:

- Inter-domain QoS/SLA monitoring,
- Assessment of network connection infrastructure (i.e. network QoS) for Quality based applications,
- Inter-domain connectivity analysis and fault detection
- QoS modelling and planning in inter-domain environment
- Causal behaviour study of QoS, topology and traffic.

Policy based control is a main design concept of the INTERMON toolkit allowing the flexible selection, configuration and usage of tools included in the architecture for provision of a particular scenario.

INTERMON architecture is aimed at scenarios focussing on end-to-end performance study in inter-domain environments. Figure 3 shows an example for an end-to-end scenario in inter-domain environment based on alternative inter-domain topologies, for instance in the multihoming case (see [24]).

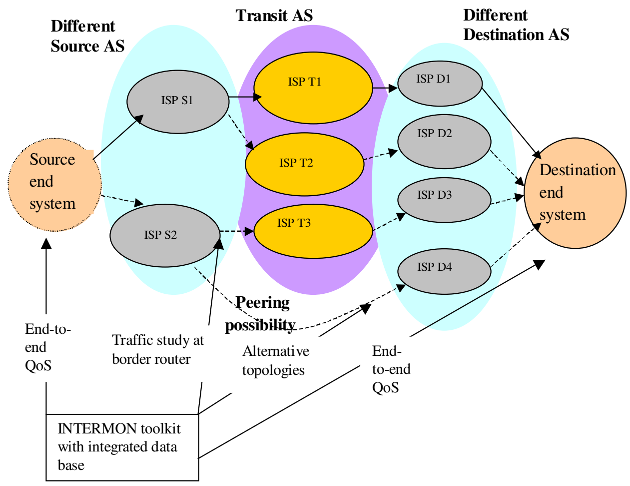


Figure 3: End-to-end scenario based on alternative inter-domain topologies

Example of scenarios, which use the benefits of automated INTERMON tool interaction and common data base access, are:

- *Complex proactive monitoring for QoS/SLA validation and analysis considering topology.* This scenario is based on integrated active monitoring of QoS parameters (CMToolset) and topology (traceroute) of the end-to-end connection. It allows obtaining the dependency of the QoS parameter behaviour on the connection topology.
- *Assessment of the ability of inter-domain connections to provide QoS requirements of Internet applications.* QoS based applications, for example VoIP, have well-defined QoS requirements to the network, which could be described in form of network QoS parameter patterns. QoS patterns describing outliers that describe abnormal QoS behaviour of network are object of interest, as well as periodical patterns

describing the QoS behaviour in specific time periods (daily, hourly patterns). The spatio-temporal pattern analyser in combination with the connection topology data (traceroute) is used to detect the QoS parameter patterns of the inter-domain connection, according the appropriate application layer quality. The derived patterns are used to assess the ability of the network connection to support the QoS based applications.

- *Reactive monitoring for detection of the impact of inter-domain routing events and anomalies) on the end-to-end QoS.* The usage of InterRoute in INTERMON allows discovering patterns of BGP-4 protocol behaviour (route misconfiguration, policy violation, route change due lack of topology info, etc.), which are explained with heuristics allowing detecting the impact of BGP-4 protocol on the QoS and traffic. The QoS patterns, obtained by the spatio-temporal analyser for the end-to-end connections, are related to the BGP-4 Update patterns, to consider the inter-domain routing impact on the end-to-end QoS.
- *Link failures and their impact on the QoS.* The end-to-end connection QoS can be impacted by border router, core router or edge router failure. Using traceroute connection monitoring or MRCollector, it is possible to detect the exact cause of the failure and to relate it to the QoS parameter pattern, which could be extracted by the Spatio-temporal pattern analyser for the time interval of the failure.
- *"What if" scenarios for inter-domain QoS analysis based on the integrated INTERMON simulation environment.* Automated inclusion of alternative inter-domain topologies (obtained by InterRoute), border router traffic (monitored by IPFIX meter), border router resources (discovered by MRCollector) and QoS patterns describing links (obtained by Spatio-temporal QoS pattern analyser) support efficient measurement based simulation which could be done in "real time" manner dependent on the interaction policies of simulation and measurement tools.
- *Capacity planning (e.g. bandwidth resource allocation at the border router) considering QoS patterns for specified periods (hourly, daily).* QoS measurements are important for optimal bandwidth planning – in case of congestion (e.g. QoS parameter patterns exceeding some threshold level), the resource management at the border router should schedule the allocation of new resources for later periods. The reinforcement learning strategies for optimal bandwidth allocation as discussed in some scenarios (see, e.g. [17]) could be adapted considering periodical QoS behaviour patterns obtained by linear approximation for the purpose of QoS and resource planning.

4. Discussion of an example scenario

Service Level Agreements (SLA), or generally speaking, QoS provision in inter-domain environments is highly dependent on topology changes.

The INTERMON tool interaction is used to study the topology behaviour for a specified period and obtain QoS patterns, which characterise the particular topologies for forecasting and planning purposes.

Topology discovery could be based on interaction of two technologies:

- *Topology discovery with InterRoute that is applied to study the changes of the inter-domain topology of the end-to-end connection, as well to the discovery of the alternative inter-domain topologies.* InterRoute is able to detect topology changes based on BGP-4 Updates sent to border routers, contributing to public route repositories (i.e. RIPE-NCC [20]). The usage of the approach is limited by the content of the public available data, but it can be overcome if a provider using the INTERMON toolkit sets up a RIPENCC-like private route repository for his Autonomous System.
- *Active topology discovery based on the traceroute facility of the CM Toolset that is aimed at active probing and detection of the route changes of the connection.* Results are stored in a traceroute database for later dependency study. In case, that fine-grained analysis of the alternative inter-domain topologies is required, this tool obtains the hop-by-hop (i.e. intermediate router) topology and evaluates the round trip times to the intermediate routers. The topology data is stored as function of the time in the integrated database. The active topology probing impacts network performance. The used 5-minute time scale for tracing the route corresponds to the SNMP intervals for performance data collection (see [22]).

The QoS patterns discussed in this scenario are obtained for the end-to-end connection between Madrid and Salzburg, which has alternative topologies derived by the InterRoute tool.

Using additional information from traceroute data base, fine-granular analysis of the alternative topologies was possible, as for instance AS internal connectivity of core router, round trip times to the intermediate router of the connection, characteristics of the intermediate routers, etc. Figure 4 shows the alternative routes of end-to-end connection Madrid and Salzburg considering two access ISP provider with following Autonomous systems (ASs) assigned to them:

- AS 8847 is the Autonomous System providing Internet access to the sender end system.
- AS 3352is the Autonomous System providing Internet access to the receiver end system.

The intermediate ASs with their routers are shown:

- In the first topology -> AS 1239 with 9 routers.
- In the second topology -> AS 6762 with 2 routers.

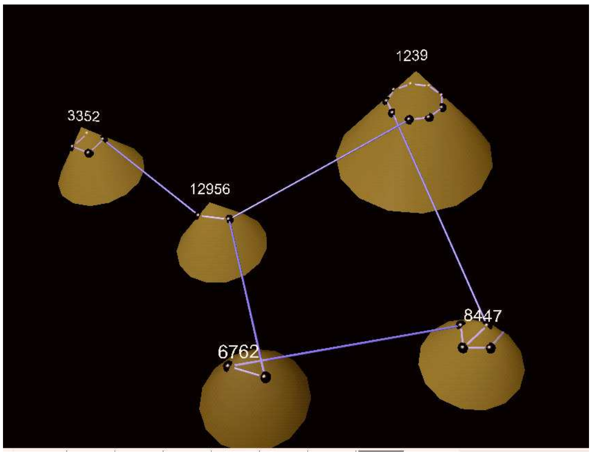


Figure 4: Alternative inter-domain topologies of the end-to-end connection Madrid - Salzburg

The particular QoS measurement scenario is aimed to support studies in the area of capacity and QoS planning based on the discovery of:

- The structure of the QoS behaviour of the end-to-end connection Madrid-Salzburg in a long time period considering periodical patterns, i.e. daily patterns and calendar effects.
- The QoS pattern behaviour for the alternative inter-domain topologies of the end-to-end connection Salzburg-Madrid.

Patterns are used to extract important structures in the QoS parameter data using linear approximation methods incorporated in the Spatio-Temporal pattern analyser (see [3]).

This allows describing QoS parameter structures on simple and efficient way in order to support abstractions of QoS parameter data for QoS planning and management purposes. In particular, the following analysis are used:

- Basic patterns (increase, decrease and plain) and their composition focussing on their frequencies and statistical descriptions (gradients, mean values, etc.).
- Outlier study, statistical analysis of QoS structures, which describe abnormal or unacceptable QoS behaviour for applications.

Figure 5 shows end-to-end mean delay for different topologies of the end-to-end connection. It contains two pictures with delay patterns obtained for an aggregate traffic of 64 Bytes/sec:

- (1) End-to-end mean delay in case of topology over AS 6762.
- (2) End to end mean delay for topology over AS 1239.

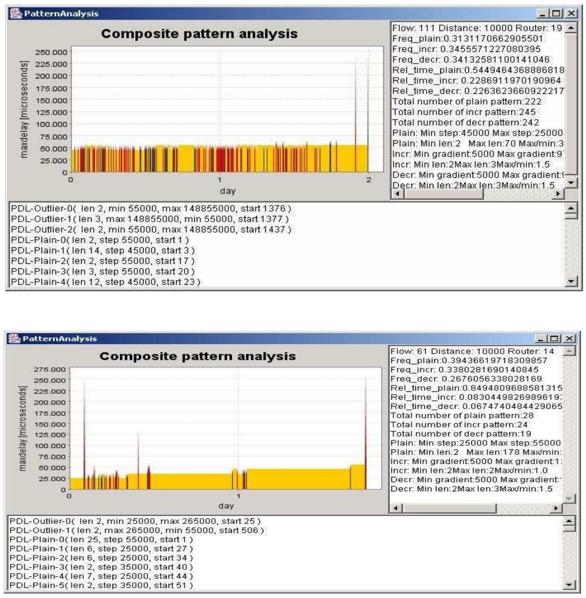


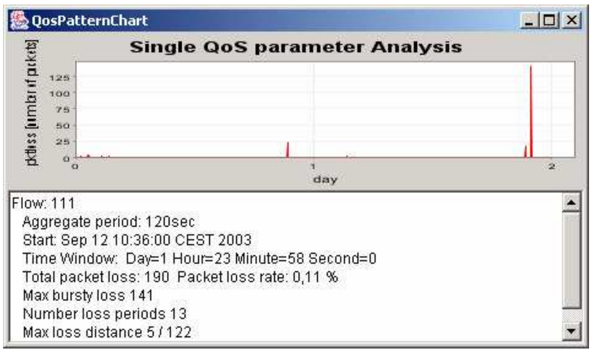
Figure 5: End-to-end delay for different inter-domain topologies of the connection

Setting the parameters of the linear approximation of 10 ms, we could abstract from the details in the delay.

The QoS pattern structures are similar in the two topology cases – increasing and decreasing patterns with slow rate (small gradients), basically plain structures and 1-2 outliers which has very small duration.

The difference of the QoS behaviour in the two inter-domain topologies is the mean value of end-to-end delay which is approximately 20 ms.

Figure 6 shows packet loss behaviour for the two topologies based on daily patterns:



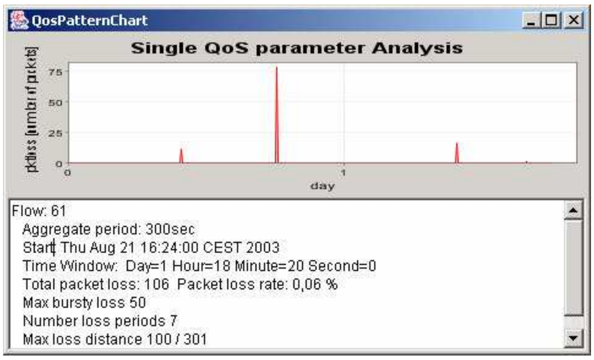


Figure 6: Packet loss for alternative inter-domain topologies of the end-to-end connection

The behaviour is similar characterised with small frequency of packet loss bursts. The conclusion is, that the alternative inter-domain topologies support in similar way the QoS with small differences in the mean end-to-end delay. Such result is useful for capacity planning; showing normal delay behaviour of the alternative inter-domain topologies of the end-to-end connection with no congestion.

5. Conclusion

This paper was focused on INTERMON technology based on automation of facilities for measurement, monitoring, data mining, modelling and simulation. The features of this technology for enhanced understanding of end-to-end QoS relationships are addressed.

Based on tool interaction and common database, end-to-end QoS analysis scenarios for inter-domain environment are discussed. The approach of the automation of inter-domain analysis could be further enhanced for “causal” studies in inter-domain environment based on applications using the INTEMON integrated databases.

Future possibilities to use the INTERMON architecture are in the area of QoS planning, traffic engineering, fault management, and network tomography (see [18]).

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