Analysis of end-to-end Quality of Service behaviour in inter-domain environment

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Abstract

This paper is focussed on Quality of Service (QoS) analysis of applications in inter-domain environment using different monitoring tools in "policy" based manner to study the impact of specific performance factors such as inter-domain routing and topology on the end-to-end QoS. Integration of active end-to-end QoS monitoring with topology probing and discovery is discussed in order to evaluate the influence of routers (border router, core and egress) and Autonomous systems of the inter-domain path on the end-to-end QoS behaviour.

A inter-domain scenario for study of end-to-end QoS was established between Austria (Salzburg) and Spain (Madrid). Based on real world QoS and topology measurement data obtained for this scenario, dependencies of end-to-end QoS on inter-domain topology are shown.

Keywords: inter-domain topology and routing, end-to-end QoS analysis, multivariate QoS time series data

1. Introduction – inter-domain topology and routing impact on QoS

Inter-domain routing and topology behaviour has a crucial impact on the end-to-end QoS of applications in inter-domain environment.

Internet Service Providers (ISPs), corporative users and customers as well as application service providers need tools to analyse and verify the inter-domain provision of the end-to-end QoS, i.e. how the end-to-end QoS parameters are impacted by the QoS provided by the different Autonomous Systems (AS) and routers on a given path along the Internet.

Monitoring concepts for policy based QoS analysis in order to study the impact of inter-domain routing and topology (failures, changes, etc) on end-to-end QoS are important in order to verify SLAs and to evaluate spatio-temporal QoS provision of applications in the inter-domain environment.

It is already well known that inter-domain route characteristics greatly influence the end-to-end performance and should be considered for inter-domain QoS studies and SLAs specifications. Some inter-domain route characteristics are:

- Availability of inter-domain routes [LWF 00], i.e. availability of a given default-free route is the period of time that a path to the network destination, or a less specific prefix, was presented in the provider's routing table.
- Route failure is the loss of a previously available routing table path to a given network, or a less specific, prefix destination.
- A failover of a route represents a change in the inter-domain path reachability of that route. Specific inter-domain policies and topologies could impact the speed of routing failover.

In many actual researches is shown, that BGP-4 convergence, inter-domain routing policies and misconfigurations, route flap damping and inter-domain routing overhead, are important factors impacting the end-to-end QoS .

BGP-4 message updates [CBD 02] could increase the traffic (routing load) and cause route instability. Many BGP speaking routers are already heavily overloaded due to the rapid growth of the Internet.

Being a path vector protocol, BGP limits the distribution of a router's reachability information to its neighbour routers. A large number of temporary routing table fluctuations (also known as route flaps) may be generated in response to a single link failure, change in AS topology or change in routing policy. In such cases, BGP-4 convergence times will limit the network's ability to perform quick route repairs, cause additional delay, and thus degrade the end-to-end QoS (drop packets and increase delay).

In addition to delaying the route selection process, route flapping can cause rapid changes in network reachability. Such a situation is called routing instability. Route is considered stable if it lasts at least tens of minutes. Routing instability consisted of pathological updates, not reflecting actual network topological or policy changes could be due to software and hardware bugs.

Griffin et al ([GW 99], [PGWR 00]) have shown analytically that BGP-4 will not converge stably or is only meta-stable (i.e. will not reconverge in the face of a single failure) when certain types of policy constraint are applied to categories of network topology. The addition of policy to the basic distance vector algorithm invalidates the mathematical proofs that apply to intra-domain routing, i.e. RIP protocol.

Policy misconfigurations violate the intended policy of the ASs, causes route instability, increase the load on the routing system by inserting spurious prefixes in the global BGP tables, and more importantly, by generating unnecessary updates to be processed by other BGP speakers. Origin and export types of inter-domain routing misconfigurations are studied in [MWA 02].

Misconfigurations can disrupt connectivity, either partially (from some parts of the Internet) or globally (from everywhere) or remotely (in some innocent third party), because incorrectly leaked prefixes can be chosen over intended routes, and transit can be inadvertently provided to other ASes.

The above described impact of inter-domain routing and topology on performance should be considered for policy oriented QoS analysis of applications in the inter-domain environment using dedicated monitoring environments.

In this paper, an integrated end-to-end QoS measurement and inter-domain topology discovery environment for detecting QoS dependencies on routing and topology is discussed based on practical deployment. The technology is used in a real scenario between Austria (Salzburg) and Spain (Madrid) and the results are presented.

The paper is organised as follows. Chapter 2 presents the monitoring environment for end-to-end QoS studies considering inter-domain topology behaviour. Chapter 3 describes the practical inter-domain QoS measurement scenario and describes the results of the QoS analysis. Chapter 4 is aimed at conclusions and further work.

2. Monitoring environment for end-to-end QoS studies considering inter-domain topology impact

The aim is to study the end-to-end QoS in inter-domain environment, concentrating on the impact of inter-domain topology and routing, and the QoS provided by the autonomous systems along the inter-domain path.

The experimental measurement environment is based on integration of active QoS monitoring and topology discovery tools:

- End-to-end QoS monitoring based on active probing with CM Toolset (with an interval of one second between QoS probes) and
- Topology discovery based on traceroute (with active probes sent in 10 minutes intervals).

The QoS monitoring in 1 sec interval is chosen to allow possible detection of QoS behaviour changes in precise intervals. Considering that the topology changes in inter-domain environment should take longer than this interval, this setup should allow us to detect topology changes and correlate them to the QoS time series data.

The QoS of the aggregated traffic of the inter-domain connection (Salzburg, Madrid) was monitored with the CM Toolset, an agent based QoS monitoring tool for application flows. [AQUILA], [MH 01], [SDH 01}, [HMSP 02].

NTP clock synchronisation was used to assure the accuracy of the end-to-end delay measurements.

Figure 1 shows the end-to-end connection in the inter-domain environment including the autonomous systems (inferred from the DNS information provided by traceroute) between the measured end systems (CMToolset client and server).

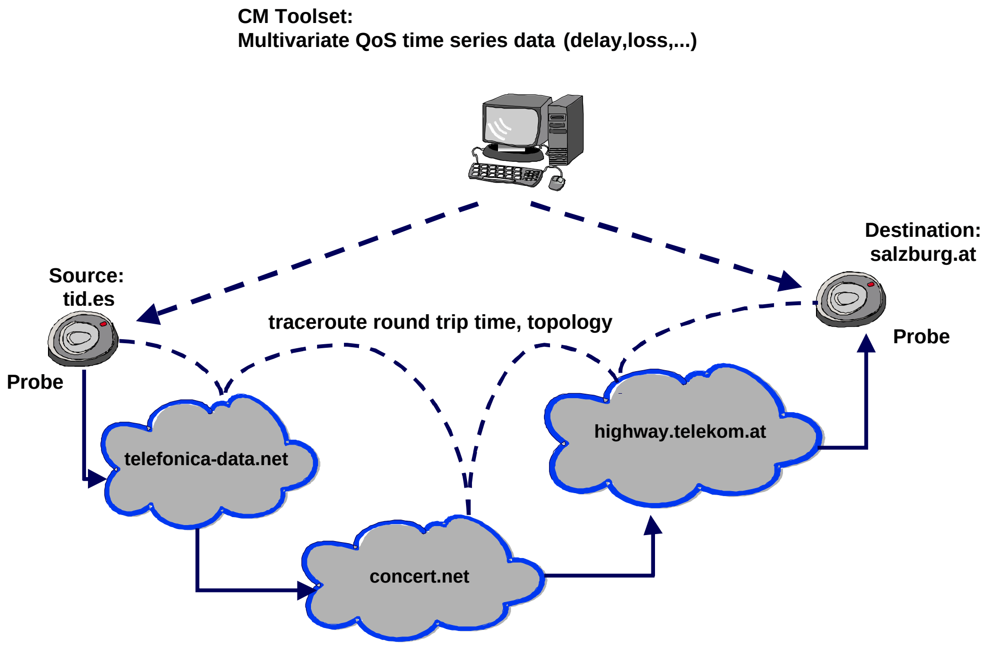

Figure 1: End-to-end QoS measurement scenario in inter-domain environment

In this scenario, the end-to-end path involves 3 Autonomous Systems between the server and receiver, the one of them is the access router of the customer network.
Using traceroute, we were able to study the impact of the border and core routers on the end-to-end performance and capture topology changes.
The end-to-end QoS information was provided as a multivariate QoS time series with 1 second measurement interval.
Using data mining techniques, it was possible to filter this data on a minute, hourly, daily and weekly time scale basis, i.e. to obtain QoS parameters for each of these periods, in order to detect the impact of inter-domain topology and routing on end-to-end QoS provision in this inter-domain environment for different time scales.
Traceroute was not only used as topology discovery tool to detect topology changes, but also to discover spatial QoS composition based on round trip time estimation to the different routers in the path.
The round trip time information of the end-to-end connection was filtered per border, core and egress system routers in order to discover the topology impact on the QoS data, particularly the border and core router of Autonomous systems, egress router and end-to-end systems.
The round trip time estimation data obtained with the topology discovery is important for evaluation of QoS of inter-domain applications using TCP as well as bi-directional communication applications such as request response and transactions.

3. Discussion of measurements and results

3.1. Measurement data

During one week, the measurements for the QoS studies of the end-to-end services in the inter-domain environment were done and stored in multiple data sources:

- CM Toolset data base for collection of multivariate time series data of QoS parameters describing end-to-end behaviour
- Topology data set including the round trip times to the intermediate routers (border, core, access) of the inter-domain path as output of traceroute.

The usage of multiple data sources for QoS analysis is a part of the INTERMON [INTERMON], [PMHN 03] "open" data base concept. This concept is based on a XML interface to the different data base sources for integrated inter-domain QoS and traffic visual data mining.

3.2. QoS studies in inter-domain environment

The focus of the QoS analysis in the inter-domain environment is:

- Analysis of behaviour of multivariate time series data of end-to-end QoS parameters in the inter-domain environment
- Study of inter-domain QoS "outlier" patterns, i.e. multivariate QoS behaviour in case of topology and routing change

3.2.1. Multivariate QoS data behaviour of end-to-end traffic in inter-domain environment

Multivariate QoS studies are aimed to discover dependencies of time series data describing QoS parameters obtained in the same intervals.

The multivariate end-to-end QoS data analysis in the inter-domain environment is aimed to investigate dependencies of:

- parameters characterising differently some QoS aspect like loss and end-to-end delay. For instance, QoS information on the end-to-end delay could be obtained in the form of minimum, mean and maximum end-to-end delay. The packet loss could be expressed as packet loss, bursty loss, maximum loss distance, number of loss periods.
- different kinds of QoS parameters – end-to-end delay , loss, throughput.

Figure 2 illustrates the mean and maximum delay behaviour.

As it is seen the behaviour of the maximum delay of the end-to-end connection in the inter-domain environment is characterised with more variations than the mean delay behaviour.

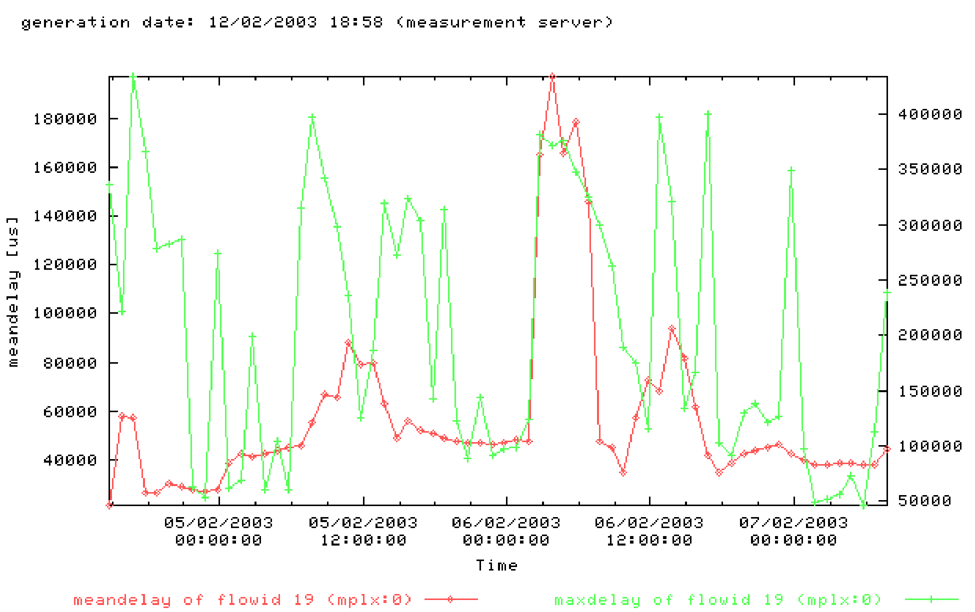

Figure 2: Multivariate QoS behaviour of end-to-end traffic – mean and maximum delay

Figure 3 shows the behaviour of two kinds of QoS parameters in the end-to-end environment - the packet loss and end-to-end mean delay.

We see in nearly periodical intervals there are dependencies of maximum delay and packet loss. The maximum delay is increasing and combined with packet loss.

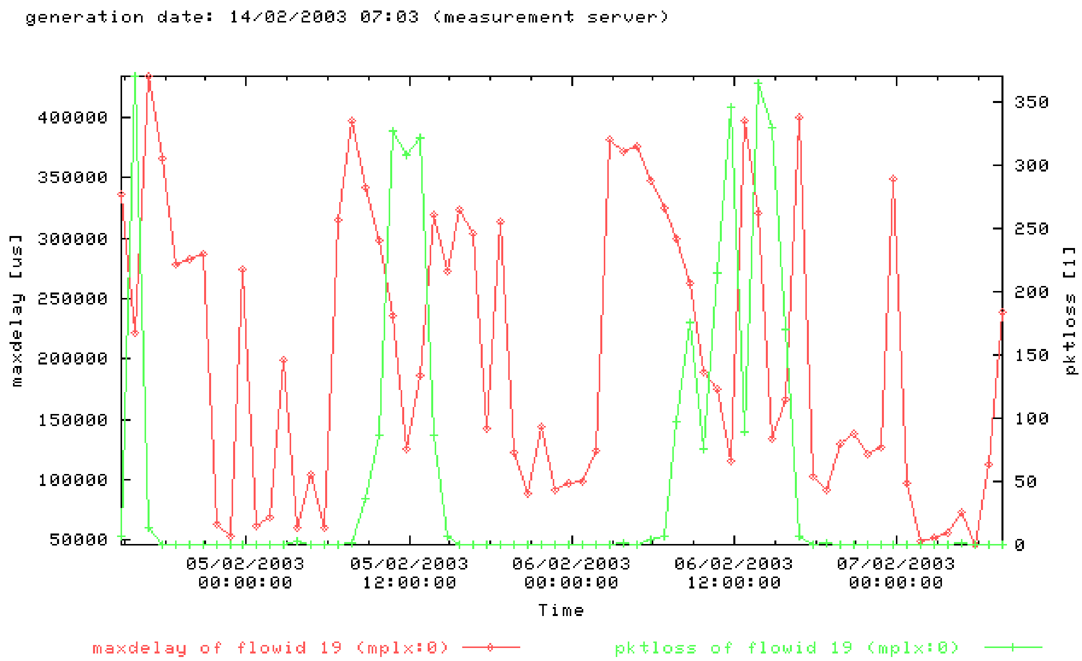

Figure 3: Behaviour of two kinds of QoS parameters - the packet loss and maximum delay

3.2.2 Study of „outlier“ patterns of end-to-end QoS in the inter-domain environment

For QoS studies, planning and forecasting should be considered that the most real-world time series QoS measurements contain outliers, that is, extreme fluctuations due to rare and anomaly events [BID 02],[YSJ 00].

Outliers are identified with specific QoS pattern which reflect QoS behaviour due to abnormal events and exceptions, such as network anomalies and crash, Denial of Service Attacks, inter-domain behaviour due to misconfigurations, topology changes, etc.

There are different ways to identify QoS outliers:

- compare multivariate QoS time series data which have specific behaviour
- to study dependencies of multivariate categorical time series data – for instance QoS parameter and topology data (in our case traceroute outputs).

Figure 4 shows a possible QoS outlier considering multivariate QoS time series analysis – mean delay and packet loss.

We see very specific behaviour of packet loss and mean delay in the last part of the picture (6.02.2003) – after mean delay is growing , i.e. reaching a “peak” value, than there is a long period packet loss followed by a mean delay which changes its behaviour .

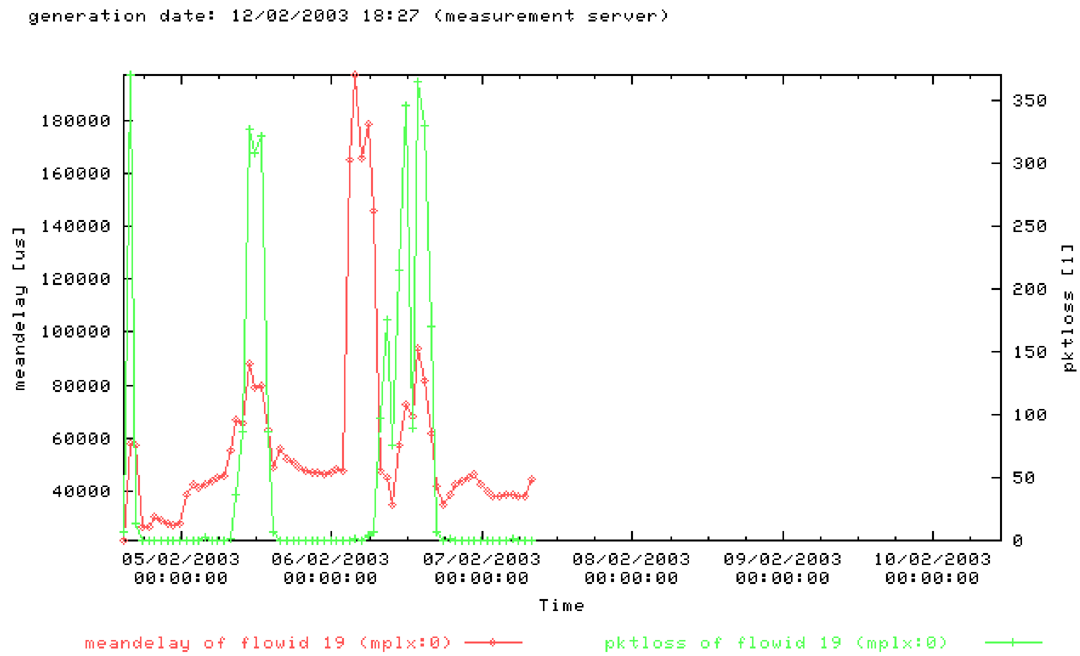

Figure 4: Multivariate QoS analysis for outlier detection – mean delay and packet loss

This pattern could be caused by topology change. To discover the topology impact, further multivariate QoS dependency in this period is shown in figure 5.

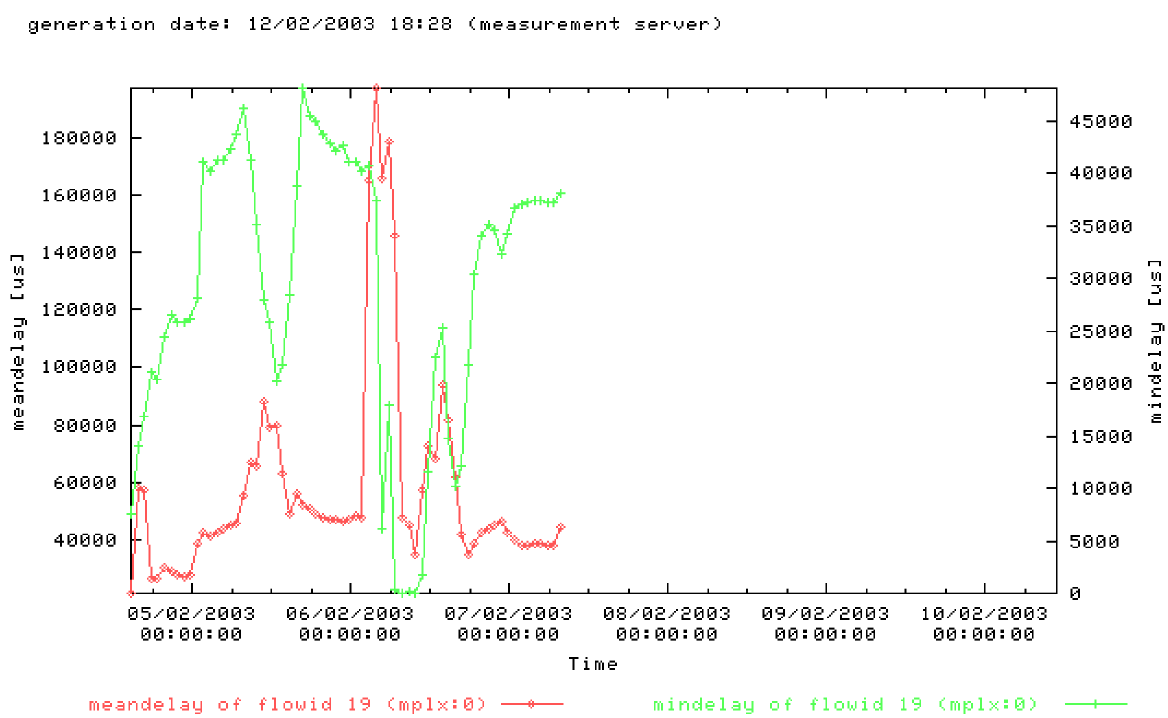

Figure 5: Multivariate QoS time series analysis for outlier detection – mean delay and minimum delay

What is expected in the most research articles [PMFT 02] that the minimum delay has a stable behaviour reflecting the propagation delays.

When some router(s) of the end-to-end path have system problems there are overloaded or are busy with BGP-4 routing tasks or topology changes, they can not process in the given interval the arrival queue and minimum delay is increasing. This behaviour is illustrated in figure 5.

Because of the different sources of inter-domain topology and routing troubles [GW 99], [PGWR 00], [MWA 02], [BID 02], the cause for the QoS outliers could be detected considering topology data sets. To identify the concrete source for the “QoS outlier” we have to look at the topology data in this time period as obtained by traceroute.

Because the monitoring of the topology data and QoS data was defined for different time scales , we should consider the longer scale (i.e. 10 minute for topology data discovery) and map the fine grained time scales of the QoS monitoring data to the topology data.

Indeed in this period of 6.02.2003, in which we suspected QoS “outliers” due to topology and routing troubles, we found a topology change in the core routing system of the concert.net autonomous system between 8:19 and 8:29 time. On this way we were able to identify the source for the QoS „outlier“ due to core router topology change in an Autonomous system of the inter-domain path.

The core route change of the concert.net impacts the topology of the inter-domain path – the number of the router reduced. Probably, this fact influences the mean and minimum end-to-end delay after the topology change, decreasing their values, as this is shown in figure 5.

The topology data are shown in figure 6 and 7 before and after the topology change.

Thu	6	08:19:01	CET 2003	
1	bens	ms		
2	194.179.25.1	(194.179.25.1)	2.581	ms
3	193-152-61-77.uc.nombres.ttd.es	(193.152.61.77)	13.557	ms
4	tmrro1-amrro1-2.nuria.telefonica-data.net	(213.0.249.190)	13.242	ms
5	S3-0-0-0-grtmadrr2.ri.telefonica-data.net	(213.140.50.49)	14.285	ms
6	So5-3-0-0-grtlontl3.ri.telefonica-data.net	(213.140.43.1)	46.231	ms
7	core2.uk1.concert.net	(195.66.224.108)	41.659	ms
8	t2c2-ge5-0.uk-lon2.concert.net	(166.49.208.5)	41.532	ms
9	t2c1-p8-0.it-mil2.concert.net	(166.49.164.241)	70.149	ms
10	t2c2-p2-1.it-mil2.concert.net	(166.49.164.142)	69.454	ms
11	t2c2-p0-0-0.at-vie.concert.net	(166.49.208.38)	83.115	ms
12	t2a1-ge8-0-0.at-vie.concert.net	(166.49.188.49)	82.840	ms
13	166-49-222-150.concert.net	(166.49.222.150)	75.863	ms
14	AUX3-IIX.highway.telekom.at	(195.3.68.235)	75.502	ms
15	LIX2-AUX3.highway.telekom.at	(195.3.68.169)	78.232	ms
16	LIX1.highway.telekom.at	(195.3.68.165)	78.164	ms
17	SAX2-LIX1.highway.telekom.at	(195.3.68.161)	82.552	ms
18	*	*	*	
19	*	*	*	
20	*	*	*	
21	212.183.10.180	(212.183.10.180	123.63	ms

Figure 6: Traceroute topology data before route change

Thu Feb		6 08:29:00 CET
1 bens	(10.95.1.255)	1.860 ms
2 194.179.25.1	(194.179.25.1)	2.536 ms
3 193-152-61-77.uc.nombres.ttd.es	(193.152.61.77)	13.676 ms
4 tmrro1-amrro1-2.nuria.telefonica-data.net	(213.0.249.190)	14.523 ms
5 S3-0-0-0-grtmadrr2.ri.telefonica-data.net	(213.140.50.49)	13.319 ms
6 So5-3-0-0-grtlontl3.ri.telefonica-data.net	(213.140.43.1)	41.131 ms
7 core2.uk1.concert.net	(195.66.224.108)	41.428 ms
8 t2c1-ge6-2.uk-lon2.concert.net	(166.49.208.241)	43.580 ms
9 166-49-208-194.concert.net	(166.49.208.194)	55.361 ms
10 t2c1-p6-0-0.at-vie.concert.net	(166.49.208.233)	70.335
11 t2a1-ge8-0-0.at-vie.concert.net	(166.49.188.49)	70.748 ms
12 166-49-222-150.concert.net	(166.49.222.150)	74.181 ms
13 AUX3-IIX.highway.telekom.at	(195.3.68.235)	69.065 ms
14 LIX2-AUX3.highway.telekom.at	(195.3.68.169)	72.587 ms
15 LIX1.highway.telekom.at	(195.3.68.165)	71.758 ms
16 SAX2-LIX1.highway.telekom.at	(195.3.68.161)	74.554 ms
17 *	*	*
18 *	*	*
19 *	*	*
20 212.183.10.180	(212.183.10.180)	174.276 ms

Figure 7: Traceroute topology data after core route change in concert.net AS

4. Conclusion and further work

This paper describes an integrated measurement environment and scenarios for inter-domain QoS studies with special focus on behaviour of multivariate QoS data as well as study of QoS „outlier“ of inter-domain paths. This preliminary experiment has shown the impact of the inter-domain routing and topology on the QoS of end-to-end traffic in an inter-domain environment.

The proposed monitoring environment could be used for the today providers and customers of networking services and applications interested in capacity planning and QoS provision considering access routers. A good example could be the usage in a VPN (virtual private network) management.

The research is done in the framework of European INTERMON IST project [INTERMON].

Further work will include integration of BGP-4 message analyser in order to study the impact of topology and inter-domain routing on the spatial QoS composition.

The integrated monitoring toolkit will be deployed in other European countries for inter-domain QoS studies focussed also on inferencing and estimation of QoS, i.e. inter-domain tomography [PMHN 03].

The first experimental studies of end-to-end QoS in inter-domain environment considering more European countries and cross inter-domain connections are planned in the framework of the INTERMON project.

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