Scalability Issues in Inter-domain Signalling for Establishing End-to-End QoS Aggregated Paths[1]

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Abstract

Offering end to end multimedia services, over IP multi-domains, with quality of services (QoS) guarantees, need to establish end to end paths having controlled QoS characteristics. This requires inter-domain signalling between domain managers. Scalability is a crucial issue in all multi-domain signalling and aggregation is one usual technique to reduce the amount of messages. This paper proposes an aggregation method to achieve efficient inter-domain signalling between domain network managers in order to build inter-domain QoS enabled pipes. Tradeoffs are searched between the amount of signalling reduction factor versus response time, when considering a whole chain of signalling. The proposed method is currently implemented in a research project.

1. Introduction

Complex multimedia services offered over IP based or heterogeneous networks are nowadays more and more required. A frequently encountered context is that of several networks (multi-domain) separately managed but still offering end to end guarantees quality of services (QoS)and to the users. Delivery of multimedia flows over IP based networks is one major area of investigation, still open for research. This is challenging, especially in the context of heterogeneous technologies (IP, DVB-T/S, UMTS, GSM/GPRS, etc.).

An end to end *Service Management (SM)* architecture, is necessary involving several actors such as *Service Providers (SP)*, *Content Providers (CP), Network Providers (NP) and Content Consumers (CC).*

The SM supposed here is an architectural component of an *Integrated Management System (IMS),* [12], [13], [14], [15], having as a prime objective to support end-to-end QoS based services through the integrated management of content, networks and terminals in heterogeneous networks contexts. This IMS defines an appropriate architecture for cooperation between the above business entities in order to achieve the E2E service offering to customers.

Controlling and offering end to end services in multi-domain environment requires a high amount of inter-domain signalling, between IMS domain managers inherently raising scalability issues.

Different methods are used to control the (E2E) QoS enabled paths. In large network domains, controlling each individual path in RSVP-like style is not scalable. On the other side, reservation plus admission control seems to be the only method to offer QoS guarantees. DiffServ technology is scalable but it alone cannot offer Qos quantitative guarantees. Therefore bandwidth managers (*bandwidth brokers - BB*) have been proposed to control the domain resources, [1], [2], [3], [4]. Generalization of BB concept leads to *resource domain managers*. In multi-domain environment the domain managers should inter-communicate, but keeping per/flow signalling between domain managers is still not scalable. In this paper is supposed that IMS contains domain managers able to exchange signalling between them while aiming to establish QoS enabled aggregated inter-domain pipes.

The amount of signalling is a major concern in inter-domain environment. The first method to

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significantly reduce the signalling is to signal for aggregated paths only. The second method is signalling aggregation itself, to further reduce the total volume of such messages.

This paper presents a simulation study dedicated to analyse the benefits and tradeoffs of QoS related signalling aggregation between managers of large domains. It is shown that in the context of so called "cascade model" of inter-domain peering the signalling aggregation can significantly reduce the total number of messages while still expose only a moderate increase in signalling system response time.

Some ideas developed in this study have been applied in an IST European Project ENTHRONE, [12]-[16], currently in development, having as objective to cover an entire audio-visual service distribution chain, including content generation, protection, distribution across QoS-enabled heterogeneous networks and delivery of content at user terminals.

The paper is organized as follows. Section 2 briefly discusses some previous and current related work. Section 3 introduces the Service Management framework in which our subsystem is included, presents how SLA/SLS concepts are used. Section 4 presents the inter-domain signaling problems. A simplified analysis is given in section 4 for aggregation methods used in order to reduce the amount of signaling messages. Section 5 introduces a simulation model for the inter-domain signaling system based on *Specification and Description Language (SDL)*, [17], [18]. Simulation results samples are described in Section 6, which validate the ideas proposed in Section 5. Finally conclusions are drawn in section 7 and open issues are outlined.

2. Related Work to Inter-domain Signalling

Numerous contributions (papers, projects, reports, standards, etc.) are dedicated to E2E QoS enabled services and their associated problems. Here we mention some of them having stronger relationship with our approach.

Several European IST research projects proposed and studied solutions for inter-domain QoS enabled services and resource management. AQUILA, [6], implemented a QoS-based architecture for controlling, monitoring, and accessing the resources in DiffServ networks by developing an overlay *Resource Control Layer (RCL)* over DiffServ. The scalability of signalling is assured by the special BGRP protocol (modified version of Border Gateway Protocol) used for inter-domain resource allocation. It did not consider neither the higher layer services nor business model apects such as SLAs, business processes, billing, etc.

The IST project MESCAL [11], proposed a set of *connectivity services* and *Traffic Engineering (TE)* tools to obtain quantitative E2E QoS guarantees over multiple IP domains. The approach makes distinction [7], [11], between *service* and *resource* functions and its overall system consists of: S*ervice Management (SM), TE* and *Monitoring Subsystem (MS).* MESCAL proposes a business model including SP, NP, etc. MESCAL constructs edge to edge QoS controlled pipes over mutiple domains (core domains) by using a cascaded model peering and inter-domain signalling at service management level.

A service oriented architecture is developed in IST project CADENUS [9], including functional blocks at the user-provider interface, within the SP domain, and between the SP and the NP. The CADENUS business model considers the SPs and NPs and service creation and offering process. It does not detail the resource management and TE at the network level.

In [8] an inter-domain signalling system between domain managers is presented. The managers are mapped onto Policy Based Management functional blocks: the initiating domain (customer role) is mapped onto *Policy Enforcement Poins (PEP);* the responding domain (provider) is mapped onto *Policy Decision Point (PDP).* Between them the COPS-SLS is used as a generic protocol for dynamic service level negotiation. This protocol is integrated into an overall QoS management architecture that defines a flexible building block to provide the end-to-end service level over a heterogeneous environment. The scalability issues are not discussed.

In approach [10], a central manager per domain is used with with off-path inter-DRM signaling. The main motivation to use a central approach is usage in mobile context, that is the support for anticipated handover with pre-reservations. With the DRM approach, a DRM can determine the route and reserve resources for a new access point within its domain or by contacting a neighboring DRM. While focusing on capability of such a system to integrate mobility, the scalability aspects are not discussed.

The ENTHRONE project, [12]-[16], has as its overall objective to cover an entire audio-visual service distribution chain, including content generation, protection, distribution across QoS-enabled heterogeneous networks and delivery of content at user terminals. The whole content delivery chain (CC, SP, NP, CP) is considered. ENTHRONE is also based on cascaded inter-domain peering model and constructs QoS controlled mutiple domains pipes by using inter-domain signalling at service management level. The access network part is treated separately in order to achieve E2E feature.

The work presented here is applied in ENTHRONE system.

3. Service Management Framework

The business model supposed in this paper contains the following actors (entities): *Service Providers (SP), Content Providers (CP), Network Providers (NP), Customers (CST) (e.g. Content Consumers – CC).* The SP does not mandatory owns a network infrastructure but cooperates with NPs to get connectivity services. The SP deals also with CCs.

The general architecture contains four planes, [12], [13]: the *Service Plane (SPl)* establishes appropriate SLAs/SLSs among the operators/providers/customers. The *Management Plane (MPl)* performs long term actions related to resource and traffic management. The *Control Plane (CPl)* performs the short term actions for resource and traffic engineering and control, including routing. In multi-domain environment the *MPl* and *CPl* are logically divided in two sub-planes: inter-domain and intra-domain. This allows each domain to have its own management and control policies and mechanisms. The *Data Plane (DPl)* is responsible to transfer the multimedia data and to set the DiffServ (for IP) or DiffServ like (for DVB) traffic control mechanisms to assure the desired level of QoS.

An Integrated Management System (IMS) is supposed to exist. In each entity of the business model there is an IMS component cooperating with other managers. It contains a *service management (SM)* and *resource management (RM)* components, the latter including the *traffic engineering (TE)*. The SM deals with service offering to customers and is transport independent. The TE manages and controls the intra and inter-domain resources, optimising their usage but offering desired level of QoS to the media flows.

Aggregated QoS enabled pipes are established at SM level, (based on forecasted traffic data) crossing several domains. These pipes are intended to later transport many individual flows and they are built at request of a SP willing to get connectivity services from a network provider. Each pipe belongs to a given QoS class (QoS-class denotes a specific set of transport capabilities that can be supported by the AS network). We assume a few number well known QoS classes. The dialogue between managers are finalised by establishing *Service Level Agreement/ Specification (pSLA/pSLS)* contracts between providers.

Each pSLS request contains [5], [7], [11], [12], all QoS parameters desired and necessary bandwidth. A typical list of a SLS is given in [10]. In view of ENTHRONE, a SLA template may include elements like, [7], [12]: *Resource, Scope, Type of service, Service schedule & Activation time, Application level (Traffic and Performance) requirements/constraints, Terminal capability, Content adaptation models, Connectivity/ Access, Availability Guarantees, Reliability Guarantees, Security, Billing, etc.*

The pipes associated to pSLSes are setup in advance with respect to real media flow transfer. Their scopes are from content servers access points up to regions where potential users are located. After their logical setup, the pipes are installed in the network (Diffserv, MPLS capable) through vertical signalling (e.g. via COPS protocol). This provisioning is done in each domain or Autonomous Systems (AS) in the chain, at aggregated levels, with such actions being performed infrequently.

Several domain pering models are possible in order to establish aggregated QoS enabled pipes: *hub model, centralised model and cascaded model,* [11], [12], [14], [15]. The *latter* has been selected here, as being more scalable, in terms of the amount of signalling, because (a) the SP does need to know the inter-domain routing information and (b) each NP has to discuss only with their neighbours.

After QoS aggregated pipes have been constructed, the SP may start to advertise the services to the users. Individual contracts *customer-SLA/SLS (cSLA/SLS)* between the SP and each interested customer are established and then the individual flows can use the aggregated pipe. This solution is adopted here because it avoids per flow signalling inter-domain [12], [13]. Detailed typical scenarios illustrating all containing signalling phases, are given in [12], [15].

We focus here on the overhead of inter-domain signalling when establishing inter-domain pSLSs, for cascaded model peering. A simplified analytical model is built and then a simulating model using the *Specification and Description Language (SDL)* is proposed to validate the ideas.

4. Inter-domain Signalling Aggregation

Figure 1 presents a scenario of establishing a uni-directional pSLS pipe in cascaded model peering. The request is made by SP, to build a pipe for delivery of the content from a content server CSrv to the region where CCs are connected. The requested pipe is e.g., from ingress point A32 to egress point A11.

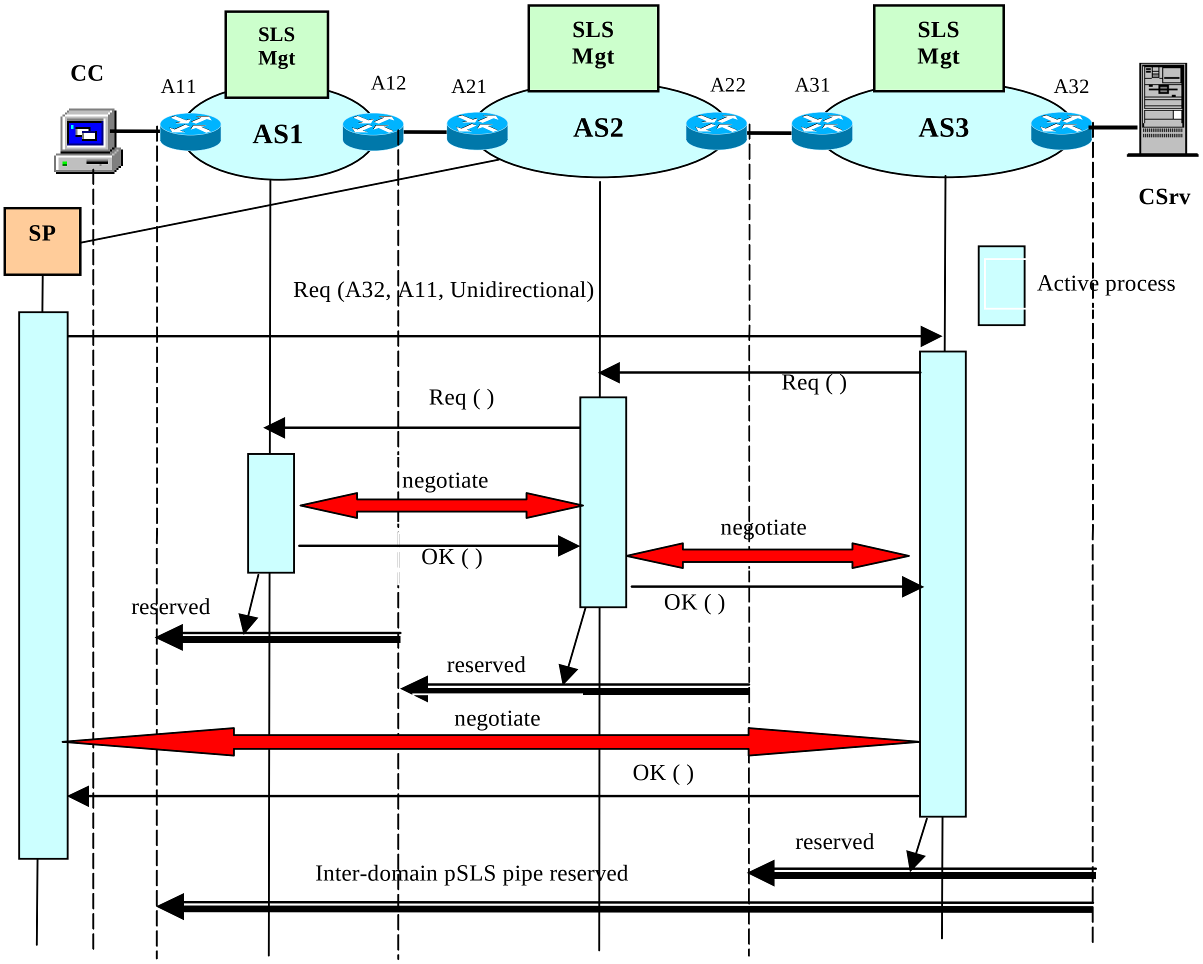
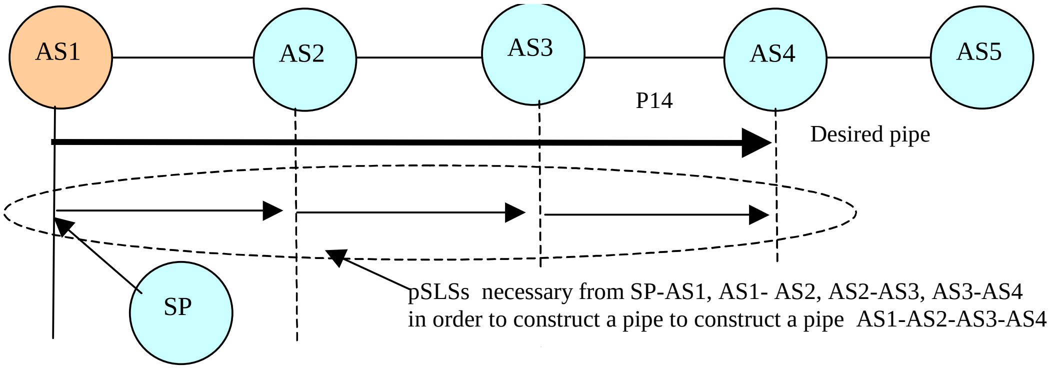


Figure 1 : Example of pSLS uni-directional pipe establishment – cascaded model- successful scenario



pSLSs necessary from SP-AS1, AS1- AS2, AS2-AS3, AS3-AS4
in order to construct a pipe to construct a pipe AS1-AS2-AS3-AS4

Figure 2 : Necessary pSLSs between adjacent ASes in order to establish a pipe AS1→ AS4

The requests and responses of the negotiation protocol are denoted in a simplified manner by Req( ) and OK( ) assuming the negotiation is successful. Negotiation can exist between entities, but are out of scope of the paper. For each pipe building such a signalling chain is necessary.

To reduce the number of messages we already used a solution: aggregated pipes. A second idea is to aggregate the pSLS requests themselves. A simple solution can be found for those pSLSs that have as target the same end of the pipe.

In order to see if pSLS aggregation is valuable, we first analyse the individual processing of pSLSs. We consider only one well known QoS class. The following notations are used:

N = number of ASes;

N_{1-k} = *no. of pSLSs* needed in order to connect AS1 to every other Ask;

N_{t1}= *no. of* pSLSs needed in order to connect AS1 to every other ASi, i=2, ..N.

Suppose we have the chain of ASes as in Figure 2 (worst case topology). We are interested by the total number of pSLS dialogues necessary to establish pipes from AS1 to AS2, AS3, … ASN. We have:

$$N_{1-k} = 1 + (k-1) = k;$$

$$N_{t1} = 1 + 1 + 2 + \ldots + (N-1) = 1 + N(N-1)/2 \sim O(N^2)$$

Therefore, for cascaded model, the *total* number of pSLSs contracts needed to construct a pipe from one AS (in most unfavourable case) is not better than for *Hub* or *centralized model* (which is is also $O(N^2)$), [14]). The cascaded model is scalable in the sense that for each transit ASj there are necessary only two pSLSs.

For other topologies the number N_t depends mainly on the topology (mesh, ring, tree, mixed) and the location of the given AS in this topology (mean length of the path from this AS to different other ASes). We have less dependence of N_t on the model Hub, cascade, centralized.

The cascaded model allows *aggregation* of requests *going to the same direction* inside a given QoS class. A problem is what pSLS should be aggregated without complicate the decision logic of negotiation. Considering the chain of signalling messages we see that a response to a request is given by an AS after it got (in its turn) the responses from the downward domains. Therefore the aggregation should be done in such a way that allows a collective response to several requests. That is why we propose to aggregate in each node (AS) those requests only (if they exist) that target to the same end of the pipe. An example is given in the Figure 3. Each node AS can aggregate its own request with the request that has come from upward. Therefore the total number of messages needed to establish the N-1 pipes ASk-ASN will be:

$$N_{t1} = (N-1)_{SP-NP} + (N-1)_{NP-NP} = 2(N-1) \sim O(2N),$$

showing a significant reduction for large N. To this we can add that each pipe should be installed in the network domain, so the number of vertical messages necessary for pSLS installment is also reduced.

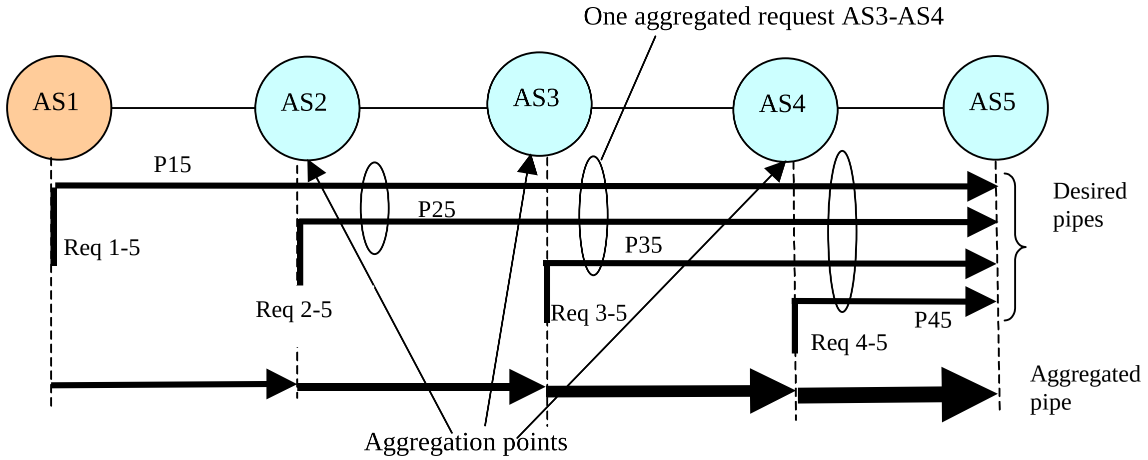


Figure 3 : Aggregation of pSLS requests in the cascaded model

But reduction in amount of signaling by waiting to aggregate several requests, means increase in response time. We suppose that the pSLS request are asynchronously to each other and therefore we have to allow a waiting interval at each AS to collect some requests to be aggregated. Due to waiting in each AS, an increase in the overall response time is expected. We have to find a trade-off between the aggregation degree and the increasing in the response time. Of course the aggregation is valuable if the density of requests that can be aggregated is sufficiently high during the aggregation interval.

We present below results of a simplified analytical study, to compare a SM system with individual pSLS requests processing versus an aggregation capable SM. We assume the topology of the Figure 3. The analysis is valid under the following assumptions:

- Each domain has a collection time interval T_c in which it waits for requests to come without serving them. At the end of the interval it aggregates the appeared requests and sends a single aggregate request to the downward domain.
- The arrival of request are independent processes at each domain with an intensity λ [arrivals/second] and these are stochastic processes. We supposed each one having an uniform distribution with the same λ.
- We consider the worst case in each all T_c intervals are non-overlapping (the response time is maximum).
- The one-trip time for propagation within the network has an average value of T_{avg1}
- The length of message and processing time is neglected (or we include it in T_{avg1}).

In order to compare the individual processing solution (let it be *a.*) to the aggregated one (let it be *b.*) we define a *merit factor* for each solution which is :

$$MF = 1/(TNM*OMWT)$$

where *TNM* - is the total number_of_messages and *OMWT* – is the overall mean waiting time for a request until it get the answer.

The MF should be as large as it is possible. Its value itself it is not absolutely relevant, but it can serve to give an overall measure useful to compare the solutions *a* and *b*, by computing the ratio MF_b/ MF_a. If the above assumptions are valid then it can be shown that:

$$MF_b/ MF_a = (\lambda N\ T_{avg1}) / (1 + 2\ T_{avg1}/ T_c)$$

The reduction factor of number of messages of solution *b* versus *a* is:

$$RF= Reduction\_factor = (total\ nb\_of\_messages)_a /(total\ nb\_of\_messages)_b = (\lambda T_c)N/2$$

The increase in mean waiting time for serving a request is :

$$IMWT= Increase\_in\_mean\_waiting\_time= TW_b/TW_a = 1 + T_c/2\ T_{avg1}$$

Without analysing in details the formulas we easily see that aggregation is good when we have large N, and large density of requests, i.e. $(\lambda T_c)\geq 1$. Also we see that if we have values of $(T_c/2\ T_{avg})$ comparable with unity, then the increase in waiting time is acceptable.

Numerical example: for $\lambda= 20$ *msg/sec,* $T_c= 500$ *ms,* $T_{avg1}= 50$ *ms,* $N=10$, we get: $MF_b/ MF_a \approx 10$, $RF \approx 50$, $IMWT \approx 6$ which is a good result.

A SDL [18], simulation model (run on Telelogic Tau v. 4.4 tool, [17]) of a system having several NPs and SPs is currently in progress. The pSLSreq messages are generated randomly at each SP and the forwarding delay is also random; we can control via an input file the limits within which the random values are generated.

The input parameters involved in this model are: the *rate of the pSLSreq messages*, the *length of the aggregation interval* and the *delay* encountered by these messages along the chain. The output parameters are the *total number of signalling messages at each NP* and the *average response time at each SP* (the time difference between the instant when a request is generated and the instant when a response is received). Because in the aggregated model we receive only one response for all the requests generated in a aggregated interval, the delay is computed as an average.

5. The IMS Simulation model

A SDL, [18], simulation model of a system having several NPs and SPs is shown in Figure 4.

We define block types for the NP and SP blocks so individual NP/SP block instances can be added or removed from the chain without much effort. Some special blocks are needed for simulation (they are not present in the ENTHRONE architecture). The statistics block (STAT) performs 2 functions: collecting statistics at predefined intervals, via the *collect_stat* message, and sending parameters to each block at start-up, including each block's position in the chain, since the blocks are all identical instances of block types and cannot know their relative position. The block marked NP_3 is needed for consistency so that the last NP (NP_i4) has both a left and right neighbour; it is not used in the simulation, the chain effectively ends at NP_i4.

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The pSLSreq messages are generated randomly at each SP and the forwarding delay is also random; we can control via an input file the limits within which the random values are generated. For the random number generation we assume an uniform distribution, however other distribution types can be used.

The output files are then processed by a GnuPlot script in order to obtain a graphical representation of the result.

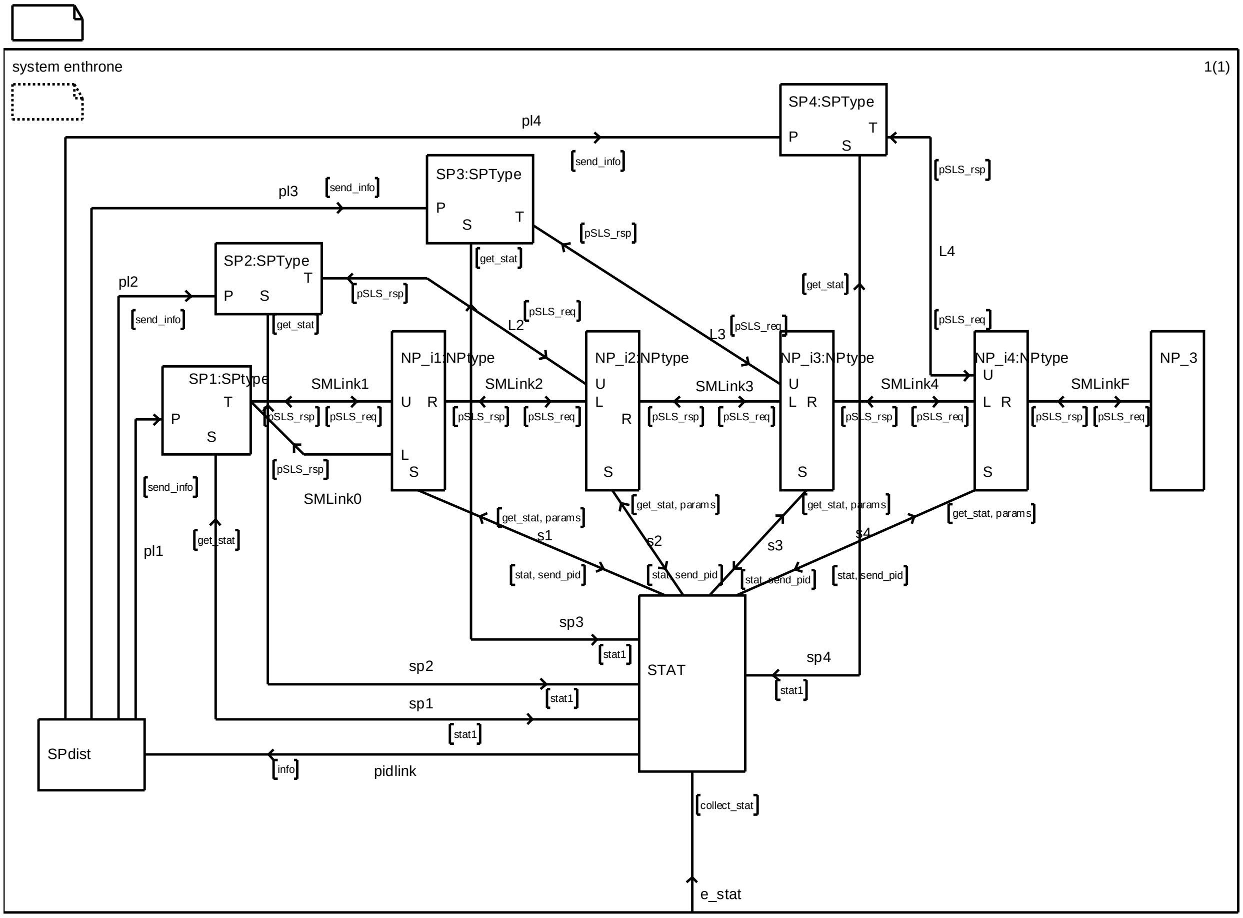

Figure 4: The structure of the IMS simulation model with four Ases – represented in in SDL graphic language

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6. Simulation results

Several simulation runs have been performed. A first example is shown in Figure 5. Note that the time is conventionally measured in seconds but in fact the tool works with an arbitrary generic time unit.

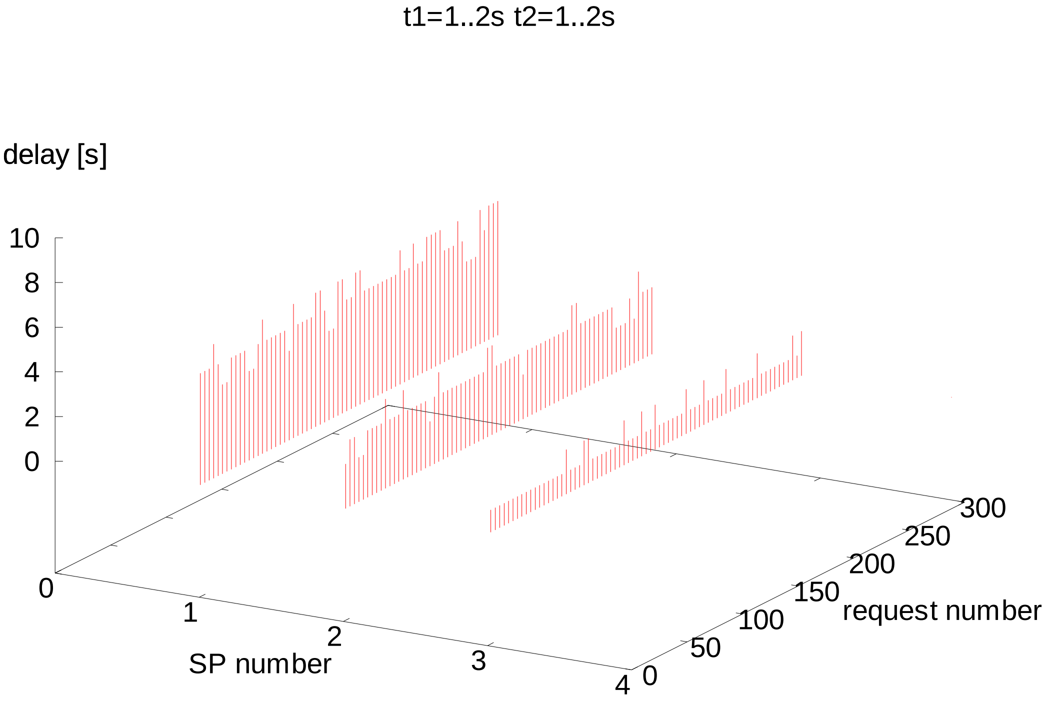

Figure 5: Average delay time at each SP, no aggregation

In this graph, *t1* is the delay between generation of *pSLSreq* messages at each SP and in this case varies randomly between 1 and 2s, *t2* is the forwarding delay of the *pSLSrsp* messages at each NP, and is also chosen randomly between 1..2s, and *request number* is the number of each pSLSreq. One can see the average delay decreases with the increase of the SP number. This result is consistent with the input values; the farther away from the destination, the longer the wait time.

Next, we can observe the effect of the aggregation. We run 3 times simulations with aggregating times *ta* respectively 0 (no aggregation), 5s and 10s the same set of parameters. The other parameters have been the same. The results are presented numerically in Table 1 and depicted in Figure 6.

SP	*Delay* [s]		
	Ta=0	*Ta=5s*	*Ta=10s*
SP1	5	8.5	11
SP2	3	6	8.75
SP3	1.25	4.75	7
SP4	0	3.25	6

Table 1: Mean delay values at each SP

Due to aggregation, the delay time increases but the effect is acceptable; we can see for SP1 which had the longest delay time, the value roughly doubles. For the next SPs the increase factor is larger yet the final value is still below the value for SP1, which means the delay decreases less abruptly with the number of the SP than in the non-aggregated case. The largest increase of delay is at SP4 but this is normal because SP4 normally experiences no forwarding delay (no transit through other SPs means no forwarding and hence forwarding delay is 0) and in the aggregation case, we add the aggegation delay.

Figure 6: Effect of aggregation on the delay time

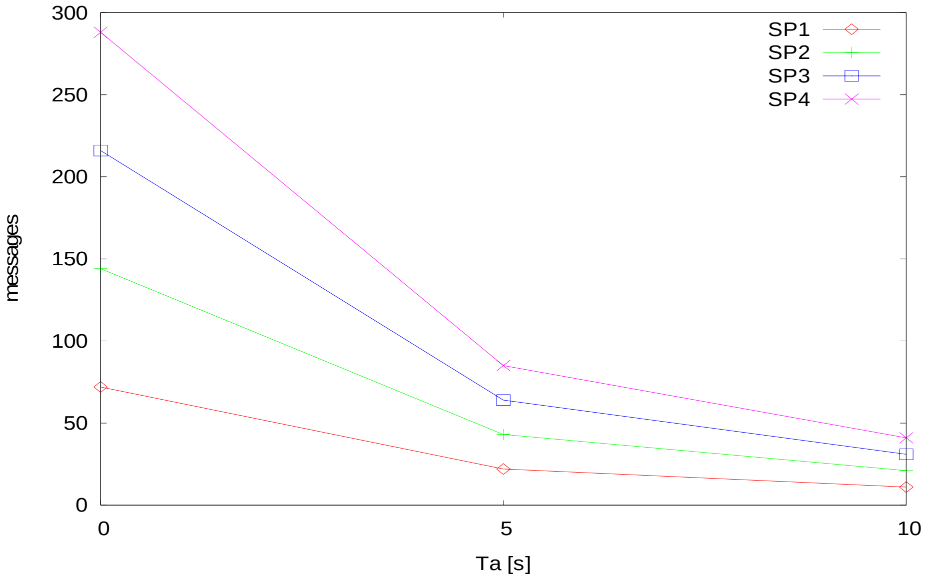

Figure 7: number of pSLSreq messages at each SP

Also, in figure 6, one can see the number of *pSLSreq* messages decreases: there are much less squares (*ta=10s*) than rhomboids (*ta=0*). The graphical representation of the number of messages versus aggregation time at each SP is shown in Figure 7. The reduction in number of messages is roughly 3:1 from *ta*=0 to *ta*=5s and a further 2:1 from *ta*=5s to *ta*=10s.

Many other simulations runs have been conducted and they validated the qualitative conclusion got from simplified analyitical study. The aggregation method will be implemented in the ENTHRONE system , [12], [13] and further sumulations will be performed with realistic values in order to gave hints about aggregation parameters dimensioning. The results can quantitatively determine some regions in the ranges of parameters in which the aggregation is useful. The adjustment of such parameters can be subject of different management policies applied in PBM framework.

7. Conclusions

An aggregation method is proposed in order to reduce inter-domain signalling amount when establishing QoS enabled inter-domain aggregated pipes, in IP environment, when using the cascaded model domain peering. The tradeoff between time response increase and signalling amount reduction factor is determined analytically and using a simulation model. The method can increase the scalability of signalling methods applied in large domains in order to assure QoS enabled end to end pipes. Additional work is in progress to detail analysis of non-successful scenarios (downward negative response) and finding optimisation methods.

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