PDB-Based SLS Decomposition in Heterogeneous IP Network

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***Abstract*—In order to provide QoS-assured service for end users, Service Providers (SP) must obtain sufficient network resource from Network Providers (NP). However, current network infrastructures belong to different NPs and are divided into a number of domains. SP may need to rely on more than one NP to get the connectivity. Thus the SLA between SP and NPs may span several domains with heterogeneous QoS technologies. Without knowing the network details, such as topology, infrastructure and QoS technology, SP is difficult to sign a proper SLA with a tradeoff between end-to-end QoS and his budget. A SLS (Service Level Specification) Decomposition Service is proposed here to solve the problem. The service implementation uses distributed PDB information to conceal the network heterogeneity from SP, which acts as an indication of network performance for a certain QoS level packets. The service enables SP to get an optimized SLA and achieve inter-domain QoS without knowing the network details. A SLS Decomposition Service prototype is implemented and its feasibility is validated.** *(Abstract)*

Keywords- SLA; SLS; SLS Decomposition Service; PDB; QoS; Service Provider; Network Provider (key words)

I. INTRODUCTION

As the development of Internet, people realize that providing value-added services in Internet will bring high profits. Thus various value-added services appeared in Internet: 1) Content providers, such as Sina and Sohu, attract users to browse their web pages by providing all sorts of information for users. They get advertising fee from merchants. 2) VoIP, as a cheap communication, attracts a lot of users, and becomes an impulse for Internet. 3) VPN, providing security information channels for large enterprises which have subsidiary companies all over the world, gains great concerns of enterprises. 4) Video conference, enable interaction among participants without gathering together, thus decrease the traveling spending. We call the entities providing value-added services as Service Providers (SP).

The value-added services also bring profits for Network Providers (NP) who possess the network infrastructures, because value-added service needs support of the network, in other words, Service Provider must buy bandwidth from Network Provider. In the current network, network infrastructures belong to various Network Providers. In China, China Mobile, China Telecom, CNC all have respective network infrastructures. SP may need to rely on more than one NP to get the connectivity. Even in the network of a single NP, the network is divided into multiple autonomous systems (AS) or domains for management convenience. Thus SP may buy bandwidth of different domains from different NPs.

Furthermore, value-added services have different QoS requirements for network capability. VoIP is sensitive for delay and jitter, but video conference needs stable throughput. To optimize users' experience and attract more customers, SP needs to provide services with QoS guarantee. When the service spans several domains, inter-domain QoS should be provided.

Nowadays, Internet can just provide best-effort services. Delay, loss rate and throughput can not be guaranteed. IETF suggests three architectures to provide QoS in Internet: IntServ [1], DiffServ [2] and MPLS [3]. Since different NPs possess different network devices and have different budgets, they will adopt different QoS technologies according to their status in quo.

When a SP buys bandwidth from a NP, they will sign a contract – Service Level Agreement (SLA). The concept of SLA is used in various fields; refer to some IETF drafts for more details [2, 5-8]. SLA consists of two parts: 1) Business part, specifying parties, rights, responsibilities, billing and etc. 2) Technical part, i.e. Service Level Specification (SLS), specifying source and destination IP addresses, bandwidth to be reserved, QoS parameters such as delay, jitter, loss rate, and some other network related parameters. The SP only concerns with the end-to-end QoS. For example, VoIP Service Provider cares about the delay and jitter between VoIP gateways, and Enterprise users pay attention to the delay of VPN between their subsidiary companies. As for how to provide the bandwidth, how many networks and domains the SLA crosses, how to guarantee inter-domain QoS, SP has no interest in and knows nothing about these issues. However, the SP needs to specify QoS guarantees of network infrastructure when signing SLA. This conflict causes several problems in signing cross-domain SLA.

In order to solve the problems, we propose a SLS Decomposition Service for SPs in heterogeneous IP network, and use PDB [4] (Per-Domain Behavior) information to describe the network capability. PDB is proposed in IETF DiffServ architecture. DiffServ workgroup proposes PDB to describe the expected treatment that an identifiable or target group of packets will receive from "edge-to-edge" of a DS domain. We think that PDB can be used to characterize

*This work is supported by the Research Fund of National Nature Science (NO.90204003), the National 863 Program of China (No.2003AA121220 and No.2002AA103063), the Research Fund of the doctoral Program of Higher Education of China (No.20010013003), 973 Project (2003CB314806), and EYTP: The Excellent Young Teachers Program of M0E, China

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network capability not only in DiffServ architecture, but also in domains with any QoS technologies. In our research, PDB is not restricted to specify the forwarding behavior of packets. Instead, it is an indication of network performance for a certain QoS level packets. PDB information can be obtained from measurement statistics. Delay, jitter and loss rate between edge-routers in a domain are PDB information.

There are a number of researches focused on IP QoS. CADENUS [9], TEQUILA [10] and AQUILA [11] have implemented architectures to provide QoS in IP network. These three projects are part of Euro Commission's IST (Information Society Technologies) projects. They are independent and all of them are complete solutions for IP QoS. E2E Analyzer is used in CADENUS to analyze the end-to-end performance, but it doesn't deal with the decomposition of SLS. TEQUILA proposes a SLA based QoS management architecture in DiffServ domains, but doesn't touch the issue of end-to-end QoS management in multiple DiffServ domains. Another project of IST, HARMONICS, proposes an end-to-end QoS management in DiffServ architecture by exchanging DSCP and bandwidth information between domains. But it can not guarantee the delay, loss rate and some other parameters required by users' applications.

Literature [12] also studies decomposition of SLS, and suggests an end-to-end QoS management mechanism in DiffServ architecture. It provides a quantify end-to-end QoS management by an optimized QoS parameters decomposition. Our research has some differences from it: Firstly, customers are different. Our system is oriented to Service Provider, and we intent to solve the problems existing in signing a cross-domain SLA. Thus our SLS decomposition is done in aggregate granularity. However, [12] is oriented to end users and do SLS decomposition in micro-flow granularity. Secondly, [12] majors in optimization of QoS parameters decomposition using PHB information from the price point of view. But our SLS decomposition uses the PDB information and just considers the technical parameters. Thirdly, [12] assumes the route between domains is fixed. But in practical network, there are multiple routes between domains, which are considered in our research. The last and the most important difference between [12] and our research is that [12] doesn't illustrate the source of the parameters, but our research does provides a feasible SLS decomposition solution in practical network. In addition, most of the current literatures assume the network uses a single QoS technology. This is not the case in practice. We use PDB and distributed technology to conceal the heterogeneous QoS technologies of the network. All aforementioned are creativities of our research.

The rest of this paper is organized as follows: In section II, we analyze the problems exist in signing cross-domain SLA. SLS Decomposition Service is proposed in Section III to solve the problems. We then present our implementation of SLS Decomposition Service in Section IV. The paper is concluded in Section V.

II. PROBLEMS IN SIGNING CROSS-DOMAIN SLA

Before Service Providers (SP) provide service for customers, they must buy bandwidth from Network Providers (NP). For example, VoIP Service Provider needs to buy bandwidth between their VoIP gateways. To build a VPN, enterprise should rent the bandwidth between their subsidiary companies. However, the network infrastructures belong to different NPs, and NPs divide their network into several autonomous systems (AS) or domains. A NP has only spotty coverage, therefore the SP will need to rely on more than one NP to get the connectivity that they need. When signing the business contract, i.e. SLA, SP should designate how many bandwidth should be reserved in what domains and specify the QoS parameters of each domain to gain end-to-end QoS. Thus SP needs to sign SLA with different NPs about different domains. Further more, bandwidth of different domains may have different prices. Choosing what domains decides the cost. Thus the SPs have a dilemma: On one hand, they want to optimize their choice of signing SLA. On the other hand, because they know neither the routing of his packets nor the QoS technologies of network, they have no notion of how to sign the SLA.

There is another business model that the SP only needs to sign SLA with the first NP. NPs interact with each other to guarantee the inter-domain QoS. Comparison of these two business models is outside the scope of this paper. Even in the second business model, SLS decomposition is also necessary when the first NP decides which partners will join in the end-to-end QoS provisioning.

The problems existing in signing cross-domain SLA are described as follows.

A. *Problem 1: Who will I sign SLA with?*

As illustrated in figure 1, enterprise user wants to establish VPN between his subsidiary companies, and VoIP Service Provider wants to reserve bandwidth between two VoIP gateways. AS1 and AS3 belong to NP1, AS2 and AS5 belong to NP2, and AS4 belongs to NP3. From the figure, we can see there are multiple solutions to build the VPN: 1) AS1->AS2->AS4; 2) AS1->AS3->AS4; 3) AS1->AS5->AS4, and etc. In the first and third solutions, enterprise user needs to sign SLA with NP1, NP2 and NP3. In the second solution, he needs to sign SLA with NP1 and NP3. However, enterprise user is only aware of the IP address scope of his private network1 and private network2, but knows nothing about the network infrastructures. Thus, enterprise user doesn't know how many choices he has and would raise a question "Who will I sign SLA with?"

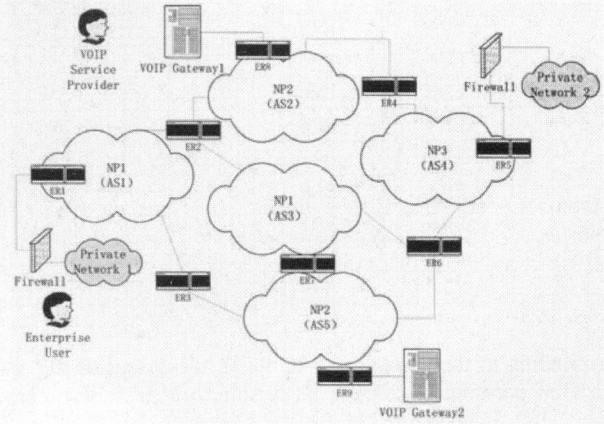

Figure 1: Who will I sign SLA with?

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The same problem also exists for VoIP Service Provider. There are multiple bandwidth reservation solutions between two VoIP gateways: 1) AS2->AS1->AS5; 2) AS2->AS3->AS5; 3) AS2->AS4->AS5. Choosing what solution determines signing SLA with whom.

B. *Problem 2: What SLS would be in SLAs?*

SP needs more from network besides bandwidth. They need guarantees for delay, jitter, loss rate and other QoS to optimize users' experience. Obviously, the information of a single domain can not decide whether the end-to-end performance of the network can satisfy the SLA's requirements. As aforementioned, SP knows neither the routing information nor the performance parameters of the network. They can not decide how the packets are routed to get desirable QoS. We take the VPN example to explain this problem:

QoS parameters, i.e. SLS of enterprise user's VPN SLA are given in Table 1, which are clear to enterprise users. PDB information for gold service of each domain in figure 1 is given in Table 2, which are transparent for enterprise users.

TABLE I. SLS OF VPN SLA

Parameter	value
Source IP	IP Address of private Network 1 Gateway
Destination IP	IP Address of Private Network2 Gateway
Service Class	Gold
Bandwidth	80M
End-to-End Delay	≤110ms
Loss Rate	≤0.6%
Jitter	(Not considered in this paper)

TABLE II. PDB INFORMATION OF GOLD SERVICE IN EACH DOMAIN

ASID	Src ER	Des ER	Delay	Loss Rate
AS1	ER1	ER2	35ms	0.1%
	ER1	ER3	45ms	0.3%
	ER2	ER1	40ms	0.15%
AS2	ER2	ER8	30ms	0.22%
	ER2	ER4	30ms	0.2%
	ER4	ER8	35ms	0.3%
AS3	ER2	ER6	45ms	0.15%
	ER2	ER7	37ms	0.23%
	ER6	ER7	32ms	0.35%
AS4	ER4	ER5	40ms	0.15%
	ER4	ER6	50ms	0.2%
	ER5	ER6	35ms	0.3%
AS5	ER3	ER6	30ms	0.25%
	ER3	ER7	27ms	0.15%
	ER3	ER9	35ms	0.1%
	ER6	ER7	43ms	0.2%
	ER6	ER9	36ms	0.26%
	ER7	ER9	45ms	0.3%

According to the statistics in Table II, we calculate the end-to-end QoS parameters of each VPN solutions presented before. In the following formulas, $t_{ERi,ERj}$ is the delay between ER_i and ER_j, $P_{ERi,ERj}$ is the loss rate between ER_i and ER_j.

1) AS1->AS2->AS4:

In this solution, the end-to-end path crosses the following edge routers: ER1->ER2->ER4->ER5

Its end-to-end QoS parameters are shown below:

a) $E2E\ Delay = t_{ER1,ER2} + t_{ER2,ER4} + t_{ER4,ER5}$

$$= 35ms + 30ms + 40ms = 105ms$$

b) $E2E\ Loss\ Rate = 1-(1-P_{ER1,ER2})(1-P_{ER2,ER4})(1-P_{ER4,ER5})$

$$= 1-(1-0.1\%)(1-0.2\%)(1-0.15\%) = 0.45\%$$

2) AS1->AS3->AS4:

The end-to-end path crosses the following edge routers: ER1->ER2->ER6->ER5

End-to-end QoS parameters:

a) $E2E\ Delay = t_{ER1,ER2} + t_{ER2,ER6} + t_{ER6,ER5}$

$$= 35ms + 45ms + 35ms = 115ms$$

b) $E2E\ Loss\ Rate = 1-(1-P_{ER1,ER2})(1-P_{ER2,ER6})(1-P_{ER6,ER5})$

$$= 1-(1-0.1\%)(1-0.15\%)(1-0.3\%) = 0.55\%$$

3) AS1->AS5-AS4:

The end-to-end path crosses the following edge routers: ER1->ER3->ER6->ER5

End-to-end QoS parameters:

a) $E2E\ Delay = t_{ER1,ER3} + t_{ER3,ER6} + t_{ER6,ER5}$

$$= 45ms + 30ms + 35ms = 110ms$$

b) $E2E\ Loss\ Rate = 1-(1-P_{ER1,ER3})(1-P_{ER3,ER6})(1-P_{ER6,ER5})$

$$= 1-(1-0.3\%)(1-0.25\%)(1-0.3\%) = 0.85\%$$

Compared with the QoS requirements of VPN SLS, only solution 1 can satisfy the end-to-end delay and loss rate requirements, delay of solution 2 exceeds the delay bound, loss rate of solution 3 can not meet the requirement. Therefore, solution 1 is the only choice for enterprise user. However, because enterprise user knows nothing about the topology and the PDB information of each domain, they don't know how many choices they have and can not compare the available choices.

We propose SLS Decomposition Service for SPs to solve the problems existing in signing cross-domain SLA. The reason why we propose SLS decomposition instead of SLA decomposition is that the source IP address, destination IP address and QoS parameters are specified in the technical part of SLA, i.e. SLS. In addition, the business part of SLA touches upon the economic issues and needs to be negotiated between the SP and the NP. Therefore, we just deal with SLS decomposition. The SP only needs to submit an end-to-end SLS to our SLS Decomposition Service, designating source IP, destination IP and QoS parameters. Then our service will return a series of single SLSs needed to be signed in SLA with NPs along the end-to-end path. Furthermore, the decomposition can satisfy the end-to-end QoS requirements.

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III. PDB-BASED SLS DECOMPOSITION SERVICE IN HETEROGENEOUS IP NETWORK

SLS Decomposition Service is described in this section. Firstly, we would like to introduce two new important concepts used in our service: Global SLS and Single-Domain SLS. They are defined as:

Global SLS means the end-to-end SLS before decomposition. It is provided by the SP and may cross multiple domains of different NPs. The QoS parameters in Global SLS, such as delay, jitter, loss rate and other parameters are all from the end-to-end point of view.

Single-Domain SLS corresponds to a single domain. It is the result of decomposing the Global SLS. Delay, jitter, loss rate and other QoS parameters are between two edge routers in a same domain.

SLS Decomposition Service is a distributed service, as presented in figure2. There is a service instance in one or several domains. The service instances exchange messages by distributed technologies such as web service or CORBA. The service can present itself to customers in various ways. Customers can access the service by web, or by a client program. As long as the global SLS conforms to the standard format defined in the interface, SLS Decomposition Service will return the result to customers. There may be several solutions returned. Customers can choose from them according to their actual requirements.

SLS Decomposition Service is composed of the following components: User Interface Module, Routing Analyzer, PDB Information Detector and Parameters Decomposition Module. These modules are illustrated in figure3 and are described in detail in the following text.

A. *User Interface Module*

User Interface Module is the entrance of SLS Decomposition Service. It provides a GUI for users, defining the standard format of Global SLS and the decomposition results. User can browse the web page in his browser, fills in the Global SLS sheet according to the guide and submit the Global SLS. When received the Global SLS, SLS Decomposition Service will deal with it and return the series of Single-domain SLS to the user. Global SLS includes the following parameters:

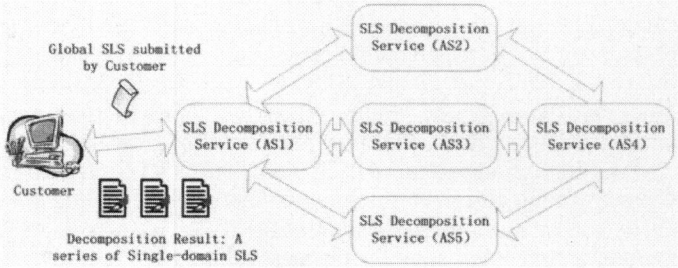

Figure 2: Distributed SLS Decompostion Service

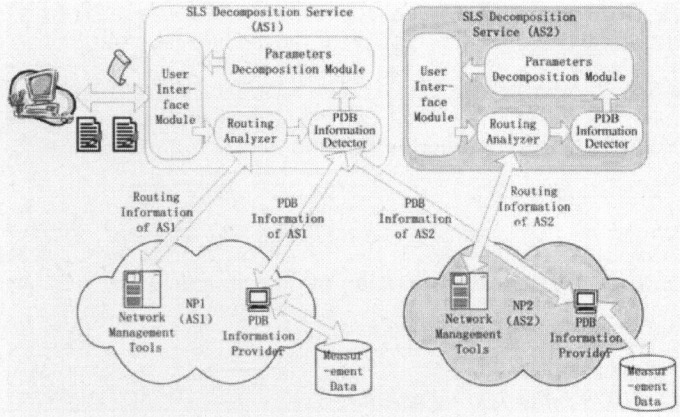

Figure 3: Components of SLS Decomposition Service

Source IP Address = *SrcIP*

Destination IP Address = *DesIP*

Service Class = Gold / Silver / Bronze

Bandwidth = *BW*

End-to-end delay = $Delay_{SrcIP,DesIP}$

End-to-end Loss Rate = $Loss_{SrcIP,DesIP}$

The Global SLS can also contain other QoS parameters. We consider a limited set of QoS parameters to demonstrate the decomposition process more clearly.

B. *Routing Analyzer*

The main function of Routing Analyzer is to find out the possible end-to-end paths and the domains they cross according to the source and destination IP address designated in Global SLS. Each domain is identified by an ASID (Autonomous System Identifier).

The Routing Analyzer needs to know the routing information, which can be obtained from network management tools. The module can also get the routing information by adding a similar routing function as in the router, and exchange routing updates with the real routers periodically to maintain the up to date information. But its routing function is different from that of the router. It doesn't really forward packets. Besides the routing information, Routing Analyzer should also know the domain information such as the ASID of the domain it resides, and the edge routers which connect with other domains. Because there is a service instance in one or a few domains, the routing information will not exceeds the scale of a few domains, thus the routing table will not be large.

When SLS Decomposition Service received the Global SLS from user, it hands over the source and destination IP address to Routing Analyzer. The module consults its routing table, interacts with the Routing Analyzers of other domains and gets the possible end-to-end paths. The paths may include the IP addresses of core routers and edge routers. After obtained the end-to-end paths, according to domain information and edge router information, Routing Analyzer translate them in the

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form of containing only the edge routers and give out the ASID list of the domains. The outputs of the module are given below:

ASs in the end-to-end path: $ASInfo = \{ASID_1, ASID_2 .....ASID_n\}$

Edge Routers in the end-to-end path:

$ERInfo = \{< ERID_1, ERID_2 >, < ERID_2, ERID_3 > ..... < ERID_n, ERID_{n+1} >\}$

Where $< ERID_i, ERID_j >$ corresponds to domain $ASID_i$, $ERID_i$ is the ingress edge router of domain $ASID_i$, and $ERID_j$ is the egress edge router of domain $ASID_i$.

C. PDB Information Detector

PDB Information Detector obtains results from Routing Analyzer. It uses the ASIDs in the end-to-end path as indexes and acquires PDB information of each domain in the paths. The PDB information contains delay, jitter, loss rate and some other QoS parameters of a certain service class (Gold/Silver/ Bronze) between edge routers in each domain. There is a PDB information provider in each domain, providing interface for SLS Decomposition Service. The PDB information provider can be a web service or is implemented by other distributed technologies, as long as the interface conforming to the standard format. PDB information can be calculated from the historical statistics or be produced by real-time measurement. According to the ASIDs provided by Routing Analyzer and the service class designated in Global SLS, PDB Information Detector gets the following data:

Delay between edge routers in all domains: $Delay_{ERIDi,ERIDj}$, where $< ERID_i, ERID_j > \in ERInfo$,obtained from Domain $ASID_i$

Loss Rate between edge routers in all domains: $Loss_{ERIDi,ERIDj}$, where $< ERID_i, ERID_j > \in ERInfo$,obtained from Domain $ASID_i$

D. Parameters Decomposition Module

Parameters Decomposition Module calculates end-to-end QoS parameters of each possible paths provided by Route Analyze Module, using the PDB information acquired from PDB Information Detector. If the end-to-end QoS parameters of a certain path fulfill the requirements of Global SLS, Parameters Decomposition Module will decompose the Global SLS according to the path. The judgment and decomposition algorithm of a certain path is given below:

1) Judge whether the end-to-end delay fulfills the requirement:

If $Delay_{SrcIP,DesIP} \le \sum_{< ERID_i, ERID_j > \in ERInfo} Delay_{ERIDi,ERIDj}$ Then delay is ok.

2) Judge whether the end-to-end Loss rate fulfills the requirement

If $Loss_{SrcIP,DesIP} \le 1 - \prod_{< ERID_i, ERID_j > \in ERInfo} (1 - Loss_{ERIDi,ERIDj})$

Then Loss Rate is ok.

3) If both of Delay and Loss Rate fulfill the requirements, decompose the Global SLS into N Single-domain SLSs. N is the number of domains the Global SLS crosses. The QoS parameters of ith Single-domain SLS are given as:

For SLS corresponding to $ASID_i$ (i≤N):

Source IP address = $ERID_i$

Destination IP address = $ERID_j$

Service Class = the Service Class in Global SLS

Bandwidth = BW

Delay = $Delay_{ERIDi,ERIDj}$

Loss Rate = $Loss_{ERIDi,ERIDj}$

The whole process and the data exchange between entities are illustrated in figure 4.

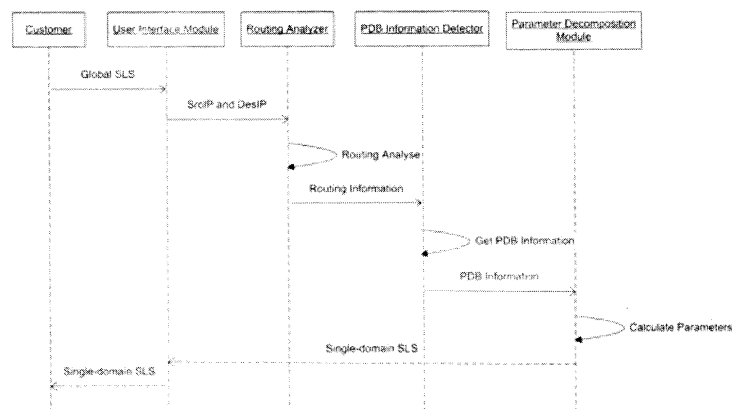

Figure 4: SLS Decomposition Process

IV. IMPLEMENTATION

Our SLS Decomposition Service is implemented as a part of National 863 project in China (No. 2003AA121220), whose purpose is to provide QoS-assured service for SPs in IP network. The testbed is divided into five domains as presented in figure 1. Both DiffServ and MPLS are used in the testbed. We setup a SLS Decomposition Service for each domain. The routing information is provided by a network management tool developed by ourselves, and PDB information is offered by our measurement tool. Customers access our system by their browsers, submit the Global SLS to SLS Decomposition Service and wait for the result. When the series of Single-domain SLS are returned, the customers can hand over them to the online admission control of each domain. It is an e-business process from the customer submits his Global SLS to Single-domain SLS admission. SLS Decomposition Service acts as an important part in automating the business process.

The example of VPN SLS decomposition is given in figure 5. Since the interactivities of components in SLS Decomposition Service are implemented in software, which are

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invisible for readers, we illustrate the whole process in figure 5 and describe it in detail as follows:

1) User Interface Module receives the Global SLS from enterprise user.
2) When received the Global SLS, User Interface Module translates it into internal expression without changing its content. The internal expression of Global SLS is visible to all modules.
3) User Interface Module hands over the internal expression of Global SLS to Routing Analyzer.
4) Routing Analyzer takes out source IP and destination IP addresses from Global SLS and finds out all the possible end-to-end paths. Refer to figure 5. The path includes the information of edge routers and all domains.
5) Routing Analyzer sends all the possible paths to PDB Information Detector.
6) PDB Information Detector acquires PDB information of each domain in end-to-end paths according to the edge routers and AS information provided. Refer to the rectangles in the right-bottom.
7) PDB Information Detector hands PDB information to Parameters Decomposition Module.
8) When received PDB information, Parameters Decomposition Module calculates end-to-end QoS parameters of each possible paths. If the path can fulfill the QoS requirements of the Global SLS, Parameters Decomposition Module will decompose it into a series of Single-domain SLS.
9) Parameters Decomposition Module transfers the Single-domain SLS to User Interface Module.
10) User Interface Module delivers the results to the corresponding customer.

V. CONCLUSION

There are several problems in signing cross-domain SLA in heterogeneous IP network. On one hand, the SP wants to get an optimized SLA signing solution; on the other hand, he knows nothing about the topology and the technologies of network infrastructures. In this paper, we proposed a SLS Decomposition Service to solve the problem. It uses distributed technology and PDB information to conceal the different QoS technologies of the network. It enables SP to get an optimized SLA signing solution without knowing the details of the network. By submitting a Global SLS, SP will receive a series of single-domain SLSs from SLS Decomposition Service, which can fulfill the end-to-end QoS requirements of the Global SLS. We have implemented a prototype of the service to validate its feasibility. The prototype works as we expected.

However, we just focus on the delay and loss rate in this paper. Besides these QoS parameters, users may have other QoS requirements. In addition, though our SLS Decomposition Service works well in the testbed composed of five domains, its feasibility and performance is still to be evaluated in the large network containing numbers of domains. In our future work, we will do some research on other QoS requirements such as jitter, throughput, and etc. Furthermore, we will establish a larger testbed or use simulation to evaluate the performance of the service.

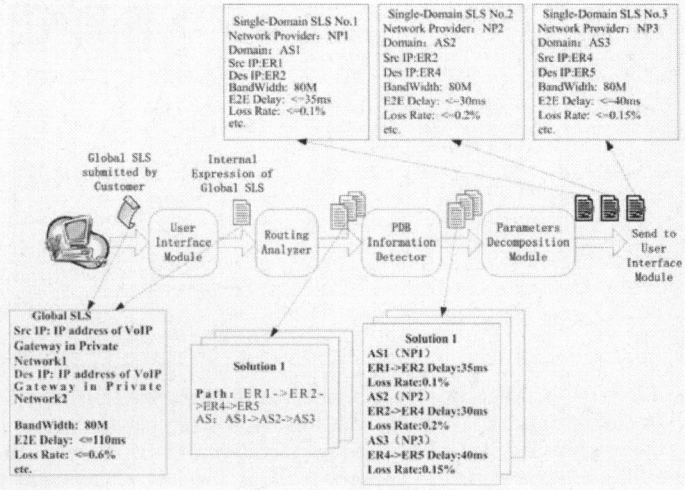

Figure 5: Example of VPN SLS Decomposition

ACKNOWLEDGMENT

Thanks to Cui YiDong, JiaoLi, Tian Huirong and Xiao Junfeng for their help and support in the early stage of our research. Thanks to Pei Yujie and Ding Yiqiang for their help in our implementation work. And thanks to the reviewers for their many useful comments.

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