Preliminary Field-Trial for QoS Routing and Dynamic SLA

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SUMMARY Improvements of Internet technology during the last decade have shifted the technical focus from reachability to the quality of communication. There are many technical frameworks, such as Integrated Service and Differentiated Services, which have been standardized to assure the quality of communication. QoS routing is also one of such frameworks. It changes or fixes a route that IP datagrams take, and is also indispensable to put a variety of services into practice. Nevertheless, experiment reports of QoS routing on operational network are quite few, especially with dynamic SLA. Therefore, we still do not know much about the important factors for QoS-enabled network to be realized, such as users’ behavior, suitable services to offer, and configuration parameters. In this paper, we carried out field-trial with pseudo QoS routing and dynamic SLA in an actual network built at the WIDE retreat in autumn 2000. In this field-trial, we provided two different types of links to attendees. Attendees chose one of the links, through which their flows go, with our dynamic SLA. We describe the details and the results of this experiment. Our results could help to understand the customers’ behavior for differentiated services, and therefore be useful for designing and deploying various QoS technologies.

key words: class of service, QoS routing, dynamic SLA, differentiated services, resource brokering

1. Introduction

The advances of routing and operational technologies in the last decade have drastically improved the packet reachability in the Internet. This stability of the Internet allows us to take steps forward to achieve QoS management. Once the QoS management is achieved, Internet service providers (ISPs), that are now selling the reachability to the Internet, could expand services to have differentiated quality such as prioritized data transfer, maximum delay assurance, and other “premium services” where the customer pay more for better services. Although expectations for QoS are growing, it is still not clear at this moment that what services are useful for both customers and ISPs.

There are many proposals and implementations of QoS technologies. Both Integrated Services (Intserv) [1] and Differentiated Services (Diffserv) [2], [3] are the major standardized architecture for the QoS management. On the other hand, QoS routing changes or fixes a route that IP datagrams take, and is also a vital technology to provide QoS. QoS routing is orthogonal to Intserv and Diffserv so that it can be used with Intserv or Diffserv. QoS routing generally has two functions: route selection and load balancing. Route selection chooses an appropriate route for a flow according to the requirements of the flow. It is possible that multiple paths exist to a certain destination, and all the paths offer the same level of quality. Load balancing can be achieved by using these multiple paths simultaneously for a single flow: the flow is split into these multiple paths and carried over the network.

Although QoS routing will be indispensable to put a variety of services into practice, experiment reports of QoS routing on operational networks are quite few, especially with dynamic SLA (Service Level Agreement). Therefore, we still do not know much about the important factors for designing and operating actual QoS-enabled networks. Those include users’ behavior, suitable services to offer, and configuration parameters. In order to obtain expertise for operation and to feedback them to the operation technologies, it is quite important to conduct series of experiments which applies QoS technologies to operational networks.

With this idea, we conducted a field-trial with dynamic SLA and pseudo QoS routing in an actual network built at the WIDE retreat in autumn 2000. In this field-trial, we provided two different types of links to attendees. Attendees chose one of the links with our dynamic SLA management system, and then the requests are realized by our route selection mechanism. In this paper, we report the details and the results of this experiment. Our results could be a hint to understand the customers’ behavior for differentiated services.

2. Overview of Field Trial

We conducted a field-trial on QoS routing and dynamic SLA at the WIDE Camp on September 11–14, 2000, to study how users behave with QoS routing and dynamic SLA, and how parameters of QoS routing should be configured.

In this section, we explain the WIDE Project...
Camp-net, and then describe the overview of the system design and its components.

2.1 WIDE Project Camp-net

WIDE Project [4] holds a 4-day retreat called “WIDE Camp” twice a year. An on-site network called Camp-net is built to provide Internet connectivity to the attendees, and Camp-net is also a test-bed for a variety of new technologies.

The WIDE Camp nowadays has over 250 attendees, and almost all the attendees bring one or more laptop computers and connect them to the Camp-net. Therefore, the connection to the Internet should have enough bandwidth to carry a wide range of commodity traffic. We know from the last few WIDE Camp-net that the external line needs at least 400 kbps. At the same time, we usually prepare a satellite link and exercise a drill to construct an emergency ad-hoc network. The satellite link is 2 Mbps and bidirectional, and the channel capacity can be divided into multiple up-links and down-links.

Therefore, we can design a network to make use of ground links and satellite links. For this Camp-net, we prepare 1.5 Mbps ATM link (with several PVCs) and two satellite links (which has 2.0 Mbps bandwidth altogether as mentioned above) to two separate locations.

2.2 System Overview

To study how users behave with QoS routing and dynamic SLA, we designed the Camp-net combining several technologies. Figure 1 illustrates overview of whole system and interaction between its components.

First, we employed Differentiated Services (Diffserv) [3] to provide prioritized services. Diffserv is a framework to provide service differentiation by combining multiple QoS mechanisms such as metering, marking and scheduling. A set of Diffserv-capable networks that are administrated under the same policy is called a DS domain. At the boundary of the DS domain, there are ingress/egress edge nodes. At an ingress edge node, packets entering the DS domain are conditioned according to the SLA. Traffic conditioning includes classifying a packet, metering and marking the packet with DS Code-Point (DSCP) [2] in the IP header. Within the core of the DS domain, packets with the same DSCP are aggregated into a single Behavior Aggregate (BA) and treated in the same manner. This behavior of a router associated with the DSCP is called Per-Hop Behavior (PHB). We defined the network around the external links of the Camp-net as a single DS domain, and used ALTQ [5] as ingress/egress edge nodes and core nodes. We offered Assured Forwarding (AF) [6] as PHB to make use of the external links.

We also used the external links as the target of QoS routing, that is, selecting a path from either the ATM link or the satellite link according to SLA. QoS routing requires a mechanism to select a route based on parameters besides the destination address, which complicates protocol design and their implementations. For this experiment, however, it was enough to provide only two routes with different attribute. Hence, to make implementation simple, we introduced the concept of a link selection router to virtually create an environment with QoS routing, and implemented a prototype of the link selection router. The detail of the link selection router is described in the next section.

The defined SLA consists of assured bandwidth and link selection between ATM and satellite. Assured bandwidth is realized by AF PHB and link selection is realized by the link selection router. DSCP is used for both mechanisms.

The attendees issue QoS requests dynamically from the web interface. When a request is issued, the Policy Decision Point (PDP), which is responsible for resource management, user authentication, and accounting, decides if the request could be accepted or not. The PDP sends the decision to Policy Enforcement Points (PEPs). We used Common Open Policy Service (COPS) [7] as a protocol for transport of decision. COPS is a simple query and response protocol that can be used to exchange policy information between a PDP and PEPs. We had already implemented the COPS protocol for provisioning the QoS control parameters in the experiments reported in [8]. In addition, we implemented a client-type module for this field-trial. The detail of these implementations is given in the next section.

We used a simple HTTP-based authentication for
attendees to issue QoS requests from a web page. The web server was also located in the PDP. We also introduced virtual currency, called “WIDE Unit,” for accounting. When the PDP decided to accept a request, it charged WIDE Units based on the length of the requested period, the amount of bandwidth and the choice of the link.

3. Field Trial

We provided the WIDE Camp attendees with a mechanism to issue QoS requests dynamically. Through this mechanism, they were able to establish SLAs with the Camp-net, choosing a link and reserving bandwidth on it. In this section, we present the details of the Camp-net topology, the implementations and the configurations of the components of our system.

3.1 Camp-net Topology

The network topology around the external link is illustrated in Fig. 2. Two paths (and one backup path) were prepared for layer 3 routing from the Camp-net to the Internet: one to Keio University Shonan Fujisawa Campus (SFC), and the other to Nara Institute of Science and Technology (NAIST). The route to NAIST then reached SFC via another ATM link. Thus, both routes finally go through the edge router at SFC. This allows us to use a single edge router to control traffic for both paths still with two distinct routes.

Each external link except the backup link consisted of an ATM link and a satellite link. Therefore, there were two external links and one backup link from the view of layer 3. We prepared a 1.5 Mbps ATM link and a 2.0 Mbps bidirectional satellite link. Two 256 kbps VCs for our experiment and one 512 kbps VC for backup were created within the ATM link, and the rest of the ATM bandwidth was not used for this experiment. The satellite link was connected to both SFC and NAIST with 512 kbps. The up-links and down-links of satellite share the channel capacity, adding up to 2.0 Mbps altogether. We placed the link selection routers at both ends of the external links.

The Camp-net supported both IPv4 and IPv6. Routing for the external links was performed with OSPFv2/OSPFv3 for IPv4/IPv6 respectively. By adjusting the cost values of OSPF, we configured the SFC link to have priority over the NAIST link. The cost for the backup link was set to a very large value so that this link was used only when the rest of the links became unreachable.

As mentioned above, regardless of the route se-
Table 1 DSCP.

<table>
<thead>
<tr>
<th></th>
<th>BLUE</th>
<th>YELLOW</th>
<th>RED</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF Class 1</td>
<td>001010b</td>
<td>001100b</td>
<td>001110b</td>
</tr>
<tr>
<td>AF Class 2</td>
<td>010010b</td>
<td>010100b</td>
<td>010110b</td>
</tr>
</tbody>
</table>

lected by OSPF, all traffic between the Camp-net and the Internet goes through a single router located at SFC. Thus, traffic conditioning was performed at two places: the edge routers at SFC and Camp-net. These two routers worked as the PEPs and received QoS parameters from the PDP located in the Camp-net.

3.2 Component Implementation and Configuration

3.2.1 Differentiated Services

We used ALTQ as ingress/egress edge nodes and core nodes. ALTQ was configured as follows: DSCP of each packet flowing into the ingress router is first cleared before traffic conditioning. Packets are then classified according to the filter configuration of the ingress router. These filters are installed by the PEPs as explained later. Then traffic conditioning is performed by metering, marking, and possibly shaping and/or policing.

Packets are marked according to the result of classification and metering. Three service classes are offered: BE (Best Effort), AF (Assured Forwarding) Class 1, and AF Class 2. Within each AF Class, packets are marked with one of three possible drop precedence values which determine the relative importance of the packet. For the packets within the requested bandwidth, the drop precedence was set to BLUE. For packets sent between the requested bandwidth and 1.2 times the requested bandwidth, YELLOW was set, and anything above that was marked RED. The list of DSCP is shown in Table 1. In this table, the 3 bits of MSB (Most Significant Bit) represents AF Class, 001b for AF Class 1 and 010b for AF Class 2 respectively. The next 2 bits represent the drop precedence mentioned above, 01b for BLUE, 10b for YELLOW and 11b for RED, respectively.

Finally shaping and/or policing are applied to the packets according to its DSCP and the result of metering. RIO [9] was used for queue management in the outgoing interface of each ingress router. The RIO parameters were configured so as to drop packets in the order of RED, YELLOW and BLUE as the level of congestion increases.

3.2.2 Link Selection Router

QoS routing implicitly or explicitly requires a mechanism to select routes based on parameters such as the IP source address or the port numbers, in addition to the IP destination address. In the current Internet architecture, a router determines the next hop for a packet by looking up the routing table only by the destination address of the packet. Therefore, it is not possible to select a route based on a policy. A possible solution would be to extend the routing table to select the next hop based on various parameters in order to reflect policies to routing. However, a new routing protocol is needed to make use of this modification. In addition, it will have inconsistency with the existing routing protocols, if they run at the same time.

Since our goal is not to design a protocol but to gain field experiences, we introduced the link selection router to virtually create an environment with QoS routing. For this experiment, it was enough to provide a few routes on different types of links. We also had to run the existing routing protocols.

The link selection router binds two or more different physical links together, and treats them as a single pseudo Point-to-Point link. When transmitting a packet via the pseudo link, the physical link for transmission is selected according to some policy installed beforehand. For example, the policy can use the following fields in the IP header to select the physical link: IP source and destination address, IP protocol number, source and destination port numbers, and DSCP. The configuration of a policy mechanism should be flexible in mapping these fields to a physical path. The existing routing protocols can be used over this pseudo link since it is handled as a traditional Point-to-Point link. Our prototype implementation of the link selection router is shown in Fig. 3.

This limited version has two fixed physical links, i.e., an ATM link and a satellite link, and selects one of the two links according to the DSCP. Although DSCP selects only a PHB in the original Diffserv concept, we extended the model so that DSCP selects both path and PHB. That is, packets flow through different links according to the SLA between attendees and Camp-net. Flows mapped to BE class were transmitted via the satellite link without any reservations. Flows with SLA were transmitted with bandwidth reservation, via the ATM link for AF Class 1, and the satellite link for AF Class 2, respectively.

The round trip time (RTT) between Camp-net and
SFC is shown in Table 2. This table shows minimum RTT, maximum RTT and average RTT of the flows that transited the ATM link and satellite link. The RTT was measured using the ping command. The ping command was invoked at a host in the Camp-net towards a host in SFC behind the PEP, with two different conditions. One was with AF Class 1 reservation, and the other was without any reservations. 800 packets of \texttt{ICMP ECHO REQUEST} were sent for each condition, and there was no packet loss during the execution. There was about 500 msec difference between the minimum RTTs of AF Class 1 and BE. This difference was caused by the large RTT of the satellite link. For the maximum RTTs, there was about 400 msec difference between the two conditions. In this field-trial, the attendees were able to choose the RTT of their communications by selecting the transit link, and experienced the difference in RTT.

### Table 2 Round trip time.

<table>
<thead>
<tr>
<th>Class Type</th>
<th>min (msec)</th>
<th>max (msec)</th>
<th>avg (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF Class 1 (ATM)</td>
<td>36.063</td>
<td>515.888</td>
<td>48.419</td>
</tr>
<tr>
<td>BE (Satellite)</td>
<td>552.909</td>
<td>904.997</td>
<td>568.590</td>
</tr>
</tbody>
</table>

3.2.3 Common Open Policy Service

We used COPS as a protocol for transport of decision and provisioning the QoS control parameters to the routers. A PDP and a PEP communicate with each other within a context of a particular type of client, corresponding to the QoS mechanisms available in PEPs. Interpretation of all objects in COPS messages is specific to the client type. Therefore, COPS can carry client specific information without knowing the contents of the objects. Moreover, there are enterprise specific client types which can be used without standardization. Consequently, this protocol is quite extensible and can support all sorts of client types which may appear in the future.

We have been implementing the COPS protocol on FreeBSD 3.5-RELEASE with KAME as an implementation platform. KAME is an IPv6 stack provided by the KAME Project [10]. Our implementations include daemons, \texttt{pdpd} and \texttt{pepd}, responsible for exchanging and parsing COPS messages without depending on client types. Enterprise specific client types are implemented as loadable modules so that we can easily add client types later. This loadable module in our implementation is called the client type module. Figure 4 shows the overview of our implementation.

For this field-trial, we implemented an enterprise client-type module for both PDP and PEP named “widecamp.” When a request is issued from an attendee, the client-type module for the PDP receives it from CGI via the web server. The PDP module then begins processing the admission control: confirming if any reservation with the same flow spec already exists, comparing the requested bandwidth with the available bandwidth, calculating the price for this request, and examining the attendee’s balance. After completing this process, it decides whether the request is accepted or not. In case that the PDP module gives admission to the request, it composes the message including the QoS parameters to the PEPs at both sides of the external link. This message is handed over to \texttt{pepd}, and sent to the PEPs via the COPS protocol.

A reservation for a flow with SLA is realized by putting a filter that represents the flow and other parameters to the ingress routers. The module for PEP parses messages from the PDP and applies these filters and parameters to ALTQ. The module of PEP at the Internet side installs the same parameters but swaps the source and destination addresses so that the SLA is valid for both directions, i.e. both flows from/to the host at the Camp-net to/from the host or network at the Internet. Then the PEP module sends the result back to the PDP via \texttt{pepd}. In all cases, the PDP reports the result to the requester via the web page.

3.2.4 Authentication and Accounting

The PDP box also ran the Apache web server that provided the web page to issue the QoS requests. We used simple HTTP-based authentication, and issued UserID and default password to each attendee to access this page. Users could also change their passwords on the web page. User ID was handed over to CGI and \texttt{pdpd}. The attendees could dynamically issue QoS requests via this page by filling the forms with information about the type of external link (ATM or satellite), the amount of bandwidth and the length of time that they wished to reserve, along with specifications of the target flow (a pair of IP addresses and its prefix length).

After successfully installing QoS parameters at the PEPs, the PDP charged WIDE Units according to the length of requested period, the amount of bandwidth and the choice of link that the flow of the requester goes through. We defined 1 WIDE Unit to be the unit price for reserving 1 kbps bandwidth for 1 minute at AF Class 1 (ATM link). To suppress demands during busy periods, the unit price was raised by 10% once the available bandwidth became less than 50%.
more, the unit price continues to go up as the available bandwidth decreases. When the available bandwidth was less than 10%, the unit price became twice as much of the lowest price. The relation between the available bandwidth and the unit price of AF Class 1 is shown in Fig.5. The RTT for the satellite link is remarkably larger than the RTT of the ATM link, as shown in Table 2. Therefore, we defined the unit price of AF Class 2 (satellite link) to be 1/4 of AF Class 1 (ATM link). When calculating the charge for the satellite link, WIDE Units less than 1 were rounded up to the next whole number. 10000 WIDE Units were given to each attendee at the beginning of the WIDE Camp, and their balance of WIDE Unit was shown in the web page. Besides this, information about SLA status and remaining bandwidth was also available in this page.

Information used by the authentication and accounting mechanism was managed using PostgreSQL. Apache web server had access to user database using PostgreSQL authentication module, web pages obtained information from database via PostgreSQL-enabled PHP3, and the module for PDP accessed to this database using PostgreSQL library.

4. Results of the Experiment

4.1 User Behavior

The total number of attendees at the WIDE camp retreat of autumn 2000 was 252. The number of attendees who used our dynamic SLA system was 126, and the number of reservations during the 4-day experiment was 605. Among the 605 reservations, 477 (78.8%) were reservations for the ATM link.

Figure 6 shows the distribution of the requested bandwidth on the ATM link. As shown in this figure, 46.3% of the reservation requests were for 1kbps, followed by 22.2% requests for 2–10kbps. Few users requested more than 100kbps. In short, the majority of the requests on the ATM link were for narrow bandwidth.

Figure 7 shows the distribution of the requested period on the ATM link. 48.2% of the requests were for 6–30 minutes. On the other hand, the requests for more than an hour accounted for 23.3%.

Figure 8 shows how the requested period and bandwidth changed over time. As the upper figure shows, the reservation requests increased in length during the Camp. Especially, on the third day, some attendees requested reservations up until the end of the Camp. On the other hand, the lower figure shows that the requests
Figure 9 shows how reserved bandwidth and unit price for the ATM link changed over time. As shown in this figure, the available bandwidth was not completely reserved throughout the Camp.

4.2 Evaluation and Consideration

As already mentioned, the attendees found that reserving 1 kbps for a long time was most effective in this environment. This information was spread among the attendees during the Camp. As a result, many users chose to reserve narrow bandwidth on the ATM link for long periods. This is a consequence of mismatches in our service design.

First, we found that it is difficult to control the user behavior in the assured rate service. In AF, there is no clear difference for different assured rates unless the network is heavily congested. We used RIO to manage the queue in all the routers within the DS domain. With RIO, even packets marked as RED are unlikely to be dropped unless the queue constantly becomes long. In our experiment, as shown in Fig. 9, the bandwidth of the ATM link was large enough to serve users requiring small RTT, so the queue hardly became long. This allowed users to use much more bandwidth than they reserved.

Second, the fact that the ATM service was not too narrowband obscured the advantage of the satellite service. The ATM service was targeted for interactive applications needing small RTT, and the satellite service was targeted for bulk transfer applications needing large bandwidth. However, the difference in RTT between the two links was far greater than the difference in bandwidth so that the advantages of the satellite link’s large bandwidth diminished by the greater advantage of small RTT of the ATM link.

QoS routing can provide users a selection of different services by different routes. However, certain attributes may differ substantially, and the most significant feature tends to wipe out the effects of the other factors. Thus, it is important to carefully select the properties that users may choose so that the total service is well-balanced.

Third, our pricing method based on reservation bandwidth was not effective to control the user behavior. We changed the charge according to available bandwidth, but the users did not spend much for narrow but long reservations. As a result, it became possible to reserve 1 kbps during the entire Camp. We should have charged the choice of the link instead of reserved bandwidth for the ATM service, because the main attribute of the ATM service was small RTT. When providing several services with a drastic difference in a certain attribute, it is important to carefully choose the attribute for the target of charge.

On the other hand, the fact that users found the benefit of reservations resulted in the increase of reservations. In the previous experiment at WIDE Camp 2000 spring reported in [8], 98 (43.8%) attendees out of the total 224 made at least one reservation. This number increased to 126 (50%) attendees out of 252 in the WIDE Camp of autumn 2000. This shows that dynamic QoS reservation is gradually spreading within the WIDE Camp. The same thing could probably be said about the public community, once services are started, although it may take some time.

As for the system operation, there were no major problems, other than a few instances of the PDP failures. Even then, service down time was minimal because, when the PDP restarted, the locally-cached SLAs were loaded to the PDP and exchanged with the PEPs.

5. Conclusion

Demands for assured quality of communication have been growing along with the emergence of new Internet applications such as VoIP. QoS routing and dynamic SLA will be essential technologies to offer a variety of dynamic services to customers. However, experiments of QoS routing with dynamic SLA in live networks are still limited. Consequently, we still do not know much about the important factors for designing and operating actual QoS-enabled networks. Those include users’ behavior, suitable services to offer, and configuration parameters.

We conducted a field-trial with dynamic SLA and pseudo QoS routing in a live network at the WIDE Camp of September 2000. In this field-trial, we provided two types of links with different characteristics and let the attendees dynamically choose the link for their communications.

From the results of the experiment, it became clear that the most dominant attribute tends to outbalance the effects of other features. Therefore, the selection of
options and the target of charge must be chosen carefully. In this field-trial, although we provided two lines with drastically different RTT, many attendees chose to reserve the narrow bandwidth for long periods because the target of reservation and charge was bandwidth.

In the future, we plan to continue investigating dynamic SLA and QoS routing, along with measurements, to provide feedback to users. We believe that our continuing effort on this topic will be useful for deploying various QoS technologies including dynamic SLA and QoS routing.

References


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