EDGE-TO-EDGE RESOURCE PROVISIONING AND ADMISSION CONTROL IN DIFFSERV NETWORKS

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Abstract: *This paper describes an edge-to-edge dynamic resource provisioning and admission control process over multiple domains through a Bandwidth Management Point (BMP). The main goals are to achieve signaling scalability and optimum resource utilization. The BMP of each domain makes a pipe type reservation to possible destination regions on behalf of its customers and modifies the pipe size based on the traffic rate. For the traffic rate estimation and admission control process, we use two different methods: parameter-based, and measurement-based. Both of them are based on a Gaussian distribution under an assumption of the Central Limit Theorem. The scalability and utilization problems are minimized by using a threshold based dynamic provisioning scheme.*

KEYWORDS*: Dynamic provisioning, admission control, bandwidth broker, scalability, Diffserv, reservation.*

1. INTRODUCTION AND PROBLEM DEFINITION

Currently, the Internet is “built on a best-effort” service model where all packets are treated in the same way regardless of their service types. As the Internet evolves into a global commercial infrastructure, there is a need for more enhanced services than the best-effort service. The IETF has proposed a number of QoS models, including the Integrated Services (Intserv) with RSVP signaling [7] and Differentiated Services (Diffserv)[6]. The Intserv/RSVP model introduces a per-flow reservation in the network for end-to-end QoS guarantees. Each node along the path maintains state, performs scheduling, and manages buffers for each individual flow. Because of large numbers of flows in the Internet, the Intserv/RSVP model is not recommended to be deployed in the network core.

Diffserv, on the other hand, has been conceived to provide QoS in a scalable way. It pushes the complexity to the network edges and keeps very simple scheduling and dropping mechanism in the network core. At the edge of the network packets are classified and assigned to the limited number of Diffserv code points (DSCP) according to their service types. The traffic is policed at the entry (ingress) points of networks based on the service profile between users and ISPs. Inside the network all the packets tagged with the same DSCP are aggregated and receive the same per-hop behaviors (PHB) associated with that DSCP. Thus, Diffserv keeps the network core very simple and scalable.

The Diffserv model is based on the concept of Service Level Agreements (SLA). An SLA is a service contract between a customer and its service provider that specifies the PHB that a customer should receive. A customer might be a user organization, another service provider (upstream domain) or a single user. There are many possible variations of SLA definitions. Currently, some ISPs define the SLA based on the aggregated customers’ traffic entering the domain and place policers in the ingress points to check their commitments. The customer traffic is accepted to the domain as long as it is in-profile regardless of the destination address and no further policing is performed inside the domain. This kind of approach is scalable and easy to implement, however, it cannot provide reliable service and wastes network resources, as the following example shows.

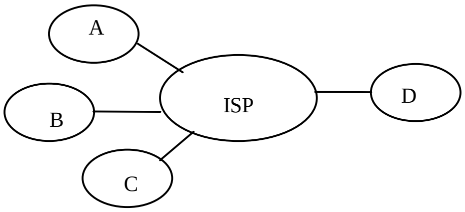


Figure 1a:A network with single domain

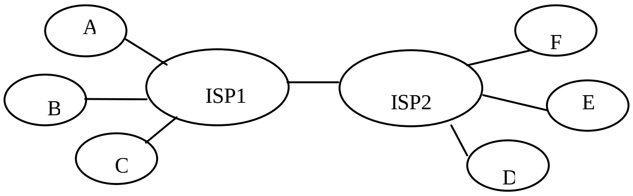


Figure 1b: A network with two domains

Let us consider a simple scenario shown in Figure 1a. The ISP assigns 10Mbps bandwidth to its customers A, B, and C and the maximum capacity of the link to D is 15Mbps. Suppose that all the customers want to send traffic to D with maximum rate, 10 Mbps. Now, although the ISP allows 30Mbps traffic to enter its network, it cannot deliver more than 15Mbps to D. Therefore, the excess traffic will be either dropped or delayed after using substantial network resources. Thus, with this approach an ISP cannot provide the QoS desired by its customers.

An alternative approach can set SLA according to the worst-case requirements. A similar mechanism called "Premium Service" was proposed by Jacobson et al. [16]. The total acceptable priority traffic from ingress routers into the network is limited to the capacity of the egress router connected to the weakest link. Consider the single egress router case in Figure 1a. Since the capacity of egress router is 15Mbps, the user A, B, and C can be assigned to 5Mb equally. This provides the equivalent of a dedicated link of fixed bandwidth between two nodes, thus it can guarantee QoS. However, since there is no dynamic SLA set up, the share that is not being used by one customer cannot be used by others. The situation becomes more complex in the case of multiple domains. In Figure 1b, ISP1 cannot provide reliable QoS to its customers for the traffic destined to any customer connected to ISP2 just by setting SLAs according to the egress router's capacity. This is because ISP1 does not know the resource availability in ISP2.

There is a fundamental conflict between network utilization and high service assurance. Since an ISP does not know in advance the volume of traffic to each destination, to get desired QoS guarantee, it needs to set SLA agreement according to the worst case (it is assumed that all host send traffic to the same destination with highest rate). This results in a severely inefficient use of resources. The solution to this problem requires fundamental extensions to the current Diffserv model. Essentially, ISPs should provide intra-domain and inter-domain SLA that not only guarantees QoS but also utilizes the network resources efficiently while having a scalable signaling mechanism.

We present a Bandwidth Management Point (BMP)[1,9,10] based scheme to solve this problem. A BMP is similar to a Bandwidth Broker [5], which was first introduced by Jacobson et al. [16]. The BMP of each domain is responsible for intra-domain and inter-domain dynamic resource provisioning and control management. The key aspect of the model is that the BMP makes destination-based SLAs with its downstream domains' BMP according to the aggregated traffic demand from its customers, and then dynamically modifies SLA when there is a substantial change in the traffic rate. This scheme obtains optimum resource utilization while avoiding signaling scalability problems in the network core. The rest of this paper is organized as follows; Section 2 outlines the BMP system model; Section 3 describes our traffic rate estimation and admission control techniques. In section 4 we present our dynamic pipe-based provisioning mechanism; Section 5 concludes the paper.

2. BANDWIDTH MANAGEMENT POINT SYSTEM MODEL

The SLAs between customers and providers are dynamically managed by Bandwidth Management Point (BMP) [1,9,10]. A customer may be a user organization or another domain (upstream). Individual hosts are not considered as customer in case of dynamic SLA. The main role of BMP is to perform resource provisioning and policing within its domain and negotiate with its neighboring peers for external resources. The BMP can obtain both topology and resource information of its domain from the nearest router by using either COPS or SNMP. Because of the hierarchical routing structure and intra-domain protocol and management independence, we assume that each domain has at least one BMP.

It has become evident that having SLA without specifying destination region, it is impossible to grant QoS assurance unless very low resource utilization [2,3,4,8,9,12,14]. Therefore, as we presented in the previous paper [9], our SLAs are destination based. Basically, the model is designed as follows. Each BMP collects destination specific requests from its customers' BMPs, aggregate them and then requests pipe type reservation from downstream domain for that particular destination region(s). A pipe is defined by DSCP and destination region identifier (e.g. destination domain IP prefix, a set of region represented by CIDR [20]). After the reservation requests are approved, the SLAs are made or modified according to the commitments, and the policers in the ingress points are set to the new values for checking the commitments. To avoid signaling overhead, the size of pipes are chosen more than the current usage value and modified based on substantial changes in the aggregated demand. As shown in Figure 2, the pipes destined to the same region and carry the packets of the same class are aggregated along the path when they merge. The isolation between reservations is maintained by placing destination specific policers at the ingress points.

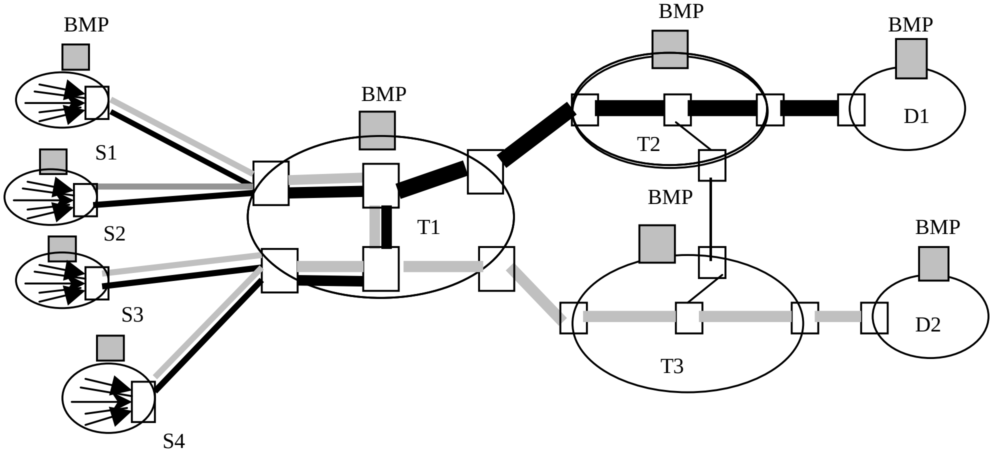


Figure 2: Edge-to-Edge architectural model inter-domain reservation

In Figure 2, we define $S = \{S1, S2, S3, S4\}$ as source access domains, $T = \{T1, T2, T3\}$, as transit domains, and $D = \{D1, D2\}$ as destination access domains respectively. It is assumed that reservation requests are from Si to $D1$ or $D2$. Suppose that the source domains' BMP want to establish pipes to $D1$ and $D2$ on behalf of their customers. The BMP of $T1$ collects the demands from $S1, S2, S3, S4$ for each domain $D1$ and $D2$, and then make pipe type reservation requests from the BMP of $T2$ for $D1$ and from the BMP of $T3$ for $D2$. Similarly, the BMPs of $T2$ and $T3$ collect their customer requests ($T1$ and $T3$ are the customers of $T2$, $T1$ and $T2$ are the customers of $T3$) and then request a pipe from the BMPs of $D1$ and $D2$, respectively. Let's assume that all the requests are approved. Now, each domain can guarantee service assurance for particular destinations based on the resource provided by downstream domain. Once the pipes are established, the BMP can admit their customer requests without sending signaling messages to the downstream BMP for individual customers' requests. This is because the pipe sizes are chosen more than its current load by taking the future requests into consideration. As it is explained in section 4, when the traffic rate in the pipe exceeds high threshold (before it reaches to maximum size), the BMP attempts to increase the pipe size. Thus, if there are resources along the path to a particular destination, the BMP will always makes available room in the pipe for its customers to use.

All the traffic in a pipe is policed as single flow; there is no isolation between the flows in the same pipe. The pipes from different sources to the same destination can be aggregated as their path merge [9]. It is up to the upstream domain to do accurate policing to its customers. The basic advantages of this model are:

Signaling Scalability: The numbers of inter-domain signaling messages are independent of the numbers of flows. Since the pipe size is not changed with individual requests, the BMP can add or remove customers from the pipe without informing downstream domain. The readers are referred to [1,9] for more detail.

Aggregation: Reservations (pipes) destined to the same destination region are aggregated toward to the destination. Thus, the number of states that border routers maintain are independent of the number of flows or the numbers of customers (stub domain, organization, or a AS domain). Instead border routers keep states only for destination region(s).

Efficient Network Utilization: There is no worst-case provisioning. The BMP reserves the resources from downstream domain based on its customers' demand and release it when it is not used.

Multiplexing Gain: Because of statistical multiplexing gain, the pipe size can be less than the sum of individual users and customer requests. This is because each pipe contains a large number of reservations.

Traffic Engineering support: Unlike the typical aggregation and tunneling models, this model does not have encapsulation and de-capsulation. Thus, since the packets' headers are still visible within the pipe, the pipe's traffic can be split over multiple paths in order to take advantage of traffic engineering. The packets of same session are sent over same path in order to avoid out of order delivery. For example; in the case of there is a bottleneck on the link between $T1$ and $T2$ (Figure 2), in $T1$, the traffic destined to $D1$ can be split over the paths $T1-T2-D1$ and $T1-T3-T2-D1$.

3.TRAFFIC RATE ESTIMATION AND ADMISSION CONTROL

In this section, we describe the schemes for estimating the online traffic rate. The traffic rate in a link has significant meaning for admission control, QoS routing, and negotiation of resources between two administrative domains. Since resource reservations are pipe-based in our model, we are specifically interested in the traffic rate of a pipe. This is important because both the admission control and pipe size modification are based on usage resource rate of a pipe. We use two different schemes: parameter-based and measurement-based.

3.1 Parameter-Based

The traffic of a source can be presented by a set of traffic descriptor parameters ($m, \ \sigma^2, L_{\max}, D_{\max}$). m and σ^2 are the mean and the variance of the source, $L_{\max}$, and $D_{\max}$ are the maximum loss rate and delay, respectively. At this point we assume that the pipe size, P_{cd}, is constant and it carries the packets of class c to destination region d.

The BMP of each domain knows the size of each pipe P_{cd} and the number of flows (N) in the pipe. We assume that the flows in a pipe are independent and identically distributed (i.i.d). By having the number of flows in a pipe, the BMP can easily calculate the current traffic rate of the pipe. At any time, t, the traffic rate of the pipe is:

$$R(t) = \sum_{i=1}^{N} R_i(t) \qquad (1)$$

Where $R_i(t)$ represents individual flow rate and flows are i.i.d with the mean , m, and variance, σ^2, and $R\ (t)$ is the aggregate traffic rate. The aggregate stream mean rate, m_a, and variance, $\sigma_a{}^2$, can be expressed as, $m_a = Nm$, $\sigma^2{}_a = N\sigma^2$. For large N, $R(t)$ tends to the Gaussian (Normal) distribution under Central Limit Theorem (CLT)[17], $R(t) \sim N(Nm, N\sigma^2)$. For simple analysis we assume that each flow requires one unit of bandwidth, so that the pipe size, P_{cd}, and the current traffic rate, $R(t)$, are multiple of single flow rate. Under the assumption of bufferless system, to meet QoS requirements, the following condition must hold.

$$P(R(t) > P_{cd}) \le L_{\max} \qquad (2)$$

To solve this equation, the well- known Q-functions are used [17]:

$$P(R(t) > P_{cd}) \le L_{\max} ==> Q(\frac{P_{cd} - Nm}{\sqrt{N}\sigma}) \le L_{\max} \qquad (3)$$

Where $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-y^2/2} dy = \frac{1}{2} erfc(\frac{x}{\sqrt{2}})$

In order not to exceed $L_{\max}$, the following equation must be held.

$$P_{cd} \ge Nm + Q^{-1}(L_{\max})\sqrt{N}\sigma \qquad (4)$$

A new reservation request is admitted if the equation (4) is satisfied, where N is the sum of the number of current flows in the pipe plus the number of requested flows.

The value of $L_{\max}$, has significant meaning here. Large $L_{\max}$ aggressively admits new reservations and results high network utilization, however, it degrades QoS. On the other hand, small $L_{\max}$ makes high QoS but conservatively admits new reservations therefore results low network utilization. Since there is a buffer in the system, the practical loss rate will be less than the $L_{\max}$.

3.1.1 Effective Bandwidth

Effective bandwidth [21,22] serves as a useful tool in admission control and capacity planning in packet-oriented networks. Although the flows rate vary over time, a flow can be considered as if it required reservation with the size of effective bandwidth throughout the active period of the connection. Thus, the link load can be simply calculated by the sum of effective bandwidth of individual flows and then admission control can be performed based on these values [23]. From equation (4) we can define effective bandwidth as follows:

$$R = Nm + Q^{-1}(L_{\max})\sqrt{N}\sigma \Rightarrow B_{eff} = \frac{R}{N} = m + Q^{-1}(L_{\max})\frac{\sigma}{\sqrt{N}} \quad (5)$$

Where R is the current traffic rate of a pipe, and N is the number of flows. In case of large N, the effective bandwidth is between the mean rate and the peak rate. As it is shown in figure 3, the above equation is valid only for large value of N, for small N, the effective bandwidth is larger than peak rate, which is practically not true. Figure 3 illustrates that as N gets large, the effective bandwidth get close to mean rate. When the number of reservations goes infinite, the effective bandwidth tends to the mean rate. Increasing the loss rate decreases the effective bandwidth, this means that the pipe can accepts new reservations more aggressively.

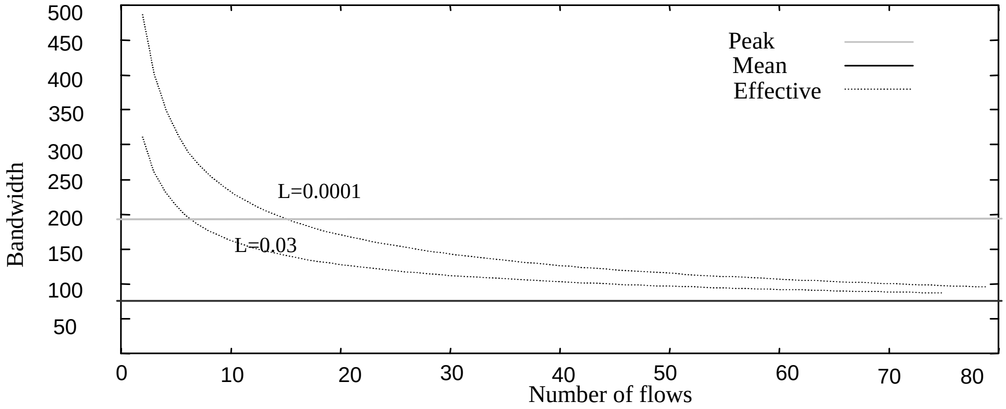


Figure 3: Effective Bandwidth

3.2 Measurement-Based

In measurement-based schemes [18,19], the traffic rate samples are collected at regular small time intervals called sampling period, S, during the duration of a measurement window W (W is multiple of S). The average rate of each sample is computed as dividing the sum of packets collected during S by the length of S. By using these values traffic rate is estimated. The admission control is then based on this value rather than the worst-case bounds.

Similar to the previous method, we are interested in estimating the traffic rate in a pipe P_{cd}. To do that the egress router (ER) periodically measure the mean rate of the aggregate traffic, m, and variance, σ^2, of the pipe, P_{cd}, during window W. It then sends these values to the BMP. By using these values, the BMP estimates the traffic rate of the P_{cd}. Since the pipe has a large number of flows multiplexed in, the rate tends to have a Gaussian distribution according to the Center Limit Theorem [17]. The traffic rate, R_{cd}, then can be computed as follows:

$$R_{cd} = m + \eta\sigma \quad (6)$$

Where η is a QoS factor which controls the estimation rate accommodates variability in the samples. For a given $L_{\max}$, η can be defined as:

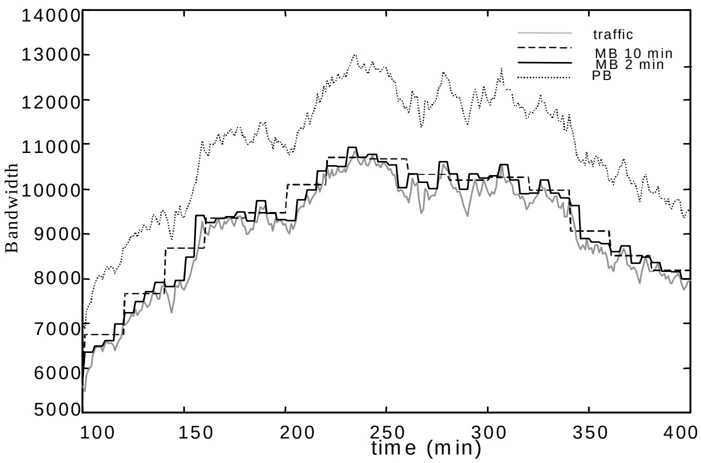
$$\eta = Q^{-1}(L_{\max}), \text{ where } Q(x) = \frac{1}{2} erfc(\frac{x}{\sqrt{2}})$$

The large number of samples (small length of S) in a window (W) result more accurate traffic rate measurement, however, it might cause more processing overhead. Selecting large W (hours, days) may result inaccurate measurement values, this is because the traffic rate may substantially change during period of W. Therefore, the value of W should be chosen according to the traffic characteristics.

After obtaining the traffic rate, the BMP can perform admission control as follows: The new request N_q is admitted if the following condition is satisfied otherwise it is rejected.

$$N_q \le P_{cd} - R_{cd} \quad (7)$$

Measurement-based schemes can obtain high network utilization. However, unlike parameter-based scheme, they can only get statistical guarantees with high probability. Thus, they can be used for traffic that does not require deterministic loss guarantees such as voice, video. In case of deterministic traffic such as distributed computations, parameter-based schemes with zero loss tolerant are recommended.



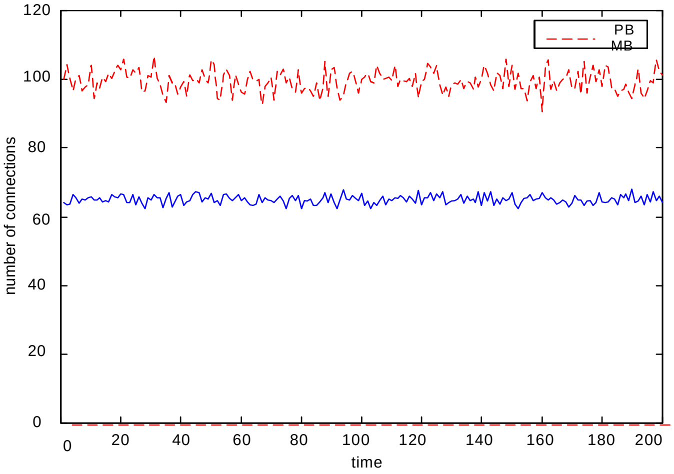


Figure 4:Traffic rate estimation by PB and MB

Figure 5:Admission control process by PB and MB

Figure 4 and 5 show the simulation results of the reference network in Figure 1b. We assume that the link between ISP1 and ISP2 has a bottleneck and all the other links have plenty of bandwidth. As shown in figure 4, the measurement-based (MB) scheme gives us more realistic value. The MB scheme with 2 minutes follows the traffic rate changes more accurate than 10 minutes and reduces loss rate, but is causes signaling messages between egress router and the BMP. On the other hand, the MB with 10 minutes reduces the number of signaling messages, however, it is less responsive to the traffic changes than 2 minutes. This increases the loss rate as well as the blocking probability. The parameter-based scheme guarantees certain QoS, but the predicted traffic rate is much higher than the actual rate.

Figure 5 shows the maximum number of flows that can be accepted to the bottleneck link, which has a 6 Mbps available capacity. As shown in figure, the measurement-based scheme admits more flows than the parameter-based scheme. The gain changes between 1.3 and 1.7. There is a trade off between QoS (loss rate) and the resource utilization. While PB guarantees deterministic bounds for delay and loss rate, it causes poor resource utilization. On the other hand, the MB can achieve high network utilization, but it can only statistically guarantee QoS.

4. DYNAMIC PROVISIONING

It is difficult to select a suitable pipe size at the establishment time because of unpredictable traffic demand. For example, the traffic load of a pipe between a campus and its provider can be substantially changed hourly, daily, weekly etc. While the load is minimum during the night, it might be maximum at noon. Modifying the pipe size based on demand eliminates the need for accurate prediction. (such as Intserv /RSVP). The pipe size can be changed when reservations are added to or removed from the pipe. This can provide maximum network utilization. However, since in the Internet most of the flows are short lived (such as WWW) compared to connection establishment time and the number of connections are high, BMP will have severe signaling overhead similar to Intserv /RSVP even worse.

The problems with demand-based approach can be minimized by choosing very large pipe size compared to the current load. Reservations can be added to or removed from pipe without requiring signaling. However, this causes severe under-utilized network resources. Therefore, the challenging problem is to maintain a balance between high network utilization and signaling scalability. We propose a scheme that seeks to avoid the above problems by increasing and decreasing the pipe size according to the thresholds.

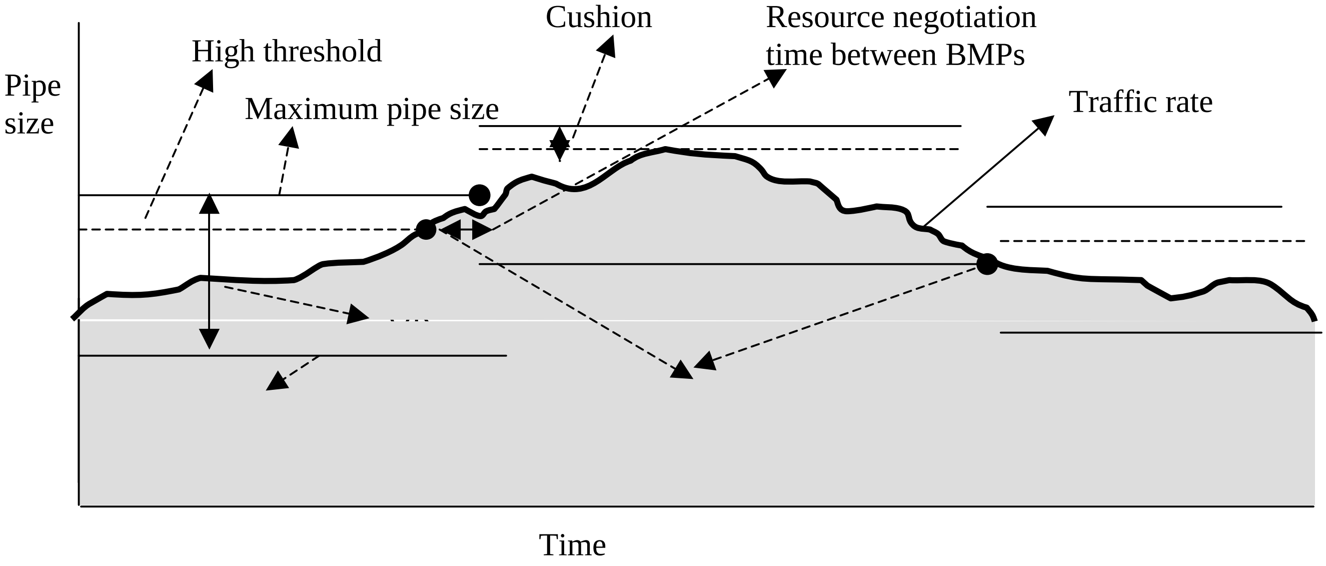


Figure 6: the operation of dynamic resource provisioning in a pipe.

Figure 6 illustrates the operation of a dynamic pipe size modification. An operation region (OR) is defined by low threshold (LT) and high threshold (HT). There is no modification takes place as long as the traffic rate fluctuates within OR. Once the pipe size crosses the OR region boundaries (LT or HT), the BMP attempts to change the pipe size according to new traffic rate by negotiating with its adjacent BMP (provider's BMP).

The most significant parameter of this algorithm is the width of OR. As it is mentioned before, the network utilization and the frequency of the renegotiation fluctuation are directly depend on the width of OR. Since the traffic rate requesting reservation is unpredictable, it is difficult to use a constant OR for long term. Thus, we propose a simple algorithm that changes the OR width according to the incoming traffic characteristics.

Lets define $t_n, t_{n-1} ... t_1$ as the time at which pipe size changes happen, and T as the expected pipe size modification period. As we mentioned early, the change can only be made when the traffic rate crosses any threshold points. Thus, the change may be done before or after T. Assume that at $t = t_n$ a change is needed and we define $T_{cur,} T_{prev}$ as:

$$T_{cur} = t_n - t_{n-1},\ T_{prev} = t_{n-1} - t_{n-2}$$

by using exponential averaging, OR can be adjusted as follows:

$$OR = \frac{T}{\lambda T_{prev} + (1-\lambda)T_{cur}} OR \qquad (8)$$ where λ is a damping parameter ($0 < \lambda < 1$)

$$P_{cd} = R_{cur} + OR/2 \qquad (9)$$

If the last two values of pipe size change period (T_{cur}, T_{prev}) are equal to T, there will be no change with the OR. If they are short, in order to avoid scalability, the OR is increased. In case of long period meaning that the traffic rate is changing slowly, the OR is decreased. This results higher resource utilization.

The blocking or refusing reservations during re-negotiation time between BMPs is prevented by defining a cushion shown in Figure 7. Since inter-BMP re-negotiation process is very slow, once the traffic rate reaches to HT, the BMP attempts to increase the size of pipe. By the time new resources are allocated, the incoming reservation requests can be accepted, because there will be still some available resource (cushion). The large value of cushion ($P_{cd} - HT$) can tolerate longer negotiation time without affecting QoS.

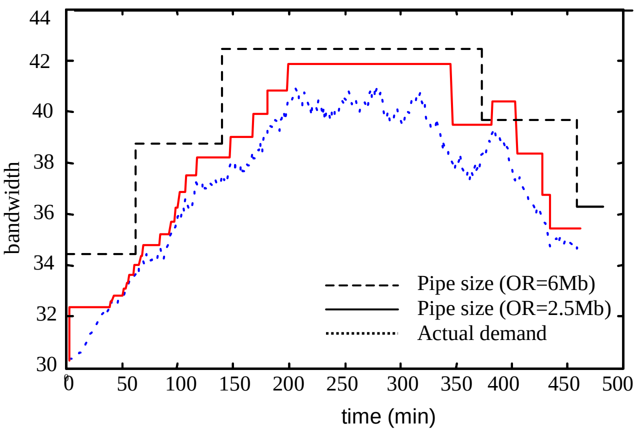


Figure 7a:The pipe size modification messages with respect to the aggregated traffic demand

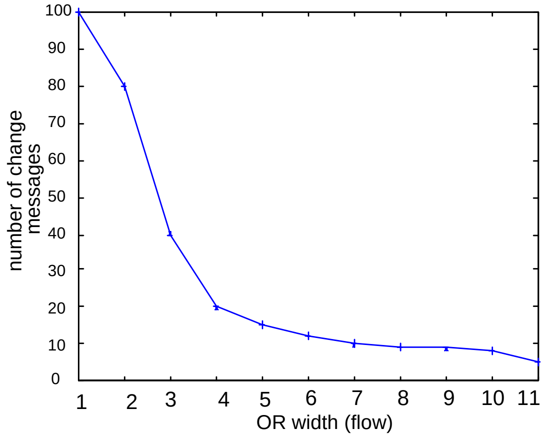


Figure 7b:The change reduction respect to OR

We took a data set from a company (Nurtel)[24] that provides VoIP service. The data set here is the actual demand that the company received from its customers during 8 hours. We assume the service contract between the company and its provider is adjusted according to traffic demand.

Figure 7 shows the pipe size changes with respect to the aggregated traffic demand and the width of OR. The changes are based on the thresholds specified by of OR. As expected, when the width of OR increases, the number of change messages are decreased and over-reservation amount is increased. When the aggregated traffic demand is within OR, no change takes place. For example, although there are over 600 reservations join and leave the pipe between time 150 and 360, there is no change when the width of OR is 6 Mb, and there are five change when the with of OR is 2.5 Mb. If we consider the steady-state case, there will be only few change even with the small width of OR.

5. CONCLUSION

This paper presents a scalable and an efficient edge-to-edge resource reservation via BMP. A BMP of each domain collects destination specific requests from its customers and then requests pipe type reservation from its downstream domain for particular destination region(s). Because of the destination specific reservation commitment provided by downstream domain, each BMP grants reliable reservation to its customers. We accomplish two significant challenges of QoS in the Internet today: scalability and efficient resource utilization. BMP aggregates all the reservations that require same PHB and belong to the same destination region(s), and border routers therefore maintain states only for <destination region, DSCP> pair (per pipe). Thus, the number of states in border routers are independent of the number of individual reservations or source regions. By using threshold-based algorithm for pipe size modification, BMP substantially reduces the number of inter-domain setup messages while having efficient resource utilization. For the traffic rate prediction in a pipe, we use two methods based on Gaussian predictor under assumption of Central Limit Theorem; Parameter-based and Measurement-Based. While a parameter-based provides deterministic QoS guarantees with poor resource utilization, measurement-based provides statistical guarantees with efficient resource utilization.

This architecture moves control path functionalities from routers to BMP. While BMP deals with resource reservation, admission control, provisioning, and pricing, routers keep small limited number of reservation states fro packets, and do their basic functionalities; routing and forwarding. Our future plans are to investigate more enhanced provisioning and policing mechanism, and to implement BMP. We will evaluate BMP in terms of scalability, resource utilization, policing, and pricing in our test-bed.

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