A Benchmark for QOS Guarantee Schemes

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Abstract

An application with guaranteed service only cares about whether or not the network can satisfy its performance requirement, such as end-to-end delay. However, the network wants to achieve the high utilization and performance guarantee simultaneously. If the end-to-end delay provided by the network can be allocated properly to each switching node, then the network resources can get a better utilization. Conventionally, the delay is allocated equally to each switching node along the path that the connections pass through, referred to as equal (EQ) allocation policy. The advantage of this policy is easy to implement. However, we can not understand how this policy will affect the network utilization. In this paper, we will prove the EQ policy has good performance in excess bandwidth. We proposed an allocation scheme called MaxMin allocation to improve network utilization. With the excess bandwidth as the performance index, we have showed that MaxMin policy is an optimal scheme. In addition, we use the MaxMin allocation policy as the benchmark to compare with EQ policy, and we find the distinction of the performance between the EQ and MaxMin policy is tiny.

Keywords: guaranteed service, scheduling, local QOS allocation

1. Introduction

Most of recent research effort [1-7,11,12] only focus on worst-case end-to-end delay bound but pay no attention to the problem of distributing the end-to-end delay to local switching node. In fact, if the end-to-end delay can be allocated to local switching node properly, the network utilization will be improved efficiently. How to map the end-to-end QOS requirements into the local switch's QOS requirement and then maximize the network utilization is an important issue. In [5], the authors proposed a scheme called EQ policy that computes the aggregated local worst case delay bound, and calculates the difference between the aggregated value and the application-required delay. Then, the extra value is equally assigned to the local switching node along the route. This policy is easy to implement. But, we do not understand how it will affect the network performance. In [8], the author proposed the concept of the network service curves. It said that the network service curves could be allocated to local switching node. But, the author does not describe that how to allocated these curves. This paper proposes a novel local QOS allocation policy called MaxMin allocation policy to maximize the network utilization based on the performance index: the excess bandwidth. The excess bandwidth means the sum of the available output capacity at each switching node that the connection passes through along the path. Why we choose this performance index? We may use the maximum allowable connections as the performance index. But this index only benefits the path that these connections pass through. From the viewpoint of the entire network, if the allocation makes the maximum available bandwidth, then the network can allow more applications from other paths to utilize the resources. We had proved that MaxMin policy is an optimal scheme by the excess bandwidth of the network as performance index. When we compared EQ with MaxMin policy, we found that the EQ policy is not only easy to implement, but also has the similar performance with MaxMin policy.

As widely assumption, the deterministic

leaky bucket [9] (σ,ρ) model is adopted to describe the traffic characteristics by a token arrival rate ρ and a bucket size σ. In addition, the delay bound is adopted as the end-to-end QOS request and it is translated into local requirement. This study considers the NPEDF(Non-Preemptive Earliest Deadline First) as packet scheduling policy at each switch. As the packets arrive at the switch, NPEDF packet scheduling algorithm assigns each packet a deadline. This deadline is obtained by summarizing the arrival time and the delay bound at this switch of each packet. The scheduler selects the packet with the earliest deadline to transmit non-preemptively. End-to-end delay bound is obtained by summarizing of the worst case local delay bound at each switch. That is, if there are M switches in the route which has the end-to-end delay bound d for the application, and the local delay bound at the node m is d^m, then the following equation is obtained:

$$d = \sum_{m=1}^{M} d^m .$$

The rest of this paper is organized as follows: Section 2 introduces the MaxMin allocation scheme. Section 3 shows the numerical results. Conclusions are finally made in section 4.

2. MaxMin allocation policy

2.1 Network model

Assume that a model consisting of M network elements in tandem. Each network element could be a packet switch along the route of a given connection. In addition, these switches are taken to a set of source-destination pairs. The input traffic for connection n is (σ_n,ρ_n) model. And the delay requirement for this connection is d_n. For each switching node m, the scheduling policy is NPEDF, and the output link capacity is R^m. A traffic shaper is added at each switch to reshape the traffic pattern before the traffic entered the scheduler. It can indeed ensure that the output traffic satisfies a burstiness constraint.

2.2 Allocation of delay

First, we specify the local delay bound at local switching node m as follow [10]:

$$d^m = \frac{L}{g_n^m} + \frac{L}{R^m}, \qquad (1)$$

where L is the maximum packet size in the network and g_n^m is the bandwidth allocated to connection n at node m. Therefore, g_n^m must be greater than or equal to ρ_n and be less than or equal to residual bandwidth of the output link at the node m, otherwise the input buffer and output buffer will build up. To determine g_n^m at each switch m such that the sum of the residual bandwidth at each switch along the path can be maximized, the allocation problem is described as follows:

Consider that a new connection n with (σ_n,ρ_n) traffic model and delay requirement d_n, wants to join the network and passes M nodes. And there have already been n-1 connections in the same route. The bandwidth for connection n at server m, g_n^m (i,e. the service rate), is allocated to maximize the utilization of the network. We want to find some g_n^m such that

$$\sum_{m=1}^{M} [(R^m - \sum_{i=1}^{n-1} g_i^n) - g_n^m] \text{ is maximized,} \qquad (2)$$

subject to

$$\sum_{m=1}^{M} d^m \le d_n, \qquad (3)$$

and

$$\rho_n \le g_n^m \le R^m - \sum_{i=1}^{n-1} g_i^m,\ \forall m = 1,\cdots,M .$$

From Eqs.(1) and (3), we have

$$\sum_{m=1}^{M} d^m = \sum_{m=1}^{M} \left(\frac{L}{g_n^m} + \frac{L}{R^m}\right) \le d_n .$$

Since there have been n-1 connections in the route, so $\sum_{m=1}^{M} (R^m - \sum_{i=1}^{n-1} g_i^m)$ is a fixed value and we can transfer the allocation problem to minimize the value of $\sum_{m=1}^{M} g_n^m$.

To obtain the maximum total residual bandwidth, thereby minimizing the sum of the bandwidth that allocated to this connection at each switching node, we first showed the following lemma.

<u>Lemma 1</u> *Subject to*

$$Q = \sum_{m=1}^{M} \frac{1}{g_m}, \qquad (4)$$

where Q is a constant.

If $g_1 = g_2 = \cdots = g_M$ then $\sum_{m=1}^{M} g_m$ has minimum.

Proof:

By induction

(1) Let *M*=2 then $Q = \frac{1}{g_1} + \frac{1}{g_2}$.

Case 1: Without loss of generality (WLOG), we let $g_1 < g_2$.

Assume that $g_1 = cg_2$, 0 < c < 1,

then $\frac{1}{cg_2} + \frac{1}{g_2} = Q$,

and $g_2 = \frac{1+c}{c} \bullet \frac{1}{Q}$, $g_1 = \frac{1+c}{Q}$.

Finally, we have

$$g_1 + g_2 = \frac{c^2 + 2c + 1}{c} \bullet \frac{1}{Q}. \qquad (5)$$

Case 2: Let $g_1 = g_2$,

then $\frac{2}{g_1} = Q$ and $g_1 = \frac{2}{Q} = g_2$,

therefore, we have

$$g_1 + g_2 = \frac{4}{Q}, \qquad (6)$$

$$(5) - (6) = \frac{c^2 - 2c + 1}{cQ} = \frac{(c-2)^2}{cQ} > 0.$$

Hence, we derive that: If $g_1 = g_2$ then $g_1 + g_2$ have the minimum.

(2) Assume *M*=*n*, and $Q = \frac{1}{g_1} + \cdots + \frac{1}{g_n}$.

Let the following statement hold: if $g_1 = g_2 = \cdots = g_n$,then $\sum_{i=1}^{n} g_i$ have the minimum.

(3) Let *M*=*n+1*.

Case 1: $g_1 < g_2 = \cdots = g_{n+1}$.

Eq. (4) can be written as:

$$Q = \frac{1}{g_1} + \cdots + \frac{1}{g_{n+1}}.$$

Assume $g_1 = c_1 g_2$, 0 < c_1 < 1,

then

$$\frac{1}{c_1 g_2} + \frac{n}{g_2} = Q \Rightarrow \frac{1 + \mathrm{n}c_1}{c_1 g_2} = Q.$$

Hence $g_2 = \frac{1+nc_1}{c_1 Q}$, $g_1 = \frac{1+nc_1}{Q}$,

and

$$\sum_{i=1}^{n+1} g_i = ((1+nc_1) + \frac{n + n^2 c_1}{c_1}) \bullet \frac{1}{Q}. \qquad (7)$$

Case 2: $g_1 = g_2 = \cdots < g_{n+1}$.

Assume $g_{n+1} = c_2 g_1, c_2 > 1$,

then

$$\frac{1}{c_2 g_1} + \frac{n}{g_1} = Q \Rightarrow \frac{1 + \mathrm{n}c_2}{c_2 g_1} = Q,$$

and $g_1 = \frac{1+nc_2}{c_2 Q}$, $g_{n+1} = \frac{1+nc_2}{Q}$.

We have

$$\sum_{i=1}^{n+1} g_i = ((1+nc_2) + \frac{n + n^2 c_2}{c_2}) \bullet \frac{1}{Q}. \qquad (8)$$

Case 3:

$$g_1 = g_2 = \cdots = g_{n+1} \Rightarrow \frac{n+1}{g_1} = Q \Rightarrow g_1 = \frac{n+1}{Q},$$

then

$$\sum_{i=1}^{n+1} g_i = \frac{(n+1)^2}{Q}. \qquad (9)$$

Hence

$$(7) - (9) = \frac{n(c_1^2 - 2c_1 + 1)}{c_1 Q} = \frac{n(c_1 - 1)^2}{c_1 Q} > 0,$$

$$(8) - (9) = \frac{n(c_2^2 - 2c_2 + 1)}{c_2 Q} = \frac{n(c_2 - 1)^2}{c_2 Q} > 0.$$

As $g_1 = g_2 = \cdots = g_{n+1}$,

$\sum_{i=1}^{n+1} g_i$ have the minimum value.

The lemma is proved. □

Consider the problem of translating an end-to-end delay requirement into a set of local requirements. Our goal is to maximize the sum of the residual bandwidth at each switching node. Assume that a series of M switches that have unused bandwidth r^1, r^2, ..., r^M. WLOG, let $r^1 \leqq r^2 \leqq ... \leqq r^M$. In addition, we assume that the input traffic model of the connection n is (σ_n, ρ_n) model and has an end-to-end delay requirement d_n for this connection. The maximum packet size in the network is L. Furthermore, the service rate allocated at each switch are $g_n^1, g_n^2, \cdots, g_n^M$. From Eq. (1), we have

$$d_n \geq \sum_{m=1}^{M} \frac{L}{g_n^m} + \sum_{m=1}^{M} \frac{L}{R^m}. \tag{10}$$

Let $\frac{d_n - \sum_{m=1}^{M} \frac{L}{R^m}}{L} = Q$ then Eq.(10) can be rewritten as $Q \geq \sum_{m=1}^{M} \frac{1}{g_n^m}$. For unwasting the bandwidth, let $Q = \sum_{m=1}^{M} \frac{1}{g_n^m}$. By lemma 1, if $g_n^1 = g_n^2 = \cdots = g_n^M = g$ then $\sum_{m=1}^{M} g_n^m$ is minimized. $g = \frac{M}{Q}$ is obtained. That is, if the allocated service rate for each switching node that the connection passed through is the same, then the sum of the allocated service rate is minimum. Therefore, we can obtain the maximum of the excess bandwidth. Then, an allocation scheme, referred to as MaxMin allocation, is proposed as follows:

First, we have the following notes :

1. No switch gets a delay allocation smaller than it can provide.
2. Delay is allocated in the increasing order of the unused bandwidth at each switch.

The bandwidth, $\frac{M}{Q}$, is initially allocated to the switch which has unused bandwidth r^1. If $g \leq r^1$, then all the switches are allocated the same service rate being equal to $\frac{M}{Q}$. Otherwise, the switch which has unused bandwidth r^1 is allocated the service rate r^1 owing to note 1. Compute the service rate for the other switches as follows:

$$Q = \sum_{m=1}^{M} \frac{1}{g_n^m} = \frac{1}{g_n^1} + \sum_{m=2}^{M} \frac{1}{g_n^m} = \frac{1}{r^1} + (M-1)\frac{1}{g}$$

$$\Rightarrow Q - \frac{1}{r^1} = (M-1)\frac{1}{g}$$

$$\Rightarrow g = \frac{M-1}{Q - \frac{1}{r^1}}.$$

If $\frac{M-1}{Q - \frac{1}{r^1}} \leq r^2$, then all the switches except the switch with the residual bandwidth r^1 are allocated the same service rate being $\frac{M-1}{Q - \frac{1}{r^1}}$. Otherwise, the switch which has unused bandwidth r^2 is allocated the service rate r^2. Repeat this process until all the switches are allocated.

MaxMin allocation algorithm:

Input: input traffic-(σ_n, ρ_n), delay requirement-d_n, packet size in the network-L, link capacity-$R^m, \forall m = 1, \cdots, M$.

Output: the allocated bandwidth-$g_n^m, \forall m = 1, \cdots, M$.

Phase 1:

1 Sort the residual bandwidth at each node

such that $r^1 \le r^2 \le \cdots \le r^M$.

$g = \dfrac{ML}{d_n - \sum_{m=1}^{M} \frac{L}{R^m}}$.

If $g \le r^1$,

Then $g_n^m = g, \forall m = 1,\cdots,M$,

End.

If $g > r^1$.

Then i=1.

go to Phase 2.

Phase 2:

$g_n^i = r^i$, $Q = Q - \dfrac{1}{r^i}$.

If $i=M$,

End.

Else $g = \dfrac{M-i}{Q}$.

If $g \le r^{i+1}$,

Then $g_n^m = g, \forall m = i+1,\cdots,M$,

End.

If $g > r^{i+1}$,

Then $i=i+1$.

go to Phase 2.

When the allocated bandwidth g_n^m is computed for each node m, the delay is derived as $d^m = \dfrac{L}{g_n^m} + \dfrac{L}{R^m}$, $\forall m = i+1,\cdots,M$. That is, if the delay bound for each node m is assigned as d^m, the excess bandwidth in the network is maximized without violating the delay bound guaranteed for the connection. In next section, we will analyze the distinction between EQ and MaxMin policy.

2.3 The distinction between EQ and Maxmin policy

First, we consider the EQ policy which assigns an extra amount of the end-to-end delay requirement for a connection to each node. In [13], we had derived that the delay allocated to each node m using EQ policy is :

$$d^m = \frac{N^m L}{R^m - \sum_{i=1}^{n-1} g_i^m} + \frac{L}{R^m}, \qquad (11)$$

where $N^m = \dfrac{(d_n - D_l)(R^m - \sum_{i=1}^{n-1} g_i^m)}{ML} + 1$,

$$D_l = \sum_{m=1}^{M} \left(\frac{L}{R^m - \sum_{i=1}^{n-1} g_i^m} + \frac{L}{R^m} \right).$$

Therefore, by $d^m = \dfrac{L}{g_n^m} + \dfrac{L}{R^m}$, we have that the service rate for connection n at node m under the EQ policy is

$$g_{EQ} = g_n^m = \frac{R^m - \sum_{i=1}^{n-1} g_i^m}{N^m}$$

$$= \frac{R^m - \sum_{i=1}^{n-1} g_i^m}{\dfrac{(d_n - D_l)(R^m - \sum_{i=1}^{n-1} g_i^m)}{ML} + 1}$$

$$= \frac{ML}{(d_n - D_l) + \dfrac{ML}{R^m - \sum_{i=1}^{n-1} g_i^m}}$$

$$= \frac{ML}{d_n - \sum_{m=1}^{M} \left(\dfrac{L}{R^m - \sum_{i=1}^{n-1} g_i^m} + \dfrac{L}{R^m} \right) + \dfrac{ML}{R^m - \sum_{i=1}^{n-1} g_i^m}}$$

$$= \frac{ML}{d_n - \sum_{m=1}^{M} \dfrac{L}{R^m} + M \dfrac{L}{R^m - \sum_{i=1}^{n-1} g_i^m} - \sum_{m=1}^{M} \left(\dfrac{L}{R^m - \sum_{i=1}^{n-1} g_i^m} \right)}.$$

Next, we consider the MaxMin policy. We know that when the available bandwidth of all links are enough, the service rate in each node for connection n is allocated as

$$g_{MaxMin} = g_n^m = g = \frac{ML}{d_n - \sum_{m=1}^{M} \frac{L}{R^m}}. \qquad (13)$$

From Eq. (12) and Eq. (13), we found the distinction between EQ and MaxMin is the

3rd and 4th term of the denominator of Eq. (12). Define

$$\Delta^m = M \frac{L}{R^m - \sum_{i=1}^{n-1} g_i^m} - \sum_{m=1}^{M} \left(\frac{L}{R^m - \sum_{i=1}^{n-1} g_i^m} \right) . \qquad (14)$$

Since

$$d_n - \sum_{m=1}^{M} \frac{L}{R^m} >> \Delta^m .$$

Therefore, g_{EQ} is close to g_{MaxMin}. That is, the performance of the EQ policy is close to the MaxMin policy. In the next section, we will use numerical results to show this distinction.

3. Numerical results

Figure 1 shows the tandem network model. The model consists of a single source-destination pair of nodes. The network has 3 nodes and a single route. The bandwidth for all links are $R^2 = R^3 = 150$ units, and R^1 is varied. There have been 3 connections in this route. We take the maximum packet size L=5. The value of parameters for all connections in the route are as following. The input traffic model for connection 1 is (σ_1, ρ_1)=(2,5), and delay request is 3 units. The input traffic model for connection 2 is (σ_2, ρ_2)=(3,4), and delay request is 3 units. The input traffic model for connection 3 is (σ_3, ρ_3)=(4,3), and delay request is 4 units. The new connection has input traffic model being (σ_4, ρ_4)=(5,2). We compare MaxMin policy with EQ policy.

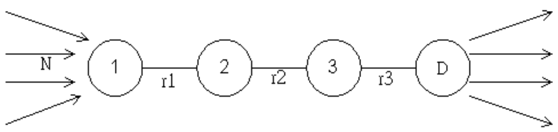

Figure 1 The Tandem Network Model

We perform two experiments. The first we use EQ and MaxMin policy separately to observe the variation of the residual bandwidth over the end-to-end delay request ranged from 1 to 7.3 units with $R^1 = 50$. Figure 2 shows the result. We find that the total residual bandwidth is very close for the two policies. The second, we fixed d_n with 1.7 and compute the EQ/MaxMin ratio for EQ policy relative to MaxMin policy with different bottleneck ratio. The EQ/MaxMin ratio is defined as follow:

$$\text{EQ/MaxMin} = \frac{\text{The total residual bandwidth using EQ policy}}{\text{The total residual bandwidth using MaxMin policy}} . \qquad (15)$$

And the bottleneck ratio is the ratio of bottleneck bandwidth with the other link bandwidth, i.e, R^1 / R^3. Figure 3 shows the result. We find that the EQ/MaxMin ratio is close to 1. From the analysis of last section, we know that using the MaxMin policy the network can have the most residual bandwidth and have the largest network utilization. And from the two results in this section, we find that the performance of the EQ policy is close to the MaxMin policy. That is, the EQ is not only simple, but also has good performance in excess bandwidth for the network. Therefore the network can have more available bandwidth to accommodate more connections.

Figure 2 The variation of the residual bandwidth over the end-to-end delay request

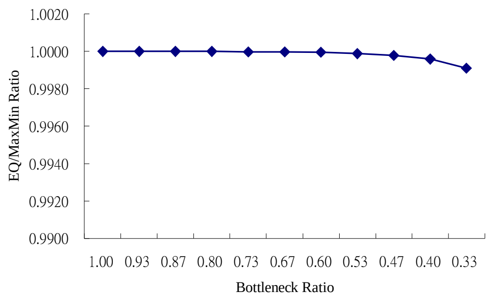

Figure 3 The variation of the EQ/MaxMin over the bottleneck ratio

4. Conclusion

This paper presents a novel approach to maximize the network's efficiency, referred as to the excess bandwidth, without violating each end-user's QOS requirement. The proposed scheme appropriately obtain the maximum of the network's excess bandwidth. Moreover, using our method as benchmark, the numerical results verify that the EQ policy proposed by D. Ferrari has the similar performance as this method. This fact implies that the EQ policy is worth to use in the network since its simple and good performance in network utilization.

The concept of the excess bandwidth is to treat the resources of the network being all equal important. We can join the weighted concept to the excess bandwidth to emphasize the effect of bottleneck link in the networks. With this modification, we believe that this performance index will be more suitable to evaluate the allocation policy.

REFERENCES

[1] A. Demers, S.Keshav, and S. Shenker, "Analysis and simulation of fair queuing algorithm," Journal of Internetworking Research and Experience, pp. 3-26, October 1990.

[2] A. Parekh and R. G. Gallager, "A generalized processor sharing approach to flow control in integrated services networks: The single-node case," IEEE/ACM Transaction on Networking, vol.2, no.2, pp.344-357, June 1993.

[3] A. Parekh and R. G. Gallager, "A generalized processor sharing approach to flow control in integrated services networks: The multiple-node case," IEEE/ACM Transaction on Networking, vol.2, no.2, pp.137-150, April 1994.

[4] D. Ferrari, "Real-time communication in an internetwork," Journal of High Speed Network, vol. 1, no. 1, pp. 79-103, 1992.

[5] D. Ferrari and D. Verma, "A Scheme for Real-time Channel Establishment in Wide-Area Network," IEEE Journal Selected Areas of Communications, 8(4), pp.368-379, April 1990.

[6] G. G. Xie and S. S. Lam, "Delay guarantee of VirtualClock server," IEEE/ACM Transaction on Networking, vol.3, no.6, pp.683-689, December 1995.

[7] H. Zhang and D. Ferrari, "Rate-controlled static priority queuing," Proceedings of the IEEE INFOCOM '93, San Francisco, pp.227-236 1993

[8] H. Sariowan, A service curve approach to performance guarantees in integrated-service networks, Ph. D. thesis, Dept. of Electrical and Computer Engineering, Univ. of California, San Diego, 1996.

[9] J. Turner, "New directions in communications (or which way to the information age?)," IEEE Communication Magazine, vol. 24, pp. 8-15, October 1986.

[10] L. Georgiadis, R. Guerin, and A. K. Parekh, "Optimal multiplexing on a single link: delay and buffer requirements", IBM T. J. Watson Research Center, Res. Rep. RC 19711(97393), Aug. 1994.

[11] P. Goyal, H. Vin, and H. Cheng, "Start-time Fair Queuing: a scheduling algorithm for integrated services packet switching networks," IEEE/ACM Transaction on Networking, vol. 5, no. 5, pp. 137-150, October 1997.

[12] S. Golestani, "Network delay analysis of a class of fair queuing algorithms," IEEE Journal Selected Areas of Communications, vol. 13, pp. 1057-1070, August 1995.

[13] Y. P. Chu, C. H. Chen, E. H. Hwang and K. C. Lin "Efficient Allocation For

Quality of Service Guarantees", Submitted to IEICE Transaction on Communications.