JOINT SELECTION OF SOURCE CLASS AND CALL ADMISSION POLICY FOR THE BOUNDED DELAY SERVICES

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ABSTRACT

An essential challenge of incorporating VBR video traffic into networks with service guarantees lies in the difficulty of finding an appropriate traffic characterization that captures the dynamics of the source. A simple traffic model, such as leaky bucket, will lead to low network utilization, especially for burst traffic. However, both multiple leaky bucket and D-BIND are more accurate traffic model, but it is more complex to implement the policy function for high-speed network. And also close form formula of the call admission algorithm is not easily to be derived. In this study, we improve the network utilization by using σ(ρ) (burstiness curve) traffic specification instead of single set of (σ,ρ) while the complexity of the network still same as the network of single leaky bucket traffic model. We derived the close form formula of call admission control and show how to select the optimal class from the burstiness curve. After the call admission algorithm gets the optimal class, it polices the input traffic with this set of (σ,ρ) parameters by using a leaky bucket regulator only the call admission algorithms are different. Therefore, the regulator is only a leaky bucket at first node that the connection passes through. The network is same as single leaky bucket traffic model. The performance is over 1.21 times for burstiness curve model to single (σ,ρ) model in our experiments.

1. INTRODUCTION

With the improvement of computer and communication hardware, future multiservice packet-switching networks will support applications with diverse traffic characteristics and performance requirements. Of many traffic classes, delay-sensitive variable bit rate (VBR) video poses a unique challenge. Since the performance of a bounded delay service is largely influenced by three factors: (1) the specification which describes the worst case traffic from a connection, (2) the scheduling discipline the network switches use, and (3) the accuracy of the admission control functions. The main design goal is to maximize the performance of the network; that is, to maximize the number of connections that can be supported without violating any delay bound guarantees. Many network architectures have been proposed in [1,2,3,4]. In this study, we focus on issue (1) and (3). We improve the network utilization by using burstiness curve traffic specification $s(r)$ instead of single (s,r). We define the burstiness curve $s(r)$of a message as the maximum number of bits that must be buffered at a node if message allocate a fixed rate r bps. While the complexity of the network, still same as the network of single leaky bucket model. The network employs DJ regulator to reconstruct the traffic pattern and first-come-first-service (FCFS) to schedule the service order of each input packet. By using the call admission formula of [5] which is base on single leaky bucket traffic, we derived the close form admission control formula for burstiness curve traffic model. We focus on the trade-off involved in the selection of the value of (s_i,r_i) parameters and their impact on the number of connections.

The traffic specification of a connection describes the worst case traffic that is generated by this connection. Admission control functions use this specification and resource available to determine to either accept or reject a new connection. In addition, traffic monitoring by the policing functions is based on the traffic specification. If the traffic specification for a connection does not precisely describe its actual traffic, the admission control functions will overestimate the resource requirements for a connection. There are several proposals for both deterministic traffic specifications and statistical traffic specifications. The deterministic traffic specifications, such as (s,r), multiple leaky bucket and D-BIND [6] characterize the VBR traffic in terms of a worst-case description. All traffic models except the most accurate time–invariant video traffic model have deviation with the actual size of video stream data. In general, a model with more parameters can achieve a more accurate traffic constraint functions; the additional parameters cause an increase in the complexity of policing the traffic model. Since (s,r) is a more simplify policing function and easily to implement, that will be suitable for future high-speed network. How to extend its performance is the main issue in this study. We proposed a method to select optimal (s,r) value from burstiness curve in order to improve the network utilization.

User needs to propose traffic specification for resource allocation. By analyzing the packet stream of input data, user gets a burstiness curve $s(r)$, which can be used as traffic specification. If the allocation rate (r) is smaller than the average rate of input data, the queue will build infinitely. If the allocation rate is larger than the peak rate of input data, the extra rate is waste. So the allocation rate is between the average rate and peak rate of input data. We can increase the value of the burst (s) and lower value of the rate (r), all these sets of (s,r) value still can conform the input data stream as shown in figure 1. Figure 5 is an example of burstiness curve shown in σ-ρ coordinate. We can piecewise the burstiness curve and define each corner (s_i,r_i) point as a class. Which class is best choice for getting maximum number of connections? According to [7], the knee of burstiness curve is good choice. A knee in the burstiness curve has a distinct indicates that for descriptors that are slightly away from the knee, either the s or the r parameter rapidly increases. With our study, this is not always correct. Since the optimal class, depend on the environment of network. We derived the close form formula of call admission control jointly selects optimal class from burstiness curve. The method to select the optimal traffic class is simple and the improvement to the network utilization is clear. The average performance is over 1.21 times for burstiness curve model to single (s,r) model in our experiments. The remainder of the paper is structured as follows. In Section 2, we describe the network architecture and proposed the optimal class selection formula. In Section 3, we use traces of MPEG-encoded VBR video traffic to empirically evaluate the performance of class selection algorithm.

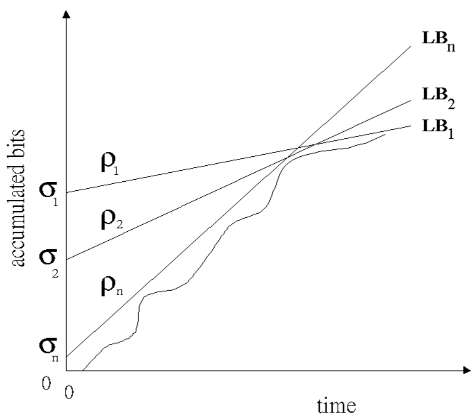

Figure 1 Variant sets of leaky bucket parameters

2. OPTIMAL CLASS SELECTION

2.1 Network Architecture and Traffic Model

In [5], we proposed a network architecture that permits N kinds of (s_i, r_i) classes of input traffics. Class j is conformed to leaky bucket (s_j, r_j). The architecture of switch node of network is as figure 2. At the first node of each connection, we add a leaky bucket regulator to policy the input data. At each hop, we add a delay jitter regulator to reconstruct the traffic pattern. The characteristics of the source traffic are modified as the source traffic passes through the network, we add a Delay Jitter (DJ) regulator [8] for each connection at the switch to reshape the traffic pattern to conform to the same traffic pattern at the first node before the traffic enters the FCFS queue. By using burstiness curve traffic specification, users sand piecewise (s_j, r_j) parameters to the network as shown in figure 2.

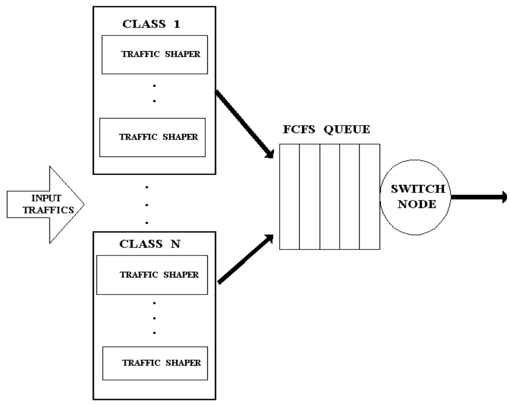

Figure 2 The Architecture of Switching Node

2.2 Joint Selection

The input data consider in this paper can be audio, MPEG, and JPEG etc. Among above data type, MPEG Vi deo is most highly burst, so we use MPEG as an example here. According to [9], For an input data, such as MPEG video stream, there is a $s(r)$ function can conform it. According to [7], the knee of burstiness curve is good choice. However, which point is optimal? Since the goal of network is to maximum the number of connections, optimal class is dependent on call admission policy. We propose a method to jointly select the (s,r) class according to the admission control policy. User provides burstiness curve in piecewise form. The call admission policy will select the class with maximum function value in order to get maximum number of connections. In this study, the schedule policy can be either OPT (optimal) or EQ (Equal Allocation).

2.3 Call Admission Formula

For the proposed network architecture, call admission policy can be either optimal distribution (OPT) or equal distribution (EQ). We neglect propagation and node processing delays. In [5], two formulas are derived for OPT and EQ policy. We use these formulas as our cost functions. The user can put parameters of each class into this cost function. The class with maximum value is the optimal.

Theorem 1 For the proposed network with OPT policy, consider a connection passing through n switches connected in cascade and the bandwidth of node i is l_i. The delay requirement is Q. Assumed current number of connections of class $1, 2, ,\cdots, N$ at node i is $N_1^{\,i}, N_2^{\,i}, \cdots, N_N^{\,i}$, respectably, then the number of connections of class k that is permitted to enter again is N_{OPT}. We define $N_{OPT}(k)$ as the cost function of OPT policy.

$$N_{OPT}(k) = \min\{N_s(k), N_r(k)\} \quad (1)$$

Where N_s is the number of connections depend on σ and N_r is the number of connections depends on ρ.

$$N_s(k) = \left\lfloor \frac{Q - \sum_{i=1}^{i=n} \frac{\sum_{j=1}^{N} N_j^i \sigma_j}{l_i}}{\sigma_k \sum_{i=1}^{n} \frac{1}{l_i}} \right\rfloor \quad (2)$$

$$N_r(k) = \min\{\left\lfloor \frac{l_i - \sum_{j=1}^{N} N_j^i r_j}{r_k} \right\rfloor, i = 1,2,\cdots,n\} \quad (3)$$

Theorem 2 For the proposed network with EQ policy, considers a connection passing through n switches connected in cascade and the bandwidth of node i is l_i. The delay requirement is Q. Assumed current number of connections of class $1, 2, \cdots, N$ at node i is $N_1^i, N_2^i, \cdots, N_N^{\,i}$, respectably, then the number of connections of class k that is permitted to enter again is N_{EQ}. We define $N_{EQ}(k)$ as the cost function of EQ policy.

$$N_{EQ}(k) = \min\{N_s(k), N_r(k)\} \quad (4)$$

Where N_s is the number of connections depend on σ and N_r is the number of connections depends on ρ.

$$N_s(k) = \min\{\frac{\frac{Ql_i}{n} - \sum_{j=1}^{N} N_j^i \sigma_j}{\sigma_k}, i = 1,2,\cdots,n\} \quad (5)$$

$$N_r(k) = \min\{\left\lfloor \frac{l_i - \sum_{j=1}^{N} N_j^i r_j}{r_k} \right\rfloor, i = 1,2,\cdots,n\} \quad (6)$$

Definition For the proposed network, supposed there are n sets of (σ, ρ) class can conform the input data stream. The n classes are class $C_1, C_2, \cdots, C_n$. Without lose generality, assumed $\sigma_{C_1} > \sigma_{C_2} > \cdots > \sigma_{C_n}$ and $r_{C_1} \le r_{C_2} \le \cdots \le r_{C_n}$. The option for the scheduling policy can be either OPT or EQ. We define the optimal class is

$$Optimal\ class(C_i) = \left\{ \begin{array}{l} C_k \text{ such that } N_{OPT}(C_k) = \\ Max\{N_{OPT}(C_i), i = 1,2,\cdots n\} \\ \quad \text{for OPT policy} \end{array} \right\}$$

$$Optimal\ class(C_i) = \left\{ \begin{array}{l} C_k \text{ such that } N_{EQ}(C_k) = \\ Max\{N_{EQ}(C_i), i = 1,2,\cdots n\} \\ \quad \text{for EQ policy} \end{array} \right\}$$

With the equation (1) to (6), we can develop the formula to select optimal class in next section.

2.4 Optimal Class Selection Formula

To determine how optimal class vary over delay requirement, we use OPT policy as an example and analyzed the formula (1), (2) and (3) as follows. Supposed Network supports N classes are (σ_1, r_1), (σ_2, r_2), ..., and (σ_N, r_N), respectably. Consider a connection passing through M switches connected in cascade and the bandwidth of node i is l_i. The minimum bandwidth is $l_{\min} = \min\{l_1, l_2, \cdots, l_M\}$. Supposed the current number of connections is N_i for class i. By analyzing the packet stream of input video, we get a burstiness curve. User matches this σ-ρ curve with the support classes of the network and gets n sets of (σ, ρ) class which can be used for traffic specification. Supposed these n classes are class $C_1, C_2, \cdots, C_n$. Without lose generality, assumed $\sigma_{C_1} > \sigma_{C_2} > \cdots > \sigma_{C_n}$ and $r_{C_1} \le r_{C_2} \le \cdots \le r_{C_n}$. We analysis the relation of the admission region with delay requirement for tandem network as below:

Case 1: In case of large delay requirement, we select class C_1.

When the delay requirement is more loosely, N_σ is bigger than N_ρ, the number of connections is restricted by ρ value. Since the ρ value of class C_1 is smallest one among the ρ_i value of the class C_i, $i=1,2,..,$ and n. Then, the number of connections of class C_1 is largest. Therefore, we select class C_1. When we follow the curve of class C_1 in the figure 3, we get a delay $Q^*_{C_1}$, such that $N_s^{C_1}$ is equal to $N_r^{C_2}$.

$$N_s^{C_1} = \frac{Q^*_{C_1} - \sum_{i=1}^{i=M} \frac{\sum_{j=1}^{N} N_j^i \sigma_j}{l_i}}{\sigma_{C_1} \sum_{i=1}^{M} \frac{1}{l_i}} = N_r^{C_2} = \frac{l_{\min} - \sum_{j=1}^{N} N_j^i r_j}{r_{C_2}}$$

$$Q^*_{C_1} = \left(\frac{\sigma_{C_1}}{r_{C_2}} \sum_{i=1}^{M} \frac{1}{l_i}\right)\left(l_{\min} - \sum_{j=1}^{N} N_j^i r_j\right) + \sum_{i=1}^{i=M} \frac{\sum_{j=1}^{N} N_j^i \sigma_j}{l_i}$$

Case 2: In case of small delay requirement, we can select class C_n

When the delay requirement is more stringent, N_σ is smaller than N_ρ, the number of connection are restricted by σ value. Since the value of σ of class C_n is smallest one among the σ value of all the classes, that the $N_s^{C_n}$ is the biggest one. The best choice is class C_n. When the delay is more stringent, we can get a delay $Q^*_{C_{n-1}}$ such that $N_s^{C_{n-1}} = N_r^{C_n}$, i.e.

$$N_s^{C_{n-1}} = \frac{Q^*_{C_{n-1}} - \sum_{i=1}^{i=M} \frac{\sum_{j=1}^{N} N_j^i s_j}{l_i}}{s_{C_{n-1}} \sum_{i=1}^{M} \frac{1}{l_i}} = N_r^{C_n} = \frac{l_{\min} - \sum_{j=1}^{N} N_j^i r_j}{r_{C_n}}$$

$$Q^*_{C_{n-1}} = \left(\frac{s_{C_{n-1}}}{r_{C_n}} \sum_{i=1}^{M} \frac{1}{l_i}\right)\left(l_{\min} - \sum_{j=1}^{N} N_j^i r_j\right) + \sum_{i=1}^{i=M} \frac{\sum_{j=1}^{N} N_j^i s_j}{l_i}$$

Case 3: For delay requires between $Q^*_{C_{n-1}}$ and $Q^*_{C_1}$, we select class C_k, $1<k<n$

For a class C_k, we can get a delay $Q^*_{C_k}$ such that $N_s^{C_k} = N_r^{C_{k+1}}$, i.e.

$$N_s^{C_k} = \frac{Q^*_{C_k} - \sum_{i=1}^{i=M} \frac{\sum_{j=1}^{N} N_j^i s_j}{l_i}}{s_{C_k} \sum_{i=1}^{M} \frac{1}{l_i}} = N_r^{C_{k+1}} = \frac{l_{\min} - \sum_{j=1}^{N} N_j^i r_j}{r_{C_{k-1}}}$$

$$Q^*_{C_k} = \left(\frac{s_{C_k}}{r_{C_{k+1}}} \sum_{i=1}^{M} \frac{1}{l_i}\right)\left(l_{\min} - \sum_{j=1}^{N} N_j^i r_j\right) + \sum_{i=1}^{i=M} \frac{\sum_{j=1}^{N} N_j^i s_j}{l_i}$$

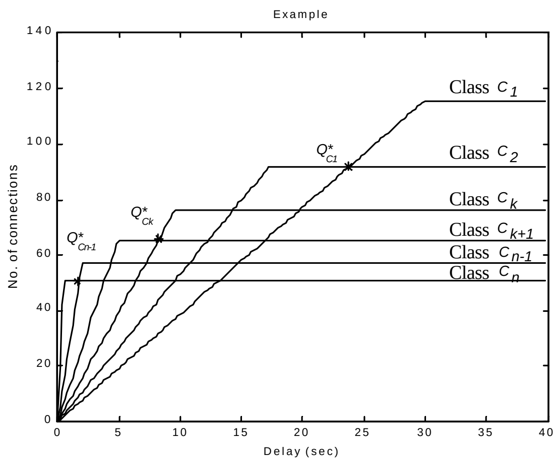

Figure 3 The points of $Q^*_{C_{n-1}}$ *and* $Q^*_{C_1}$

Since $\frac{s_{Cn}}{r_{Cn-1}} \le \frac{s_{Cn-1}}{r_{Cn-2}} \le \cdots \le \frac{s_{C2}}{r_{C3}} \le \frac{s_{C1}}{r_{C2}}$, then $Q^*_{C_{n-1}} \le Q^*_{C_{n-2}} \le \cdots \le Q^*_{C_2} \le Q^*_{C_1}$, we summary the relation of class selection and delay requirement as follows:

Case 1: $Q \ge Q^*_{C_1}$ Select class C_1

Case 2: $Q^*_{C_k} \le Q \le Q^*_{C_{k-1}}$ Select dass C_k, for $k=2,3, \cdots, n-1$

Case 3: $Q \le Q^*_{C_{n-1}}$ Select class C_n

3. NUMERICAL RESULTS

In order to evaluate the efficiency and optimality of our proposed method, a series of numerical examples are presented in this section. Two performance measure indexes are adopted to decide the efficiency and optimality of the joint selection method. One is the network utilization, in term of the number of admissible connections, which is used to represent the efficiency of the proposed method. Moreover, another index is average number of connections to evaluate the optimality of the selection method. In this paper, three experiments are employed to evaluate the efficiency and optimality of the proposed method as follows. (1) With five hops tandem network, no any connection initially, and then evaluate the two performance indexes with delay for each new class. (2) With five-hop tandem network, there are 100 and 10 connections of class 8 and 9 initially, and then evaluate two performance indexes with delay for each new class. (3) With cross network, there are 100 and 10 connections of class 8 and 9 initially, and then evaluate two performance indexes with delay for each new class. The traffic specification of class 8 and 9 are shown table 4. From [10], we get a 10 minutes of segment of starwar compressed video traces as shown in figure 4. The format, resolution, and frame rate are IBBPBBPBBPBB, 384x288, and 25 frame/sec, respectively. By analyzing the packet stream of input video, we get a σ-ρ curve as figure 5. User matches this σ-ρ curve with the support classes of the network and get 7 sets of (σ,ρ) class which can be used for traffic specification as figure 5. We list the (σ, ρ) values defined as class 1 to 7 for new connections shown in table 1. We compute the

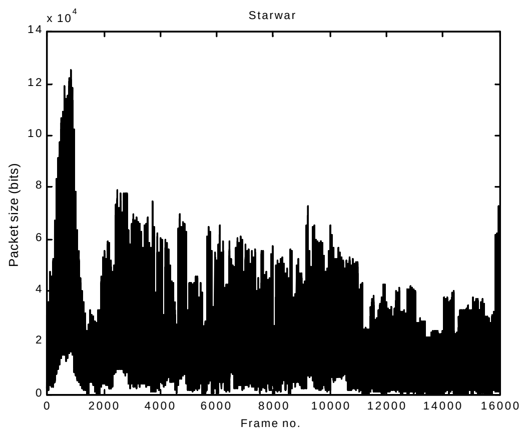

Figure 4 MPEG video stream traces (10 minutes)

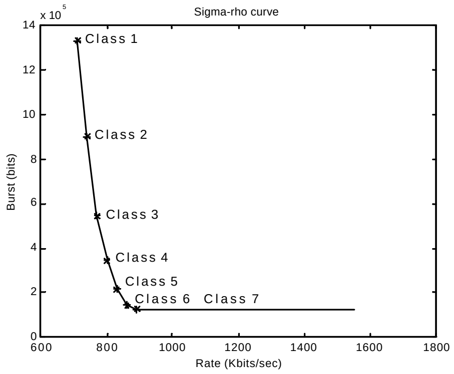

Figure 5 The sigma-rho curve of MPEG video stream

Class	σ (bits)	ρ (Kbit/sec)
1	1332104	710.
2	899816	740.
3	546400	770.
4	345792	800.
5	216704	830.
6	144792	860.
7	124816	890.

Table 1 The classes for input MPEG stream

Experiment 1: five hop tandem network with no any connection initially

The network structure is shown in figure 6. The bandwidth between each node was 622.08 Mbits/sec except for l_3, which is 51.84 Mbits/sec. The traffic specification of class 8 and 9 are shown table 4.

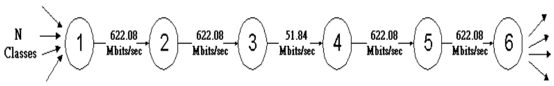

Figure 6 The tandem network

The number of connections of each class (class 1 to 7) is as figure 7 and 8 for OPT policy, and figure 9 and 10 for EQ policy, respectably. We compute all the Q_k^* and list them in table 2. According to the delay requirement, we list the optimal class in table 3. We focus on the admission region analysis between 1ms to 3sec to cover all the above time points. By equation (1) and (2), the relation of the number of connections of each class with delay is shown in figure 7. From figure 7, we see each curve of a class has two sections, one is linear increase section and the other is constant section. For example, the linear section of class 1 is from delay 0 sec to 2.5 sec and the constant section is from delay 2.5 sec to 3sec. From figure 7, we will see the class 1 is suitable for large delay requirement, while the class 7 is good for smaller delay requirement.

By the proposed method, we can get the best performance as shown in figure 8. Otherwise, in lack the information of the call admission policy, user only can select one of following two approaches; (1) fix class: for example, use knee point of the burstiness curve, such as class 5, the result is as the fix case that was shown in figure 8, and (2) peak rate class: select the class with peak rate. The result is shown as peak case in figure 8. We define the deterministic multiplexing gain (DMG) as the gain in number of connections (in average) above a peak-rate-allocation scheme that is achieved. The DMG is used to further quantify the improvements of the new model. The performance is over 1.16 times for best case to peak rate case and 1.11 times for best case to fix class case in experiment 1 for OPT policy. For EQ policy, performance is over 1.06 times for best case to peak case and 1.12 times for best case to fix class case. From figure 8 and 10, we will see the peak rate allocation get a better performance in low delay requirement.

	Q_1^*	Q_2^*	Q_3^*	Q_4^*	Q_5^*	Q_6^*
OPT	2.40	1.55	0.91	0.55	0.33	0.21

Table 2 The Q_k^* of experimrnt 1

	Delay Requirement	Optimal class
OPT	Above 2.40sec	1
	1.55sec~2.40sec	2
	0.91sec~1.55sec	3
	0.55sec~0.91sec	4
	0.33sec~0.55sec	5
	0.21sec~0.33sec	6
	Below 0.21sec	7

Table 3 The class selection for OPT policy in experiment 1

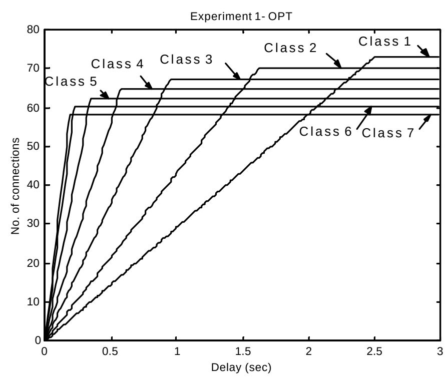

Figure 7 The admission region of OPT policy for EXP1

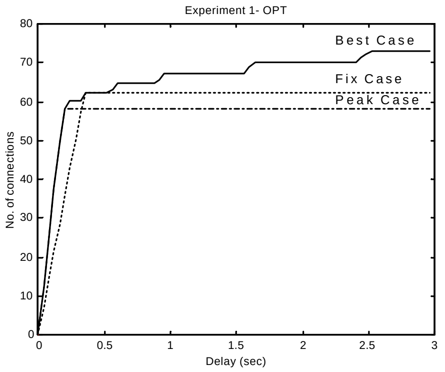

Figure 8 Comparison of admission region of different strategy for OPT policy

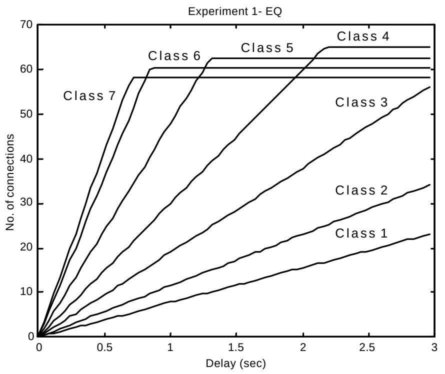

Figure 9 The admission region of EQ policy for EXP1

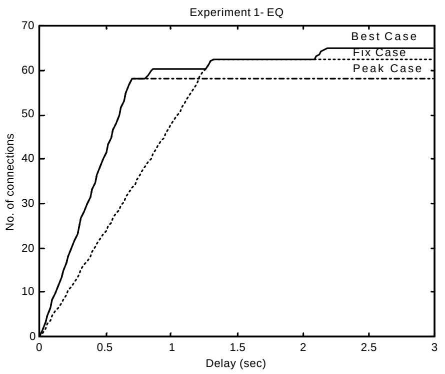

Figure 10 Comparison of admission region of EQ policy for EXP1

Experiment 2:

The network is same as experiment 1 and supposed the number of connections of class 8 and 9 are 100 and 10, respectably. Since the delay bound are same for a FCFS scheduling switch node, the call admission should assign all the connections (include class 1 to 9) with delay requirement smaller than 500ms. If the delays of class 1 to 7 are over 500ms, then the delay of class 8 will be over 500ms also. The network violates the QOS guarantee of class 8. Therefore, the delay of class 1 to 7 should be smaller than 500ms. By equation (1) and (2), the relation of the number of connections of each class with delay is shown in figure 11 and 13 for OPT and EQ policy, respectably. The performances for three strategies are shown in figure 12 and 14 for EQ and OPT policy, respectably. The performance is over 1.05 times for best case to peak rate case and 1.16 times for best case to fix class case for OPT policy. For EQ policy, performance is same for best case to peak rate case and 1.73 times for best case to fix class case.

	Class	Delay (ms)	σ (bits)	ρ Kbits/sec	connections
Low delay group	8	500	800	64.	100
Medium delay group	9	750	80000	500.	10

Table 4 Current number of connections for experiment 2 and 4

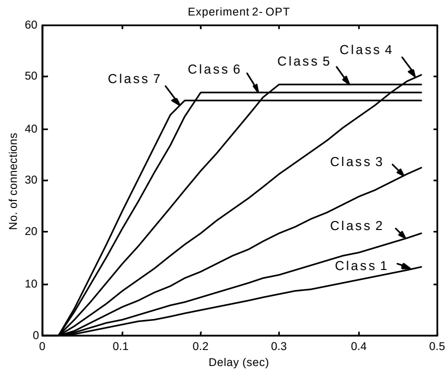

Figure 11 The admission region of OPT policy for experiment 2

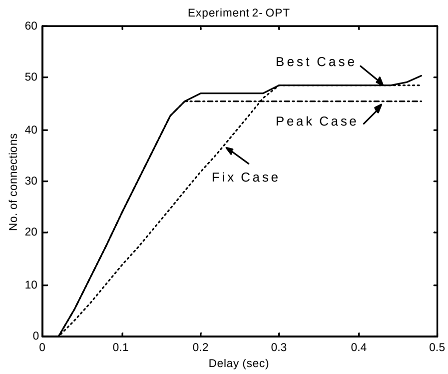

Figure 12 Comparison of admission region of OPT

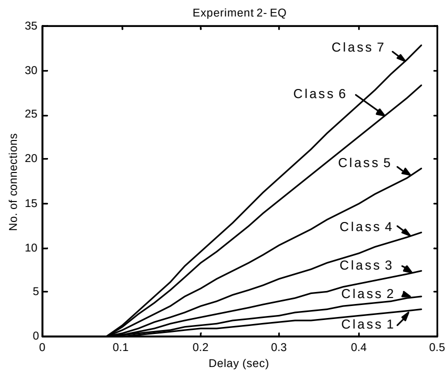

Figure 13 The admission region of EQ policy for EXP2

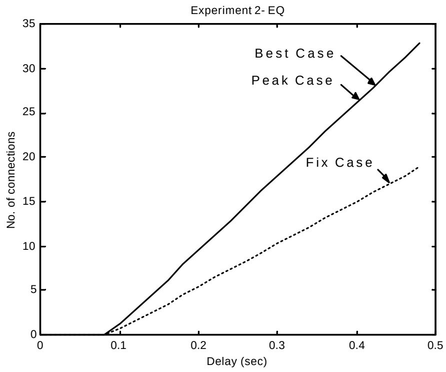

Figure 14 Comparison of admission region of EQ policy of different strategy for EXP2

Experiment 3: Cross network as shown in figure 15. The bandwidths between node 1 and node 2, node 2 and node 3, node 3 and node 4, node 2 and node 5, node 3 and node 6, were l_1= 51.84 Mbits/Sec, l_2=622.08 Mbits/Sec, and l_3=51.84 Mbits/Sec, l_4= 51.84 Mbits/Sec, l_5=51.84 Mbits/Sec respectively. Route 1 is going through node 1, node 2, node 3, and node 4. Route 2 is going through node 5, node 2 and node 6. The number of current connections is shown in table 4. The number of connections of each class (class 1 to 7) is as figure 16 and 17 for OPT policy, and figure 18 and 19 for EQ policy, respectably. The node 2 needs to consider all the number of connections from both route 1 and 2. The results of crossing network are similar to the results of tandem network. When delay time is large, use class 1. When delay time is small, use class 7. The performance is over 1.11 times for best case to peak rate case and over 1.09 times for best case to fix class case for OPT policy. For EQ policy, performance is over 1.08 times for best case to peak rate case and over 1.10 times for best case to fix class case.

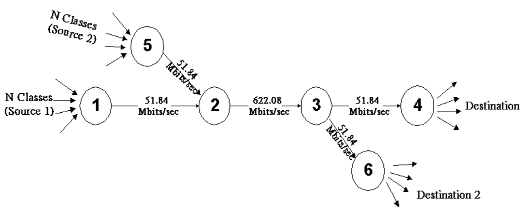

Figure 15 The crossing network

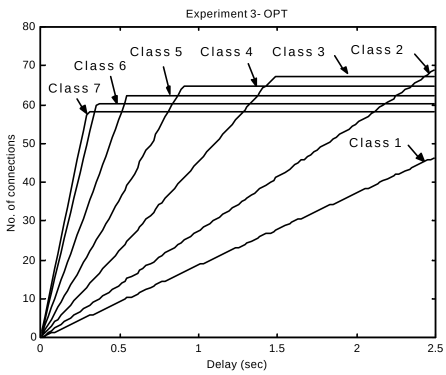

Figure 16 The admission region of class 1 to 7 for OPT policy in experiment 3

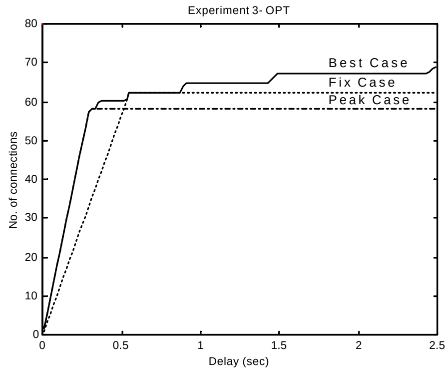

Figure 17 The admission region of different strategies for OPT policy in experiment 3

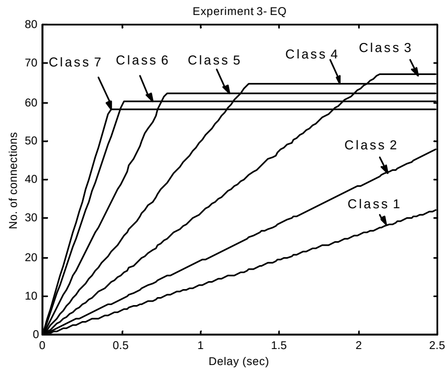

Figure 18 The admission region of class 1 to 7 for EQ policy in experiment 3

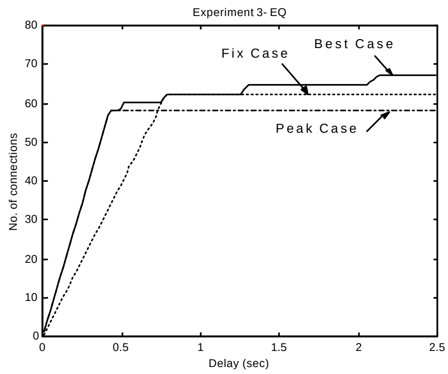

Figure 19 The admission region of different strategies for EQ policy in experiment 3

We summary the performance (average number of connections) of five experiments as shown in the table 5. There are several noteworthy points about table 5. First, OPT policy is better than EQ policy for same input traffic class. This is approved in [5]. But combined with the optimal class selection, EQ policy with optimal class selection can be better than OPT with fix class selection. Second, The DMG of the optimal class selection is 1.07. While the DMG of fix class is 0.77. Since peak rate allocation has better performance when the delay requirement is stringent that the peak rate case has better performance than fix case in our experiments. All above results are based on new connection is MPEG type video data. For another type of input sources, the results are different.

	Best case	Fix Case	Peak Case	DMG of Best Case	DMG of Fix Case	Best/ Fix
OPT in EXP1	65.2	58.4	56.0	1.16	1.04	1.11
EQ in EXP1	54.6	48.6	51.2	1.06	0.75	1.12
OPT in EXP2	37.5	32.3	35.8	1.05	0.90	1.16
EQ in EXP2	13.6	7.8	13.6	1.00	0.57	1.73
OPT in EXP3	60.8	55.6	54.8	1.11	1.01	1.09
EQ in EXP3	58.0	52.6	53.3	1.08	0.98	1.1
Average				1.07	0.77	1.21

Table 5 The performance comparison of admission region for five experiments

4. CONCLUSION

We solved class selection problem by joining burstiness curve with the call admission function. The method of optimal class selection is to put each class into the call admission formula and gets a function value. The larger of the function value, the higher the number of connections of a class can get. The computation is simple and suitable for high-speed network. The average performance is over 1.21 times for best case to fix class case in our experiments. Sine our experiments are base on one MPEG video trace. Currently, we are going to simulate connections with more diverse traffic characteristics and performance requirements to further explore the application of this method on the real network.

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