Reducing total call-blocking rates by flow admission control based on equality of heterogeneous traffic

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Keywords: CAC, call blocking, multimedia traffic, VoIP

Multimedia applications such as video and audio have recently come into wide use. Because this heterogeneous traffic occupies most networks, call admission control (CAC) is required to maintain high-quality service. User satisfaction depends on the CAC's success in accommodating application flows. However, conventional CACs do not consider user satisfaction because their main purpose is to improve resource utilization. In this paper, we propose a novel CAC to maximize total accommodated flows based on a new philosophy that heterogeneous traffic is fair in networks. Theoretical analysis was used to derive optimal parameters for various traffic configurations. We also carried out numerical analyses to show the effectiveness of our proposed CAC.

1. Introduction

Multimedia applications such as video and audio have recently become widely used, and the various bandwidth flows associated with them now occupy most networks. Under the resulting heterogeneous traffic conditions, the character of the traffic flows is different from that of best-effort data traffic. Therefore, quality-of-service (QoS) controls are important. One of these QoS controls is call admission control (CAC), which judges whether new flows that arrive can be accommodated in a network. CAC will be increasingly required to maintain QoS as streaming flows occupy more and more network bandwidth.

In a heterogeneous traffic environment, conventional CAC results in some broadband flows, such as video, etc., not being accommodated because of blocking by narrowband flows such as audio, etc. This degrades network utilization and is known as a fraction effect problem [1]. Several studies have proposed the use of reservation controls to solve these problems, which means that unused bandwidths are reserved for subsequent broadband flows [2-6]. These controls have improved resource utilization in networks [7].

It should be noted, however, that while network carriers benefit from improved utilization of network resources, it is important to improve the satisfaction of individual users. The level of individual satisfaction depends on the success of CACs in accommodating flows, but users' satisfaction is not always proportional to users' assigned bandwidth because the values of various applications are not always proportional to the bandwidth.

Therefore, conventional CACs, which aim to increase resource utilization under the condition that users' satisfaction is proportional to the bandwidth available to them, are unlikely to maximize total users' satisfaction.

As stated above, a focus on user satisfaction means that the correlation between each users' satisfaction and the users' own bandwidth must be taken into account. The basic study reported in this paper is that broadband and narrowband flows should be treated equally. Let us assume that each flow receives equal satisfaction as a result of being accommodated in a network, even if each flow has a different bandwidth. Operating under this condition should improve total user satisfaction. This means that as many flows as possible should be accommodated in networks, under the assumption that flows that have different bandwidths are equal from the viewpoint of user satisfaction.

In a conventional research approach to this problem, a CAC that accommodates as many VoIP flows as possible has been proposed [8]. However, the only form of control provided by this CAC is merely to give priority to admission of VoIP flows. Moreover, this research does not consider that users' satisfaction is equal even if there are differences in the bandwidth used for various flows. Therefore, the method does not maximize the total number of flows accommodated in a network.

In this paper, we propose a novel CAC strategy for maximizing total accommodated flows based on a new philosophy that heterogeneous flows should be treated equally in networks. We also propose a CAC algorithm that limits flows to two types, narrowband and broadband.

We first describe the concept on which our proposed CAC is based and then present a theoretical analysis of the model. We also present numerical analyses that show the effectiveness of our CAC.

2. Proposed CAC

A. Concept of new flow admission control

In typical CACs, arriving flows are evaluated whether or not they can be accommodated in a network. When a bandwidth is available to accommodate a flow, the flow is accommodated, but when no bandwidth is available, the flow is rejected. As stated in Section 1, the purpose of the CAC proposed in this paper is to maximize total accommodated flows by treating heterogeneous flows equally. In conventional CAC studies, unused bandwidth is often reserved for broadband flows to increase resource utilization. In contrast, in this paper, bandwidth is reserved for narrowband flows based on the fact that multiple narrowband flows can be accommodated if one broadband flow is rejected.

In fact, maximizing the number of total accommodated flows is equal to minimizing the total call blocking rate of broadband and narrowband flows in a network. Therefore, each arriving flow is evaluated, whether it is accommodated or not, using the procedure proposed below.

B. Proposal procedure of CAC

1) Let b_f be the bandwidth of an arriving new flow.
2) Let b_{now} be the total bandwidth of the flows currently accommodated in a network when a new flow arrives.
3) b_{now} is evaluated to assess whether b_{now} is greater than or equal to the threshold *Th* or not. If b_{now} is less than *Th*, the arriving flow is accommodated.
4) If b_{now} is greater than or equal to *Th* and $b_{now}+b_f$ is less than or equal to *B* which means bandwidth of the link, narrowband flow is accommodated, but a broadband flow is rejected. If $b_{now}+b_f$ is greater than *B*, every arriving flow is rejected.

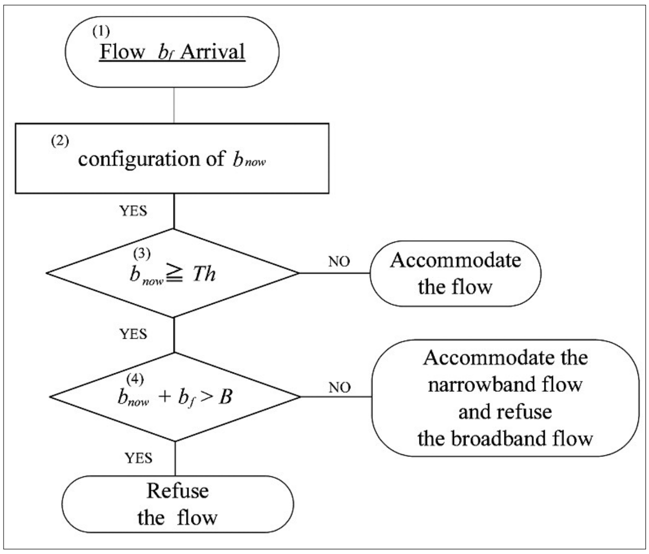


Figure 1. Flow chart

Th is the threshold that decides whether the bandwidth for broadband flows should be reserved for a narrowband flow. This *Th* should be appropriately configured to maximize the total number of accommodated flows. Below, we show the performance of our proposed CAC using a theoretical analysis based on a queuing system.

3. Theoretical analysis

A. Construction of model

In our proposed CAC, each arriving broadband and narrowband flow is evaluated to assess whether or not it can be accommodated in a network. Therefore, our proposed CAC is modeled as a $M_1M_2/M_1M_2/S/S$ loss system, which means that both broadband and narrowband flows arrive independently in a network. We derive the total flow blocking probability (total call blocking rate) from the state transition probability by solving the state transition equations of this queuing model. Thus, an optimal *Th* is calculated that minimizes the total call blocking rate. As a result, we can maximize the total number of flows accommodated in a network by applying the optimal *Th*. Let every bandwidth in this $M_1M_2/M_1M_2/S/S$ system be normalized by the bandwidth of a narrowband flow.

Then, as shown in *Figure 2,* the bandwidth of the link is normalized to s servers; one narrowband flow occupies one server, and one broadband flow occupies *m* servers. When one or more servers are idle, a narrowband flow can be accommodated in the network. When *m* or more servers are idle, a broadband flow can be accommodated in the network. In other cases, neither flow can be accommodated in the network.

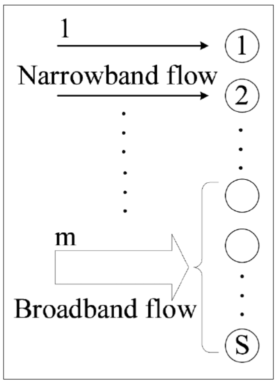


Figure 2. Model of heterogeneous traffic

Table 1 shows the definitions of each parameter. The bandwidth of the link is *kB* [Mbps]. The arrival rates of both the narrowband and broadband flows comply with Poisson distributions independently.

ρ_1 and ρ_2 denote the arrival rates, respectively. The holding times of the two types of flows comply with exponential distributions, with rates of b_1 for narrowband flows and b_2 for broadband flows. The state probability when the number of narrowband flows is n_1 and the number of broadband flows is n_2 in the networks is P(n_1, n_2). In addition, the narrowband traffic intensity ρ_1 and broadband traffic intensity ρ_2 for each flow is $\rho_1 = \frac{\lambda_1}{\mu_1}$ and $\rho_2 = \frac{\lambda_2}{\mu_2}$, respectively.

Table 1. Parameters

	Parameter	Definition
Narrow band	λ_1[flows/s]	Flow Arrival Rate
	μ_1[flows/s]	Flow Processing Rate
	n_1[number]	Flow Number in Networks
	kb_1[Mbps]	Bit-rate of Narrowband flow
Broad band	λ_2[flows/s]	Flow Arrival Rate
	μ_2[flows/s]	Flow Processing Rate
	n_2[number]	Flow Number in Networks
	N_2[number]	Maximum Number of Broadband flows
	kb_2[Mbps]	Bit-rate of Broadband flow

B. Derivation of state transition equations

The state probability and call blocking rate when there is no bandwidth reservation control in a heterogeneous traffic network were generally derived in a previous study [9]. The narrowband and broadband call blocking rates are shown as follows, respectively:

$$r_1 = \frac{\displaystyle\sum_{n_2=0}^{N_2} \frac{\rho_1^{B-b_2n_2}}{(B-b_2n_2)!}\frac{\rho_2^{n_2}}{n_2!}}{\displaystyle\sum_{n_2=0}^{N_2}\sum_{n_1=0}^{B-b_2n_2}\frac{\rho_1^{n_1}\rho_2^{n_2}}{n_1!n_2!}} \qquad (1)$$

$$r_2 = \frac{\displaystyle\sum_{n_2=0}^{N_2-1}\sum_{n_1=B-b_2(n_2+1)+1}^{B-b_2n_2}\frac{\rho_1^{n_1}}{n_1!}\frac{\rho_2^{n_2}}{n_2!}+\frac{\rho_2^{N_2}}{N_2!}}{\displaystyle\sum_{n_2=0}^{N_2}\sum_{n_1=0}^{B-b_2n_2}\frac{\rho_1^{n_1}\rho_2^{n_2}}{n_1!n_2!}} \qquad (2)$$

General state transition equations in heterogeneous traffic networks are shown in [7] for situations when the bandwidth for both narrowband and broadband flows is reserved.

In conventional research on improving resource utilization, only the bandwidth for narrowband flows has been reserved. There has been no reservation of bandwidth for broadband flows. General state transition equations in heterogeneous traffic networks are also shown [3] for situations when only the bandwidth for narrowband flows is reserved. Because it is difficult to solve both these general equations, these methods have only been evaluated using numerical analysis or an approximate solution in conventional studies [10].

In contrast, we investigated performances when the bandwidth for broadband flows was reserved for narrowband flows. The purpose of this approach, which has not been used in previous research, is to maximize the total number of accommodated flows.

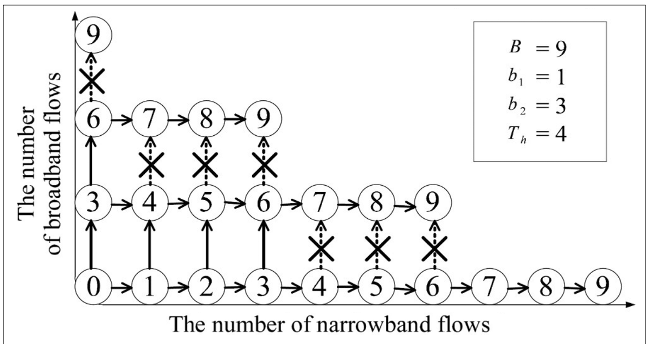


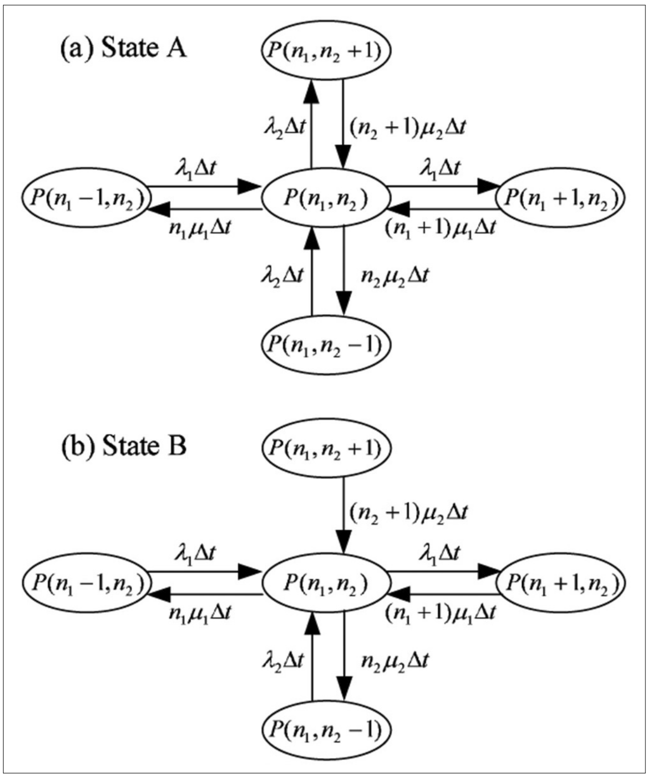
Figure 3.
Transition diagram for broadband and narrowband flows (reservation control)

Figure 3 shows a state transition diagram. In this figure, the vertical axis gives the number of broadband flows, and the horizontal axis gives the number of narrowband flows. In figure, the parameters are $B=9$, $b_1=1$, and $b_2=3$. The number in each circle indicates the total bandwidth of narrowband and broadband flows currently accommodated in a network at the state. For simplicity, arrows that show a flow leaving (in a downward or left direction) are omitted. From here on, bandwidths kB [Mbps], kb_1 [Mbps] and kb_2 [Mbps] are normalized to kb_1, that is, $kb_1=1$, $kB=B$, and $kb_2=b_2$, respectively. In addition, let B be b_2N_2 for simplicity in this study.

In our proposed CAC, as shown in Section 2.B, if the total accommodated bandwidth b_{now} is greater than or equal to the threshold Th when a new flow arrives, the bandwidth for broadband flows is reserved for narrowband flows, and an arriving broadband flow is rejected. N_2' is the maximum number of broadband flows that can be accommodated with reservation control. The range of the threshold Th is $0 \le Th \le B-b_2$.

Figure 3 shows an example when $Th=4$. When the total accommodated bandwidth b_{now} is greater than or equal to 4 ($b_{now} \ge 4$), reservation control begins, and arriving broadband flows are rejected. When our proposed system of reservation control is not applied, the number of maximum accommodated broadband flows N_2 is 3 ($N_2=3$). When our reservation system is applied with a threshold Th, the number of maximum accommodated broadband flows decreases to 2 ($N_2=2$). Instead of using this reservation, more narrowband flows could be accommodated.

To set up static state transition equations from the transition diagram which shows our proposed CAC system, let the total accommodated flows b_{now} be considered as $b_1n_1 + b_2n_2$ ($b_{now} = b_1n_1 + b_2n_2$). Here, state transition events in infinitesimal time (Δt) are limited to neighboring states because this state transition diagram assumes a Poisson distribution for arrival and an exponential distribution for processing. Therefore, each state is grouped into six state groups from state A to state F:



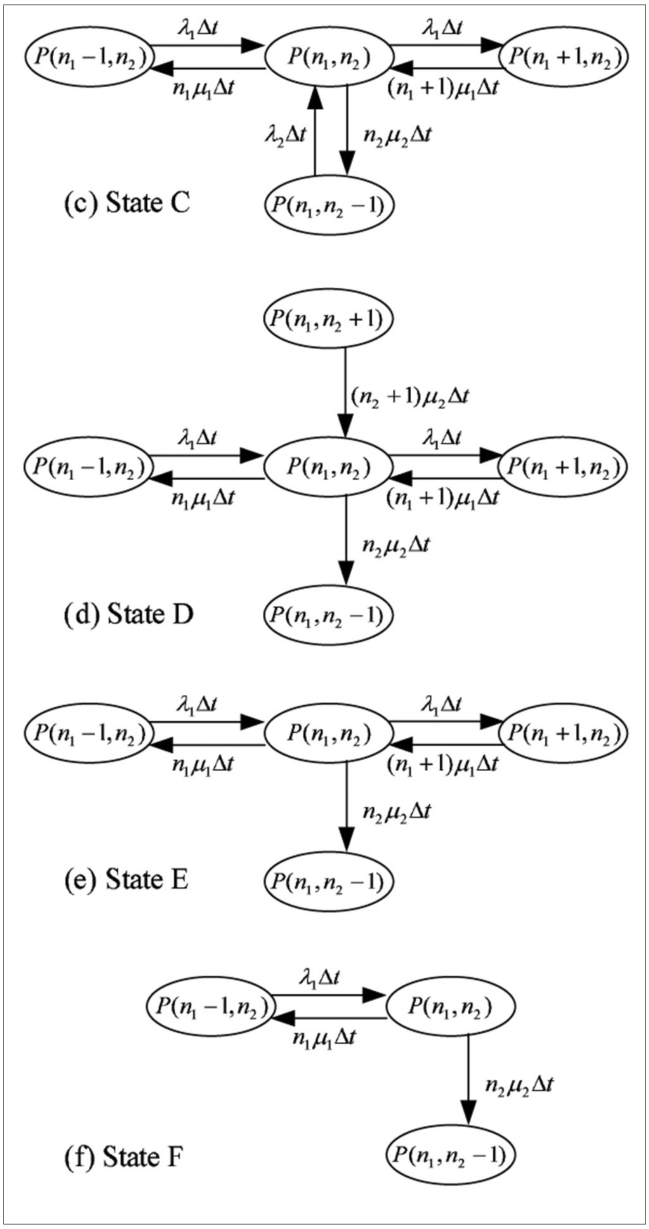


Figure 4. State transition diagram

In addition, because $n_1 \geq 0$ and $n_2 \geq 0$ are required, when $n_1 < 0$ or $n_2 < 0$, let $P(n_1, n_2) = 0$.

[1] When $n_2 < N_2'$

- When $0 \leq b_{now} < Th$ (StateA)

$$(\lambda_1 + \lambda_2 + n_1\mu_1 + n_2\mu_2)\mathrm{P}(n_1, n_2) = \lambda_1\mathrm{P}(n_1 - 1, n_2) + \lambda_2\mathrm{P}(n_1, n_2 - 1) + \mu_1(n_1 + 1)\mathrm{P}(n_1 + 1, n_2) + \mu_2(n_2 + 1)\mathrm{P}(n_1, n_2 + 1)$$

- When $\{(Th \leq b_{now} < Th + b_2) \wedge (0 \leq Th \leq B - 2b_2)\} \vee \{(Th \leq b_{now} < B - b_2) \wedge (B - 2b_2 < Th \leq B - b_2)\}$ (StateB)

$$(\lambda_1 + n_1\mu_1 + n_2\mu_2)\mathrm{P}(n_1, n_2) = \lambda_1\mathrm{P}(n_1 - 1, n_2) + \lambda_2\mathrm{P}(n_1, n_2 - 1) + \mu_1(n_1 + 1)\mathrm{P}(n_1 + 1, n_2) + \mu_2(n_2 + 1)\mathrm{P}(n_1, n_2 + 1)$$

- When $\{(B - b_2 < b_{now} < Th + b_2) \wedge (B - 2b_2 + 1 < Th < B - b_2) \vee \{(B - b_2 < b_{now} < B) \wedge (Th = B - b_2)\}$ (StateC)

$$(\lambda_1 + n_1\mu_1 + n_2\mu_2)\mathrm{P}(n_1, n_2) = \lambda_1\mathrm{P}(n_1 - 1, n_2) + \lambda_2\mathrm{P}(n_1, n_2 - 1) + \mu_1(n_1 + 1)\mathrm{P}(n_1 + 1, n_2)$$

- When $(Th + b_2 \leq b_{now} < B - b_2) \wedge (0 \leq Th \leq B - 2b_2)$ (StateD)

$$(\lambda_1 + n_1\mu_1 + n_2\mu_2)\mathrm{P}(n_1, n_2) = \lambda_1\mathrm{P}(n_1 - 1, n_2) + \mu_1(n_1 + 1)\mathrm{P}(n_1 + 1, n_2) + \mu_2(n_2 + 1)\mathrm{P}(n_1, n_2 + 1)$$

- When $\{(B - b_2 < b_{now} < B) \wedge (0 \leq Th \leq B - 2b_2 + 1)\} \vee \{ (Th + b_2 \leq b_{now} < B) \wedge (B - 2b_2 + 1 < Th < B - b_2) \}$ (StateE)

$$(\lambda_1 + n_1\mu_1 + n_2\mu_2)\mathrm{P}(n_1, n_2) = \lambda_1\mathrm{P}(n_1 - 1, n_2) + \mu_1(n_1 + 1)\mathrm{P}(n_1 + 1, n_2)$$

- When $b_{now} = B$ (StateF)

$$(n_1\mu_1 + n_2\mu_2)\mathrm{P}(n_1, n_2) = \lambda_1\mathrm{P}(n_1 - 1, n_2)$$

[2] When $n_2 = N_2'$

- When $(N_2'b_2 \leq b_{now} < Th + b_2)$ (StateC)

$$(\lambda_1 + n_1\mu_1 + n_2\mu_2)\mathrm{P}(n_1, n_2) = \lambda_1\mathrm{P}(n_1 - 1, n_2) + \lambda_2\mathrm{P}(n_1, n_2 - 1) + \mu_1(n_1 + 1)\mathrm{P}(n_1 + 1, n_2)$$

- When $\{(Th + b_2 \leq b_{now} < B) \wedge (Th \neq B - b_2)\}$ (StateE)

$$(\lambda_1 + n_1\mu_1 + n_2\mu_2)\mathrm{P}(n_1, n_2) = \lambda_1\mathrm{P}(n_1 - 1, n_2) + \mu_1(n_1 + 1)\mathrm{P}(n_1 + 1, n_2)$$

- When $b_{now} = B$ (StateF)

$$(n_1\mu_1 + n_2\mu_2)\mathrm{P}(n_1, n_2) = \lambda_1\mathrm{P}(n_1 - 1, n_2)$$

The sum of all state probabilities is equal to 1. This summation is given by the following equation:

$$\sum_{(n_1, n_2) \in \{A.B.C.D.E.F\}} \mathrm{P}(n_1, n_2) = 1 \quad (3)$$

In this equation, {A,B,C,D,E,F} mean a set of each state, A, B, C, D, E, and F, respectively.

Above these equations, which relate to all states, are simultaneous linear equations with variable $P(n_1, n_2)$.

By using $P(n_1, n_2)$, which is derived from these state transition equations, the narrowband call-blocking rate r_1 and broadband call-blocking rate r_2 can be given by the following equation, respectively:

$$r_1 = \sum_{n_2=0}^{N_2'} \mathrm{P}(B - b_2 n_2, n_2) \quad (4)$$

$$r_2 = \sum_{n_2=0}^{N_2'-1} \sum_{n_1=T_h - b_2 n_2}^{B - b_2 n_2} \mathrm{P}(n_1, n_2) + \sum_{n_1=0}^{B - b_2 n_2} \mathrm{P}(n_1, N_2') \quad (5)$$

Both r_1 and r_2 mean the summation of state probabilities which cannot transit to neighboring states when a new flow arrives.

C. Derivation of Total Call Blocking Rate

As shown in Section 3.B, when both the narrowband and broadband call blocking rates are calculated, the total call blocking rate, which reflects user satisfaction, is given by the following equation:

$$r_{total} = \frac{\rho_1 r_1 + \alpha \rho_2 r_2}{\rho_1 + \rho_2} \quad (6)$$

In this equation, α is the weight of user satisfaction when a broadband flow is accommodated in a network. For example, when user satisfaction is proportional to the user's own bandwidth, user satisfaction with the broadband flow is equal to its own bandwidth for broadband flow ($\alpha = b_2$) [7]. In this paper, the weight of user satisfaction is set to 1 ($\alpha = 1$) as a basic condition of the study. Under this condition, Eq. 6 shows the total call-blocking rate when every flow is equal.

Thus, to minimize the total blocking rate, we need to find the optimal threshold Th_{opt} under the constraint of state transition equations. However, because it is difficult to solve these state equations [3], $\mathrm{P}(n_1, n_2)$ and r_{total} are calculated using numerical calculation for numerical analysis. In the following section, we describe the performance relations between the optimal threshold Th_{opt} and the optimal total call-blocking rate r_{opt}.

4. Evaluation of the characteristics of our proposed CAC using numerical analysis

To examine the effectiveness of our proposed CAC using numerical analysis, optimal total call-blocking rates r_{opt} were calculated by changing the traffic intensity ρ_1 and ρ_2 and by changing the threshold Th. This optimal call-blocking rate r_{opt} is given by the optimal threshold Th_{opt}, which minimizes the total call-blocking rate for each traffic condition.

Figures 5, 6, 7, and 8 show the optimal total call-blocking rates r_{opt} and the total call-blocking rates without the proposed reservation control by changing the traffic intensity ρ_1 and ρ_2 and by changing the broadband bandwidth b_2.

Fig. 5. Total call-blocking rate ($b_2 = 3$)

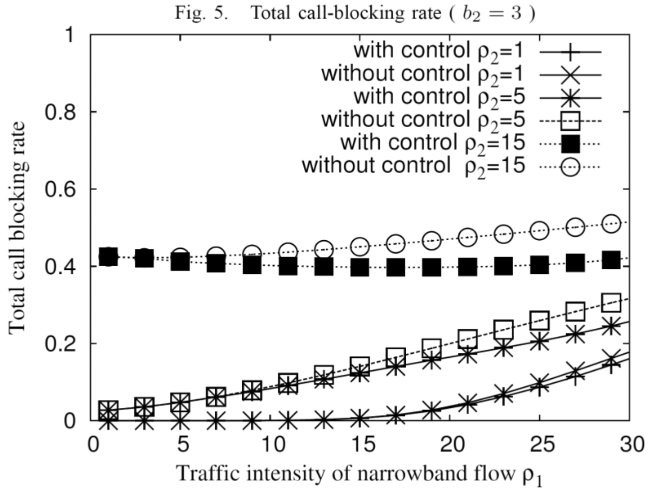


Fig. 7. Total call-blocking rate ($b_2 = 10$)

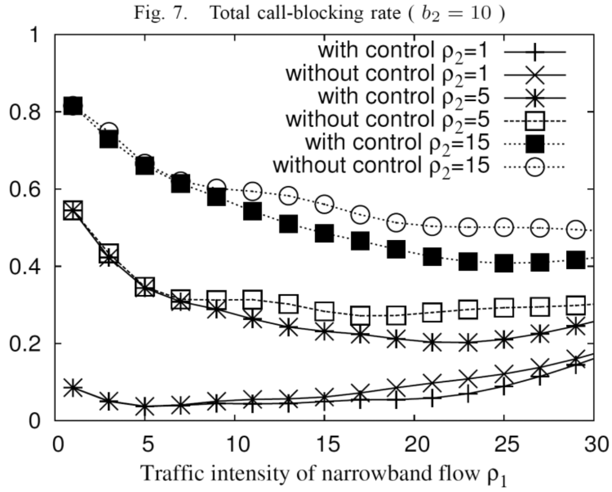


Fig. 6. Total call-blocking rate ($b_2 = 6$)

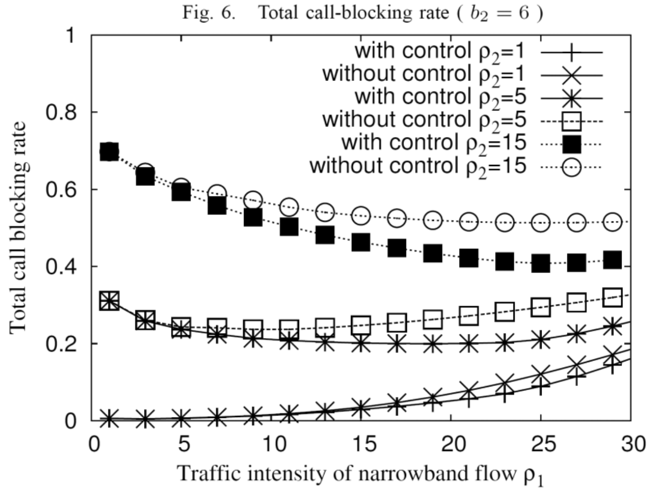
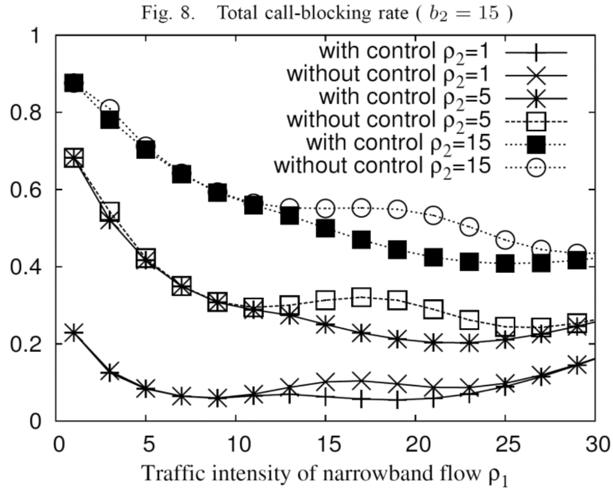


Fig. 8. Total call-blocking rate ($b_2 = 15$)



These total call-blocking rates without the proposed reservation control are calculated by substituting equations (1) and (2) into equation (6). The horizontal axis is the traffic intensity of narrowband flows ρ_1. Each parameter is shown as in *Table 2*.

Bandwidth of Link (B)	30
Flow Arrival Rate of Narrowband Flow(λ_1)	0.02[flows/s]
Flow Arrival Rate of Broadband Flow(λ_2)	0.02[flows/s]
Sending Rate of Narrowband Flow(b_1)	1
Sending Rate of Broadband Flow(b_2)	3, 6, 10, 15

Table 2.
Parameters for mathematical analysis

We can describe the characteristic relations between traffic intensity and optimal total call-blocking rate r_{opt} as follows.

1) When ρ_2 is fixed, the larger ρ_1 is, and the larger the decrease is by the proposed reservation control.
2) The larger ρ_2 is, the larger the decrease is by the proposed reservation control.
3) The larger b_2 is, the larger the wave oscillation is of r_{total} without the proposed reservation control. This is known as a fraction effect problem [9].
4) The larger ρ_1 and b_2 are, the smaller r_{opt} is.

Regarding 1), in Figure 5 when $\rho_2 = 15$ is fixed, while the difference between r_{opt} with our reservation control and r_{total} without our reservation control is about 1% when $\rho_1 = 5$, the difference is about 10% when $\rho_1 = 30$.

Regarding 2), in Figure 5 when $\rho_1 = 30$, while the difference between r_{opt} with our control and r_{total} without our control is about 1% when $\rho_2 = 1$, the difference is about 10% when $\rho_2 = 15$. Therefore, the larger ρ_1 and ρ_2 are, the larger the decrease in the total call-blocking rate is.

Regarding 3), in Figure 8, if the total call-blocking rate without our reservation control waves by the fraction effect problem, our reservation control can prevent the total call-blocking rate from increasing. For example, in Figure 8, when $\rho_1 = 21$ and $\rho_2 = 15$, the optimal total call-blocking rate r_{opt} decreases about 15% compared with the total call-blocking rate without our control.

Regarding 4), in our proposed reservation control, r_{total} includes the weight of each traffic intensity. Under this condition, the larger ρ_1 is, the more narrowband flows can be accommodated in the networks. Therefore, r_{total} decreases. In the following figure, we show characteristics of the optimal threshold Th_{opt}.

Figures 9, 10, 11, and 12 show characteristics of the optimal threshold Th_{opt} by changing the traffic intensity ρ_1 and ρ_2 and by changing the broadband bandwidth b_2. The optimal threshold Th_{opt} is the threshold that mi-

Fig. 9. Optimal threshold ($b_2 = 3$)

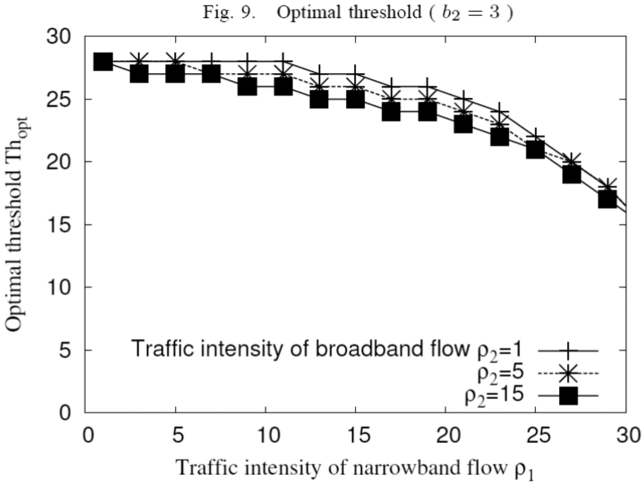


Fig. 11. Optimal threshold ($b_2 = 10$)

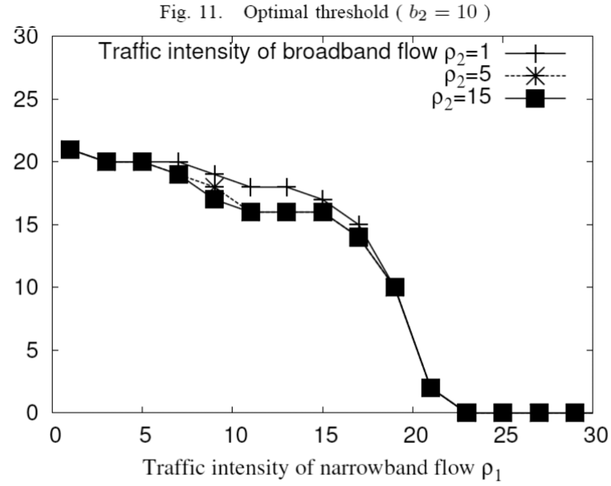


Fig. 10. Optimal threshold ($b_2 = 6$)

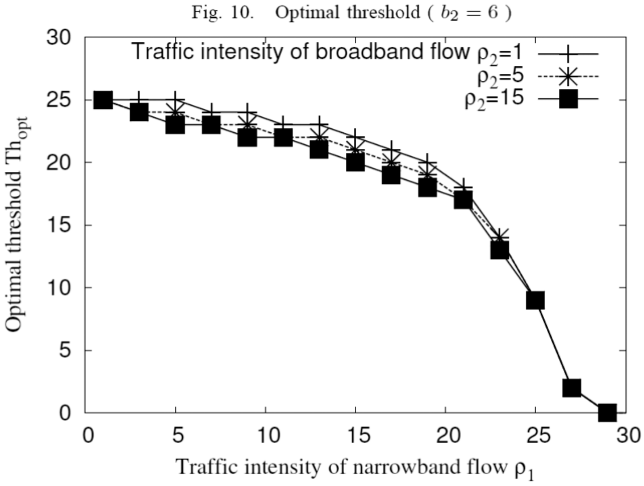
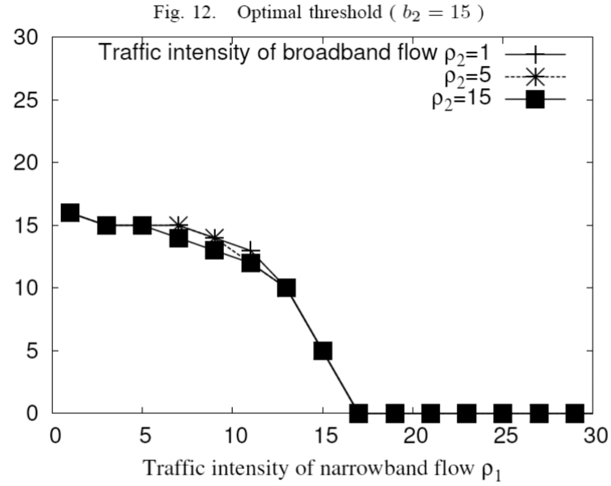


Fig. 12. Optimal threshold ($b_2 = 15$)



nimizes the total call-blocking rate for each traffic condition. The horizontal axis is the traffic intensity of narrowband flows ρ_1. When $Th_{opt} = B - b_2 + 1$, this r_{opt} is the total call-blocking rate when the proposed reservation control system is not applied. In addition, when $Th_{opt} = 0$, no broadband flows are accepted.

These figures show the results when the traffic intensity of broadband flows ρ_2 is fixed; the larger ρ_1 is, the smaller Th_{opt} is. This result indicates that the more narrowband flows there are, the more broadband flows should be rejected with a smaller Th_{opt}. This enables more narrowband flows to be accommodated, thus reducing the total call-blocking rate. Moreover, these characteristics do not depend on ρ_2. In Figures 9-12, the larger b_2 is, the smaller ρ_1 making $Th_{opt} = 0$. When $Th_{opt} = 0$, arriving new broadband flows cannot be accommodated. This result indicates that the larger broadband bandwidth b_2 is, the more narrowband flows can be accommodated by our reservation control.

Figures 13 and 14 show the total call-blocking rates when Th is changed. Figure 13 shows the results when ρ_1 is $\rho_1 = 30$ in Figure 9. In this figure, when ρ_1 is as large as $\rho_1 = 30$, the change in r_{total} becomes flatter. For example, in Figure 13 when $\rho_1 = 30$ and $\rho_2 = 15$, the optimal threshold is $Th_{opt} = 15$. However, the total call-blocking rates r_{total} are kept almost unchanged when the optimal threshold Th_{opt} is set in the range from $Th = 0$ to $Th = 21$.

In Figure 14, the difference in the decrease in the total call-blocking rates r_{total} varies according to traffic conditions when Th is nearly Th_{opt}. For example, when $\rho_1 = 10$, the optimal threshold is $Th_{opt} = 22$. However, the total call-blocking rate r_{total} increases to about 3% when the threshold Th is set to nearly Th_{opt}. Meanwhile, when $\rho_1 = 30$, the optimal threshold is $Th_{opt} = 0$. Under this condition, the total call-blocking rates r_{total} are kept almost unchanged. Therefore, under this condition, a near-optimal total call-blocking rate r_{total} is given by using reservation control when the threshold Th is nearly Th_{opt}. In other words, a near optimal total-call blocking rate r_{total} is given when Th is set to nearly $Th = 0$. In contrast, when $\rho_1 = 1$, the total call-blocking rate decreases, or cascades, suddenly every b_2, which is the bandwidth for broadband flow; the smaller the Th is, the larger the total call-blocking rate r_{total} is. Therefore, under this condition, the proposed reservation control is not expected to be effective.

Here, we focus attention on the cascade in Figure 14 when $\rho_1 = 1$. *Figure 15* shows the narrowband call-blocking rates, broadband call-blocking rates, and total call-blocking rates with this configuration. As shown in the figure, this cascade is caused by changing the difficulty in accommodating broadband flows every b_2.

Overall, we can describe the characteristic relations between traffic intensity and threshold as follows.

- When b_2 is fixed, the larger ρ_1 and ρ_2 are, the smaller Th_{opt} is, which minimizes the total call-blocking rate.
- The larger b_2 is, the larger the decrease by our proposed reservation control.
- The larger ρ_1 is, the flatter the differences in r_{total} become. Therefore, under this condition, a near optimal total call-blocking rate r_{total} is given by using reservation control when the threshold Th is nearly Th_{opt}.
- When ρ_1 is small, r_{total} steps down with every b_2. Under this condition, the proposed reservation control is not expected to be effective.

Figures 13-15.

Fig. 13. total call-blocking rate ($b_2 = 3$, $\rho_1 = 30$)

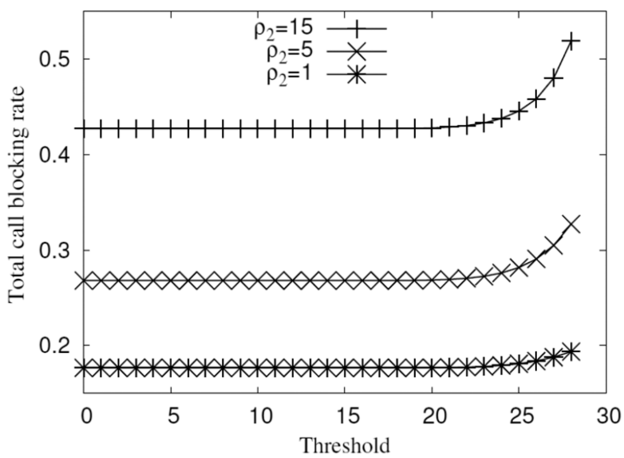


Fig. 14. total call-blocking rate ($b_2 = 6$, $\rho_2 = 5$)

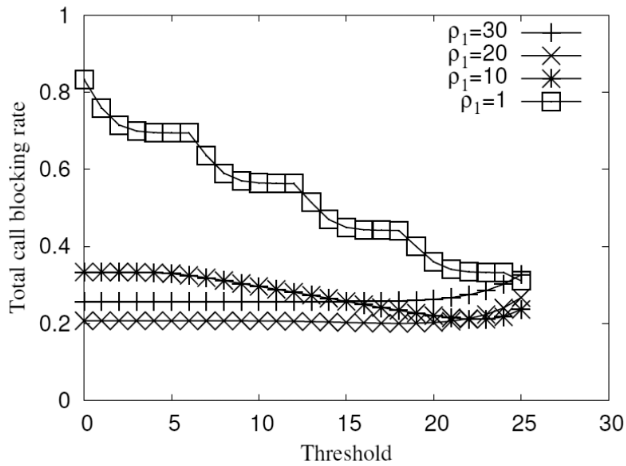
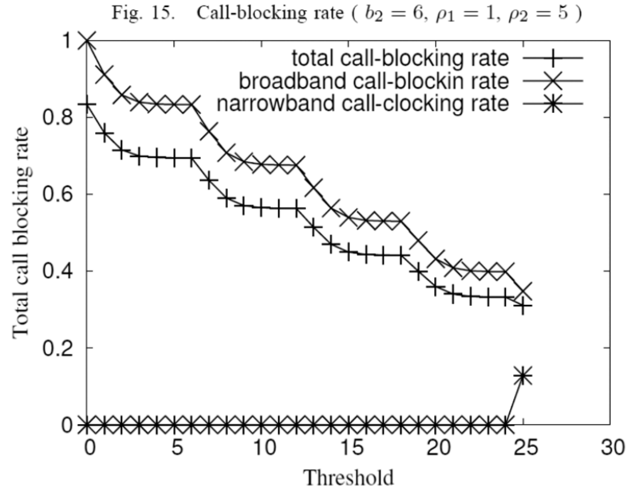


Fig. 15. Call-blocking rate ($b_2 = 6$, $\rho_1 = 1$, $\rho_2 = 5$)



Therefore, when Th_{opt} is set appropriately according to traffic intensities, r_{total} is minimized. In addition, as shown in Figure 13, r_{total} approaches the optimal total call-blocking rate under certain traffic conditions, such as when $\rho_1 = 30$, even if the threshold Th is not equal to Th_{opt}.

5. Conclusions

In this paper, we proposed a novel CAC strategy for maximizing total accommodated flows based on the new philosophy that heterogeneous flows should be treated equally in networks. Our proposed CAC is modeled on a $M_1M_2/M_1M_2/S/S$ system, and theoretical numerical analyses show its effectiveness. In future work, we will evaluate the performance of our proposed CAC under various traffic configurations because the number of accommodated flows becomes close to the maximum number of total accommodated flows under some traffic configurations, even if the optimal threshold Th_{opt} is not applied. We will also derive the optimal threshold Th_{opt} for minimizing the total call-blocking rate when the parameters B, b_1, and b_2 change, and examine how to establish the most practical Th_{opt}.

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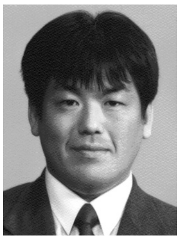

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