韓國經營科學會誌
第23卷 第3號
1998年 9月

신규호에 대한 지체가 허용된 셀룰라 이동통신시스템에서 최적 호제어 연구*

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Optimal Call Control Strategies in a Cellular Mobile Communication System with a Buffer for New Calls*

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Abstract

The demand of large capacity in coming cellular systems makes inevitable the deployment of small cells, rendering more frequent handoff occurrences of calls than in the conventional system. The key issue is then how effectively to reduce the chance of unsuccessful handoffs, since the handoff failure is less desirable than that of a new call attempt. In this study, we consider the control policies which give priority to handoff calls by limiting channel assignment for the originating new calls, and allow queueing the new calls which are rejected at their first attempts. On this system, we propose the problem of finding an optimal call control strategy which optimizes the objective function value, while satisfying the requirements on the handoff/new call blocking probabilities and the new call delay. The objective function takes the most general form to include such well-known performance measures as the weighted average carried traffic and the handoff call blocking probability. The problem is formulated into two different linear programming (LP) models. One is based on the direct employment of steady state equations, and the other uses the theory of semi-Markov decision process. Two LP formulations are competitive each other, having its own strength in the numbers of variables and constraints. Extensive experiments are also conducted to show which call control strategy is optimal under various system environments having different objective functions and traffic patterns.

* 이 논문은 1998년도 동의대학교 자체 학술연구비의 지원을 받아 작성되었음.
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1. Introduction

The demand for high capacity in future cellular mobile communication systems requires the deployment of small cells where the handoff of calls from one cell to the other occurs more frequently than in conventional cellular systems. Since the handoff failure, mentioned typically by the forced termination of a call in progress, is less desirable than the failure of a new call attempt, several strategies have been investigated to greatly reduce the chance of unsuccessful handoffs [5,8,14].

Although these strategies may be effectual ones for the protection of handoff calls, they often result in the reduction of weighted average carried traffics, which is caused by the increase of blocking of new call attempts. To alleviate this drawback of handoff prioritized strategies the strategy queueing of calls (handoff or new calls) has been suggested [2,9]. In [3], Guérin suggested a scheme of queueing new calls, which not only decreases the new call blocking probability but also lessens the degradation of the system performance caused by the control scheme.

Most of the studies of call control strategies in the cellular system have focused mainly to the suggestion of a specific strategy and its performance evaluation [2,3,6,8]. Recent efforts have considered the problem which optimizes the call control in the cellular systems [10,13]. But these studies also have some limitations in that the optimization is restricted to the associated control parameter under a given call control strategy, and thereby in that the lack of comparison between several strategies. Within our knowledge, there is no study dealing the call control problems under a general framework which incorporates simultaneously several strategies and the associated parameters.

In this study, we adopt the scheme allowing the queueing of new calls as an underlying one, and consider a call control for handoff and new calls which optimally regulates the assignments of channels for both types of calls by observing the number of each type of calls in progress. The suggested formulation of the call control problem is so general that the well-known priority strategies such as cutoff and threshold type [13] may be a feasible solution. Furthermore, the objective function takes the most general form, and includes the weighted average carried traffic and the blocking probability of handoff calls.

Focusing on a single-cell system where the arrival rates, the blocking probabilities for both types of calls, and the average waiting time of new calls in the buffer are given, considered are two different linear programming (LP) formulations for the problem of finding an optimal call control strategy for both types of calls. One is based on the direct employment of steady-state equations, and the other uses the theory of semi-Markov decision process (SMDP). Each formulation has its own strength in the numbers of variables and constraints.

This paper is organized as follows. In Section 2, the basic traffic model and control strategy are first introduced, and then the steady state equations describing the behavior of the model are established. In Section 3, the call control problem is formulated as LP by two different approaches: the direct employment of steady-state equations and the use of theory of SMDP. And a remark which gives the practical meaning of the optimal solutions is also provided. Extensive experiments showing which call control strategy becomes an optimal one under each of various objective functions and traffic patterns are conducted in Section 4, and concluding remarks are given in Section 5.

2. Model Description and Steady-State Equations

Consider a single-cell system with two types of calls (handoff and new calls) in which N channels are assigned. Assume that handoff and new calls are generated according to a Poisson process with rates λ_1 and λ_2, respectively. The channel holding times of both types of calls are exponentially distributed with rates μ_1 and μ_2, respectively.

Consider a control policy which gives priority to handoff calls by limiting channel assignment for the originating new calls, and allows queueing the new calls which are rejected at their first attempts. Handoff calls have access to all channels with no restriction.

The system state $x=(x_1, x_2, x_3)$ is denoted by a 3-dimensional vector whose elements represent the numbers of handoff (x_1) and new calls in service (x_2), and the number of new calls in the queue (x_3). We define two control parameters at system state x. One is $\alpha(x)$ denoting the probability that a channel is assigned to a new call attempt. The new call, if blocked, tries to join the buffer. Let B be the capacity of the buffer. If the buffer is full, the call is lost. The other is $\beta(x)$ denoting the probability that a channel is assigned to the new call waiting in the first position of the buffer just when an ongoing service for a new or handoff call is completed.

Note that the state space is therefore given by

$$E = \{(x_1, x_2, x_3): x_1, x_2, x_3 \geq 0, \\ x_1 + x_2 \leq N, x_3 \leq B\}.$$

Let $\pi = \{\pi(i, j, k): (i, j, k) \in E\}$ be the steady-state probabilities of the process. Then, we can obtain the state-transition equations and normalization condition as follows:

a. If $(i, j, k) = (0, 0, 0)$,

$$(\lambda_1 + \lambda_2)\pi(i, j, k) = \pi(i+1, j, k)\mu_1 + \pi(i, j+1, k)\mu_2, \quad (1)$$

b. If $i + j < N,\ k < B,$

$$(\lambda_1 + \lambda_2 + i\mu_1 + j\mu_2)\pi(i, j, k) = \lambda_1\pi(i-1, j, k) + \lambda_2\alpha(i, j-1, k)\pi(i, j-1, k) + \lambda_2(1-\alpha(i, j, k-1))\pi(i, j, k-1) + (i+1)\mu_1\beta(i+1, j-1, k+1)\pi(i+1, j-1, k+1) + j\mu_2\beta(i, j, k+1)\pi(i, j, k+1) + (i+1)\mu_1(1-\beta(i+1, j, k))\pi(i+1, j, k) + (j+1)\mu_2(1-\beta(i, j+1, k))\pi(i, j+1, k), \quad (2)$$

c. If $i+j=N,\ k<B,$

$$(\lambda_2 + i\mu_1 + j\mu_2)\pi(i, j, k) = \lambda_1\pi(i-1, j, k) + \lambda_2\alpha(i, j-1, k)\pi(i, j-1, k) + (i+1)\mu_1\beta(i+1, j-1, k+1)\pi(i+1, j-1, k+1) + j\mu_2\beta(i, j, k+1)\pi(i, j, k+1) + \lambda_2\pi(i, j, k-1), \quad (3)$$

d. If $i+j<N,\ k=B,$

$$(\lambda_1 + \lambda_2\alpha(i, j, k) + i\mu_1 + j\mu_2)\pi(i, j, k) = \lambda_1\pi(i-1, j, k) + \lambda_2\alpha(i, j-1, k)\pi(i, j-1, k) + \lambda_2(1-\alpha(i, j, k-1))\pi(i, j, k-1) + (i+1)\mu_1(1-\beta(i+1, j, k))\pi(i+1, j, k) + (j+1)\mu_2(1-\beta(i, j+1, k))\pi(i, j+1, k), \quad (4)$$

e. If $i+j=N,\ k=B,$

$$(i\mu_1 + j\mu_2)\pi(i, j, k) = \lambda_1\pi(i-1, j, k) + \lambda_2\pi(i, j, k-1) + \lambda_2\alpha(i, j-1, k)\pi(i, j-1, k), \quad (5)$$

f. normalization condition

$$\sum_{(i, j, k)\in E}\pi(i, j, k) = 1, \quad (6)$$

where

$$\pi(i, j, k) \geq 0, \text{ for all } (i, j, k) \in E,$$
$$0 \leq \alpha(i, j, k) \leq 1, \text{ for all } (i, j, k) \in E,$$
$$0 \leq \beta(i, j, k) \leq 1, \text{ for all } (i, j, k) \in E. \quad (7)$$

It may be note that $\alpha(i, j, k) = \beta(i, j, k) = 0$ for $(i, j, k) \notin E$ and for a given the values of $\alpha = \{\alpha(i, j, k) : (i, j, k) \in E\}$ and $\beta = \{\beta(i, j, k) : (i, j, K) \in E\}$ the distribution of π can be determined by the above equations.

The blocking probabilities $BH(\alpha, \beta)$ for handoff calls and $BN(\alpha, \beta)$ for new calls are obtained by

$$BH(\alpha, \beta) = \sum_{x\in E_1}\pi(x),$$
where $E_1 = \{x : x_1 + x_2 = N\}$ (8)

and

$$BN(\alpha, \beta) = \sum_{x\in E_2}(1-\alpha(x))\pi(x),$$
where $E_2 = \{x : x_3 = B\}$ (9)

And the Little's formula [7] gives the average delay of the new calls as follows:

$$W(\alpha, \beta) = \sum_{x \in E} x_3 \pi(x) / \lambda_2 \sum_{x \in E \setminus E_2} (1 - \alpha(x)) \pi(x), \tag{10}$$

where the denominator represents the average effective arrival rate of new calls to the buffer, and the numerator the average number of new calls in the buffer.

3. LP Formulations for Call Control Problem

3.1 Direct Employment of Steady-State Equations

With the traffic model made in the previous section, the call control problem (CCP) is to find out control parameters $\alpha(x)$ and $\beta(x)$, $x \in E$ optimizing the specified performance objective while ensuring the GOS's constraints of blocking probabilities for both types of calls and the average delay for new calls. The CCP is more precisely stated as follows.

$$(CCP) \text{ Minimize } Z(\pi, \alpha, \beta) = r_1 BH(\alpha, \beta) + r_2 BN(\alpha, \beta)$$

subject to

(i) steady-state equations (1) to (5)

(ii) normalization condition (6)

(iii) inequalities (7)

(iv) handoff call blocking constraint:

$$BH(\alpha, \beta) \le BH_T$$

(v) new call blocking constraint:

$$BN(\alpha, \beta) \le BN_T$$

(vi) new call delay constraint: $W(\alpha, \beta) \le W_T$

where BH_T, BN_T and W_T represent tolerable blocking probabilities of handoff calls, new calls and average delay of new calls, respectively.

Note that the objective function $Z(\pi, \alpha, \beta)$ takes the most general form with the weight parameters $\{r_i\}$ whose values depend on the specific performance objectives to be employed. So, $Z(\pi, \alpha, \beta)$ includes the prominent objective functions adopted by the other studies in the literature: the minimization of blocking probability of handoff calls and the maximization of the weighted average carried traffic, which can be expressed by setting $r_1 = 1$, $r_2 = 0$ and $r_i = \lambda_i / \mu_i$ for $i = 1, 2$, respectively.

Moreover, the well-known call control strategies such as cutoff and threshold types may be the feasible solutions of the CCP as follows: in case of cutoff strategy with parameter g where the new calls either newly generated or delayed in the buffer are permitted to be served only when the number of free channels is greater than or equals to g [5], i.e.,

$$\alpha(i, j, k) = \begin{cases} 1 & \text{if } N-(i+j) \ge g, \\ 0 & otherwise. \end{cases}$$

$$\beta(i, j, k) = \begin{cases} 1 & \text{if } N-(i+j) \geq g, \\ 0 & otherwise. \end{cases}$$

In case of threshold type strategy with parameter l where the new calls are permitted to be served only when the number of new calls in progress is less than or equals to l [13], i.e.,

$$\alpha(i, j, k) = \begin{cases} 1 & \text{if } j \leq l, \\ 0 & otherwise. \end{cases}$$

$$\beta(i, j, k) = \begin{cases} 1 & \text{if } j \leq l, \\ 0 & otherwise. \end{cases}$$

The *CCP* is a nonlinear programming problem which has a nonlinear objective function and a number of nonlinear constraint equations. Moreover, due to the non-explicitness of the objective function it is very difficult to devise an efficient solution method by employing the existing solution methods. Therefore, we introduce below an approach to express the CCP as a linear programming (LP) problem, called problem (P1), without introducing any additional variables and constraints for which the well-known solution method such as simplex method can be applied efficiently even for large-sized problems[11].

Noting the nonlinearity embedded in the CCP, being induced by the terms of $\alpha \cdot \pi$ and those of $\beta \cdot \pi$, we can then obtain the following theorem.

Theorem 1. Consider the following variable substitutions and constraints modifications: (a) For the equations in from (1) to (5), (9) and (10),

$$\alpha(i, j, k)\,\pi(i, j, k) \rightarrow \gamma(i, j, k), \qquad (11)$$

$$\beta(i, j, k)\,\pi(i, j, k) \rightarrow \delta(i, j, k) \qquad (12)$$

(b) For the equations in (7), for $(i, j, k) \in E$,

$$0 \leq \alpha(i, j, k) \leq 1 \rightarrow$$

$$0 \leq \gamma(i, j, k) \leq \pi(i, j, k), \qquad (13)$$

$$0 \leq \beta(i, j, k) \leq 1 \rightarrow$$

$$\leq \delta(i, j, k) \leq \pi(i, j, k). \qquad (14)$$

(c) otherwise, the same as the original *CCP*.

Then the resulting formulation (P1) becomes an LP problem, and the optimal solutions of the original nonlinear CCP can always be obtained by those of the pertinent LP formulation.

Proof. It is straightforward to verify that the reformulated problem is a LP problem. Therefore, we prove the theorem just by showing that the optimal solutions of the original problem can always be induced by the reformulated LP problem. Note that in the irreducible Markov process like our model, $\pi(i, j, k) > 0$ for all $(i, j, k) \in E$. Hence, the optimal solution of the original problem α^* and β^* can be obtained by the following:

$$\alpha^*(i, j, k) = \gamma^*(i, j, k) \,/\, \pi^*(i, j, k),$$

$$\beta^*(i, j, k) = \delta^*(i, j, k) \,/\, \pi^*(i, j, k).$$

□

In the following theorem, we suggest an interesting result for the optimal solutions of the problem (P1)

Theorem 2. Under the condition that the LP problem P1 has an optimal solution, there exists an optimal solution α^*, β^* for the problem P1 such that at most 3 out of $2|E|$ parameters $\alpha^*(i, j, k)$, $\beta^*(i, j, k)$ take a fractional value between 0 and 1, and all the others take a value of 0 or 1.

Proof. Let $(\pi^*, \gamma^*, \delta^*)$ be an optimal solution for $P1$. First suppose that $\pi^*(i, j, k) > 0$ for each $(i, j, k) \in E$. Since the number of variables is $3|E|$, from the property of linear programming problem, there exists an optimal solution where at least $3|E|$ constraints out of total $5|E|+3$ ones are satisfied with equality. It follows from the above property of linear programming that the number of cases such that $0 < \gamma^*(i, j, k) < \pi^*(i, j, k)$ or $0 < \delta^*(i, j, k) < \pi^*(i, j, k)$ is at most 3. Therefore, there exists an optimal solution for P such that at most 3 parameters $\alpha^*(i, j, k)$, $\beta^*(i, j, k)$ take a fractional value between 0 and 1, and all the others take a value 0 or 1.

Next suppose that $E_0 = \{(i, j, k) \in E | \pi^*(i, j, k) = 0\}$ is not empty. Then replace the problem $P1$ with the following smaller problem. First eliminate all variables corresponding to $(i, j, k) \in E_0$, and then eliminate all linear constraints corresponding to $(i, j, k) \in E_0$ from the problem $P1$. The reduced problem has the same structure as P1 but with the state space E replaced by $E-E_0$. Note that $\pi^*(i, j, k) > 0$ for all $(i, j, k) \in E-E_0$. The preceding argument therefore applies to the reduced problem. Consequently, there exists an optimal solution such that at most 3 out of $2|E-E_0|$ parameters $\alpha(i, j, k)$, $\beta(i, j, k)$ can take a value from the range of $0 < \alpha^*(i, j, k) < 1$ or $0 < \beta^*(i, j, k) < 1$, and all the other parameters take a value of 0 or 1. If (i, j, k) is not in $E-E_0$, $\alpha^*(i, j, k) = \beta^*(i, j, k) = 0$. □

Note that the numbers of variables and constraints of problem $P1$ are $3|E|$ and $B(N+1)(\frac{N}{2}+1)+2|E|+3$, excluding non-negative constraints, respectively. Although the solution methods for LP problems developed so far solve effectively the very large-sized problems like ours, the formulation with the fewer constraints has often some strength in the computational time. In the following section, another LP formulation for the CCP is introduced, which yields the one with the smaller number of constraints and the larger number of variables.

3.2 Markov Decision Process Approach

The purpose of this section is to reformulate the CCP as another LP formulation, called problem (P2), by employing semi-Markov decision process (SMDP) approach [4,15]. The SMDP approach has been an useful technique for the optimal control of several types of telecommunication systems which have a dynamic behavior [12].

An SMDP state (x, a) can be built by embedding an action variable $a=(a_1, a_2)$ to each system state x, $x \in E$ defined in the previous subsection as follows: at an arrival or service completion of any type of call, the system state moves to a state x or stays in x, and an action is taken with regard to either of giving a channel or not for both of the next arriving new calls (a_1) and new calls in the buffer (a_2) during the state x. The actions of giving a channel or not for new calls are discriminated by the values 0 and 1, respectively.

Then the steady-state behavior of traffic model introduced in Section 2 is expressed as an SMDP with the following state space E_D:

$$E_D = \{x_D=(x, a): x=(x_1, x_2, x_3) \in E,\ a=(a_1, a_2) \in A_x\},$$

where

$$A_x = \{(a_1, a_2): a_1 = 0 \text{ if } x+e_1 \notin E,\ a_2 = 0 \text{ if } x+e_2-e_3 \notin E\}.$$

To apply the technique of LP formulation for SMDP, we need P_{xay} which is the probability that the next state is $y \in E$ given that the current state is $x \in E$ and the action $a \in A_x$ is taken.

The expected time until a new state is entered when the current state is $x \in E$ and action $a \in A_x$ is chosen, $\tau(x, a)$, is given by:

$$\tau(x, a) = [x_1\mu_1 + x_2\mu_2 + 1_{x+e_1}\{E\}\lambda_1 + 1_{x+e_3}\{E\}\lambda_2]^{-1}$$

where $1_e\{E\}$ take a value 1 if E contains e, 0 otherwise. Then we can obtain the transition probabilities as follows:

$$P_{xay} = \begin{cases} \lambda_1 \tau(x, a), & y=x+e_1 \\ \lambda_2 a_1 \tau(x, a), & y=x+e_2 \\ \lambda_2(1-a_1)\tau(x, a), & y=x+e_3 \\ x_1\mu_1(1-a_2)\tau(x, a), & y=x-e_1 \\ x_1\mu_1 a_2 \tau(x, a), & y=x-e_1+e_2-e_3 \\ x_2\mu_2(1-a_2)\tau(x, a), & y=x-e_2 \\ x_2\mu_2 a_2 \tau(x, a), & y=x-e_3 \end{cases}$$

Let $p=\{p(x, a): x \in E,\ a \in A_x\}$ denote the steady-state probabilities of the process. Then, the blocking for handoff calls and new calls, and new call delay can be expressed as follows:

$$BH(a) = \sum_{x \in E_1} \sum_{a \in A_x} p(x, a),$$

$$BN(a) = \sum_{x \in E_2} \sum_{x \in A_x} (1-a_1)\, p(x, a),$$

$$W(a) = \sum_{x\in E} \sum_{a\in A_x} x_3\, p(x, a) \,/\, \lambda_2 \sum_{x\in E\setminus E_2} \sum_{a\in A_x} (1-a_1)\, p(x, a).$$

Consequently, the LP formulation associated with the SMDP is given below with decision variables $p(x, a), x\in E, a\in A_x$.

$$(P2)\ \min\ r_1 \sum_{x\in E_1} \sum_{a\in A_x} p(x, a) + r_2 \sum_{x\in E_2} \sum_{a\in A_x} p(x, a) \quad (15)$$

$$\text{s.t}\ \sum_{x\in E} \sum_{a\in A_x} p(x, a) = 1 \quad (16)$$

$$\sum_{a\in A_y} \frac{p(y, a)}{\tau(y, a)} = \sum_{x\in E} \sum_{a\in A_x} P_{xay} \frac{p(x, a)}{\tau(x, y)},\ y\in E \quad (17)$$

$$\sum_{x\in E_1} \sum_{a\in A_x} p(x, a) \le BH_T \quad (18)$$

$$\sum_{x\in E_2} \sum_{a\in A_x} p(x, a) \le BN_T \quad (19)$$

$$\frac{\sum_{x\in E} \sum_{a\in A_x} x_3\, p(x, a)}{\lambda_2 \sum_{x\in E\setminus E_2} \sum_{a\in A_x} (1-a_1)\, p(x, a)} \le W_T \quad (20)$$

$$p(x, a) \ge 0,\ x\in E, a\in A_x \quad (21)$$

Once the optimal solution p^* of the linear programming problem (P2) is obtained, the steady state distribution π^* of the system with the optimal control can be computed by

$$\pi^*(x) = \sum_{a\in A_x} p(x, a),\ \text{for all}\ x\in E$$

And the optimal control parameter α^*, β^* are obtained by

$$\alpha^*(x) = \sum_{(1, a_2)\in A_x} p^*(x, a) \,/\, \pi^*(x), \quad \text{for all}\ x\in E,$$

$$\beta^*(x) = \sum_{(a_1, 1)\in A_x} p^*(x, a) \,/\, \pi^*(x), \quad \text{for all}\ x\in E.$$

Note that the total number of constraints other than (21) is $|E|+4$.

4. Numerical Examples

Consider a single cell system with parameters $N = 30$, $B = 3$, $1/\mu_1 = 1/\mu_2 = 180$ seconds, and (λ_1, λ_2) which were selected so that $\lambda_1/\mu_1 + \lambda_2/\mu_2 = 21.9$ Erlang. The sum of arrival rates for both types of calls was chosen such that blocking probability of the system with 30 channels will be 0.02 when neither any call control scheme nor the buffer for queueing of new calls is implemented. And tolerable blocking probabilities of handoff, new calls and average new call delay given by $BH_T = 0.01$, $BN_T = 0.02$ and $W_T = 10$ seconds, respectively. In fact, the introdoction of the buffer for new calls increases the system capacity to 23.3 Erlang without any call control scheme. This parameterization is to assimilate the traffic and performance environment to the reality.

With the system parameters defined above, the LPs were first run (with CPLEX [1] on the pentium PC) for the problem of maximizing weighted average carried traffics, and [Fig.1] shows the results. [Fig.1-(a)] gives blocking probabilities of handoff and new calls with respect to a variety of normalized handoff load $\lambda_1/(\lambda_1+\lambda_2)$. On the other hand, [Fig.1-(b)] gives the average number of calls in the buffer and the effective arrival rate of new call to the buffer, denoted by L and a, respectively. Therefore, ($L/a \times 180$ seconds) indicates the value of average waiting time of new calls in the buffer.

The objective maximizing carried traffics forces blocking probabilities of calls, regardless of the types of calls, to be small as possible. As shown in [Fig.1], this yields the result that the constraints on blocking of handoff calls and delay of new calls were satisfied with equality. It is also worth noting that the blocking probability of new calls is smaller than that of handoff calls when the ratio of handoff and new calls, $\lambda_1/(\lambda_1+\lambda_2)$, is small. This phenomenon is induced by implementation of buffer and adoption of objective maximizing carried traffics.

Next, the LPs were run for the problem with objective of minimizing handoff call blocking probability, whose results are given in [Fig.2]. Other problem parameters were given the same as above except for the objective function. In this case, we can observe some different pattern of optimal call control solutions as compared with the case with objective of maximizing carried traffics: in most data instance, the constraints on new call blocking were satisfied with equality except the case of $\lambda_1/(\lambda_1+\lambda_2) = 0.5$, as shown in [Fig.2-(a)]. This is mainly due to the fact that the blocking probability of handoff calls is maintained as small as possible by limiting channel assignments for new calls as long as the constraints on the blocking probability and delay of new calls are satisfied.

The exceptional case, $\lambda_1/(\lambda_1+\lambda_2) = 0.5$, can be explained by the fact that the constraints on the delay of new calls cannot be satisfied any more without the decrease in blocking probability of new calls. Really, the test run show that if the blocking probability of new calls is fixed to 0.02, the problem yields the infeasible solution.

In some traffic environment such as highway, the fraction of handoff calls is usually greater than that of new calls. [Fig.3] shows the results for this environment. The value of $\lambda_1/\mu_1 + \lambda_2/\mu_2$ is chosen as 21.1 Erlang instead of 21.9 Erlang simply to guarantee the existence of feasible solutions in the considered range of $\lambda_1 / (\lambda_1 + \lambda_2)$. The other problem parameters are the same as in [Fig.1]. In case of the objective maximizing carried traffic, the constraint on the blocking probability of handoff calls satisfied with equality ([Fig.3 (a)]), whereas in case of the objective minimizing the blocking probability of handoff calls, the blocking probabilities of handoff calls strictly increases and the those of new calls strictly decreases, as the ratio of handoff calls increases ([Fig.3 (b)]). This phenomenon can be explained by the similar arguments mentioned above for the case of $\lambda_1 / (\lambda_1 + \lambda_2) = 0.5$ in [Fig.2-(a)].

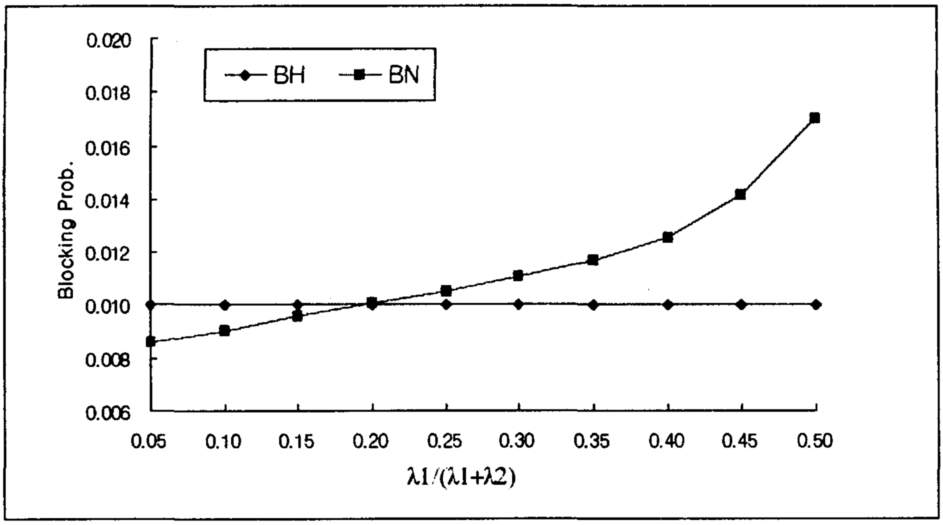
[Fig.4] shows the effect of the constraints on delay of new calls for both types of objectives. As expected, the objective maximizing carried traffics forces the blocking probability of handoff calls satisfied with equality ([Fig.4 (a)]), whereas the objective minimizing blocking probabilities of handoff calls forces the blocking probability of new calls satisfied with equality ([Fig.4 (b)]). In this experiment, the value of $1/\mu_1 = 1/\mu_2$ is set to 120 seconds instead of 180 seconds simply to guarantee the existence of feasible solutions in the considered range of W_T.

Finally, in order to see the effect of buffer size, the LPs were run for the problems with the same parameters as in [Fig.1] except that the ratio of handoff load is set at 30% ([Fig.5]). As expected, increasing the buffer size impels the new call blocking probability to be small as possible. This is because that increase of the number of new calls to be queued will reduce the possibility of rejection of new calls at the first attempt.

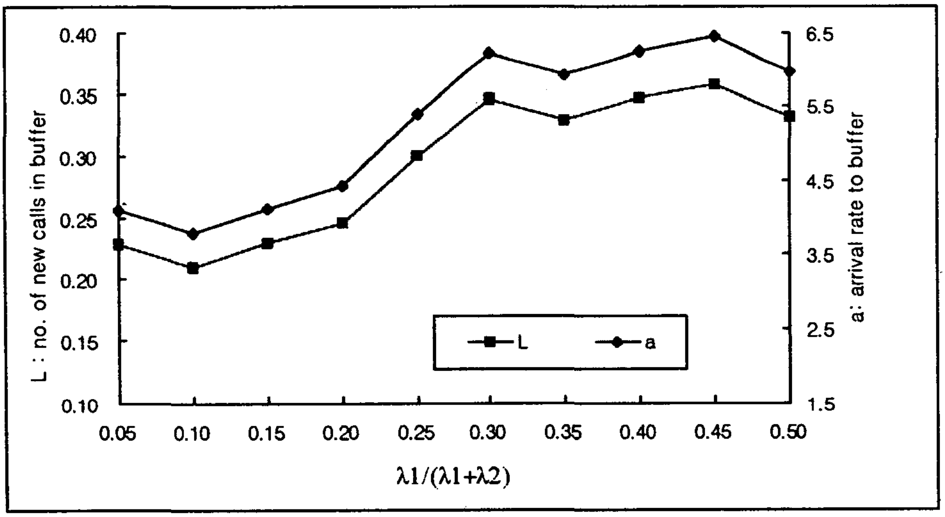
The types of optimal call control strategies represented by the optimal solutions for the above several experimental problems with both types of objective functions are in general close to cutoff priority rather than the threshold type, which implies that the cutoff priority scheme gives effectively a priority to handoff calls while reducing sacrifice of new calls.

5. Concluding Remarks

We have studied the optimal call control of the cellular system which has two typical calls, new and handoff calls by incorporating queueing delay of new calls. A call control problem(CCP) was developed to find a call control strategy which optimizes the objective function value, while satisfying the requirements on the handoff and new call blocking probabilities and the new call delay. And two types of LP formulations for the CCP have been suggested along with a remark on theproperty of the optimal solutions induced from the LP problem. And extensive experiments have been conducted to show which call control strategy is optimal under various system environments having different objective functions and traffic patterns.



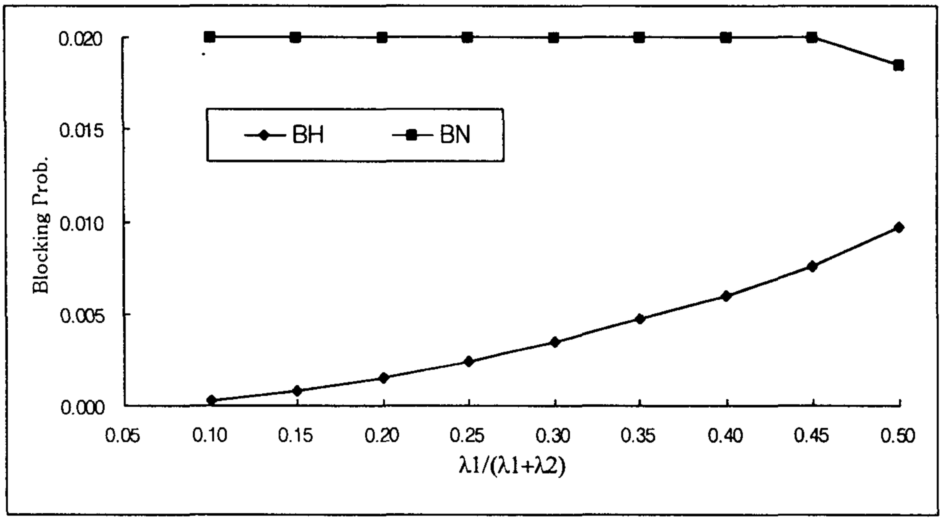
(a) Blocking probabilities of handoff and new calls



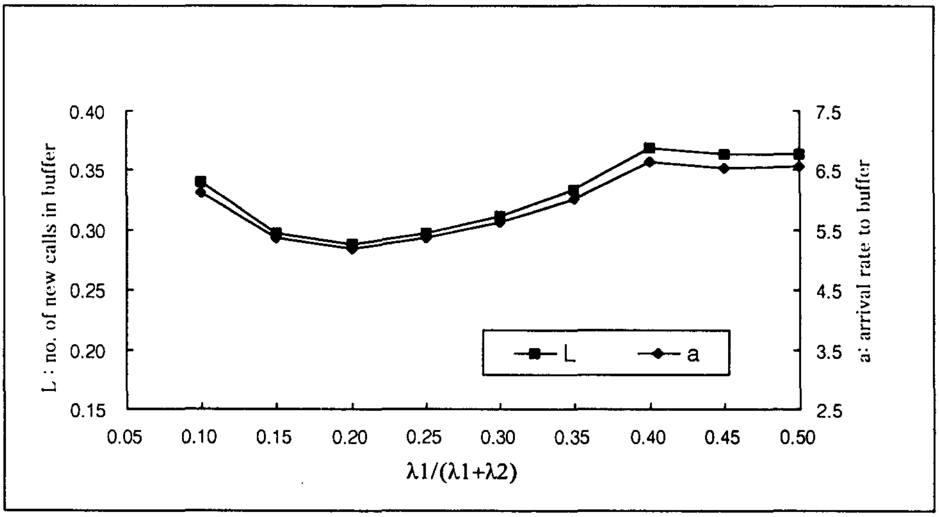
(b) L and a

[Figure 1] Results under objective maximizing carried traffic

$N=30,\ B=3,\ BH_T=0.01,\ BN_T=0.02,\ W_T=10$ seconds, $\frac{\lambda_1}{\mu_1}+\frac{\lambda_2}{\mu_2}=21.9$



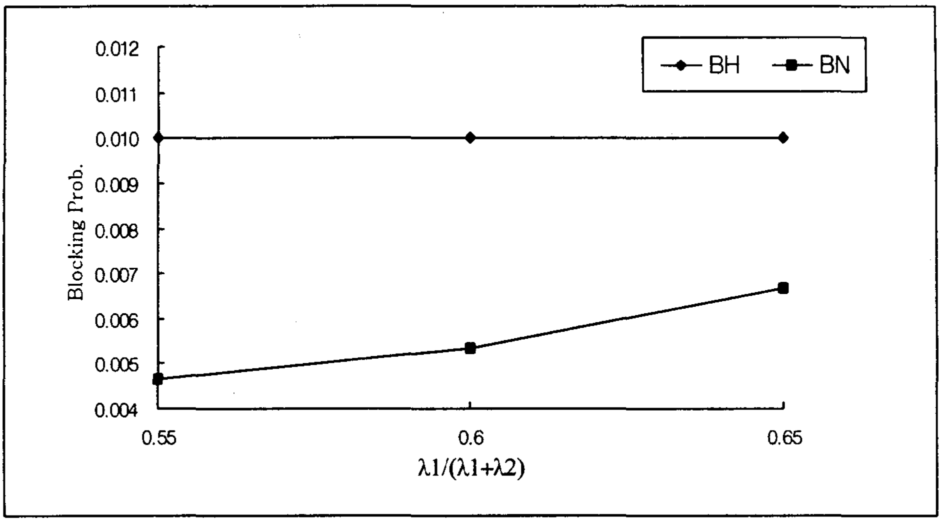
(a) Blocking probabilities of handoff and new calls



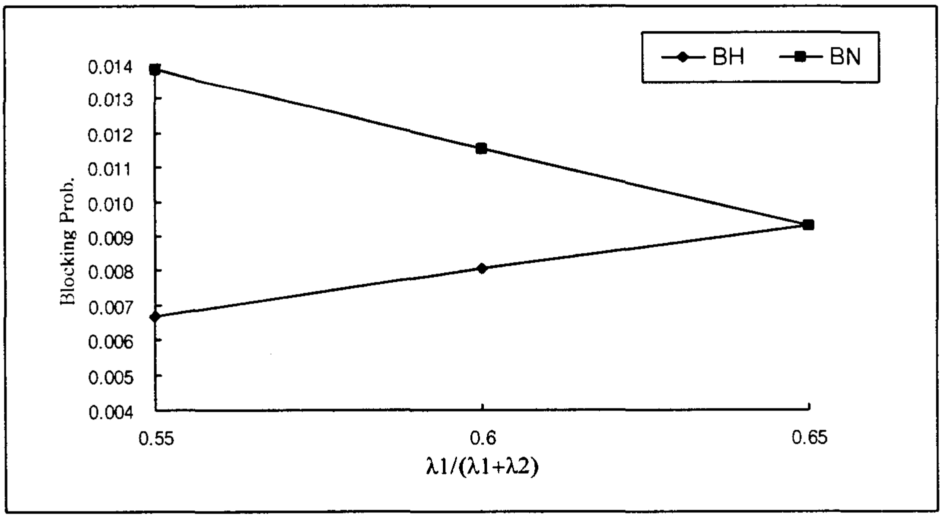
(b) L and a

[Figure 2] Results under objective minimizing handoff blocking

$N = 30$, $B = 3$, $BH_T = 0.01$, $BN_T = 0.02$, $W_T = 10$ seconds, $\frac{\lambda_1}{\mu_1} + \frac{\lambda_2}{\mu_2} = 21.9$



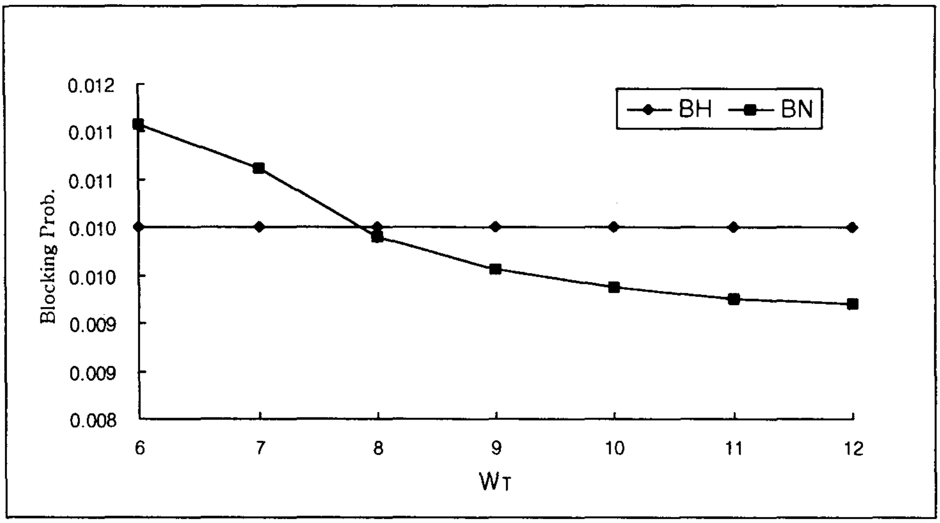
(a) Results under objective maximizing carried traffic



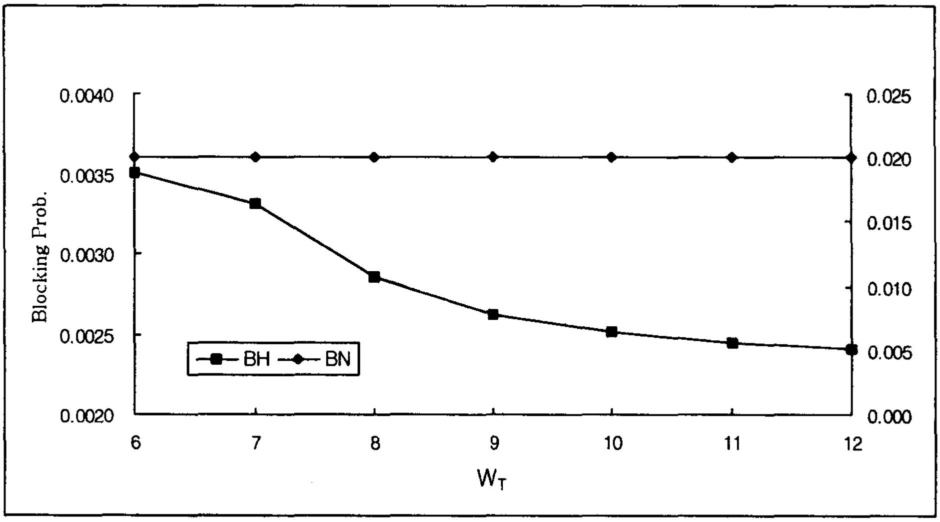
(b) Results under objective minimizing handoff blocking

[Figure 3] The case of $\lambda_1 / (\lambda_1 + \lambda_2)$ is greater than 0.5

$N = 30$, $B = 3$, $BH_T = 0.01$, $BN_T = 0.02$, $W_T = 10$ seconds, $\frac{\lambda_1}{\mu_1} + \frac{\lambda_2}{\mu_2} = 21.1$



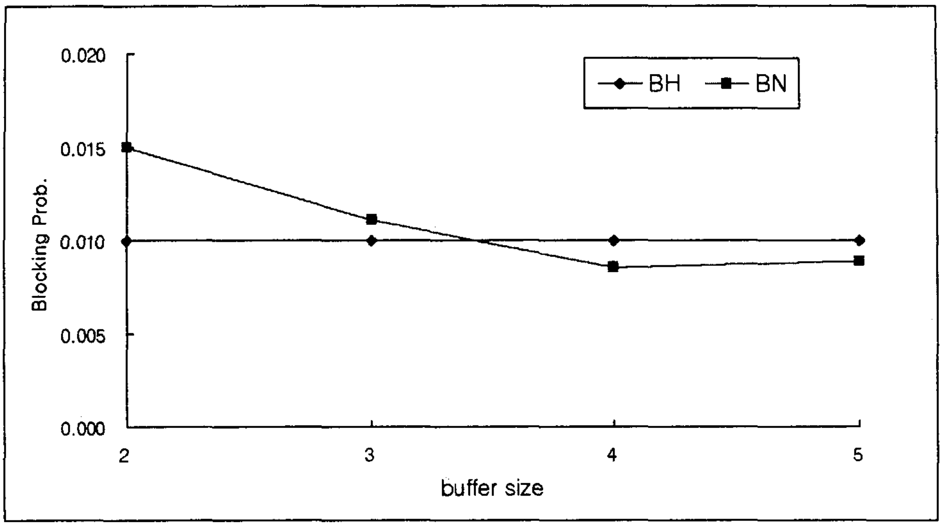
(a) Results under objective maximizing carried traffic



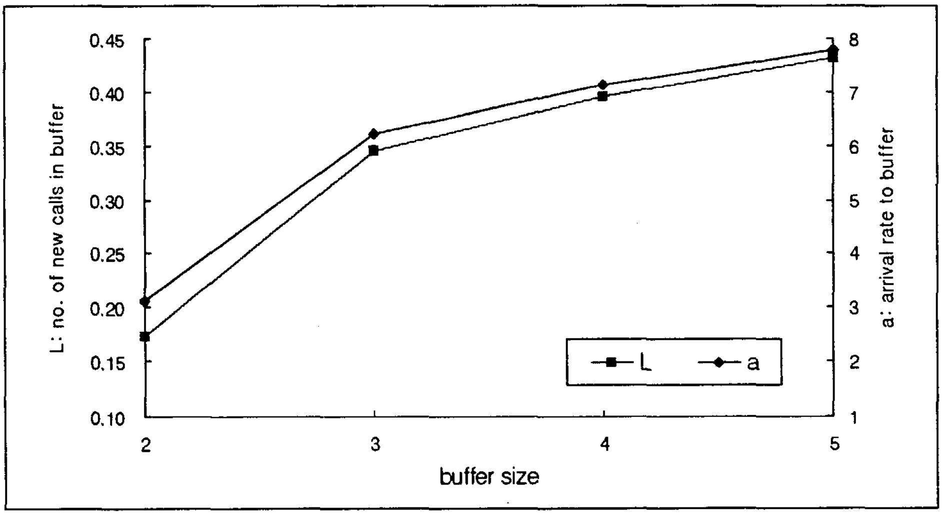
(b) Results under objective minimizing handoff blocking

[Figure 4] The effect of W_T

$N = 30$, $B = 3$, $BH_T = 0.01$, $BN_T = 0.02$, $W_T = 10$ seconds, $\frac{\lambda_1}{\mu_1} + \frac{\lambda_2}{\mu_2} = 21.9$



(a) Effect on blocking probabilities



(b) Effect on L and a

[Figure 5] Effect of buffer size

$N = 30$, $BH_T = 0.01$, $BN_T = 0.02$, $W_T = 10$ seconds, $\frac{\lambda_1}{\lambda_1 + \lambda_2} \times 100 = 30\ \%$

REFERENCE

[1] CPLEX Optimization, Inc. *Using the CPLEX Callable Libray*, 1995.

[2] Chang, C.J., Su, T.T and Chiang, Y.Y., "Analysis of a Cutoff Priority Cellular radio system with Finite Queueing and Reneging/Dropping", *IEEE Trans. Networking*, Vol.2(1994), pp.166-175.

[3] Guérin, R., "Queueing-Blocking System with Two Arrival Streams and Guard Channel", *IEEE Trans. Commun.*, Vol.36 (1988), pp.153-163.

[4] Heyman, D.P. and Sobel, M.J., *Stochastic Models in Operation Research Vol.II: Stochastic Optimization*, New York: McGraw-Hill, 1984.

[5] Hong, D. and Rappaport, S.S, "Traffic Model and Performance Analysis for Cellular Mobile Radio Telephone Systems with Prioritized and Non-prioritized Handoff Procedures", *IEEE Trans. Veh. Technol.*, Vol.VT-35(1992), pp.72-92.

[6] Keilson, J. and Ibe, C.C., "Cutoff Priority Sceduling in Mobile Cellular Communication Systems", *IEEE Trans. Commun.* Vol.43(1995), pp.1038-1045.

[7] Kleinrock, L., *Queueing Systems, Volume I: Theory*, New York: Wiley, 1975.

[8] Lin, Y.B., Mohan, S. and Noerpel, A., "Queueing Priority Channel Assignment Strategies for PCS Hand-off and Initial Access", *IEEE Trans. Veh. Technol.*, Vol. 43(1994), pp.704-712.

[9] Lin, Y.B., Mohan, S. and Noerpel, A., "PCS Channel Assignment Strategies for PCS Hand-off and Initial Access", *IEEE Personal Commun.*, Third Quarter (1994), pp.47-56.

[10] Oh, S.H. and Tcha, D.W., "Prioritized channel assignment in a cellular radio network", *IEEE Trans. Commun.* Vol.40 (1992), pp.1259-1269.

[11] Papadimitrou, C.H. and Steiglitz, K., *Combinatorial Optimization: Algorithms and Complexity}*, New Jersey: Prentice-Hall, Inc, 1982.

[12] Ross K.W. and Tsang D.H., "Optimal Circuit Access Policies in an ISDN Environment : A Markov Decision Approach", *IEEE Trans. Commun.* Vol.37(1989), pp. 934-939.

[13] Tcha, D.W., Paik C.H and Chung Y.J., "Spectrum-Efficient Call Control in s Dual-Mode TDMA Cellular System", *IEEE Trans. Veh. Technol.* Vol.45, No.2(1996), pp.148-156.

[14] Tekinary, S. and Jabbari, B., "Handover and Channel Assignment in Mobile Cellular Networks", *IEEE Commu. Magazine*, November(1991).

[15] Tijms, H.C., *Stochastic Modelling and Analysis : A Computational Approach}*, New York: Wiley, 1986.