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Mobility-based call admission control schemes for wireless mobile networks

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Summary

Call admission control (CAC) plays a significant role in providing the desired Quality of Service (QoS) in wireless networks. In this paper, we present some new call admission control schemes: mobility-based call admission schemes and new call bounding schemes, for wireless mobile networks providing services to multiple classes of mobile users (i.e. pedestrians and vehicular travelers). Since the salient feature of wireless mobile networks is the mobility, an ongoing call in one place may have potential impact on the resource usage in another place in the future, the concept of influence curve is introduced to characterize such influence that an ongoing call exerts on the adjacent cells, according to which the channel reservation can be adjusted dynamically and mobility-based call admission control schemes can be designed. To overcome potential congestion, we also propose a new call bounding scheme which places a direct limitation on the number of new calls admitted to a cell. Four CAC schemes are proposed and analyzed via analytical modeling and simulation study. It is shown that our schemes are more effective in providing QoS than other previously known schemes. Copyright © 2001 John Wiley & Sons, Ltd.

KEY WORDS

call admission control
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blocking probability
call dropping probability

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1. Introduction

In wireless mobile networks, the service area is divided into cells each of which is equipped with a number of channels. Two types of calls are sharing these channels: the new calls and the handoff calls. New calls are those initiated by mobile users in the current cell; while the handoff calls are those initiated in other cells and handed over to the current cell. When a call arrives at a cell in which a channel is not available, it may be blocked or may be queued, depending on the call admission control schemes used. The probability that a new call is blocked is called *New Call Blocking Probability* (P_{nb}), the probability that a handoff call is blocked is called *Handoff Call Blocking Probability* (P_{hb}), and the probability that a call is either blocked or accepted but immaturely terminated during the call life is termed as *Call Dropping Probability*. These quantities are most significant QoS metrics in wireless mobile networks. We notice that call dropping probability can be calculated from new call blocking probability and handoff call blocking probability [1], new call blocking probability and handoff call blocking probability are specified in the network design [21]. Since each arriving call, no matter whether it is a new call or a handoff call, will occupy a channel if it is accepted for service, new calls and handoff calls are competing for the usage of a finite number of channels in a cell, therefore, the new call blocking probability and handoff call blocking probability cannot be decreased simultaneously; a tradeoff has to be made.

From users' point of view, a call being forced to terminate during the service is more annoying than a call being blocked at its start, hence the handoff call blocking probability is much more stringent than the new call blocking probability. Therefore, handoff calls are commonly given a higher priority in accessing the wireless channels. This can be realized by handoff priority-based *Call Admission Control Schemes* (CAC). Good CAC schemes have to balance the new call blocking and handoff call blocking in order to provide the desired QoS requirements. Various handoff priority-based CAC schemes have been proposed [22]; they can be broadly classified into two broad categories:

(1) *Guard Channel Schemes:* A number of channels in each cell are reserved for exclusive use by handoff calls; the rest of the channels are shared by both new and handoff calls [2–9];
(2) *Queuing Priority Schemes:* When all channels are occupied, either new calls are queued while handoff calls are blocked [10–12], or new calls are blocked while handoff calls are queued [13], or both calls are queued [14].

Various combinations of the above schemes have also been proposed and studied in literature [12, 14]. In this paper, we concentrate on the guard channel schemes in combination with mobility information.

The critical element in a guard channel scheme is *channel reservation*. Channel reservation strategies are designed by either reserving a fixed number of channels or adjusting the reservations dynamically. The fixed reservation schemes are also called *cut-off priority* schemes [2, 3]. They are very simple in that no communication and computation overheads are involved. However, such schemes are not flexible to handle the changing traffic situations, since these schemes do not use the traffic information in the current cell and its neighboring cells, hence cannot adapt to the real-time network conditions. According to information theory, information available should be used to achieve better performance, therefore, dynamic reservation schemes [15–17] are proposed to overcome the disadvantages of the fixed reservation schemes. In Reference [15], the number of channels to be reserved is calculated according to the requested bandwidth of all ongoing connections or the number of ongoing connections. Each base station keeps monitoring the handoff call blocking probability and the utilization of channels in its cell, then uses this information to adjust the reservation accordingly. In Reference [16], the authors proposed a scheme based on the prediction of the probability that a call will be handed off to a certain neighboring cell from the aggregate history of handoffs in each cell and determine the number of reserved channels; each base station records the number of handoff failures and adjusts the reservation by changing the estimation window size.

We observe that none of the above schemes explicitly takes the mobility of users into consideration. In Reference [18], the authors show that user mobility has a profound effect on QoS provisioning. The most salient feature of the mobile wireless network is the mobility. Hence, in order to make a reservation scheme effectively adapt to the network traffic situations, the user mobility information must be deployed. In Reference [17], the shadow cluster concept is introduced to estimate the future resource requirements based on the current movement pattern of mobile users. However, the strength of the scheme depends on the accuracy of the knowledge of users' movement patterns, such as the trajectory of a mobile user, which is difficult to predict in the real system.

One critical issue in all reservation-based CAC schemes is how the reservation is made. In traditional guard channel scheme or the cutoff priority scheme, the number of guard channels is determined based on the prior knowledge of the cell traffic and the call blocking requirements. Obviously, the performance will degrade if the cell traffic is not conformal to the prior knowledge, thus it will be better to use dynamic channel allocation schemes: adjusting the number of guard channels with the network traffic. In order to determine an optimal or near optimal reservation value, one must first answer the following question: *When do we reserve channels for the incoming handoff calls*? If the reservation is made at the time when it is needed, the resulting scheme will definitely achieve the best performance. However, such timing will be very difficult, if not impossible, to acquire. Since the reservation is a waste of resources if it is not used by handoff calls, the shorter the time between the time a reservation is made and the time the reservation is actually used, i.e., *the reservation time*, the better performance we will achieve. We observe that handoffs occur when mobile users are moving during the call connection. Thus, a good reservation scheme should be designed based on the users' mobility pattern. Mobility patterns are determined by many factors, such as mobile users' destinations, the layout of the wireless network, the traffic condition in the network, hence it is not easy to characterize the mobility pattern in great detail for each specific user. However, it should be noted that call quality performance is a collective outcome of all users in the network, and therefore the statistical users' mobility patterns are more useful [20].

Another observation is that all guard channel schemes in the literature use the number of occupied channels as a decision variable: when this number exceeds a certain threshold, arriving new calls are blocked and only handoff calls are accepted. The CAC takes effect only when this threshold is reached, in which case, the cell will be congested in the future if too many new calls are accepted. This is the case when calls arrive in bursts (say after a ball game). The purpose of CAC in a wireless network is aiming at: (1) providing desired QoS to the newly admitted call; (2) guaranteeing that the QoS of ongoing calls still meets the requirements. When congestion occurs, neither goals can be achieved. In order to avoid such a problem, we suggest a *New Call Bounding* scheme, which directly controls the number of admitted new calls. Using this strategy, we can prevent the cell congestion as described above.

Based on the above two observations, we will use the following two basic ideas: *mobility-based channel reservation* (MBCR) and *new call bounding* (NCB). Four call admission schemes based on these ideas are proposed to provide the QoS guarantee for a mobile wireless network that has multiple platforms (pedestrians and vehicular travelers). The rest of this paper is organized as follows. In Section 2, we present the concept of influence curve, based on which we develop the mobility-based channel reservation schemes. In Section 3, we propose four CAC schemes. Performance analysis for these schemes is given in Section 4. We conclude the paper in the last section.

2. Mobility-based Channel Reservation

Consider a wireless mobile network in which each cell is equipped with C channels. In order to assign higher priority to handoff calls, a number of channels among C channels, say, C_h channels, can be reserved for the incoming handoff calls. In this paper, we classify mobile users into two classes according to velocities: high-speed users (vehicular users) and low-speed users (pedestrians), for illustrative purposes. The average cell dwell time of a high-speed user is shorter than that of a low-speed user. Based on such a classification, we predict the handoff probability of each class and make reservations accordingly. Although we only use this coarse classification, the technique can be easily generalized to handle more general situations. Our purpose is to demonstrate how predictive reservation can be improved when additional information such as mobility pattern is used.

2.1. Influence Curves

In order to understand the rationale behind our schemes, we first notice the following observations:

(1) A user is more likely to request a handoff in the far future than in the near future after it enters a cell ('enter' means either the initiation of a new call or a successful handoff of an ongoing call into this cell), which implies that the handoff probability (the probability that a call needs at least one handoff during remaining call life) is a function of the time elapsed after a call enters a cell;

(2) After dwelling in a cell for the same length of time, a high-speed user is more likely to request a handoff than a low-speed user is, which implies that the handoff probability is also related to the speed class of a user.

Because of call handoffs, traffics among cells are no longer independent: when a call enters a cell, it not only consumes a channel of current cell, but also generates a certain requirement on the channels in the neighboring cells (with certain probability). In other words, an ongoing call in the current cell exerts some influence on the channel assignment in the neighboring cells. From the aforementioned observations we can conclude that the extent of such influence can be characterized by both the elapsed time and the velocity class. The number of channels to be reserved, C_h, has a close relationship to the extent of the influence. The more influence a call exerts on its neighboring cells, the more likely a channel should be reserved in the neighboring cells to maintain the QoS requirement of this call. In order to characterize such influence, we introduce the concept of influence curve as follows.

Let $f_h(t)$ and $f_l(t)$ denote the cell-dwell-time probability density functions (pdf) of the high-speed users and the low-speed users, respectively. If a high-speed user enters this cell at time t, the probability that it will request a handoff after time T is:

$$\begin{aligned}
&\Pr\text{ (this call will request a handoff sometime after } T)\\
&\quad = \Pr\text{ (this call will stay in current cell before } T)\\
&\quad = \int_0^{T-t} f_h(\tau)d\tau\\
&\quad = L_h(t, T) \qquad (1)
\end{aligned}$$

Similarly we can obtain $L_l(t, T)$ by substituting $f_h(t)$ with $f_l(t)$.

Let $\alpha_{i,j}$ $(j \in N_i)$ be the directional factor, i.e., the probability that the handoff target cell is cell j when the call is being served in the cell i, where $\sum_{j\in N_i} \alpha_{i,j} = 1$, N_i is the set of the neighboring cells to the cell i. For a totally random movement pattern in a homogeneous cellular network, the users move to all possible directions with equal probabilities, $\alpha_{i,j} = \frac{1}{|N_i|}$ for all the $j \in N_i$, where $|N_i|$ denotes the cardinality of the set N_i. For a cellular network with hexagonal layout, each cell has six neighbors, the directional factor for this case will be 1/6. In an environment (such as highway) that users' movements follow a highly directional pattern, some factors can be much greater than others; the exact values can be obtained through field tests.

With $L_l(t, T)$, $L_h(t, T)$ and $\alpha_{i,j}$, we can define the influence curve for an ongoing high-speed call or low-speed call as follows:

$$I(i, j, t, T) = \begin{cases} \alpha_{i,j}L_h(t, T) & \text{for a high speed call} \\ \alpha_{i,j}L_l(t, T) & \text{for a low speed call} \end{cases} \qquad (2)$$

The influence curve characterizes the influence exerted on cell j at time T by an ongoing high-speed call or a low-speed call which enters the cell i at time t.

2.2. Mobility-based Channel Reservation

With the influence curve for every ongoing call, we can further determine the number of channels needed to be reserved in each cell. The total influence that all the ongoing calls in cell i exerting on cell j is

$$I_{i,j} = \sum_{k\in S} \alpha_{i,j}L(t_k, T) \qquad (3)$$

where S is the set of all the currently ongoing calls in cell i, $L(t_k, T)$ can be either $L_l(t, T)$ or $L_h(t, T)$ depending on the velocity class of the call. The influence between neighboring cells is shown in Figure 1. As we have mentioned before, the number of channels needed to be reserved has a close relationship to the extent of the influence. In this paper, we choose this number to be proportional to the extent of the influence, thus we define the number of the reserved channels in cell j for calls in cell i as

$$R_{i,j} = BI_{i,j} \qquad (4)$$

where B is a tunable constant. Hence at time T, cell j needs to reserve

$$R_j = \sum_{i\in N_j} R_{i,j} \qquad (5)$$

channels for possible handoff calls from its neighboring cells. This scheme requires that neighboring cells exchange information with each other: cell i should report $R_{i,j}$ to all its neighbors. Since the users are mobile, the information exchange must be done regularly (periodically) to guarantee that a cell can always have the latest information about the reservation requirements of its neighbors.

2.3. A Special Case

If the cell dwell times for both classes of users have negative exponential distributions, then $f_h(\tau) =$

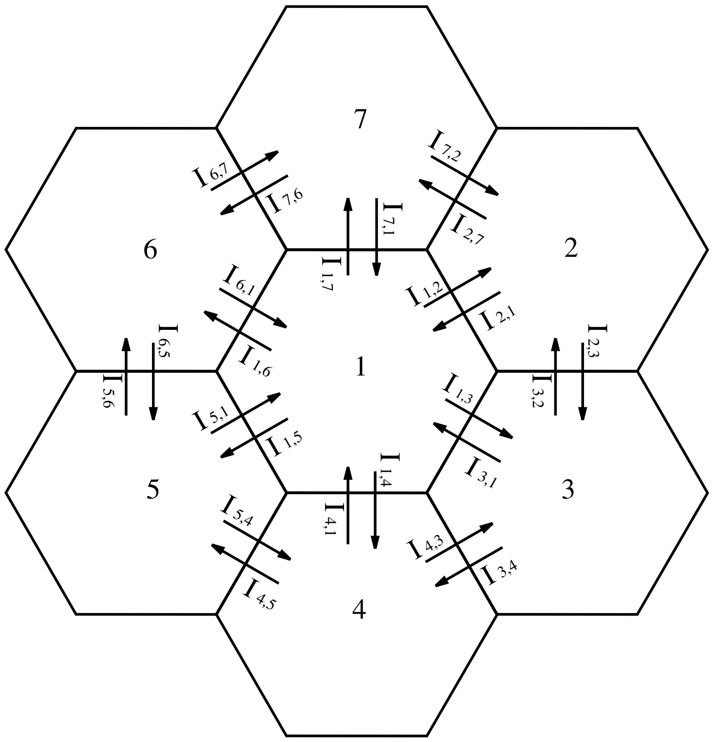

Fig. 1. The influence between neighboring cells.

$\mu_h e^{-\mu_h \tau}$ and $f_l(\tau) = \mu_l e^{-\mu_l \tau}$, where $1/\mu_h$ and $1/\mu_l$ are the average cell dwell times for high-speed users and low-speed users, respectively. We further assume that users are moving in a random movement pattern in a cellular network with hexagonal layout. Following the above procedures (from Equations (1) to (5)), we obtain

$$L_h(t, T) = 1 - e^{-\mu_h (T-t)}$$

$$L_l(t, T) = 1 - e^{-\mu_l (T-t)}$$

$$I(i, j, t, T) = \begin{cases} \frac{1}{6}(1 - e^{-\mu_h (T-t)}) & \text{for high-speed user} \\ \frac{1}{6}(1 - e^{-\mu_l (T-t)}) & \text{for low-speed user} \end{cases}$$

$$R_{i,j} = \frac{B}{6}\left[\sum_{k \in S_h}(1 - e^{-\mu_h (T-t_k)}) + \sum_{k \in S_l}(1 - e^{-\mu_l (T-t_k)})\right] \quad (6)$$

where t_k is the enter time of ongoing call k to the current cell of interest, S_h is the set of all the ongoing high-speed calls and S_l includes all the ongoing low-speed calls.

3. Call Admission Control Schemes

Call Admission Control schemes are used to decide whether an incoming call (mostly a new call) is admitted for network service or not. In order to meet the desired QoS requirements, some calls have to be blocked although current network resources (channels) are still available. In Reference [7], a general setting for CAC is proposed: guard channel schemes can be formulated by call admission probability, i.e., if i is a decision variable (say, the number of busy channels), a new arriving call is admitted into the network with probability $P(i)$. Depending on the choice of $P(i)$, we can obtain different CAC schemes. In this section, based on this approach, we propose four different CAC schemes. Schemes A and B are two different implementations of MBCR; scheme C imposes a limitation on the number of new calls admitted, called *new call bounding* scheme, and scheme D is the combination of the new call bounding scheme and the MBCR scheme.

3.1. (A) Integral MBCR

At time T, cell j calculates R_j according to Equation (5). Note that R_j may not be an integer. In this scheme, we round R_j to the nearest integer $\widetilde{R_j}$, and use $\widetilde{R_j}$ as the final target number of reserved channels. Thus the following policy is set up:

$$P_{\text{new}} = \begin{cases} 1 & B_{\text{used}} \le C - \widetilde{R_j} - B_{\text{new}} \\ 0 & B_{\text{used}} > C - \widetilde{R_j} - B_{\text{new}} \end{cases} \quad (7)$$

where P_{new} is the admission probability for new calls, B_{used} and B_{new} are the number of used channels and the number of channels required by the incoming new call, respectively.

Note that there are two other variations of this scheme based on the rounding procedure for R_j. The first variation is conservative: always use the ceiling value of R_j, i.e., the smallest integer greater than R_j, this implies that we always reserve enough channels for the request. This may not be necessary if we observe that the requested reservation is a rough estimate anyway. The second variation is aggressive: always use the floor value of R_j, i.e., the largest integer smaller than R_j. Scheme A is basically falling in the middle of these two variations. We expect that there are no significant differences for these three schemes in terms of performance, so in this part we will use scheme A for performance analysis.

3.2. (B) Fractional MBCR

In the above scheme, we used rounding scheme for the reservation request. However, some information carried by the fractional part may be lost during the rounding, for example, if the R_j is 2.6, then $\widetilde{R_j}$ becomes 3, the reservation is 15 per cent more than the requirement; on the other hand when R_j is 2.4, two channels are actually reserved. In order to fully use the information, fractional reservation is introduced. If R_j has integral part R_j^I and fractional part R_j^F, then the scheme is defined as:

$$P_{\text{new}} = \begin{cases} 1 & B_{\text{used}} \le C - R_j^I - B_{\text{new}} - 1 \\ 1 - R_j^F & B_{\text{used}} = C - R_j^I - B_{\text{new}} \\ 0 & B_{\text{used}} > C - R_j^I - B_{\text{new}} \end{cases} \quad (8)$$

3.3. (C) New Call Bounding Scheme

As we have mentioned before, in the aforementioned schemes and all other guard channel schemes in the current literature, the number of totally occupied channels is used as a decision variable for CAC. It may well happen that too many new calls are accepted into the system, which may result in congestion in neighboring cells due to the handoffs of these new calls in the future. To avoid this occurrence, in the NCB scheme, we use the number of channels that are currently occupied by new calls as a decision variable for the CAC. More specifically, the scheme works as follows:

$$P_{\text{new}} = \begin{cases} 1 & B_{\text{usednew}} \le N_{\text{bnd}} \,\&\, B_{\text{used}} \le C - B_{\text{new}} \\ 0 & \text{otherwise} \end{cases} \quad (9)$$

where B_{usednew} is the number of channels that is used by new calls, N_{bnd} is a given bound for new calls. The idea behind this scheme is that we would rather accept fewer calls than drop ongoing calls in the future, so we control the number of accepted new calls directly.

3.4. (D) Hybrid Scheme

This scheme is a combination of schemes A and C. We impose constraints not only on the number of channels occupied and reserved, but also on the number of channels occupied by the new calls. The new call admission probability for this scheme is chosen as:

$$P_{\text{new}} = \begin{cases} 1 & B_{\text{used}} \le C - \widetilde{R_j} - B_{\text{new}} \\ & \quad \& \, B_{\text{usednew}} \le N_{\text{bnd}} \\ 0 & \text{otherwise} \end{cases} \quad (10)$$

4. Performance Analysis

This section presents performance analysis for the proposed schemes. We first present the analytical results for the NCB scheme, then study the MBCR schemes comparing them with the fixed reservation scheme. We will compare P_{nb} and P_{hb} for different traffic situations.

4.1. Analysis of New Call Bounding Scheme

In this subsection, we derive the new call blocking probability and handoff call blocking probability for the NCB scheme. The NCB scheme can be analyzed by using two-dimensional Markov Chain. Let λ_n, λ_h, $1/\mu_n$ and $1/\mu_h$ denote the arrival rate for new calls, the arrival rate for handoff calls, the average channel holding time for new calls and the average channel holding time for handoff calls, respectively. Let C be the total number of channels in a cell and K be the bound for new calls. Figure 2 indicates the transition diagram for the NCB scheme. The diagram forms the two-dimensional Markov chain with the state space:

$$S = \{(n_1, n_2) | 0 \le n_1 \le K, n_1 + n_2 \le C\}$$

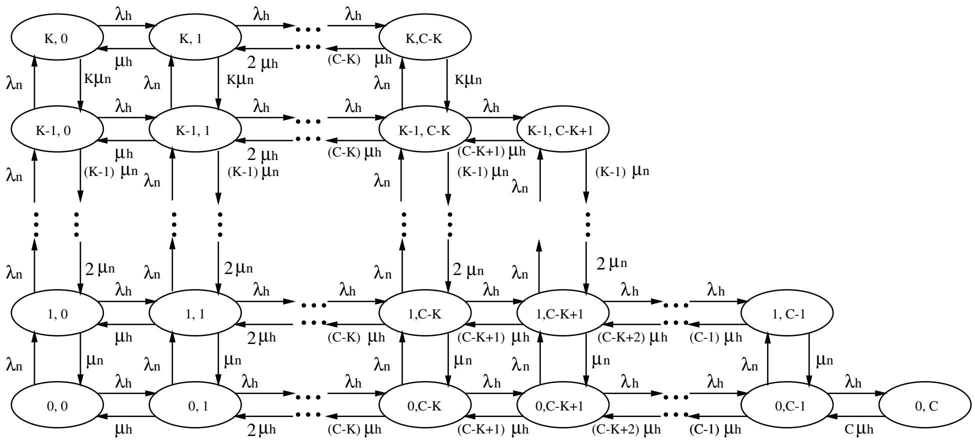

Fig. 2. Transition diagram for the new call bounding scheme.

where n_1 denotes the number of new calls initiated in the cell and n_2 is the number of admitted handoff calls in the cell. Let $q(n_1, n_2; \overline{n_1}, \overline{n_2})$ denote the probability transition rate from state (n_1, n_2) to the state $(\overline{n_1}, \overline{n_2})$, then we have:

$$q(n_1, n_2; n_1 - 1, n_2) = n_1\mu_n \quad (0 < n_1 \le K, 0 \le n_2 \le C)$$
$$q(n_1, n_2; n_1 + 1, n_2) = \lambda_n \quad (0 \le n_1 < K, 0 \le n_2 \le C)$$
$$q(n_1, n_2; n_1, n_2 - 1) = n_2\mu_h \quad (0 \le n_1 \le K, 0 < n_2 \le C)$$
$$q(n_1, n_2; n_1, n_2 + 1) = \lambda_h \quad (0 \le n_1 \le K, 0 \le n_2 < C)$$

where (n_1, n_2) is a feasible state in S. Let $p(n_1, n_2)$ denote the steady-state probability that there are n_1 new calls and n_2 handoff calls in the cell. Let $\rho_n = \lambda_n/\mu_n$ and $\rho_h = \lambda_h/\mu_h$. It is easy to verify that:

$$p(n_1, n_2) = \frac{\rho_n^{n_1}}{n_1!}\frac{\rho_h^{n_2}!}{n_2!}p(0,0), \quad 0 \le n_1 \le K, \quad n_1 + n_2 \le C, n_2 \ge 0 \tag{11}$$

From the normalization equation, we obtain

$$p(0,0) = \left[\sum_{0 \le n_1 \le K, n_1+n_2 \le C} \frac{\rho_n^{n_1}}{n_1!}\frac{\rho_h^{n_2}}{n_2!}\right]^{-1} = \left[\sum_{n_1=0}^{K} \frac{\rho_n^{n_1}}{n_1!} \sum_{n_2=0}^{C-n_1} \frac{\rho_h^{n_2}}{n_2!}\right]^{-1} \tag{12}$$

Based on this, we obtain the formulae for new call blocking probability p_{nb} and handoff call blocking probability p_{hb} as follows:

$$p_{nb} = \frac{\sum_{n_2=0}^{C-K} \frac{\rho_n^K}{K!}\frac{\rho_h^{n_2}}{n_2!} + \sum_{n_1=0}^{K-1} \frac{\rho_n^{n_1}}{n_1!}\frac{\rho_h^{C-n_1}}{(C-n_1)!}}{\sum_{n_1=0}^{K} \frac{\rho_n^{n_1}}{n_1!} \sum_{n_2=0}^{C-n_1} \frac{\rho_h^{n_2}}{n_2!}}$$

$$p_{hb} = \frac{\sum_{n_1=0}^{K} \frac{\rho_n^{n_1}}{n_1!}\frac{\rho_h^{C-n_1}}{(C-n_1)!}}{\sum_{n_1=0}^{K} \frac{\rho_n^{n_1}}{n_1!} \sum_{n_2=0}^{C-n_1} \frac{\rho_h^{n_2}}{n_2!}} \tag{13}$$

4.2. Simulation Model and Assumptions

Since it will be difficult to obtain analytical results for the MBCR schemes, we will carry out the simulation study. We first describe the simulation model and the assumptions that we made for the analysis.

The simulated wireless network consists of 37 cells, each of which has six neighboring cells. The cells are wrapped around to eliminate the border effect, as in Figure 3. We use the following assumptions for simulation:

(1) Each cell has $C = 40$ channels.
(2) The arrivals of new calls initiating in each cell forms a Poisson process with rate λ.
(3) Each call requires only one channel for service, $B_{\text{new}} = 1$.
(4) The life time of each call is exponentially distributed with mean 240 s.
(5) The cell-dwell-time probability density function $f_h(t)$ and $f_l(t)$ are exponential distributions with mean value 120 s and 600 s, respectively.

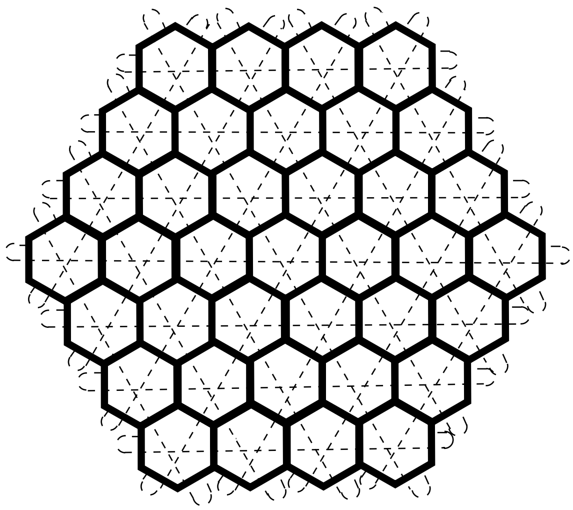

Fig. 3. The wrap-around simulation model.

(6) The new call requests are generated by either high-speed mobiles or by low-speed mobiles with probability P_{high} or $1 - P_{\text{high}}$, respectively.
(7) A cell will report the target reservation to all its neighboring cells every 30 s.
(8) In the fixed reservation scheme for comparative purpose, the number of the reserved channel is always 1.

Once a new call is admitted into the network, the life time of this call is selected according to its distribution, the value will keep fixed until the call is completed. When a new call or a handoff call enters a cell, the cell dwell time is also chosen according to its speed class. Of course, the base station does not use the information in the decision-making process, because in the real network, this is unknown to the base station. For a new call, if the cell dwell time is greater than its life time, this call will complete in the current cell; otherwise, this call must handoff to another cell. Before the handoff request is sent, a target cell is selected according to the directional factor, the residual life time is calculated by subtracting the cell dwell time in the current cell from the life time. For an successful handoff call, the residual life time and the cell dwell time in one new cell is compared and the above procedure is repeated. For MBCR schemes, $R_{i,j}$ is calculated according to Equation (6). After a base station receives all the reports from its neighbors, it adds up all the requested reservation values $R_{i,j}$ and carries out call admission control.

4.3. Simulation Results

4.3.1. Scheme A and B

We first investigate the performance of the MBCR schemes. Figure 4(a) plots the time average of the number of ongoing calls as a function of the new

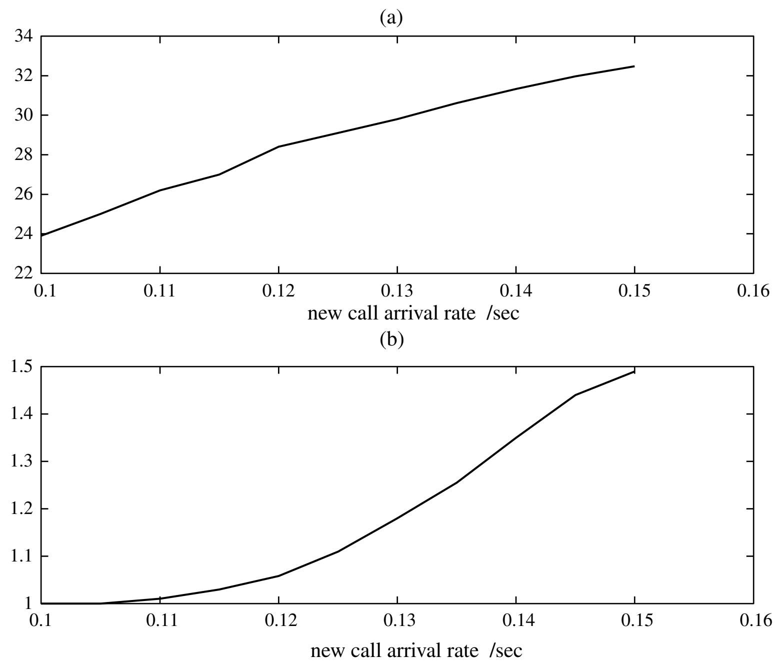

Fig. 4. The average number of (a) ongoing calls and (b) target reservation: $P_{\text{high}} = 0.2$.

call arrival rate. We can observe that as the new call arrival rate increases, there will be more ongoing calls in a cell, which implies that a cell will exert more influence on its neighboring cells, more channels should be reserved accordingly. Figure 4(b) shows the time average of the number of the target reservation channels for Integral MBCR. As we expected that the target reservation increases monotonically as the new call arrival rate increases.

Figure 5 and 6 show the handoff call blocking probabilities and the new call blocking probabilities of the two Mobility-based Channel Reservation (MBCR) schemes (Integral MBCR and Fractional MBCR); we compare them with the fixed reservation

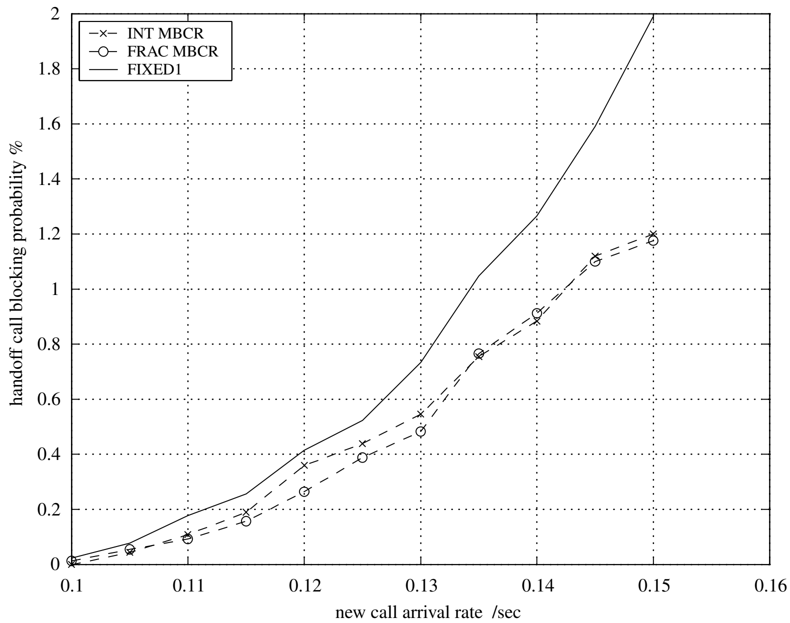

Fig. 5. The handoff call blocking probability: $P_{\text{high}} = 0.2$.

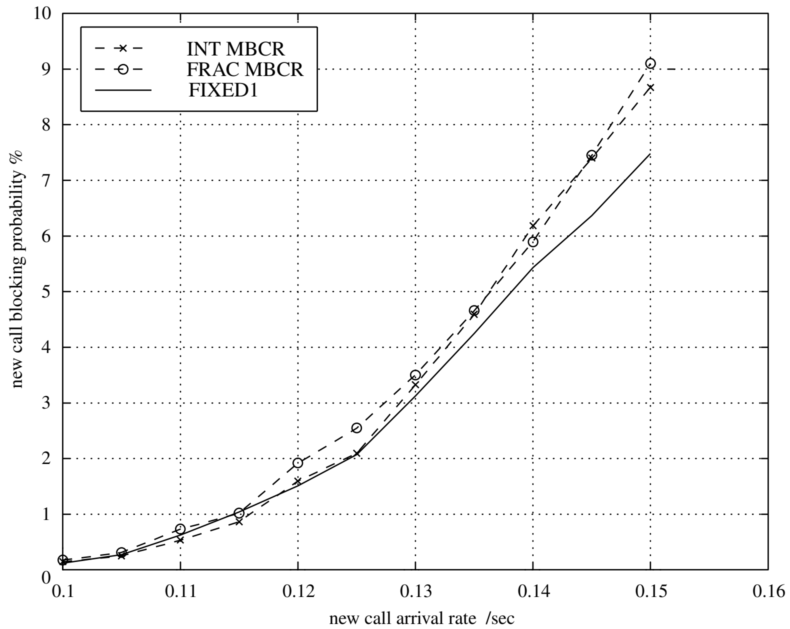

Fig. 6. The new call blocking probability: $P_{\text{high}} = 0.2$.

scheme. First, we compare the performance of the two MBCR schemes. We observe that for the given traffic composition (20 per cent of the arriving new calls are high-speed ones), when the new arrival rate is between 0.1 and 0.13, the handoff call blocking probability of the Fractional MBCR is less than that of the Integral MBCR, while the new call blocking probability of the former is higher. Recall that in the Integral MBCR, we round the calculated reservation value R_j to the integral number of channels. Figure 8 gives the average reservation values. We can find that when 20 per cent of the new call traffic is high speed with the new call arrival rate between 0.1 and 0.135, the average reservation is much less than 1.5, which means that for most of the calculated reservation values R_j, the rounding action gives $\lfloor R_j \rfloor$, the fractional part is actually thrown away. This makes the actual reservation less than required, so in this scenario, the P_{hb} of Integral MBCR is higher, while the Fractional MBCR can use the information exactly.

Despite the minor difference between the two MBCR schemes, when we compare them with the fixed reservation scheme, we obtain similar results. We observe that the handoff call blocking probabilities of MBCRs are much lower than that of the fixed reservation scheme.

Figure 6 shows that the new call blocking probability is higher for MBCR schemes comparing to the fixed reservation scheme, as we expected. This is the tradeoff between new call blocking probability and handoff call blocking probability (call dropping probability) because both new calls and handoff calls share the same pool of resources. It can be viewed as the cost one has to pay when attempting to reserve more channels to accommodate more future handoff calls. We also observe that the increase in the new call blocking probability is only slight comparing to the decrease in handoff call blocking probability. This is because in the MBCR schemes, the reservation is determined by the influence curve, which can adapt to the current offered traffic load of the network.

Figure 7 plots the target reservation for Integral MBCR as a function of time. We observe that the target reservation changes from time to time. When more ongoing calls are in the neighboring cells and/or calls are more likely to handoff into the current cell in the near future, the neighboring cells exert a higher influence on the current cell, therefore a higher target reservation value (two channels) has to be used to accommodate these handoffs. In other

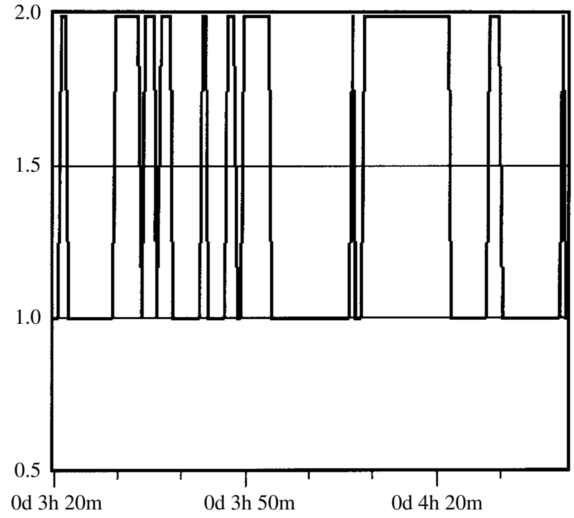

Fig. 7. Real time target reservations: $P_{\text{high}} = 0.2$, $\lambda = 0.13$.

time periods, a low reservation is enough, the target reservation is decreased (one channel), gives new calls a better chance to be accepted. This is why we can gain significantly in the handoff call blocking probability at a slight increase of new call blocking probability.

Figure 8 plots the average target reservation versus the new call arrival rate for different traffic composition: $P_{\text{high}} = 0.2, 0.3, 0.4, 0.5$. We can see from the figure that as P_{high} increases, the target reservation also increases. This is because a high-speed user spends shorter time in a cell than a low-speed user does, therefore a cell that has more active high-speed users will exert more influence on its neighbors, and more reservation is required. This, again, justifies our statement that the MBCR scheme can adapt to the change of cell traffic condition.

4.3.2. Scheme C

Figure 9 shows the performance of scheme C; the simulation result is compared with the numerical result calculated according to Equation (13). We observe that our simulation model matches the analysis model perfectly. If we change the composition of new call traffic of two speed classes, we found an interesting result as shown in Figures 10 and 11: with the decrease of percentage of high-speed users in new call traffic, the handoff call blocking probability is decreased and the new call blocking probability is increased. In order to explain this observation, we

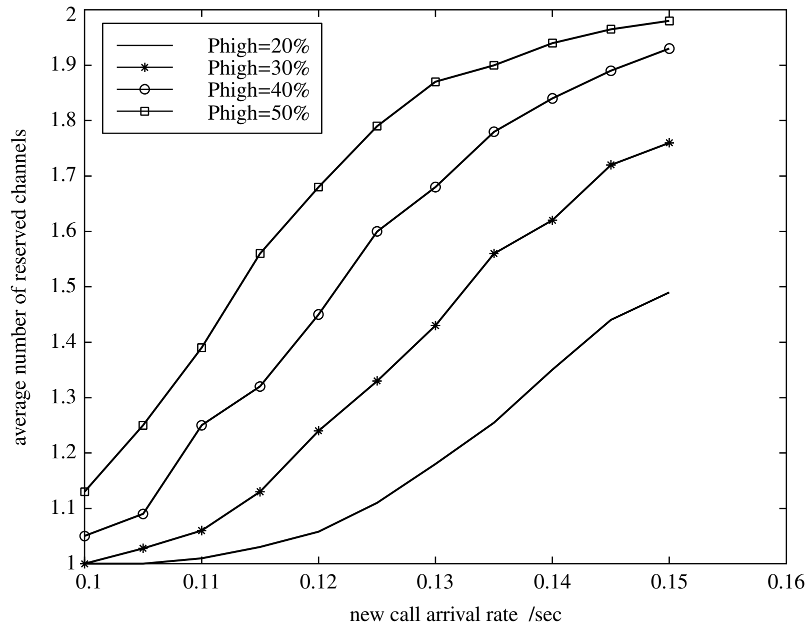

Fig. 8. Target reservations for different traffic composition.

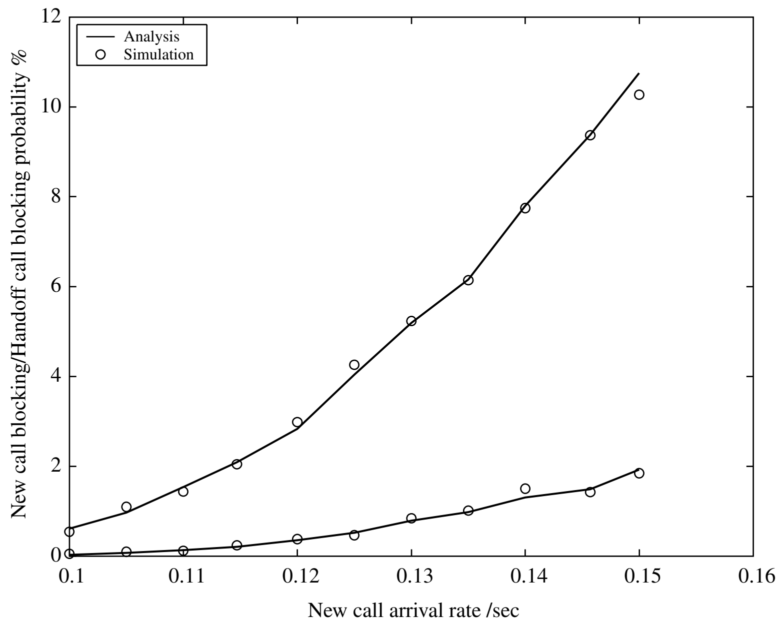

Fig. 9. Comparison of simulation results and analysis results of scheme C: $P_{\text{high}} = 0.2$.

first investigate the *channel holding time* of users. By *channel holding time*, we mean the time that a call occupies a channel in a cell [1, 19]. Simulation results are collected and listed in Table I. Tc_{new} and Tc_{handoff} are the average channel holding times of new calls and handoff calls, respectively, P_{hfhigh} is the percentage of high-speed calls in the handoff traffic. The table shows that with the decrease of percentage of high-speed users, the average channel holding time of new calls becomes longer. When a new call is admitted, it tends to occupy the channel for a longer time. Recall that the NCB scheme uses the number of accepted new users as a decision variable, thus when the channel holding time for new calls is longer, the

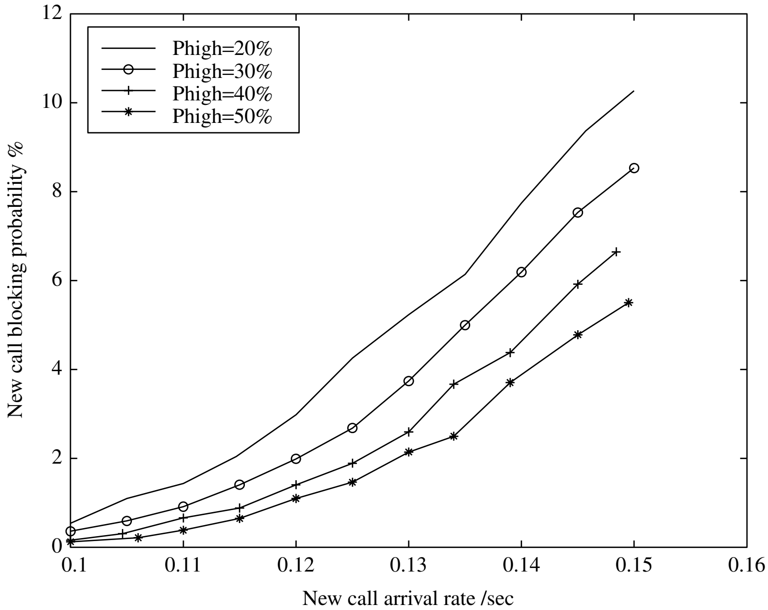

Fig. 10. New call blocking probability for scheme C with different traffic composition: $K = 25$.

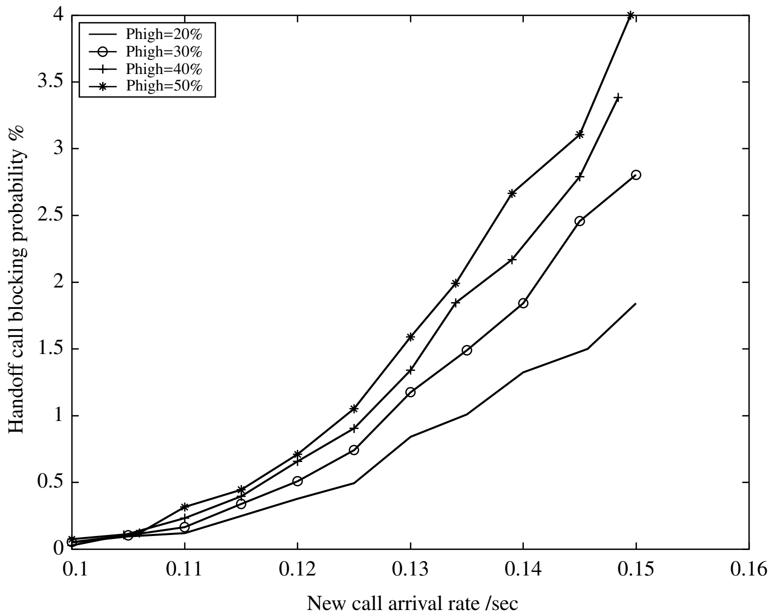

Fig. 11. Handoff call blocking probability for scheme C with different traffic composition: $K = 25$.

traffic intensity for new calls increases, which leads to the increase of new call blocking probability.

Table I also shows that the channel holding time of handoff calls is always shorter than that of new calls. The reason is that the low speed calls are more likely to finish their session in the originating cell, and the handoff traffic is dominated by high-speed calls, whose channel holding time is shorter. This is another

Table I. Channel holding time for different traffic composition.

P_{high}	Tc_{new}	$Tc_{handoff}$	P_{hfhigh}
20%	152.9 s	120.5 s	55%
30%	144.1 s	109.2 s	70%
40%	135.1 s	101.2 s	79%
50%	125.6 s	95.5 s	85%

reason we suggest the new call bound: since the average channel holding time of new calls is longer, if too many new calls are accepted in a cell (for instance the new call arrives in bursts), there will be fewer channels available in a relatively longer time, thus the cell is congested. The most straightforward way to avoid such a scenario is to limit the number of the admitted new calls.

4.3.3. Scheme D

Figures 12 and 13 show the effect of new call bounding. We observe that compared with MBCR only, the MBCR with new bound scheme (scheme D) can further decrease the handoff call blocking probability. The cost is the increase of the new call blocking probability. By integrating new call bound with MBCR,

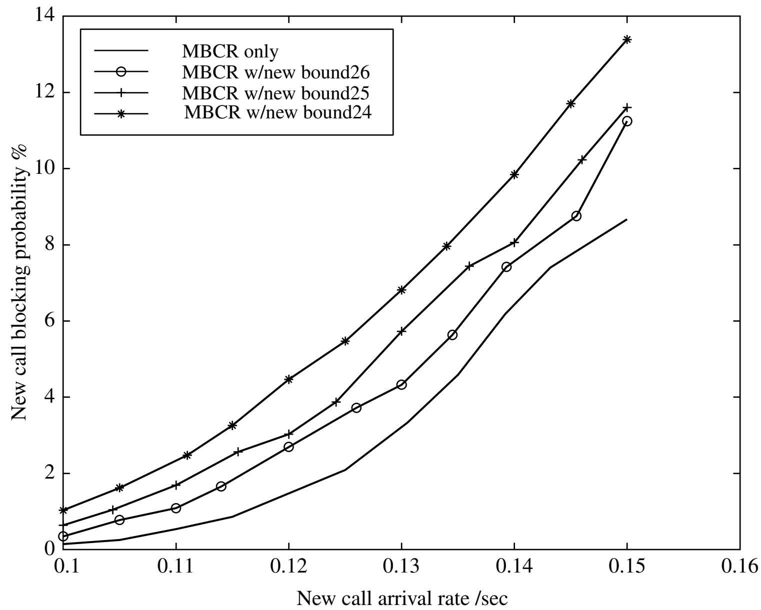

Fig. 12. New call blocking probability with new call bounding: $P_{\text{high}} = 0.2$.

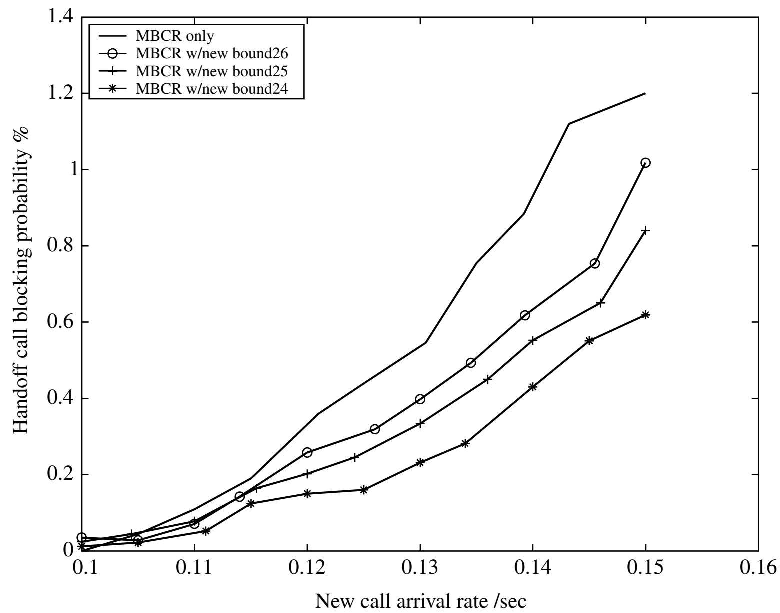

Fig. 13. Handoff call blocking probability with new call bounding: $P_{\text{high}} = 0.2$.

the admission policy for new calls becomes more strict: a new call can be admitted only when both of the requirements are met. More new calls are blocked in order to prevent the congestion. Handoff calls are given even higher priority, which means that once a call is admitted, it can obtain a better service. The lower the new bound, the stricter the limit, hence the higher the P_{nb} and the lower the P_{hb}.

5. Conclusions and Future Work

In wireless mobile networks, as the cell size becomes smaller, handoffs become more frequent. Call admission control schemes must be carefully designed to provide QoS guarantees to the mobile users. In this paper, we investigate four handoff prioritized call admission control strategies for the wireless networks with multiple platforms. The basic ideas lying behind these schemes are MBCR and NCB. Using MBCR, we can make the CAC schemes adaptive to the network traffic conditions; through NCB, we prevent the potential congestion. Analytical modeling and simulation study show that our schemes are more effective in providing better QoS for the handoff calls with slight degradation of new calls. Future work in this area includes modifying and applying our schemes to the wireless mobile networks with multiple types of integrated services such as voice, data and images.

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