A Ratioed Channel Assignment Scheme for Initial and Handoff Calls in Mobile Cellar Systems

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Abstract

In this paper, we present two schemes to improve the call completion probability of initial and handoff calls in mobile cellular systems. All the previous schemes give priority to handoff calls over initial calls to avoid the forced termination of calls in progress. We observe that giving priority to handoff calls would not yield better call completion probability in general. Moreover, the proportion of handoff to initial attempts in service will influence the call completion probability if both handoff and initial calls are queued. Our theoretical analysis and the simulation results both show that the proposed schemes are better than the NPS scheme and the FIFO scheme when the performance is measured in terms of call completion probability.

Keywords: channel assignment, mobile cellar systems, personal communication service (PCS), blocking probability.

1. Introduction

In cellular mobile communication systems, the number of channels available is limited [1,2,3]. Hence, it is very important to effectively allocate channels. Frequency reuse and channel assignment schemes were proposed to solve the problem of limited channels. In order to avoid

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interference with other channels, each channel is given a frequency, a time slot, a spreading code, or a combination of these. Let a cellular mobile communication system have 50 channels. If we do not use frequency use, we have only 50 channels in total for the system. Besides, the cellular mobile communication system may need to cover a large area. To support the mobility of an MS (also called a mobile station or a portable), the transmitters of the MS and the base station must have enough power. The requirement is not realistic, especially for the MS. In frequency reuse, the area covered by a mobile system is divided into several cells. Each cell is the radio coverage of a base station. The same channel is not assigned for adjacent channels to avoid interference. In this manner, the same channels can be reused several times to several hundred times. In general, if the area covered by each cell is smaller, the total number of channels available is increased. However, we also increase the handoff access [4,5].

For channel assignment, we can have fixed channel assignment (FCA), dynamic channel assignment (DCA), and hybrid channel assignment [6]. The purpose of the channel assignment is to increase channel utilization when both the cell size and the available channels are known in advance. For the FCA, each cell is given a group of channels. The number of channels assigned to each cell is fixed. Adjacent cells have different channels. For the DCA, the number of channels is not fixed for each cell. Channels are allocated for each cell dynamically. Adjacent cells may use the same channel at different intervals. As to the HCA, it is a combination of the FCA scheme and the DCA scheme. The paper assumes a fixed channel assignment (FCA) in which a group of channels is assigned to each cell [4,7]. Nevertheless, the results are extensible to dynamic channel assignment schemes (DCA) and hybrid channel assignment schemes (HCA) [4,7,8].

When an MS wants to begin a conversation, the MS has to request for a channel. The process is called initial access. For some personal communication service (PCS) systems, the MS uses a common signaling channel to acquire a traffic channel (DECT, or CT-2 Plus) [4]. In other PCS systems, the MS makes requests directly on traffic channels available (Bellcore WACS) [4]. For either case, if there are no channels available before the waiting time is up, the call is turned down and we have a blocked call. When an MS is in conversation, the MS is connected to a base station via a radio channel. If the MS moves to the coverage area of another base station, a new channel between the MS and the new base station is required and the original channel between the MS and the old base station is disconnected. This process is called the handoff access or automatic link transfer (ALT) [9]. If there are no channels available when the MS moves to the new coverage area, the call is disconnected and we have a forced termination.

Researchers have proposed several channel assignment schemes for initial access and handoff access [4,10,11]. Some of them are described below.

The Non-Prioritized Scheme (NPS): This scheme does not differentiate handoff access from initial access. If there are channels available for a request, one channel is assigned to the request. If there are no free channels, the request is rejected immediately and we have a forced termination or a blocked call.

The Reserved Channel Scheme (RCS): This scheme divides channels into two groups. One group can be assigned to both the initial access and the handoff access. The other group can only be assigned to the handoff access. The purpose is to reduce the probability of the forced termination.

The Queueing Priority Scheme (QPS): Because adjacent cells are overlapped, the MS in the overlapped area can use channels in either of the adjacent cells. The overlapped area is called the handoff area. When an MS is in the handoff area, if the destination cell has no free channels, the MS maintains the existing channel of the source cell. The handoff request is queued and sent to the base station of the destination cell. If a channel in the destination cell is available before the MS crosses the handoff area, the channel is assigned to the MS. Otherwise, the call is forced terminated. When there are several handoff requests in the queue, they can either be served by a First In First Out (FIFO) scheme or by a Measured-Based Priority Scheme (MBPS). The order of service in the MBPS scheme is determined by the power level that the MS receives from the new base station (the MS with the lowest signal level or the poorest quality is served first).

The Sub-Rating Scheme (SRS): When an MS is in the handoff area and the destination cell has no free channels, an occupied channel in the destination cell is divided into two sub-channels, one for the original call and one for the handoff call. These two sub-channels will become two channels again when there are channels available.

The Genetic Algorithms Scheme (GAS): Based on Genetic algorithms, the scheme assigns the channels by local state-based call admission policies. The time needed to assign channels for the GAS scheme could be a problem although the GAS scheme is good for many topologies.

It is generally believed that the forced terminations are less desirable than blocked calls. All the previous schemes give priority to handoff calls by queueing handoff calls or by reserving some channels for handoff calls or by subrating existing calls for handoff calls. The purpose of those schemes is to increase the call completion probability. However, we observe that giving priority to handoff calls over initial calls would not yield better call completion probabilities in general. Thus, in this paper we place both handoff calls and initial calls in the queues if all channels are busy, and the next free channel is assigned to a handoff call or initial call based on an pre-defined threshold value which determines the best proportion of handoff to initial calls in service. The theoretical analysis and the simulation results both show that our proposed schemes are better than the NPS scheme and the FIFO scheme in terms of call completion probability. The remainder of the paper is organized as follows. In the next section, we shall derive a criterion which determines the best ratio of handoff to initial attempts to achieve a better call completion probability. Analytic models for the proposed schemes are described in Section 3. The analytic and simulation results comparing the performance of NPS and FIFO schemes are presented in Section 4. Conclusions are given in Section 5.

2. Probabilities and Performance criteria

For cellular mobile systems, many researchers have proposed mathematical models to describe and analyze them [4,6,8,12,13,14]. In this paper, we use the analytical model proposed by Lin, Mohan, and Noerpel [4,6] as a basis to derive the best ratio of handoff to initial calls in service. Some performance criteria described in [4,6] are summarized below to clarify subsequent discussion.

2.1 Basic assumptions

- The incoming calls to an MS are a Poisson process.
- t_c is the time duration between the beginning of a call and the completion of a call, the call holding time. It is assumed to be exponentially distributed with a density function $f_c(t_c)$ and an average value $1/\mu$ (i.e., $f_c(t_c) = ue^{-ut_c}$ and $E[t_c] = 1/u$).

- $t_{m,i}$ is the time duration that an MS stays in a cell i, the residence time of an MS at i-th cell. It is assumed to be independent and identically distributed random variables with a density function $f_m(t_{m,i})$ and an average value $1/\eta$ (i.e., $E[t_{m,i}] = 1/\eta$). The relations among t_c and $t_{m,i}$'s are shown in Figure 1.
- The degradation interval of a handoff call is exponentially distributed with mean $1/\gamma$.

2.2 Notation and performance criteria given in [4,6]

- The probability of a K-handoff call is

$\Pr[K = k] = [\eta/\mu][1 - f^*_m(\mu)]^2[f^*_m(\mu)]^{k-1}$, (1)

where $f^*_m(\mu) = \int_{\mu=0}^{\infty} f_m(t) e^{-\mu t} dt$

$$= \int_{\mu=0}^{\infty} \eta e^{-\eta t} e^{-\mu t} dt = \frac{\eta}{\mu + \eta}$$

- The density function of channel occupancy time distribution is $(\mu + \eta) \cdot e^{-(\mu+\eta)\cdot t}$. Accordingly, the mean channel occupation time of a handoff or initial call is:

$E[t_{dh}] = E[t_{do}] = 1 / (\mu + \eta)$, (2)

where t_{dh} denotes the channel occupation time of a handoff call, and t_{do} represents the channel occupation time of a new call.

- The maximum queueing time of a handoff call has the density function $(\gamma + \eta) \cdot e^{-(\gamma+\eta)\cdot t}$, (3)
- The handoff call arrival rate is:

$\lambda_h = [\eta(1 - P_o)/(\mu + \eta P_f)]\ \lambda_0$,, (4)

where λ_o denotes the new call arrival rate to a cell, P_o is the new call blocking probability, and P_f is the forced termination probability.

- The probability that a call is completed (neither blocked nor force-terminated), P_c, is defined as follows.

P_c = (the probability that a channel is available for initial access) * (the probability that every handoff access is successful during the call holding time)

$$= (1 - P_o) \sum_{k=0}^{\infty} (1 - P_f)^k \Pr(K = k)$$

$= (1 - P_o)/(1 + \eta P_f / \mu)$, (5)

- The probability that a call is not completed (either blocked or force-terminated) is:

$P_{nc} = 1 - P_c = 1 - (1 - P_o)/(1 + \eta P_f/\mu)$, (6).

2.3 The criterion determining the proportion of handoff to initial attempts

To facilitate the subsequent development of the threshold which determines the best ratio of handoff to initial attempts in service, an alternative definition of call completion probability $P_c^{'}$ is given as follows.

$P_c^{'} = P$ (initial access channel assignment) $*P$ (handoff channel assignment)$^{E[k]}$

$= (1 - P_o)(1 - P_f)^{E[k]}$, (7)

where k is the number of handoffs during the call holding time and E[k] is the expected number of handoffs during the call holding time.

From Equation (1), the expectation value of k can be expressed as follows:

$$E[k] = \sum_{i=0}^{\infty}\left(\Pr[k=i]\right)\cdot i = \eta^2/[\mu(\mu+\eta)], \quad (8)$$

Let the service rate for handling the initial calls be y, and the service rate for handling handoff calls be x, where $x \le y$, and y is a system parameter. Hence, the service rate for the handling the initial calls is $y - x$. We would like to know the best ratio to have the optimal value for the alternative call completion probability P_c' defined above. Assume the cost for handling these two kinds of calls is identical in a base station, we have the following equations based on the result given in Equation (4):

$P_o = 1 - [(y - x)/\lambda_o]$, $(y - x) < \lambda_o$ (if $(y - x) \geq \lambda_o$, then $P_o = 0$)

$P_f = 1 - (x/\lambda_h) = [\eta(y - x) - x\mu]/[\eta(y - x) + x\eta]$, $x < \lambda_h$ (if $x \geq \lambda_h$, then $P_f = 0$), (9)

Let E[k] = w, then $P_c' = (1 - P_o)(1 - P_f)^{E[k]} = [(\mu + \eta)^w x^w (y - x)] / [(\eta y)^w \lambda_o]$, (10)

Since λ_o, μ, η, y, and w are constants, P_c' has the extreme value when $x^w(y - x)$ has the extreme value. Thus we differentiate $x^w(y - x)$ and get the value of x as follows:

$dx^w(y - x)/dx = wx^{w-1}(y - x) + x^w(-1) = 0$

$x = (w/(w + 1))y$, (11)

If we differentiate $x^w(y - x)$ twice, we have the following equation.

$d[wx^{w-1}(y - x) + x^w(-1)]/dx = \{w[wy/(w + 1)]^{w-2}\}(-y) < 0$, (12)

Hence, when the proportion of the handoff and the initial calls is $w : 1$ ($x = (w/(w + 1))\,y$), both $x^w(y - x)$ and P_c' has the maximum value. Assume we have a FCA scheme and there are C channels in each cell. From Equation (2), we know the service rate is $(\mu+\eta)$ per channel. Thus, y and P_c' can be calculated as follows:

$y = C\cdot(\mu + \eta)$

$P_c' = [(\mu + \eta)/(w + 1)]^{w+1}\,[w/\eta]^w\,(C/\lambda_o)$, (13)

To obtain the optimal value of the call completion probability, we need to adjust the parameters to minimize the difference between P_c and P_c'. For simplicity of derivation, we assume that the expected number of handoff calls, w, is a natural number. Hence the upper bound for P_c can be derived as follows:

$$P_c = (1 - P_o)\sum_{k=0}^{\infty}(1 - P_f)^k \Pr(K = k)$$

$\leq (1 - P_o)\Pr(K = 0) + (1 - P_o)(1 - P_f)\Pr(K = 1) + (1 - P_o)(1 - P_f)^2\Pr(K = 2) + \ldots + (1 - P_0)(1 - P_f)^w \cdot (1 - \Pr(K = 0) - \Pr(K = 1) - \ldots - \Pr(K = w - 1))$.

The upper bound for the difference between P_c and

$P_c{'}$ becomes:

$P_c - P_c{'} \leq (1 - P_o)\Pr(K = 0) + (1 - P_o)(1 - P_f)$
$\Pr(K = 1) + (1 - P_o)(1 - P_f)^2\Pr(K = 2) + \ldots +$
$(1 - P_o)(1 - P_f)^{w-1}\Pr(K = w - 1) + (1 - P_o).$
$(1 - P_f)^w(\Pr(K = 0) + \Pr(K = 1) + \ldots +$
$\Pr(K = w - 1)) \leq (1 - P_o)(1 - (1 - P_f)^{w}),$ (14)

In reality, the value of w is very close to 0 in most cases. For example, when the mean call holding time is 3 minutes and the mean portable residence time is 30 minutes, the value of w is 1/110. Hence, $(1 - P_o)(1 - (1 - P_f)^{w})$ is very close to 0, which means that both handoff calls and initial calls needs to be queued and the next free channel should be assign to either of the two kinds according to the ratio, w, to achieve better call completion probability.

3. Analytic models

3.1. A modified FIFO scheme

In the preceding section we infer that both the initial calls and handoff calls need to be queued to obtain a better call completion probability. Thus we shall investigate if the call completion probability is increased by queueing both handoff calls and initial calls in the same queue, and serving the requests in a first in first out order. For simplicity we assume each initial call has an average time-out identical to the maximum queueing time of a handoff call whose mean is $1 / (\gamma + \eta)$ as shown in Equation (3).

Based on the above assumption, a modified FIFO scheme (MFIFO) is shown in Figure 2, and the state diagram of this scheme is given in Figure 3. We say that the process is in state i, where $0 \leq i$, if there are i initial calls and handoff calls in the queue and represent state i as $S(i)$. When the process is in $S(i)$ (for $0 \leq i$), the process moves from $S(i)$ to $S(i+1)$ with the rate $\lambda_o + \lambda_h$ since the arrival rate of channel requests for a cell is the sum of the new call arrival rate and the handoff call arrival rate. The process moves from $S(i)$ to $S(i-1)$ with the rate $i\cdot(\mu+\eta)$ when $i \leq C$, whereas the process moves from $S(C+i)$ to $S(C+i-1)$ with the rate $C\cdot(\mu+\eta)+i\cdot(\gamma + \eta)$ since the number of requests in a cell is reduced when a busy channel is released or handoff (initial) calls in the queue expires or leaves the current cell.

Now consider a handoff (initial) attempt arriving at the cell in state $S(C+i)$ at time t, and one of the $C+i$ outstanding calls either completes, expires, or leaves the cell at the time $t + t_{C+i}$ after the handoff (initial) call arrives. The density function for t_{C+i} can be expressed as follows:

$$f_{C+i}(t_{C+i}) = \left[C(\mu+\eta)+i(\gamma+\eta)\right]e^{-[C(\mu+\eta)+i(\gamma+\eta)]t_{C+i}} \text{ , (15)}$$

For the remaining $C+i-1$ calls that arrive at the cell before handoff (initial) call, assume the first call either completes, expires, or leaves the cell during the interval t_{C+i-1}, then the density function for t_{C+i-1} is $f_{C+i-1}(t_{C+i-1})$ due to the memoryless property of the channel occupancy distribution and the maximum queueing time distribution. Since the handoff call is blocked when it expires or leaves the current cell before the process moves form $S(C+i)$ to $S(C-1)$, hence the blocking probability for a handoff (initial) call arriving at the cell in state $S(C+i)$ is

$$\Pr\left[t < t_C + \Lambda\ t_{C+i} \mid S(C+i)\right] = \int_{t_C=0}^{\infty}\Lambda \int_{t_{C+i}=0}^{\infty}\int_{t=0}^{t_C+\Lambda+t_{C+i}}\left[\prod_{k=0}^{i} f_{C+k}\left(t_{C+k}\right)\right] \cdot(\gamma+\eta)e^{-(\gamma+\eta)t}\,dt\,dt_C\,\Lambda\ dt_{C+i} = \frac{(i+1)(\gamma+\eta)}{C(\mu+\eta)+(i+1)(\gamma+\eta)} \text{ , (16)}$$

and the forced termination probability of the handoff call P_f, or the blocking probability of the new call P_o is

$$P_f = P_o = \sum_{i=0}^{\infty}\Pr\left[t < t_C + \Lambda\ t_{C+i} \mid S(C+i)\right]\pi_{C+i} = \frac{(i+1)(\gamma+\eta)\pi_{C+i}}{C(\mu+\eta)+(i+1)(\gamma+\eta)} \text{ , (17)}$$

where π_{C+i} denotes the steady state probability of staying in state $S(C+i)$ which can be expressed as

$$\pi_k = \begin{cases} \dfrac{(\lambda_o+\lambda_h)^k}{k!(\mu+\eta)^k}\pi_0, & k \le C \\ \dfrac{(\lambda_o+\lambda_h)^k}{C!(\mu+\eta)^C \prod_{i=1}^{k-C}\left[C(\mu+\eta)+i(\gamma+\eta)\right]}\pi_0, & k > C \end{cases}$$

and $\pi_0 =$

$$\left[1+\sum_{k=1}^{C}\frac{(\lambda_o+\lambda_h)^k}{k!(\mu+\eta)^k} + \sum_{k=C+1}^{\infty}\frac{(\lambda_o+\lambda_h)^k}{C!(\mu+\eta)^C\prod_{i=1}^{k-C}\left[C(\mu+\eta)+i(\gamma+\eta)\right]}\right]^{-1} \text{ , (18)}$$

Accordingly, the call completion probability P_c can be computed based on the results given in Equations (5) and (17).

3.2. The ratioed channel assignment scheme

The ratioed channel assignment scheme (RCAS) utilizes the facts that the call completion probability can be raised when the ratio of handoff to initial calls in conversations is adjusted to a pre-determined value. We use two queues to accommodate handoff (initial) calls waiting for the service, one for initial calls and the other for handoff calls, for easy interpretation. Both queues are served in a FIFO order and each queue is assumed to be infinite so each call is queued until the call is served or the call is dequeued because its time is up or it leaves the current cell. For simplicity we assume the maximum queueing time distribution of handoff and initial calls is identical.

To maintain the best ratio of initial to handoff calls, the Statistical TDM (all know as asynchronous TDM and intelligent TDM) [15] is used to control the service rates of the initial calls and handoff calls. If the service rate of the initial (handoff) calls is lower than expected, as long as there are initial (handoff) calls, they are served first. However, if there are only handoff (initial) calls, those handoff calls (initial calls) are still served. The mechanism of the RCAS scheme is shown in Figure 4.

The Markov chain model for the RCAS scheme is described in the sixteen cases illustrated in Figures 5 ~ 8 Due to the complexity of the system model, distinct representations are employed to denote the states of the Markov chain. Before all the free channels are used up, no handoff (initial) calls are buffered in the queues, so $S(i, j)$ is used to represent that there are i channels allocated for handoff calls, and j for initial calls as shown in Figure 5. The triple $S(i, m, n)$ denotes the states of the Markov chain in which there are i handoff calls in conversations, and m handoff calls and n initial calls waiting in the queues. Note that C is the number of channels available in a cell. If all channels are busy, we add initial request to initial queue and handoff request to handoff queue. When a channel is released, we assign the channel to one request in the handoff (initial) queue by a FIFO order if there are only requests in the handoff (initial) queue. If there are requests in both queues, we count the proportion of both calls in allocated channels and assign the released channel to either a request in the initial queue or a request in the handoff queue to make the proportion close to the threshold value w. Figure 6 shows the state transition diagram for the states where the ratio of handoff to initial calls is smaller than or equal to w, whereas the state transition diagram for the states where the ratio is greater than w is illustrated in Fig. 7. Figure 8 is the state transition diagram for the states when i, m, or n is equal to 0. From these state diagrams, we can write down and solve the balance equations for the steady-state probability for each state correspondingly and obtain the steady-state probability for each state. Because the process of calculating the probabilities is tedious, it will be not included in this paper.

A given handoff attempt which joins the queue in state $S(i, m, n)$ will be successful if all the m handoff calls in front of it and parts of n initial calls leave the queues. Let n' denote the number of the initial attempts leaving the queue, where $0 \leq n' \leq n$. Then we have $\frac{i+m(1-P_f)}{(C-i)+n'(1-P_o)} = w$ since the ratio of handoff to initial attempts should be kept at w:1 to increase the call completion probability. Note that $m(1-P_f)$ and $n'(1-P_o)$ represent the expected number of handoff and initial attempts in conversations before the arriving handoff call gets a channel. After rearranging the above equation and bounding n' between 0 and n, we get

$$n' = \min\left(\max\left(0, \frac{i + m(1-P_f) - w(C-i)}{w(1-P_o)} \right), n \right), \quad (19)$$

After obtaining the steady-state probabilities and the number of the initial attempts leaving the queue, we also need to know the density function when the process in S(i, m, n), where $i \geq 0$, $m \geq 0$, and $n \geq 0$. If a handoff (initial) attempt arrives at the cell in state $S(i, m, n)$ at time t, suppose the first call among the $C+m+n'$ outstanding calls in state $S(i, m, n)$, leaves the queue at the time $t+t_{C+m+n'}$ after the handoff call joins the queue. Recall that the $C+m+n'$ calls include C calls in conversations, m handoffs before the arriving call, and the first n' new calls in the initial queue. The density function for $t_{C+m+n'}$ is

$$f_{C+m+n'}(t_{C+m+n'}) = \left[C(\mu+\eta) + (m+n')(\gamma+\eta) \right] \cdot e^{-\left[C(\mu+\eta)+(m+n')(\gamma+\eta) \right] t_{C+m+n'}}, \quad (20)$$

Following the approach used in the preceding subsection, the blocking probability for a handoff call arriving at the cell in state $S(i, m, n)$ is

$$\Pr\left[t < t_C + \Lambda\ t_{C+m+n'} \mid S(i,m,n) \right] =$$

$$\int_{t_C=0}^{\infty} \Lambda \int_{t_{C+m+n'}=0}^{\infty} \int_{t=0}^{t_C+\Lambda\ t_{C+m+n'}} \left[\prod_{k=0}^{m+n'} f_{C+k}\left(t_{C+k} \right) \right] \cdot (\gamma+\eta) e^{-(\gamma+\eta)t}\, dt dt_C\, \Lambda\ dt_{C+m+n'}$$

$$= \frac{(m+n'+1)(\gamma+\eta)}{C(\mu+\eta) + (m+n'+1)(\gamma+\eta)}, \quad (21)$$

and the forced termination probability of the handoff call P_f, is

$$P_f = \sum_{i=0}^{C} \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} \Pr\left[t < t_C + \Lambda\ t_{C+m+n'} \mid S(i,m,n) \right] \pi_{i,m,n}\ .$$

$$= \sum_{i=0}^{C} \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} \frac{(m+n'+1)(\gamma+\eta)\pi_{i,m,n}}{C(\mu+\eta) + (m+n'+1)(\gamma+\eta)}, \quad (22)$$

Next we derive the blocking probability of a new call. If m' denotes the number of handoff attempts leaving the queue after a new call arrives in state $S(i, m, n)$, then $\frac{i + m'(1-P_f)}{(C-i) + n(1-P_o)} = w$, and after rearrangement, we get

$$m' = \min\left(\max\left(0, \frac{w[C - i + n(1-P_o)] - i}{1-P_f} \right), m \right), \quad (23)$$

If a handoff (initial) attempt arrives at the cell in state $S(i, m, n)$ at time t, suppose the first call among the $C+m'+n$ outstanding calls in state $S(i, m, n)$, leaves the queue at the time $t+t_{C+m'+n}$ after the initial call joins the queue. Then the density function for $t_{C+m'+n}$ is

$$f_{C+m'+n}(t_{C+m'+n}) = \left[C(\mu+\eta)+(m'+n)(\gamma+\eta)\right] \cdot e^{-[C(\mu+\eta)+(m'+n)(\gamma+\eta)]t_{C+m'+n}}, \quad (24)$$

Consequently, the blocking probability for an initial call arriving at the cell in state $S(i, m, n)$ is

$$\Pr\left[t < t_C + \Lambda\ t_{C+m'+n} \mid S(i,m,n)\right] = \int_{t_C=0}^{\infty} \Lambda \int_{t_{C+m'+n}=0}^{\infty} \int_{t=0}^{t_C+\Lambda\ t_{C+m'+n}} \left[\prod_{k=0}^{m'+n} f_{C+k}\left(t_{C+k}\right)\right] \cdot \left(\gamma+\eta\right)e^{-(\gamma+\eta)t}\, dt\,dt_C\ \Lambda\ dt_{C+m'+n}$$
$$= \frac{(m'+n+1)(\gamma+\eta)}{C(\mu+\eta)+(m'+n+1)(\gamma+\eta)}, \quad (25)$$

and the new call blocking probability P_o, is

$$P_o = \sum_{i=0}^{C}\sum_{m=0}^{\infty}\sum_{n=0}^{\infty} \Pr\left[t < t_C + \Lambda\ t_{C+m'+n} \mid S(i,m,n)\right]\pi_{i,m,n},$$
$$= \sum_{i=0}^{C}\sum_{m=0}^{\infty}\sum_{n=0}^{\infty} \frac{(m'+n+1)(\gamma+\eta)\pi_{i,m,n}}{C(\mu+\eta)+(m'+n+1)(\gamma+\eta)}, \quad (26)$$

4. Performance evaluation

We first apply standard numerical Markov chain techniques to compute the performance measures, which are forced termination probability of handoff calls P_f, new call blocking probability P_o, and call incompletion probability P_{nc}.

Recall that Equations (3), (4), (6), (8), (15)–(18) form a set of simultaneous nonlinear equations for the primitive MFIFO scheme which can be solved numerically using the method of successive substitution when the quantities λ_0, C, μ, η, and γ are given. The following algorithm illustrates how the performance measures are obtained.

4.1 The iterative algorithm for computing performance measures

Step 1: Set initial values for P_o, and P_f and λ_h by using Equations (4), (9), and (11).

Step 2: Compute the steady-state probability π_i for each state according to Equation (18).

Step 3: Obtain P_f and P_o based on Equation (17).

Step 4: $\lambda_{h,old} \leftarrow \lambda_h$, and compute λ_h by using Equation (4).

Step 5: If $\left|\lambda_h - \lambda_{h.old}\right| > 0.00001 \cdot \lambda_h$, then go to Step 2. Otherwise, λ_h converges and proceed to next step.

Step 6: Compute P_{nc} by using Equation (6).

For the proposed RCAS scheme, we can take similar approach to obtain P_o, P_f and P_{nc} except that Equations (19)–(26) along with the balance equations for the steady-state probability corresponding to Figures 5–8 are used instead.

Several performance measures calculated by the above algorithm are plotted in Figure 9 for the NPS, FIFO, MFIFO, and RCAS schemes, respectively. The parameters are given as follows. The mean residence time $1/\eta$ is assumed to be exponentially distributed with an average value of

30 minutes. The mean call holding time $1/\mu$ is exponentially distributed with an average value of 3 minutes. The mean degradation interval of the handoff calls and the value of time-out for initial calls $1/\gamma$ is assumed to be exponentially distributed with an average value of 18 seconds. The new call arrival rates are assumed to be exponentially distributed with average values varied from 40 Erlangs to 80 Erlangs, and the number of available channels in a cell, C, is 50.

Apparently the performances of the MFIFO and the RCAS schemes are better than the NPS scheme and the FIFO scheme in terms of call incompletion probability and new call blocking probability. However, we still pay the price of raising forced termination probability of handoff calls after we allow the initial calls to join the queue because the new call arrival rates are much larger than the handoff arrival rates in general.

4.2. Simulation results

A series of simulations are conducted to simulate the MFIFO scheme, RCAS scheme, FIFO scheme, and the NPS scheme in order to verify the correctness of our theoretical analysis. The parameters C, μ, η, and γ are the same as those used in preceding subsection, and the new call arrival rates are also exponentially distributed with average values varied from 40 Erlangs to 80 Erlangs. Figure 10 shows the incompletion probability for the four schemes after the simulation terminates. The simulation results confirm that the RCAS and the MFIFO schemes are better than the NPS and FIFO schemes if the objective is to improve perceived quality of cellular service by minimizing the call incompletion probability.

5. Conclusion

In this paper the MFIFO and the RCAS schemes are proposed to improve the call completion rates. The call incompletion probabilities, the new call blocking probabilities, and the forced termination probabilities of two proposed schemes are derived. The theoretical analysis and simulation results both show that our proposed schemes are better then the NPS scheme and the FIFO scheme when the call incompletion probability is compared. Several observations inferred from our theoretical analysis are in order:

(1) The handoff calls and the initial calls should be queued. The general belief that if we give priority to the handoff calls and reduce the probability of forced termination, we would have a better performance is not true in general. Hence, our schemes queue both the

handoff calls and the initial calls, which is different from previous schemes.

(2) The proportion of the handoff calls and the initial calls will influence the call completion probabilities in general. This is the reason why the call incompletion probability for the RCAS scheme is even lower than the MFIFO scheme as shown in Figures 9 and 10.

References

[1] Cox, D. C., Wireless Personal Communications: What is it ?, IEEE Personal Communication (April 1995) 20-35,.

[2] Raith, K. and Uddenfeldt, J., Capacity of Digital Cellular TDMA Systems, IEEE Transactions on Vehicular Technology 40 (2) (1991).

[3] Black, U., Mobile and Wireless Networks, (Prentice Hall PTR, Upper Saddle River, N. J., 1996).

[4] Lin, Y.-B., Mohan, S., and Noerpel A., Queueing Priority Channel Assignment Strategies for PCS Hand-Off and Initial Access, IEEE Transactions on Vehicular Technology 43 (3) (1994) 704-712.

[5] Chu, T.-P., and Rappaport, S. S., Generalized Fixed Channel Assignment in Microcellular Communication Systems, IEEE Transactions on Vehicular Technology 43 (3) (1994).

[6] Lin, Y.-B., Introduction to Mobile Network Management (National Chiao Tung University, Series in Telecommunications, 1997).

[7] Katzela, I., and Naghshineh, M., Channel Assignment Scheme for Cellular Mobile Telecommunication System: A Comprehensive, IEEE Personal Communications (June 1996) 10-31.

[8] Hong, D., and Rappaport S. S., Traffic Model and Performance Analysis for Cellular Mobile Radio Telephone System with Prioritized and Non-protection Handoff Procedure, IEEE Transactions on Vehicular Technology 35 (3) (1986) 77-92.

[9] Noerpel, A., and Lin, Y.-B., Handover Management for a PCS Network, IEEE Personal Communications (December 1997) 18-24.

[10] Yener, A., and Rose, C., Genetic Algorithm Applied to Cellular Call Admission: Local Policies, IEEE Transactions on Vehicular Technology 46 (1) (February 1997).

[11] Lin, Y.-B., Mohan, S., and Noerpel, A., PCS Channel Assignment Strategies for Hand-off and Initial Access, IEEE Personal Communications, (Third Quarter 1994) 47-55.

[12] Yue, W., Analytical Methods to Calculate the Performance of a Cellular Mobile Radio Communication System with Hybrid Channel Assignment, IEEE Transactions on Vehicular Technology, 40 (2) (MAY 1991).

[13] Lin, Y.-B., and Chlamtac, I., A Model with Generalized Holding and Cell Residence Times for Evaluating Handoff Rates Channel Occupancy Times, http://liny.csie.nctu.edu.tw.

[14] Fang, Y., Chlamtac, I., and Lin, Y.-B., Call Performance for a PCS Networking, http://liny.csie.nctu.edu.tw.

[15] Stallings W., Data and Computer Communications, 4th ed., (Macmillan Pub. Co., New York, 1994).

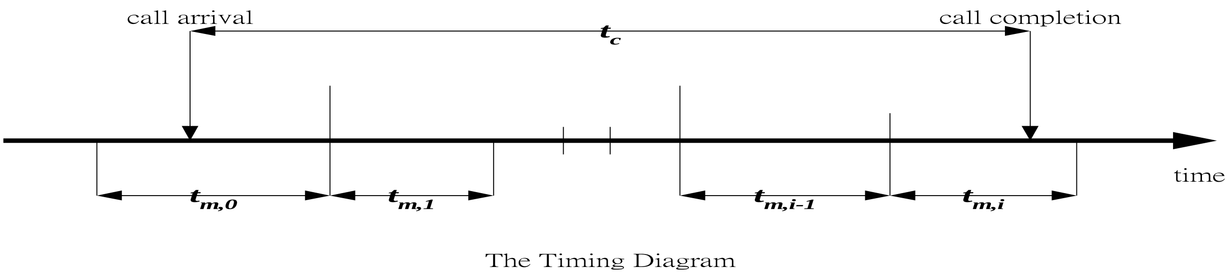


Figure 1. The timing relationship among t_c and $t_{m,i}$'s.

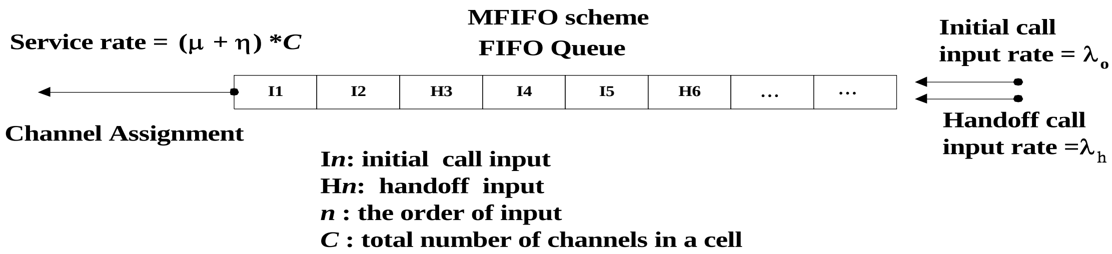


Figure 2. A single queue for the MFIFO scheme.

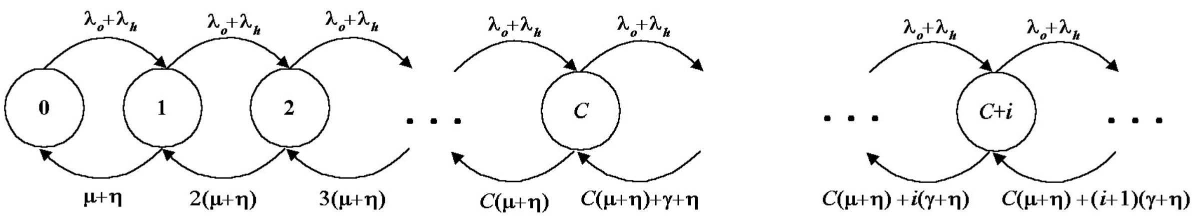


Figure 3. The state transition diagram for the MFIFO scheme.

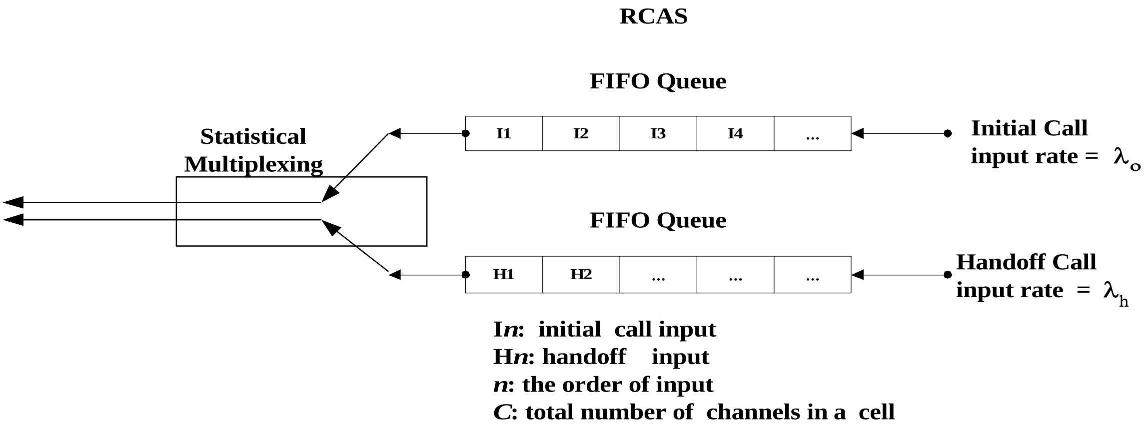


Figure 4. Dual queues for the RCAS.

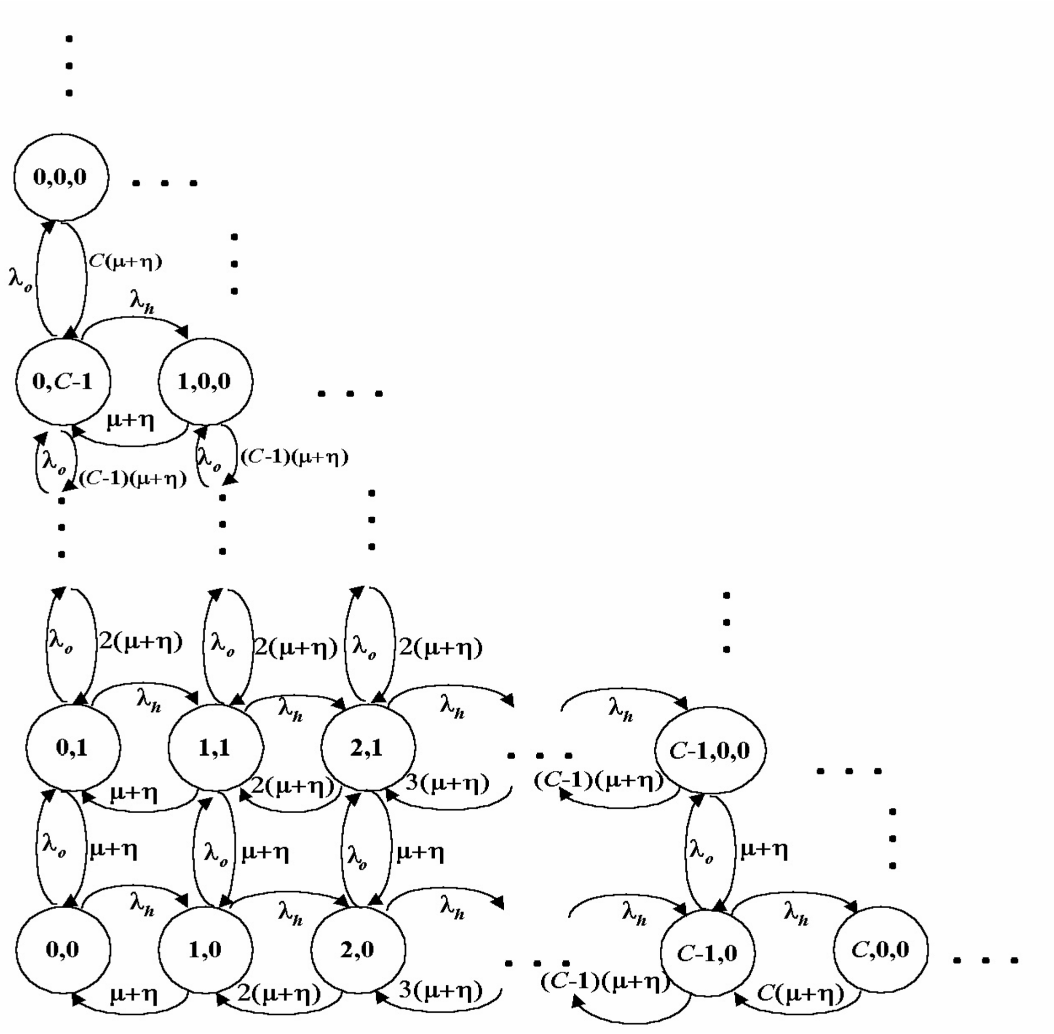


Figure 5. The state transition diagram for the states with free channels.

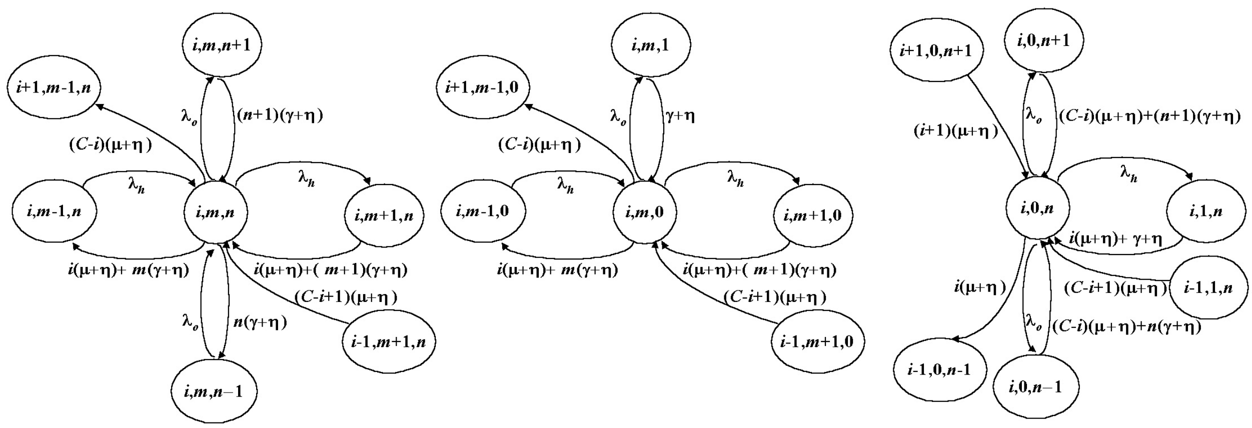


Figure 6. The state transition diagram for the states where $i : (C - i) \leq w$.

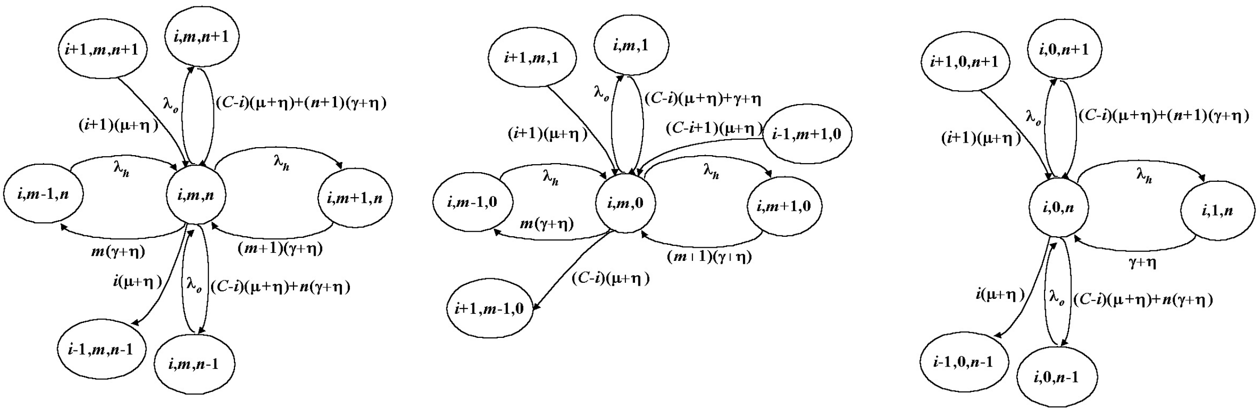


Figure 7. The state transition diagram for the states when $i : (C - i) > w$.

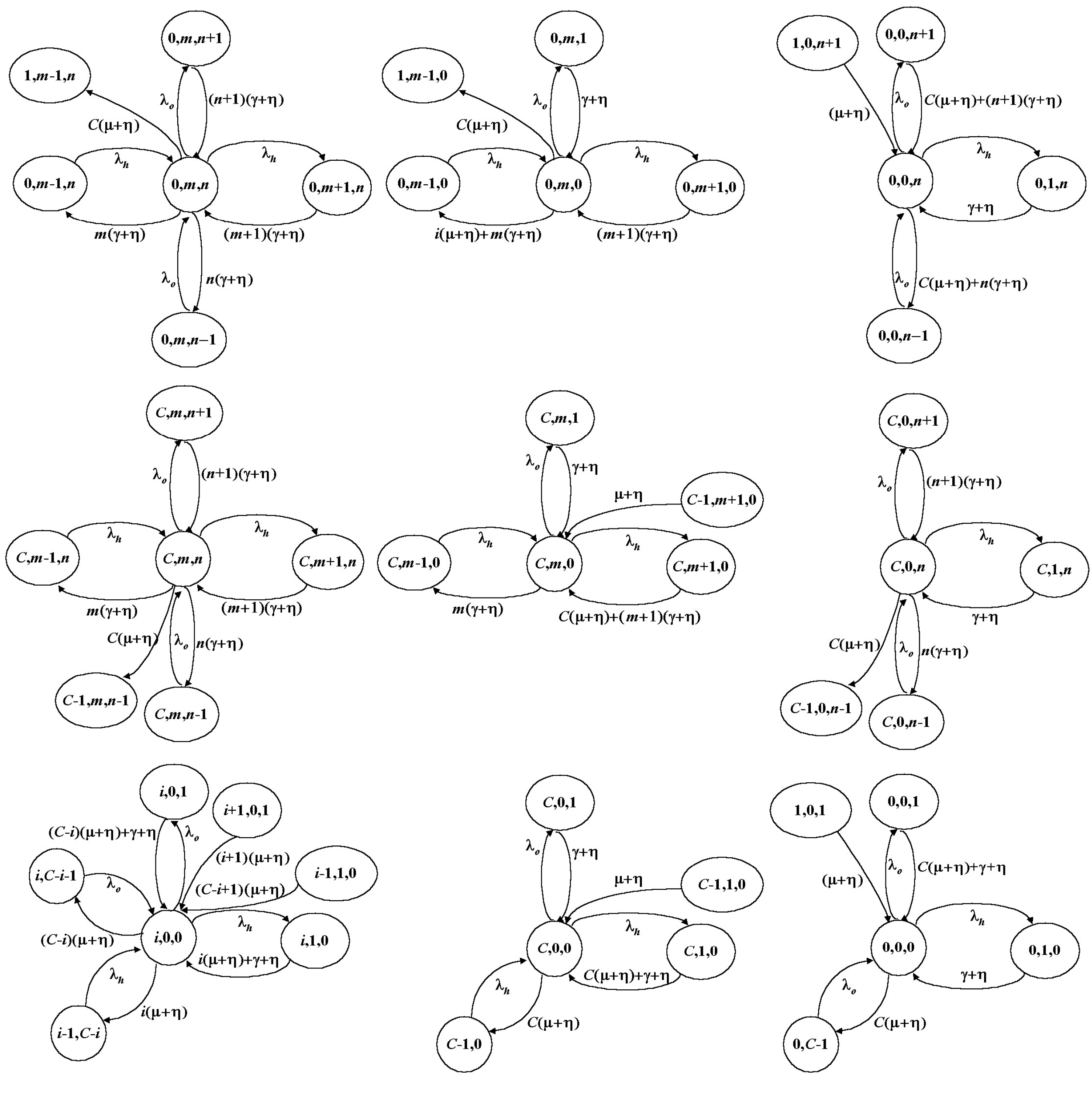
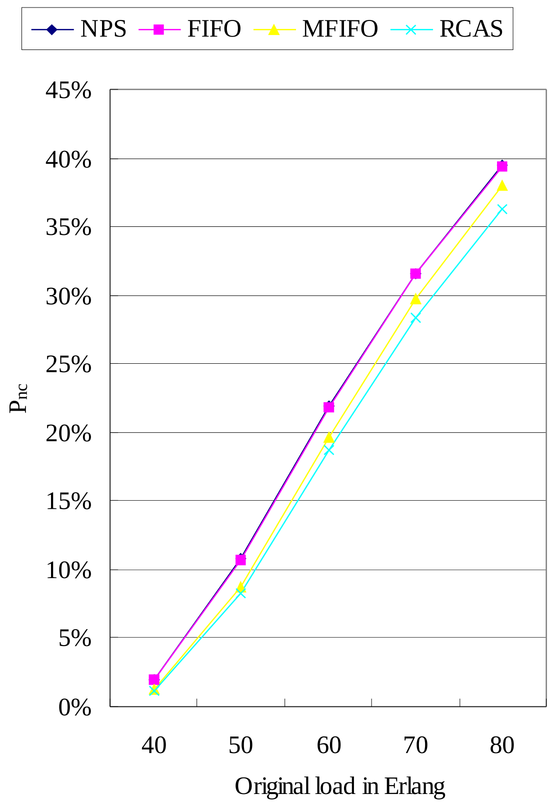
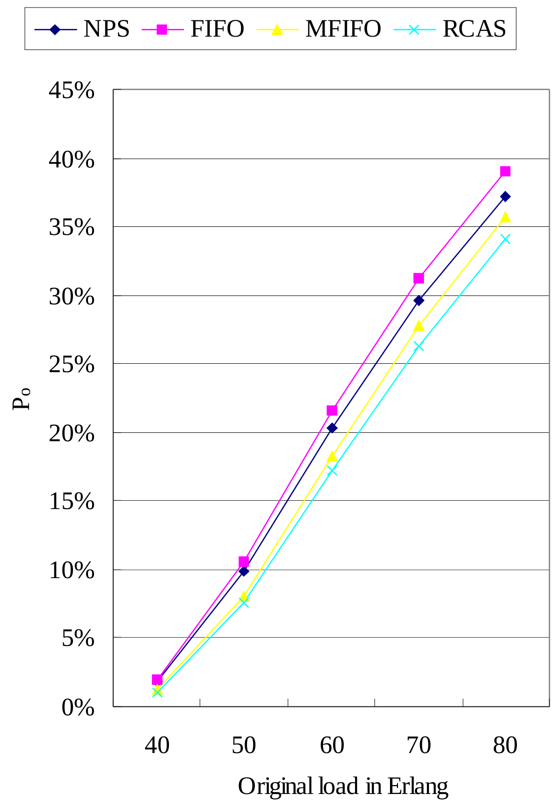


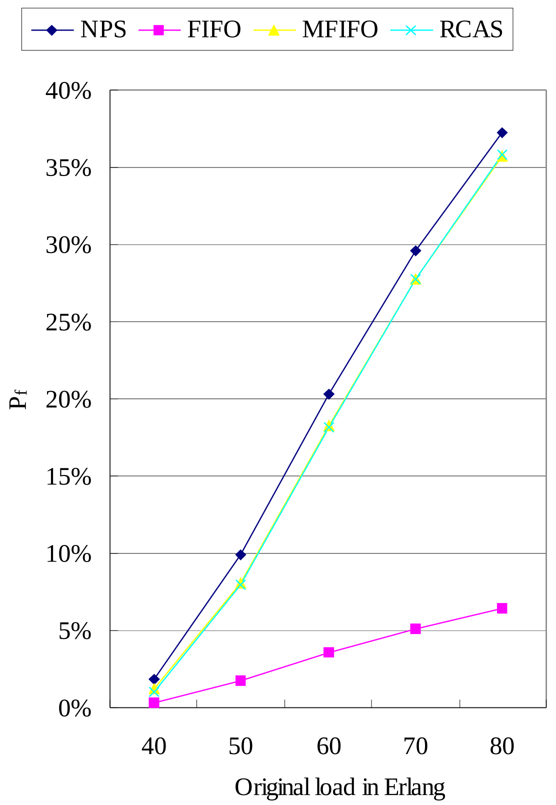
Figure 8. The state transition diagram for the states when *i*, *m*, or *n* equals zero.



(a) The call incompletion probability.



(b) The new call blocking probability.



(c) The forced termination probability.

Figure 9. Analytic results for the NPS, FIFO, MFIFO, and RCAS schemes.

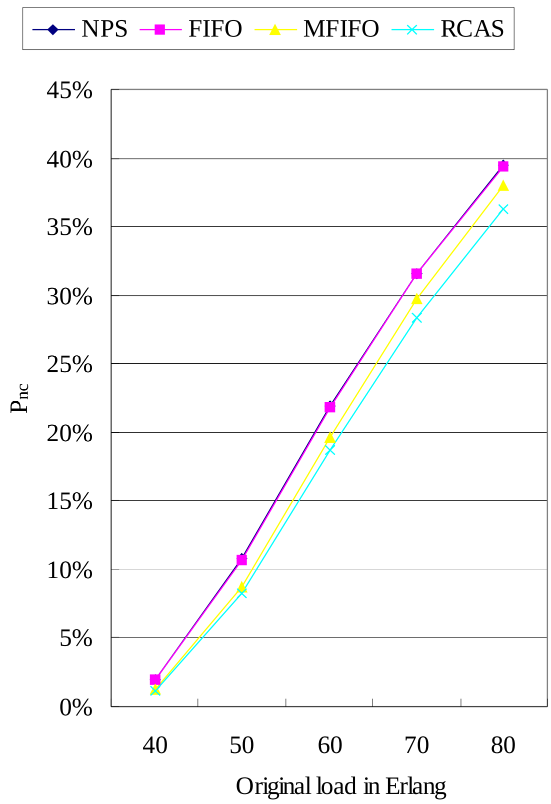


Figure 10. The simulation results comparing the call incompletion probability for the four schemes.