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Handover Priority Schemes for Multi-Class Traffic in LEO Mobile Satellite Systems

Amr S. Matar, Gamal Abd-Elfadeel, Ibrahim I. Ibrahim and Hesham M. Z. Badr

Department of Communication, Electronics and Computer Engineering, University of Helwan
Cairo, Egypt

Abstract

In this paper, an analytical framework is developed to evaluate the performance of complete sharing (CS) with two different handover priority schemes for multi-class traffic in Low Earth Orbit-Mobile Satellite Systems (LEO-MSS).
In the first priority scheme, the handover requests are given the higher priority using queuing scheme with also taking into consideration the priority between classes of traffic. Where, in the second priority scheme a combination of guard channel and queuing of handover requests scheme is developed.

Keywords: *Complete Sharing, Queuing, Multi-class traffic, LEO.*

1. Introduction

The great advance in technology in the last few years made it possible to use satellite networks as the backbone for wireless personal communication services (PCS) to meet third generation (3G) requirements of providing multimedia services, such as video-on-demand, multimedia games [1].
In recent years, LEOs and GEOs (Geostationary Earth Orbit satellites) have been used in commercial MSSs to directly provide voice and data services to handheld mobile terminals (MTs). Examples of such systems include the Iridium, the Globalstar (LEO–MSSs) [3], [4], and the Thuraya and the Asia Cellular Satellite (GEO–MSSs) [5], [6]. While fewer numbers of geostationary satellites are needed to cover the globe than low earth orbiting (LEO) satellites, a geostationary satellite network has larger propagation delays and requires more power for transmission than that experienced in LEO satellite networks. As a result, LEO satellites are better suited for providing real- time interactive and multimedia services than geostationary satellites [7].
To achieve efficient frequency reuse, the satellite footprint (which is a circular area on the earth surface) is divided into smaller cells or spotbeams [2]. Two different schemes are proposed regarding cellular coverage geometry for LEO satellites: (a) Satellite Fixed Cell (SFC) systems, and (b) Earth Fixed Cell (EFC) systems [8]. As most of the research works on handover schemes in space networks are carried out on Satellite Fixed Cell (SFC) systems, this paper deals with the second system.
The central issue in defining resource management strategies for LEO-MSS system is to select the suitable policy for managing handover requests. From the user standpoint, the interruption of a conversation is more undesirable than blocking of a newly arriving call. Previous researches have considered various resource management strategies for LEO-MSS. One approach is to reserve resources before handover occurrences in order to minimize forced termination probability [9, 10]. Another approach for managing handovers is to queue handover (QH) requests [11, 12]. In this approach, the queuing of handover requests is set to a maximum time interval in case there is no channel available in the destination cell. The call will be forced termination if no channel is made available within the defined time limit. This technique avoids protracted reservation of resources and favors low blocking probability but it introduces relatively high forced termination probability if the acceptable queuing delay is low. In the previous approaches, single class traffic was considered. For multi-class traffic, the performance analysis of a complete sharing (CS) with fixed channel reservation is considered in [14].
In this paper, we present an analytical framework for evaluating the performance of LEO-MSS multiclass traffic using complete sharing (CS) with two different handover priority schemes. The queuing of handover requests scheme is developed first. Second, a combination of guard channel and handover request queuing approach is examined. The results are compared with the handover priority scheme developed in [14].
This paper is organized as follows: Section 2 deals with the basic assumptions. Section 3 presents a suitable mobility model. Queuing time statistics are presenting in Section 4. An analytical study for the CS with the two priority schemes is presented in Section 5. Finally, Section 6 deals with the analytical results for the performance analysis.

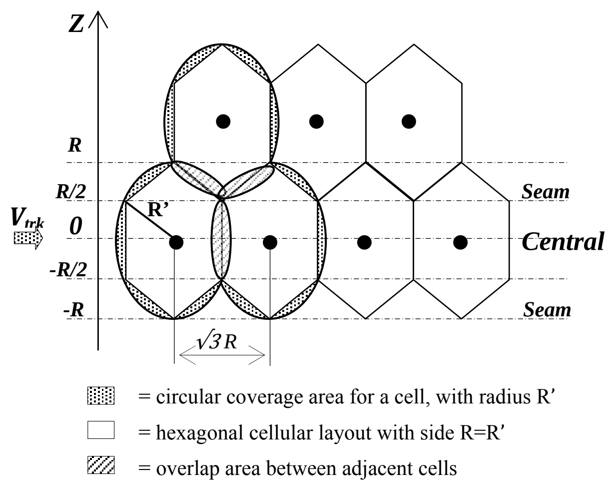

Fig. 1. The geometry assumed for the overlap areas (hexagonal cell side = circular coverage radius).

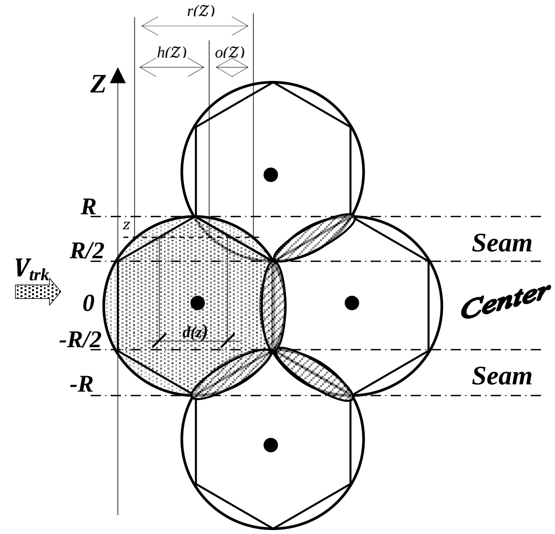

Fig. 2. The shape of the curvilinear cell and the distance crossed in the cell in the overlap area for a given height *z*.

2. Basic Assumption

Due to beam-forming, spot-beams are disposed on the earth according to a hexagonal regular layout (side R) with circular coverage of radius *R'* .The possible values for the ratio *R`/ R* range from 1 to 1.5 [13]. Clearly, the greater this ratio is, the larger the overlap area (between adjacent cells) as shown in Fig. 1. Let us assume minimum possible extension for the overlap area such that *R`=R*. The centers of adjacent cells are separated by a distance equal to $\sqrt{3}$R.

This paper is based on IRIDIUM system, but the results obtained are generally valid for all LEO-MSS's based on moving cells approach. In the IRIDIUM case, the radius, *R*, equal to 212.5 km with 66 satellites orbiting over six near polar circular orbits at about 780 km of altitude.

Assume a system serving multi-class traffic where the following quality of service (QoS) parameters [14] is used to evaluate the performance of channel resource management strategies:

1) P_{bk}, blocking probability of class-*k* new call attempts, representing the average fraction of new class-*k* calls that are not admitted into LEO-MSS because of unavailability of channels;

2) P_{fk}, handover failure probability of class-*k* calls, representing the average fraction of handover attempts of the class-*k* calls that are unsuccessful;

3) P_{dk}, call dropping probability of class-*k* calls, representing the average fraction of new class-*k* calls that are not blocked but eventually forced into termination due to the handover failure;

4) P_{usk}, unsuccessful call probability of class-*k* traffic, representing the fraction of new class-*k* calls that are not completed because of either being blocked initially or being dropped due to the failure of subsequent handover requests.

Based on ITU-T recommendations for land mobile services [15], the values P_{bk} and P_{dk} should not exceed 5.10^{-4},10^{-2} respectively. Also if they may seem too severe, we consider that these requirements will be valid for future high-quality MSS's.

3. Mobility Model

First, we point out that this model takes into account that an MS with a class-k traffic may cross the cellular layout not only along the central region of cells (see Fig. 1), but also through the seam of the cellular network [17]. In such a case, we expect that the number of inter-beam handovers during call lifetime is significantly increased which is more realistic evaluation of the impact of user mobility on the performance of channel allocation techniques for LEO-MSS's.

In the following, we define source cell: the cell where the MS call starts and transit cell: any subsequent cell reached by the MS with the call in progress. Referring to a given cell x, with the subscript *i* = 1 refers to the statistical parameters related to calls started in cell x, whereas subscript *i* = 2 refers to the parameters related to handed-over calls to cell x.

The high value of the satellite ground-track speed, V_{trk} (about 26600 km/h in the LEO case) with respect to the other motions such as earth's rotation around its axis and the user's motion relative to the earth, the relative satellite-user motion will be approximated by the vector V_{trk}. Moreover, mobile stations (MS's) cross the cellular network irradiated by a satellite according to a parallel straight lines. The proposed model for LEO mobility is based on the following assumptions [17]:

1) MS's cross the cellular network with a relative velocity (i.e., vector V_{trk}), disposed as shown in Fig. 1 with respect to the cellular layout.
2) When a handover occurs, the destination cell will be the neighboring cell in the direction of the relative satellite-MS motion.
3) MS's cross the cellular network with an offset uniformly distributed all over the network.
4) From the call arrival in a cell, a random offset $z \in [-R, R]$ is associated to this call, where z is the offset of the related MS according to the reference shown in Fig. 2. the related MS travels a distance in this cell which is :
   - Uniformly distributed between zero and d(z), if the cell is the source cell of the call;
   - Deterministically equal to d(z), if the cell is a transit cell of the call.

where

$$d(z) = \begin{cases} \sqrt{3}R & if\ |z| \le \frac{R}{2} \\ 2\sqrt{3}(R - |z|) & if\ \frac{R}{2} \le |z| \le R \end{cases} \quad (1)$$

In order to characterize the user's (relative) mobility for class-k traffic in LEO-MSS's we introduce the dimensionless parameter α_k as:

$$\alpha_k = \frac{\sqrt{3}R}{V_{trk}T_{dk}} \quad (2)$$

where
T_{dk} is the average duration time of class-k calls.

Based on [17], the handover probabilities of class-k traffic P_{H1K}, P_{H2K} : are expressed as

$$P_{H1k} = \frac{2}{3}\left\{P_{h1k} + \frac{1 - P_{h1k}}{\alpha_k}\right\} \quad (3)$$

$$P_{H2k} = \frac{P_{h1k} + P_{h2k}}{2} \quad (4)$$

where

$$P_{h1k} = \frac{1 - e^{-\alpha_k}}{\alpha_k} \quad , \quad P_{h2k} = e^{-\alpha_k} \quad (5)$$

The channel holding time for calls in cell x [16]:

$$t_{Hik} = min[t_{dk}, t_{mci}], \quad i = 1,2. \quad (6)$$

with expected value [17]:

$$E_k[t_{Hik}] = T_{dk}(1 - P_{Hik}), \quad i = 1,2. \quad (7)$$

4. Analysis of Queuing Time

Let us assume that an active MS moves from cell x toward an adjacent cell y. There is an area where this MS can receive a signal with an acceptable power level from both cells; this is the so-called overlap area. The MS crosses the overlap area in a time $t_{w\,max}$.
The position of the MS at the call arrival instant is defined, as offset z, is assigned to this MS in the source cell. According to the basic assumptions (see Section II) and the mobility model (see Section III), the randomness of $t_{w\,max}$ only depends on the offset z assigned to the call in its source cell; in particular, $t_{w\,max}$ is derived as the time spent by the associated MS to cross the overlap area at a given offset z (See Fig. 2) with a speed V_{trk}.

$$t_{w\,max} = \frac{O(z)}{V_{trk}} \quad (8)$$

where
$O(z)$ is the distance covered by the MS in the overlap area, which due to both the regular cellular layout and the mobility assumptions, it remains the same for any handover request. Let r(z) denote the distance coverd by the MS in the circular cell of radius R at offset z (see Fig.2).

$$r(Z) = 2\sqrt{R^2 - Z^2} \quad (9)$$

The circular cell is divided into two regions: 1) the overlap area with adjacent cells in the direction of the satellite-user's relative motion and 2) the remaining part of the cell that is called curvilinear cell. The curvilinear cell (whose area is equal to $3\sqrt{3}R^2/2$) is not hexagonal, but it is represented by the shaded area in Fig. 2. h(z) has denoted by the distance crossed by the MS in the curvilinear cell at a height z, and O(z) has denoted by the relevant distance covered in the overlap area.

$$h(z) = r(z) - O(z) \quad (10)$$

$$O(z) = \begin{cases} 2\sqrt{R^2 - Z^2} - \sqrt{3}R, & \text{if } |z| \le \frac{R}{2} \\ \sqrt{R^2 - Z^2} - \frac{\sqrt{3}}{2}R + \sqrt{R^2 - (|z| - \frac{2}{3}R)^2}, & \text{if } \frac{R}{2} \le |z| \le R \end{cases} \quad (11)$$

According to [17], the average value of the maximum queuing time $E[t_{w\,max}]$ results is:

$$E[t_{w\,max}] = \frac{E[O(z)]}{V_{trk}} = \alpha_k T_{dk}\beta \quad (12)$$

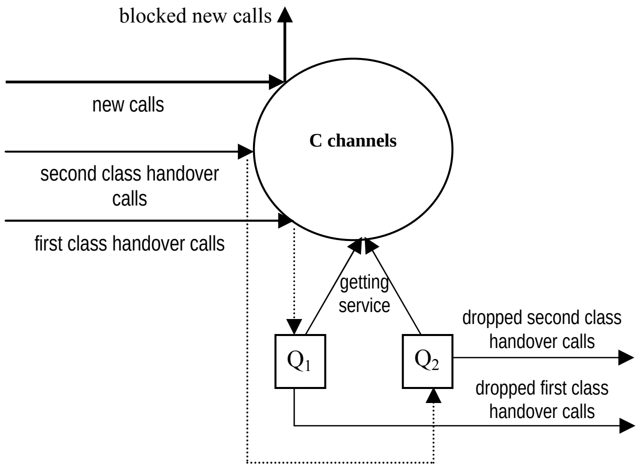

Fig. 3 Handover request queuing scheme model.

where β is given by:

$$\beta = \frac{4}{9}\left(\frac{\sqrt{3}}{3}\pi - \frac{3}{2}\right) \approx 0.1394 \quad (13)$$

From (12), the average value of the maximum queuing time $E[t_{w\,max}]$ depends on system parameters such as the speed, cell size and does not depend on the traffic class.

5. Complete Sharing Performance Analysis

In this section, analytical approaches for evaluating the CS performance with two different handover priority schemes for multi-class traffic are presented. In performing our analysis, we have assumed the following:

- C channels are assigned per cell.
- New call arrivals and handover attempts of class-k traffic are two independent Poisson processes, with mean rates λ_{nk} and λ_{hk} respectively. And with λ_{hk} related to λ_{nk} by [17]:

$$\frac{\lambda_{hk}}{\lambda_{nk}} = \frac{2}{3}(1 - P_{bk})\left\{\frac{P_{h1k}}{1-(1-P_{fk})P_{h2k}} + \frac{1 - P_{h1k} + (1-P_{fk})(P_{h1k} - P_{h2k})}{\alpha_k - \alpha_k(1-P_{fk})^2 P_{h2k}}\right\} \quad (14)$$

- Whether class-k handover requests are queued or not, the channel holding time in a cell (for both new call arrivals and handovers) is approximated by a random variable with an exponential distribution and mean $1/\mu_k$ given by [17]:

$$\frac{1}{\mu_k} = \frac{\lambda_{nk}(1-P_{bk})}{\lambda_{nk}(1-P_{bk})+\lambda_{hk}(1-P_{fk})} E_k[t_{H1k}] + \frac{\lambda_{hk}(1-P_{fk})}{\lambda_{nk}(1-P_{bk})+\lambda_{hk}(1-P_{fk})} E_k[t_{H2k}] \quad (15)$$

- The maximum waiting time is approximated by a random variable exponentially distributed, with expected value equal to $1/\mu_w = E[t_{w\,max}]$, where $E[t_{w\,max}]$ is given by (12).

5.1 Complete Sharing (CS) with Handover Request Queuing Scheme

In this subsection, an analytical approach to queuing of handover requests scheme is developed. The proposed queuing model is shown in fig.3. In general, when there are free channels in the cell, new calls and/or handover calls are equally likely to get service. However, when all the channels are occupied, new calls are blocked whereas handover call requests are queued in their respective queues (first class handover request is queued in its queue (Q1) of Length k and second class handover requests in (Q2) of Length L) for a maximum time $t_{w\,max}$, waiting for a free channel according to their priorities. The first class handover requests have higher priority over second class handover requests. If the queues are full, handover calls are dropped.

Let Λ(*j*) denotes the number of free channels in the generic cell *j*. According to this queuing scheme, the inter-beam handover requests are as follows:

1) If $\Lambda(j) \neq \emptyset$, the new and handover calls get service immediately in cell j.
2) If $\Lambda(j) = \emptyset$, the new calls are blocked and the handover requests are queued waiting for an available channel in cell *j*. In the meantime, the handover call is served by its originating cell. A handover request leaves the queue for one of the following reasons:

   a) The handover procedure is successful: The handover request is served, before the call is ended and its maximum queuing time has expired.
   b) The handover procedure has been useless: The call ends before the corresponding handover request is served and its maximum queuing time has expired.
   c) The handover procedure fails and the call is dropped.

According to the queuing scheme described, the queuing scheme can be modeled as an M/M/C/K queue. The evolution of queue can be described by the Markov chain in Fig. 4.

From the two-dimension (2-D) Markov chain shown in Fig.4, Let us define $S_{n,i,j}$ as the state of the cell where *n* is the number of busy channels (first and second classes, new and handoff call) and *i* and *j* signifies the number of handover call requests of first and second classes in queue Q1 and the queue Q2 respectively. The transition between states can be explained as follows:

• A transition from state $S_{n,0,0}$ to $S_{n+1,0,0}$ for $0 \leq n < C$ occurs when a new call or handover call (either class one or class two) arrives, thus it occurs with rate $\lambda = \lambda_n + \lambda_h$

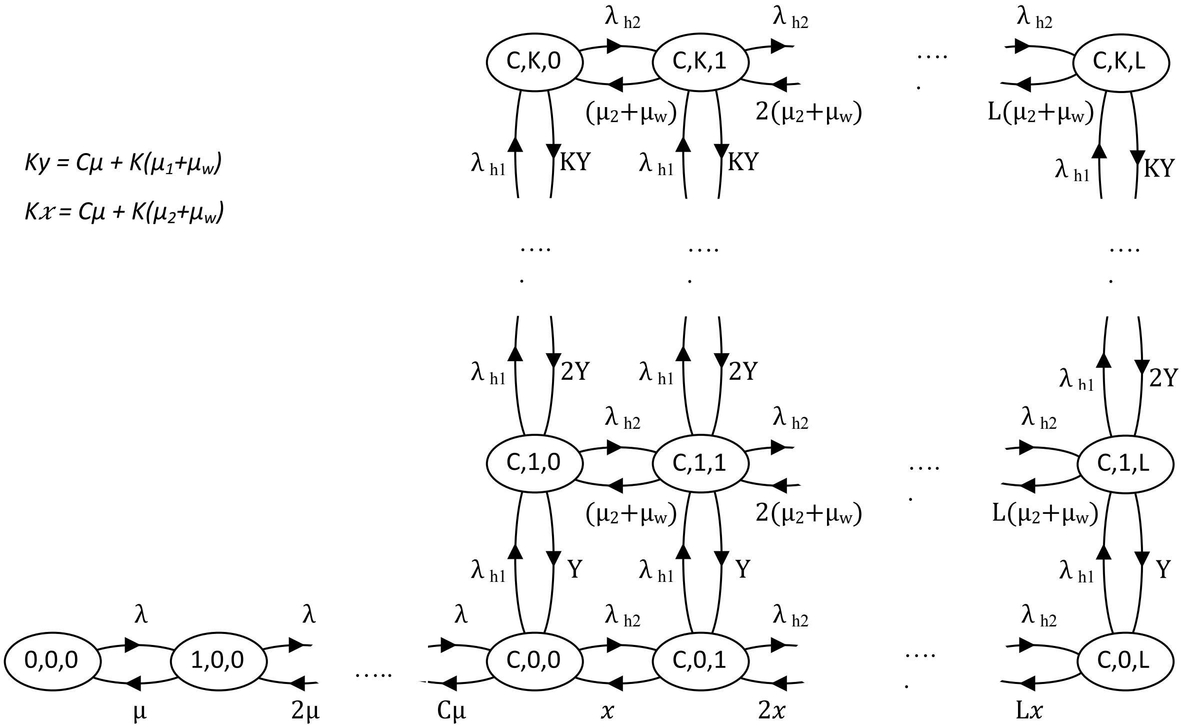

Fig.4. Markov chain representation of the CS with handover requests queuing priority scheme.

(where λ_n is the total new call arrival rate $\{\lambda_{n1} + \lambda_{n2}\}$, and λ_h is the total handover call arrival $\{\lambda_{h1} + \lambda_{h2}\}$).

• A transition from state $S_{n,0,0}$ to state $S_{n-1,0,0}$ for $0 < n \le C$ occurs if a call in progress finishes its service and releases the channel, thus occurs with rate $n\mu$ (where μ is the total call departure rate which equal to $\{\mu_1 + \mu_2\}$).

• When all channels are busy, a transition to the next states occurs if there is a first or second-class handover call arrival *and* the first or second-class queue is not full. Hence, a transition from state $S_{C,i,j}$ to state $S_{C,i+1,j}$ occurs with rate λ_{h1}, while a transition from state $S_{C,i,j}$ to state $S_{C,i,j+1}$ occurs with rate λ_{h2}.

• A transition from state $S_{C,i,j}$ to state $S_{C,i-1,j}$ occurs if a channel is released *and* the first-class handover call gets service *or* the first-class handover call finishes its call while in the queue, *or* the waiting time in the queue for a handover call is over before a channel is released, thus occurs with rate $C\mu + i(\mu_1 + \mu_w)$.

• A transition from state $S_{C,i,j}$ to state $S_{C,i,j-1}$ occurs if the waiting time for a second-class handover call is over before a channel is released *or* the second-priority handover call finishes its call while in the queue, *or* a channel is released and a second-class handover call gets served provided there is no handover call waiting in first-class handover queue, thus it occurs with rate or with rate $C\mu + i(\mu_2 + \mu_w)$.

Based on the above descriptions and Fig. 4, the Balance equation describing this model:

$$\lambda P_{n,i,j} = (n+1)\mu P_{n+1,i,j}, \qquad i = 0, j = 0, 0 \le n < C \tag{16}$$

$$(\lambda_h + C\mu)P_{n,i,j} = \lambda P_{c-1,i,j} + YP_{c,i+1,j} + \mathrm{X}P_{c,i,j+1}, \quad i = 0, j = 0, n = C \tag{17}$$

$$(\lambda_h + iY)P_{c,i,j} = \lambda_{h1}P_{c,i-1,j} + (i+1)YP_{c,i+1,j} + (j+1)(\mu_2 + \mu_w)P_{c,i,j+1}, \quad 0 < i < K, j = 0, n = C \tag{18}$$

$$(\lambda_{h2} + iY)P_{c,i,j} = \lambda_{h1}P_{c,i-1,j} + (j+1)(\mu_2 + \mu_w)P_{c,i,j+1}, \qquad i = K, j = 0, n = C \tag{19}$$

$$(\lambda_h + j\mathrm{X})P_{c,i,j} = \lambda_{h2}P_{c,i,j-1} + (j+1)\mathrm{X}P_{c,i,j+1} + (i+1)\mathrm{Y}P_{c,i+1,j}, \qquad i = 0, 0 < j < L, n = C \tag{20}$$

$$(\lambda_{h1} + j\mathrm{X})P_{c,i,j} = \lambda_{h2}P_{c,i,j-1} + (i+1)\mathrm{Y}P_{c,i+1,j}, \quad i = 0, j = L, n = C \tag{21}$$

$$\left(\lambda_{h2} + iY + j(\mu_2 + \mu_w)\right)P_{c,i,j} = \lambda_{h1}P_{c,i-1,j} + \lambda_{h2}P_{c,i,j-1} + (j+1)(\mu_2 + \mu_w)P_{c,i,j+1}, \quad i = K,\ 0 < j < L, n = C \tag{22}$$

$$\left(\lambda_{h1} + iY + j(\mu_2 + \mu_w)\right)P_{c,i,j} = \lambda_{h1}P_{c,i-1,j} + \lambda_{h2}P_{c,i,j-1} + (i+1)YP_{c,i+1,j}, \quad 0 < i < K, j = L, n = C \tag{23}$$

$$\left(\lambda_h + iY + j\left(\mu_2 + \mu_w\right)\right) P_{c,i,j} = \lambda_{h1} P_{c,i-1,j} + \lambda_{h2} P_{c,i,j-1} + (i+1) Y P_{c,i+1,j} + (j+1)\left(\mu_2 + \mu_w\right) P_{c,i,j+1} , \quad 0 < i < K, 0 < j < L, n = C \quad (24)$$

$$\left(iY + j\left(\mu_2 + \mu_w\right)\right) P_{c,i,j} = \lambda_{h1} P_{c,i-1,j} + \lambda_{h2} P_{c,i,j-1} \quad i = K, j = L, n = C \quad (25)$$

The steady-state probabilities $P_{n,i,j}$ that the cell is in state $S_{n,i,j}$ can be found by solving the previous balance equations and the normalization condition $\sum_{n=0}^{C} \sum_{i=0}^{K} \sum_{j=0}^{L} P_{n,i,j} = 1$.

New call blocking occurs if a new call arrival (either class one or class two) finds C channel occupied. Therefore, the steady state blocking probability for the new calls can be expressed as

$$P_{B1} = P_{B2} = \sum_{i=0}^{K} \sum_{j=0}^{L} P_{c,i,j} \quad (26)$$

where
P_{B1} and P_{B2} are the new call blocking probabilities for class one and two respectively.
Handover failure occurs if a handover call arrival finds all channels are occupied and its respective request queue is full *or* the handover call request is queued in its respective queue; however, it is dropped before getting service because its waiting time in the queue is expired before the handover call gets served or finished its service.
The steady-state handover failure probability of class-one traffic is given as

$$P_{F1} = \sum_{j=0}^{L} P_{C,K,j} + \sum_{i=0}^{K-1} \sum_{j=0}^{L} P_{f1;i,j} P_{C,i,j} \quad (27)$$

where the first term describes the event that the first-class handover request queue is full. While the While second term describes the event that the first-class handover call request is queued, but it is dropped before getting service because its waiting time is expired before a channel is released. The term $P_{f1;i,j}$ gives the probability of handover failure for a first-class handover call request in the queue given the handover call request joined the queue as the (i+1) call. This is found as [18]:

$$P_{f1;i,j} = \frac{(i+1)\mu_w}{C\mu + i(\mu_1 + \mu_w)} \quad (28)$$

Similar the steady-state handover failure probability of class-two traffic is given as:

$$P_{F2} = \sum_{i=0}^{K} P_{C,i,L} + \sum_{j=0}^{L-1} \sum_{i=0}^{K} P_{f2;i,j} P_{C,i,j} \quad (29)$$

where the first term describes the event that the second-class handover request queue is full. While the second term describes the event that the second-class handover call request is queued, but it is dropped before getting service because its waiting time is expired before a channel is released. The term $P_{f2;i,j}$ gives the probability of handover failure for a second-class handover call in the queue given the handover call joined the queue as the (j+1) call. This obtained as:

$$P_{f2;i,j} = \frac{(j+1)\mu_w}{C\mu + j(\mu_2 + \mu_w)} \quad (30)$$

The probability of an admitted call being forced into termination during the i^{th} handover can be expressed as

$$P_{dki} = P_{Fk}\left[P_{h1k}(1 - P_{Fk})^{i-1} P_{h2k}^{i-1}\right] \quad (31)$$

By summing over all possible values of *i*, P_{dk} can be obtained as follows

$$P_{dk} = \sum_{i=1}^{\infty} P_{dki} = \sum_{i=1}^{\infty} P_{Fk}\left[P_{h1k}(1 - P_{Fk})^{i-1} P_{h2k}^{i-1}\right] = \frac{P_{Fk} P_{h1k}}{1 - P_{h2k}(1 - P_{Fk})} \quad (32)$$

P_{usk} is also used as an important parameter for evaluating overall system performance and can be derived as

$$P_{usk} = P_{Bk} + P_{dk}(1 - P_{Bk}) \quad (33)$$

5.2 Complete Sharing (CS) with Guard Channel and Queuing of Handover Requests Scheme

This subsection presents an analytical model for the combination of guard channel and handover request queuing scheme. In this model, when there are free channels in the cell, new calls and/or handover calls are equally likely to get service. However, When the number of occupied channels are equal to threshold ($M=C-C_h$), new calls are blocked whereas handover calls are gets service. When all the channels are occupied, handover call requests are queued in their respective request queues (first class handoff call is queued in its queue (Q1) of Length k and second class requests in (Q2) of Length L) for a maximum time $t_{w\,max}$, waiting for a free channel according to the same scenario discussed in the previous scheme.
This scenario can be represented by the second-Dimension (2-D) Markov chain shown in Fig. 5. Let us define $S_{n,i,j}$ as the state of the cell where n is the number of busy channels (first and second classes, new and handoff call) and i and j signifies the number of handover call requests of first and second classes in queue Q1 and the queue Q2 respectively. The transition between states can be explained as follows:

- A transition from state $S_{n,0,0}$ to $S_{n+1,0,0}$ for $0 \le n < M$ occurs when a new call or handover call (either class one or class two) arrives, thus it occurs with rate $\lambda = \lambda_n + \lambda_h$ (where λ_n is the total new call arrival rate $\{\lambda_{n1} + \lambda_{n2}\}$, and λ_h is the total handover call arrival $\{\lambda_{h1} + \lambda_{h2}\}$).

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• A transition from state $S_{n,0,0}$ to $S_{n+1,0,0}$ for $M \le n < C$ occurs when a handover call (either class one or class two) arrives, thus it occurs with rate λ_h.

• A transition from state $S_{n,0,0}$ to state $S_{n-1,0,0}$ for $0 < n \le C$ occurs if a call in progress finishes its service and releases the channel, thus occurs with rate $n\mu$ (where μ is the total call departure rate which equal to $\{ \mu_1 + \mu_2 \}$).

• When all channels are busy, a transition to the next states occurs if there is a first or second-class handover call arrival *and* the first or second-class queue is not full.
Hence, a transition from state $S_{C,i,j}$ to state $S_{C,i+1,j}$ occurs with rate λ_{h1}, while a transition from state $S_{C,i,j}$ to state $S_{C,i,j+1}$ occurs with rate λ_{h2}.

• A transition from state $S_{C,i,j}$ to state $S_{C,i-1,j}$ occurs if a channel is released *and* the first-class handover call gets service *or* the first-class handover call finishes its call while in the queue, *or* the waiting time in the queue for a handover call is over before a channel is released, thus occurs with rate $C\mu + i(\mu_1 + \mu_w)$.

• A transition from state $S_{C,i,j}$ to state $S_{C,i,j-1}$ occurs if the waiting time for a second-class handover call is over before a channel is released *or* the second-priority handover call finishes its call while in the queue, *or* a channel is released and a second-class handover call gets served provided there is no handover call waiting in first-class handover queue, thus it occurs with rate or with rate $C\mu + i(\mu_2 + \mu_w)$.

Based on the above descriptions and Fig. 5, the Balance equation describing this model:

$$\lambda P_{n,i,j} = (n+1)\mu P_{n+1,i,j}, \quad i = 0, j = 0, 0 \le n < C - C_h \tag{34}$$

$$\lambda_h P_{n,i,j} = (n+1)\mu P_{n+1,i,j}, \quad i = 0, j = 0, C - C_h \le n < C \tag{35}$$

$$(\lambda_h + C\mu)P_{n,i,j} = \lambda_h P_{c-1,i,j} + YP_{c,i+1,j} + XP_{c,i,j+1}, \quad i = 0, j = 0, n = C \tag{36}$$

$$(\lambda_h + iY)P_{c,i,j} = \lambda_{h1} P_{c,i-1,j} + (i+1)YP_{c,i+1,j} + (j+1)(\mu_2 + \mu_w)P_{c,i,j+1}, \quad 0 < i < K, j = 0, n = C \tag{37}$$

$$(\lambda_{h2} + iY)P_{c,i,j} = \lambda_{h1} P_{c,i-1,j} + (j+1)(\mu_2 + \mu_w)P_{c,i,j+1}, \quad i = K, j = 0, n = C \tag{38}$$

$$(\lambda_h + jX)P_{c,i,j} = \lambda_{h2} P_{c,i,j-1} + (j+1)XP_{c,i,j+1} + (i+1)YP_{c,i+1,j}, \quad i = 0, 0 < j < L, n = C \tag{39}$$

$$(\lambda_{h1} + jX)P_{c,i,j} = \lambda_{h2} P_{c,i,j-1} + (i+1)YP_{c,i+1,j}, \quad i = 0, j = L, n = C \tag{40}$$

$$\left(\lambda_{h2} + iY + j(\mu_2 + \mu_w)\right)P_{c,i,j} = \lambda_{h1} P_{c,i-1,j} + \lambda_{h2} P_{c,i,j-1} + (j+1)(\mu_2 + \mu_w)P_{c,i,j+1}, \quad i = K, 0 < j < L, n = C \tag{41}$$

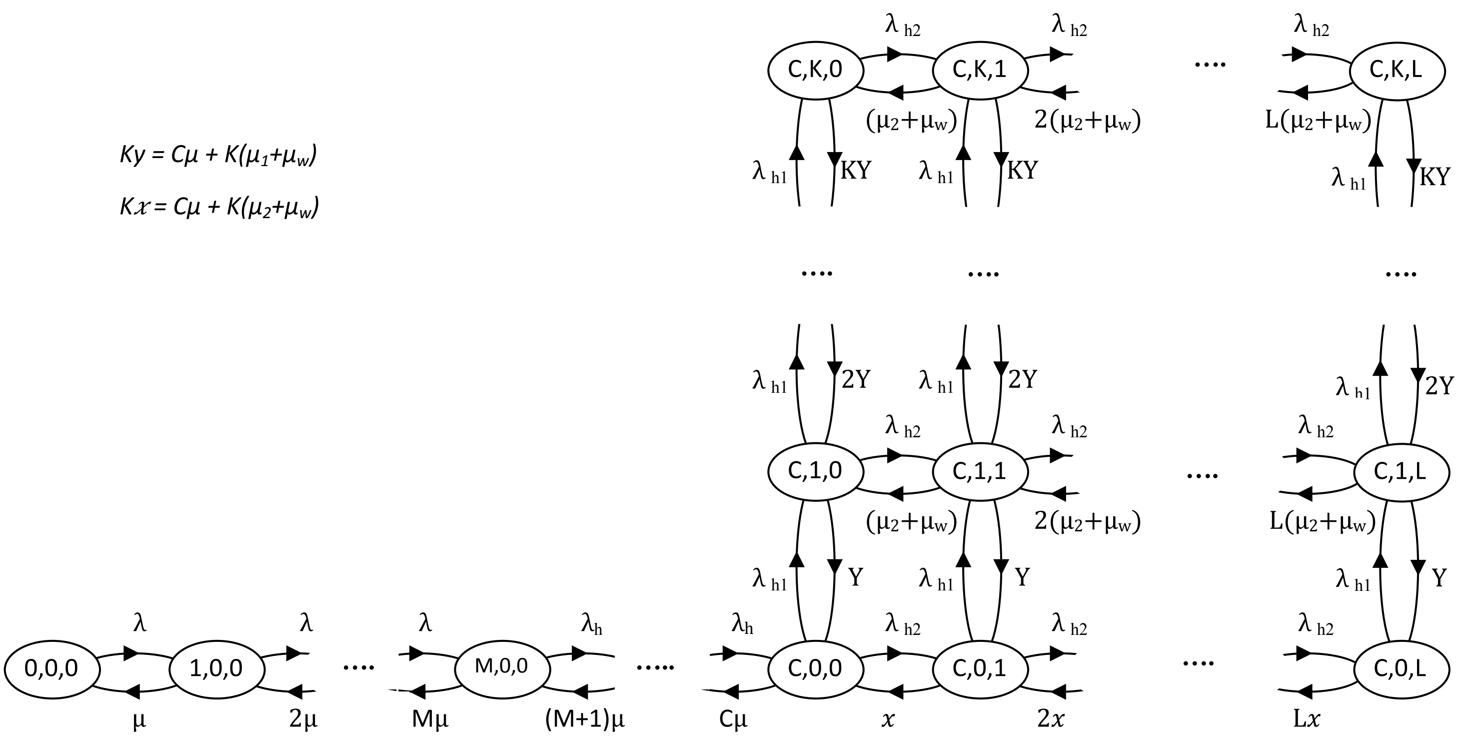
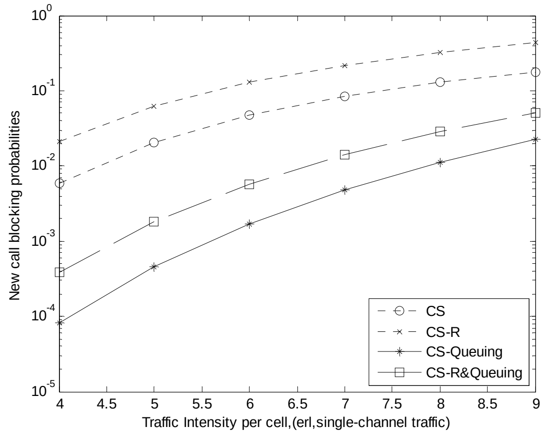
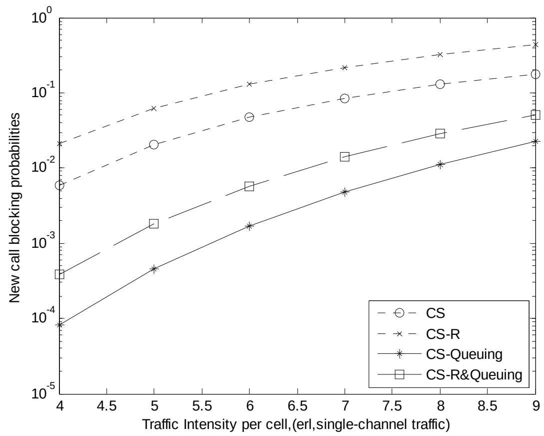


Fig.5 . Markov chain representation of the CS with combination of guard channel and handover request queuing priority scheme.

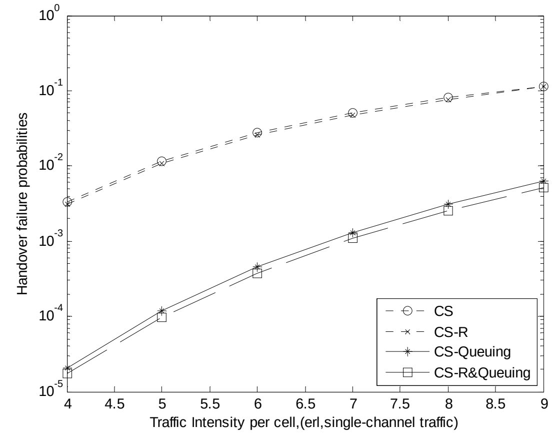


(a)

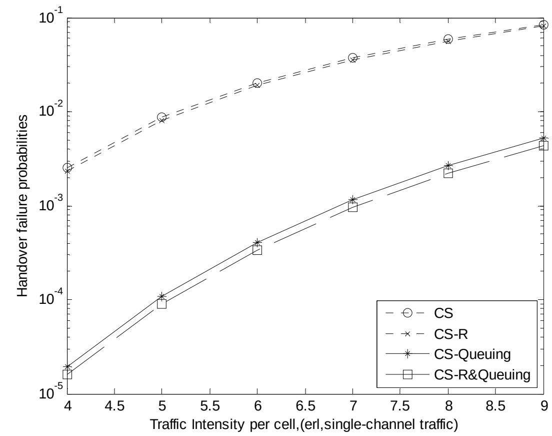


(b)

Fig. 6. Analytical results for new call blocking probabilities as function of traffic intensity of CS with different priority schemes. (a) first class. (b) second class.



(a)



(b)

Fig. 7. Analytical results for Handover failure probabilities as function of traffic intensity of CS with different priority schemes. (a) first class. (b) second class.

$$\left(\lambda_{h1} + iY + j\left(\mu_2 + \mu_w\right)\right) P_{c,i,j} = \lambda_{h1} P_{c,i-1,j} + \lambda_{h2} P_{c,i,j-1} + (i+1) Y P_{c,i+1,j} \quad 0 < i < K, j = L, n = C \qquad (42)$$

$$\left(\lambda_h + iY + j\left(\mu_2 + \mu_w\right)\right) P_{c,i,j} = \lambda_{h1} P_{c,i-1,j} + \lambda_{h2} P_{c,i,j-1} + (i+1) Y P_{c,i+1,j} + (j+1)\left(\mu_2 + \mu_w\right) P_{c,i,j+1}, \quad 0 < i < K, 0 < j < L, n = C \qquad (43)$$

$$\left(iY + j\left(\mu_2 + \mu_w\right)\right) P_{c,i,j} = \lambda_{h1} P_{c,i-1,j} + \lambda_{h2} P_{c,i,j-1} \quad i = K, j = L, n = C \qquad (44)$$

The steady-state probabilities $P_{n,i,j}$ that the cell is in state $S_{n,i,j}$ can be found by solving the previous balance equations and the normalization condition $\sum_{n=0}^{C} \sum_{i=0}^{K} \sum_{j=0}^{L} P_{n,i,j} = 1$.

New call blocking occurs if a new call arrival (either class one or class two) finds (C-C_h) channel occupied. Therefore, the steady state blocking probability for the new calls can be expressed as:

$$P_{B1} = P_{B2} = \sum_{n=C-C_h}^{C-1} P_{n,0,0} + \sum_{i=0}^{K} \sum_{j=0}^{L} P_{c,i,j} \qquad (45)$$

where

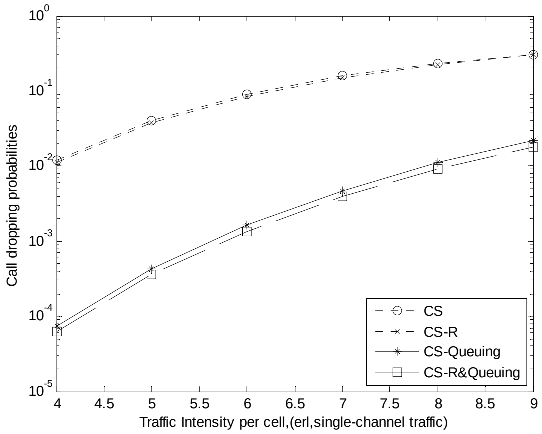
P_{B1} and P_{B2} are the new call blocking probabilities for traffic of class one and class two respectively.

Handover failure occurs if a handover call arrival finds all channels are occupied and its respective request queue is full *or* the handover call request is queued in its respective queue; however, it is dropped before getting service because its waiting time in the queue is expired before the handover call gets served or finished its service.

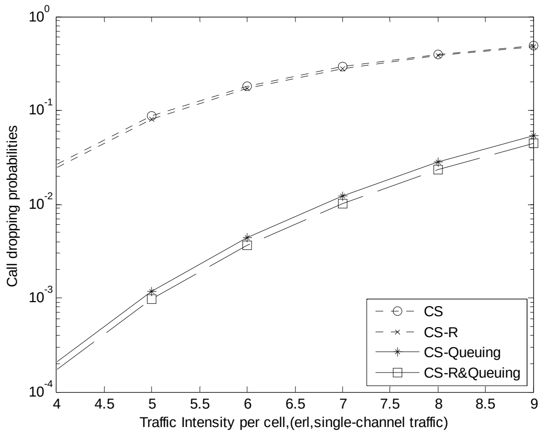
The steady-state handover failure probability of class-one traffic is given as

$$P_{F1} = \sum_{j=0}^{L} P_{C,K,j} + \sum_{i=0}^{K-1} \sum_{j=0}^{L} P_{f1;i,j} P_{C,i,j} \qquad (46)$$

where the first term describes the event that the first-class handover request queue is full, while the second term describes the event that the first-class handover call request is queued, but it is dropped before getting service because its waiting time is expired before a channel is

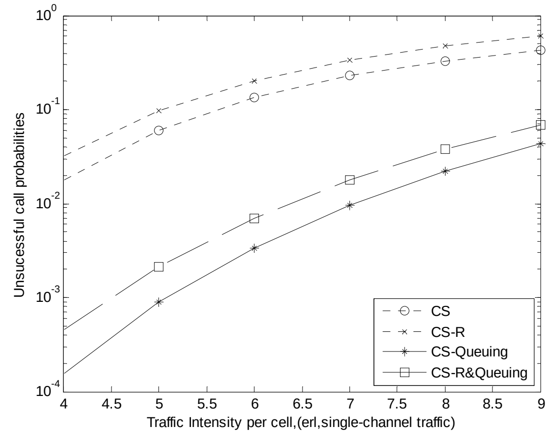


(a)

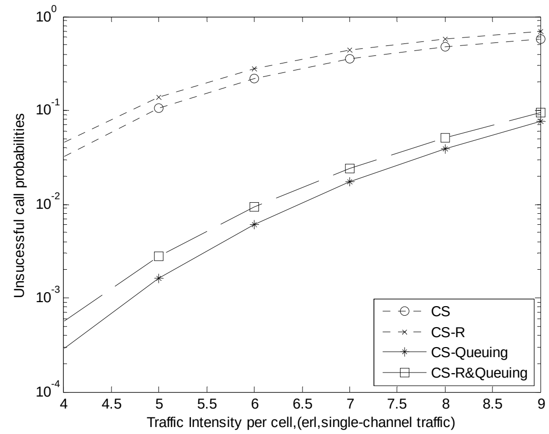


(b)

Fig. 8. Analytical results for call dropping probabilities as function of traffic intensity of CS with different priority schemes.
(a) first class. (b) second class.



(a)



(b)

Fig. 9. Analytical results for Unsuccessful call probabilities as function of traffic intensity of CS with different priority schemes.
(a) first class. (b) second class.

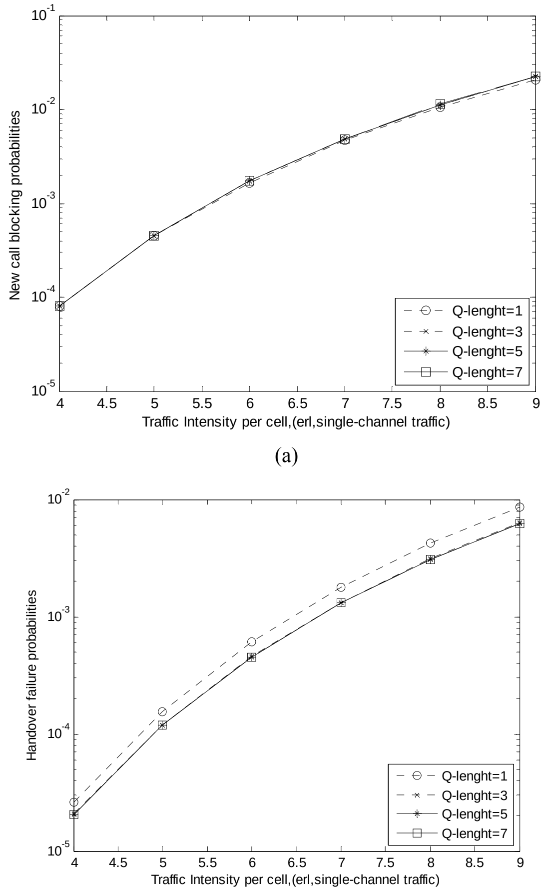
released. The term $P_{f1;i,j}$ gives the probability of handover failure for a first-class handover call request in the queue given the handover call request joined the queue as the (i+1) call. This is found as [18]:

$$P_{f1;i,j} = \frac{(i+1)\mu_w}{C\mu+i(\mu_1+\mu_w)} \quad (47)$$

Similar the steady-state handover failure probability of class-two traffic can be computed as (29).
Using (32) and (33), P_{dk} and P_{usk} can then be computed, respectively.

6. Analytical Result

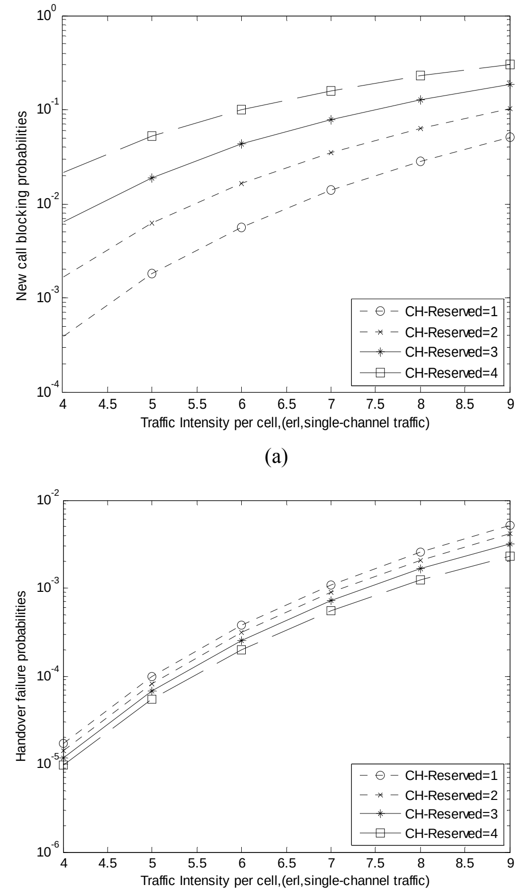
The main goal of this section is to analyze the analytical results of the CS with handover queuing priority (named as CS-Queuing) scheme and the CS with the combination of guard channel and handover queuing priority (named as CS-R&Queuing) scheme which have been presented in section **V**. The following parameter values of two different class of traffic have been chosen in the validations: C=10, T_{d1}=180, T_{d2}=540, $\rho 2$=0.02$\rho 1$, the first and second class of handover request queues are L=5 and K=5 respectively and channel reservation M=2.
Figs. 6-9 show analytical results of CS policy under different priority schemes in terms of P_{bk}, P_{fk}, P_{dk} and P_{usk} respectively. In these graphs, the behavior of CS with no priority (named as CS) and CS with fixed channel reservation (guard channel) priority (named as CS-R) scheme examined in [14] have been also considered.
As can be seen from Fig. 6-9, the handover queuing (CS-Queuing) and combination of handover queuing with guard channel (CS-R&Queuing) schemes provide significantly better results in terms of all quality of service parameters considered (P_{bk}, P_{fk}, P_{dk} and P_{usk} respectively) when compared with CS with no priority (CS) or with fixed channel reservation (CS-R) schemes[14].
In Fig. 6 the analytical results for new call blocking probability show that the handover queuing (CS-Queuing)



(a)

(b)

Fig. 10. The effect of Q1 length on the First class traffic :
a)New call blocking Probability. b)Handover failure Probability.



(a)

(b)

Fig. 11. The effect of channel reservation value on the First class traffic :
a)New call blocking Probability. b)Handover failure Probability.

scheme achieves better response than the handover queuing with guard channel combination (CS-R&Queuing) scheme. However, the CS-R&Queuing scheme is a little better in response of handover failure probability as shown in Fig. 7, and also in the response of call dropping probability (see Fig. 8). But as seen in Fig. 8, the unsuccessful call probability (P_{usk}) of CS-Queuing scheme is the best response over other priority schemes.

For CS-Queuing priority scheme and as we can see in Fig.10, the increasing of class-one handover request queuing (Q_1) length has a approximately the same effect on the response of new call blocking probability and handover failure probability of class-one traffic.

In the CS-R&Queuing priority scheme, the new call blocking probability increases significantly as the number of channel reservation increase. However, it results with a decrease in the handover failure probability as can be seen in Fig. 11

7. Conclusions

In this paper, we have developed an analytical work to evaluate the performance of CS resource management strategies for multi-class traffic in LEO-MSS. Two different handover priority schemes have been introduced: the handover queuing scheme and the combination of handover queuing with guard channel scheme.

Analytical results have shown that the CS with queuing of handover requests scheme effectively reduces new call blocking probability and the unsuccessful call probability with a little increase in handover failure probability than did the combination handover queuing with guard channel scheme. Therefore, CS with the handover request queuing scheme should be preferred to the combination scheme one.

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