Complete Partitioning Policy with Different Handover Priority schemes for Multi-Class Traffic in LEO Mobile Satellite Systems

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Abstract—**In this paper, an analytical framework is developed to evaluate the performance of complete partitioning (CP) policy with two different handover priority schemes for multi-class traffic in Low Earth Orbit-Mobile Satellite Systems (LEO-MSS). The queuing of handover requests priority scheme is examined as the first priority scheme. Where, in the second priority scheme a combination of guard channel and handover request queuing priority schemes is developed.**

Keywords- LEO-MSS; multi-class; handover; queuing.

I. INTRODUCTION

The increase of public interest and mass marketing for mobile communications is leading to support third generation (3G) multimedia services requirements at anytime and anywhere. These make Mobile Satellite Systems (MSS) to be a good attractive choice for future global wireless communication networks. Compared with Geostationary Mobile Satellite Systems (GEO-MSS), LEO-MSS require lower transmit power, shorter propagation delay and higher traffic capacities. Therefore, LEO satellites are more suited for providing real-time interactive and multimedia services than other systems [1, 2].

The resource management strategies central issue 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 queue handover (QH) requests [3, 4]. Another approach for managing handovers (Guard channel) is to reserve resources before handover occurrence [5]. In the previous approaches, only single class of traffic was considered. For multi-class traffic, the performance analysis of a complete partitioning (CP) with or without fixed channel reservation was examined in [7].

Motivated by the above, in this paper, we present an analytical framework for evaluating the performance of LEO-MSS multi-class traffic using complete partitioning (CP) policy with two different handover priority schemes. In the first priority scheme, the handover requests queuing scheme is developed. Second, a combination of guard channel and handover request queuing approach is examined. The results are compared with the handover priority scheme developed in [7].

The remainder of this paper is organized as follows. In Section II, the basic assumptions are described. Section III presents a suitable mobility model. An analytical study for the CP policy with the two priority schemes is presented in Section IV. Section V shows the analytical results for the performance analysis. Finally, conclusions are drawn in Section VI.

II. BASIC ASSUMPTION

Similar to [9], this paper is based on the IRIDIUM system, which consists of 66 satellites orbiting over six near polar circular orbits at about 780 km of altitude. Due to the high value of the satellite ground-track speed, V_{trk} (about 26600 km/h in the LEO case), with respect to the user's motion, 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 satellite footprint is divided into smaller cells or spotbeams in order to achieve efficient frequency reuse. 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 is from 1 to 1.5 [9]. Clearly, the greater this ratio is, the larger the overlap area (between adjacent cells) as shown in Figure 1. Let us assume minimum possible extension for the overlap area such that *R*'=*R*. In the IRIDIUM case, the radius *R* is equal to 212.5 km. The centers of adjacent cells are separated by a distance equal to $\sqrt{3}R$.

To evaluate the performance of resource management strategies of multi-class traffic, the following qualities of service (QoS) parameters [7] are used:
1) P_{bk}, blocking probability of class-*k* new call attempts;
2) P_{fk}, handover failure probability of class-*k* calls;
3) P_{dk}, call dropping probability of class-*k* calls;
4) P_{usk}, unsuccessful call probability of class-*k* traffic.

Based on ITU-T recommendations for land mobile services [10], the values P_{bk} and P_{dk} should not exceed 5.10^{-4},10^{-2} respectively.

III. MOBILTY MODEL

In the following, let 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. From the call arrival in a cell, a random offset $z \in [-R, R]$ is associated to this call,

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where z is the offset of the related MS according to the reference shown in Figure 1.

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

$$\alpha_k = \frac{\sqrt{3}R}{V_{trk}T_{dk}} \tag{1}$$

where

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

The proposed model for LEO mobility is based on the following assumptions [9]:

1) The new call origination is uniformly distributed over the mobile service area.
2) MS's cross the cellular network with a relative velocity, vector V_{trk} "orthogonal" to the side of the cells (as shown in Fig. 1).
3) When a handover occurs, the destination cell will be the neighboring cell in the direction of the relative satellite-user motion.
4) From the call arrival in a cell, the related MS travels a distance (depending on offset z) defined as:
   - 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

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

Based on [6], the handover probabilities of class-k traffic from the source cell and transit one (P_{H1K} and P_{H2K}, respectively) are expressed as

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

$$P_{H2k} = \frac{P_{h1k}+P_{h2k}}{2} \tag{4}$$

where

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

The channel holding time for a class-k call in cell x [8]:

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

with expected value [7]:

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

where $i = 1$ refer to the call in its source cell and $i = 2$ refer to the call in the transit cell.

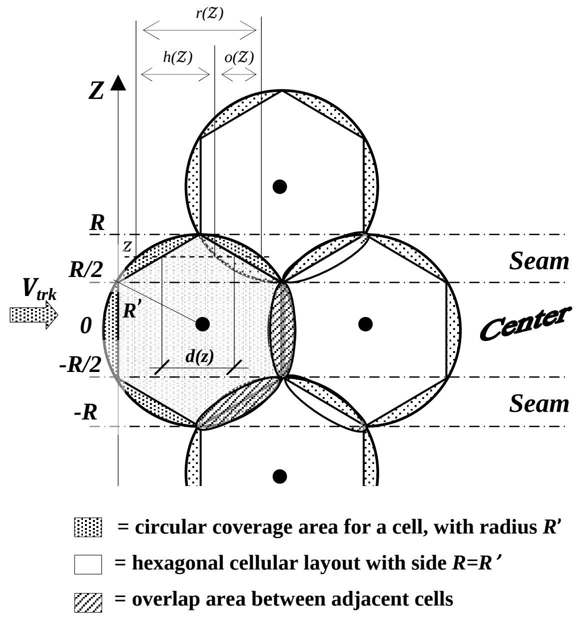

Figure 1. The shape of the cells and the distance crossed in the cell in the overlap area for a given height z.

IV. COMPLETE PARTITIONING POLICY PERFORMANCE ANALYSIS

In this section, analytical approaches for evaluating the CP performance with two different handover priority schemes for multi-class traffic are presented. In performing our analysis, we have assumed the following [6]:

- C channels are assigned per cell.
- The maximum number of the traffic classes in the system is K.
- 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

$$\frac{\lambda_{hk}}{\lambda_{nk}} = \frac{2}{3}(1-P_{bk})\left\{\frac{P_{h1k}}{1-(1-P_{fk})P_{h2k}} + \frac{1-P_{h1k}+(1-P_{fk})(P_{h1k}-P_{h2k})}{\alpha_k-\alpha_k(1-P_{fk})^2P_{h2k}}\right\} \tag{8}$$

- 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

$$\frac{1}{\mu_k} = \frac{\lambda_{nk}(1-P_{bk})}{\lambda_{nk}(1-P_{bk})+\lambda_{hk}(1-P_{fk})}E_k[t_{H1k}] + \frac{\lambda_{hk}(1-P_{fk})}{\lambda_{nk}(1-P_{bk})+\lambda_{hk}(1-P_{fk})}E_k[t_{H2k}] \tag{9}$$

- 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 obtained as

$$E[t_{w\,max}] = \frac{E[O(z)]}{V_{trk}} = \alpha_k T_{dk}\beta \tag{10}$$

where $O(z)$ is the distance covered by the MS in the overlap area, which due to both the regular cellular

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layout and the mobility assumptions, it remains the same for any handover request. While β is given by:

$$\beta = \frac{4}{9}\left(\frac{\sqrt{3}}{3}\pi - \frac{3}{2}\right) \approx 0.1394 \quad (11)$$

Under the complete partitioning (CP) policy, all C channels available in a cell are partitioned into independent K subsets, with C_k ($1 \le k \le K$) channels allocated to class-k traffic and $C_1 + C_2 + \cdots + C_k \le C$. To efficiently assign the channels among traffic classes, an optimal channel partitioning scheme that can maximize channel utilization can be found in [11].

A. *Complete Partitioning (CP) with Handover Queuing Priority Scheme*

In this subsection, an analytical approach to queuing of handover requests scheme is developed. We denote C_k as the number of channels allocated to class-k traffic. In general, when there are free channels in the class-k subset, class-k new and handover calls are equally likely to get service. However, when all the C_k channels are occupied, class-k new calls are blocked whereas handover call requests are queued in their queue (Q) of Length L for a maximum time $t_{\mathrm{w\,max}}$, waiting for a free channel. If the queue is full, the class-k handover calls are dropped.

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

1) If $\Lambda(j) \neq \emptyset$, the class-k new and handover calls get service immediately in cell j.
2) If $\Lambda(j) = \emptyset$, the class-k new calls are blocked and the class-k 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:* The handover has not been performed within $t_{\mathrm{w\,max}}$ and the call is not ended before its maximum queuing time has expired.

According to the queuing scheme described, the queuing scheme can be modeled as an $M/M/C_k/S$ queue. Its state is defined as the sum of the number of class-k calls in service and the number of queued class-k handover requests. The state transition diagram is shown in Figure 2. The steady state probability of the state j, P_j can be derived as:

$$P_j = \begin{cases} \dfrac{\lambda_k^j}{j!\,\mu_k^j}\,P_0, & 0 \le j \le C_k \\ \dfrac{\lambda_k^{C_k}\,\lambda_{hk}^{j-C_k}}{C_k!\,\mu_k^{C_k}\,\prod_{i=0}^{j-C_k}[C_k\mu_k + i(\mu_k+\mu_w)]}\,P_0, & C_k+1 \le j \le C_k+L \end{cases} \quad (12)$$

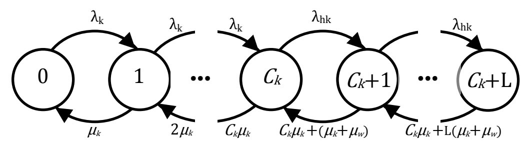


Figure 2. State Transition Diagram of CP Policy with Handover Queuing Priority Scheme.

where the rate $\lambda_k = \lambda_{nk} + \lambda_{hk}$ is the total class-k arrival rate and the idle system probability P_0 is

$$P_0 = \left\{ \sum_{j=0}^{C_k} \left[\frac{\lambda_k^j}{j!\,\mu_k^j}\right] + \sum_{j=C_k+1}^{C_k+L} \left[\frac{\lambda_k^{C_k}\,\lambda_{hk}^{j-C_k}}{C_k!\,\mu_k^{C_k}\,\prod_{i=0}^{j-C_k}[C_k\mu_k + i(\mu_k+\mu_w)]}\right] \right\}^{-1} \quad (13)$$

Class-k new call arrivals are blocked when all the available C_k channels are in use. Therefore, the steady state blocking probability for the class-k new call (P_{bk}) can be expressed as

$$P_{bk} = \sum_{j=C_k}^{C_k+L} P_j \quad (14)$$

Class-k handover failure occurs if a handover call arrival finds all class-k subset 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 class-k handover failure probability is given as

$$P_{fk} = P_{C_k+L} + \sum_{i=0}^{L-1} P_{C_k+i} P_{fk/i} \quad (15)$$

where the first term is describe the event that the class-k handover request queue is full. While the second term describes the event that the class-k 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 $P_{fk/i}$ gives the probability of handover failure for a class-k handover call request in the queue given the handover call request joined the queue as the (i+1) call. This is found as [8]:

$$P_{fk/i} = \frac{(i+1)\mu_w}{C_k\mu_k + i(\mu_k+\mu_w)} \quad (16)$$

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

$$P_{dki} = P_{Fk}\left[P_{h1k}(1-P_{Fk})^{i-1}P_{h2k}^{i-1}\right] \quad (17)$$

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

$$P_{dk} = \sum_{i=1}^{\infty} P_{dki} = \sum_{i=1}^{\infty} P_{Fk}\left[P_{h1k}(1-P_{Fk})^{i-1}P_{h2k}^{i-1}\right] = \frac{P_{Fk}P_{h1k}}{1-P_{h2k}(1-P_{Fk})} \quad (18)$$

The unsuccessful call probability of class-k traffic P_{usk} is also used as an important parameter for evaluating overall system performance and can be derived as

$$P_{usk} = P_{Bk} + P_{dk}(1-P_{Bk}) \quad (19)$$

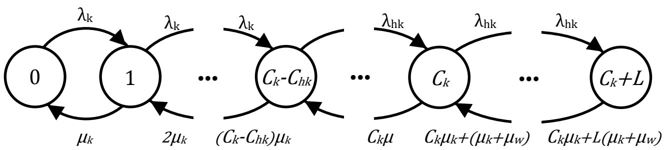


Figure 3. State Transition Diagram of CP Policy with Combination of Guard Channel and Handover Request Queuing Priority Scheme.

B. Complete Partitioning (CP) with Guard Channel and Handover Queuing Combination Priority 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 class-k subset, class-k new and handover calls are equally likely to get service. However, when the number of occupied channels is equal to threshold (C_k - C_{hk}), class-k new calls are blocked whereas class-k handover calls are gets service. When all the C_k channels are occupied, class-k handover call requests are queued in their queue (Q) 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.

As it is shown in Figure 3, the queuing scheme can be modeled as an $M/M/C_k/S$ queue. Its state is defined as the sum of the number of class-k calls in service and the number of queued class-k handover requests.

Let us analyze the state probabilities for the state transition diagram in Fig. 3, the steady state probability of the state j, P_j can be obtained as:

$$P_j = \begin{cases} \dfrac{\lambda_k^j}{j!\,\mu_k^j}\,P_0, & 0 < j \le C_k - C_{hk} \\ \dfrac{\lambda_k^{C_k-C_{hk}}\,\lambda_{hk}^{j-(C_k-C_{hk})}}{j!\,\mu_k^j}\,P_0, & C_k - C_{hk} < j \le C_k \\ \dfrac{\lambda_k^{C_k}\,\lambda_{hk}^{j-C_k}}{C_k!\,\mu_k^{C_k}\,\prod_{i=0}^{j-C_k}[C_k\mu_k + i(\mu_k+\mu_w)]}\,P_0, & C_k < j \le C_k + L \end{cases} \tag{20}$$

where the idle system probability P_0 is

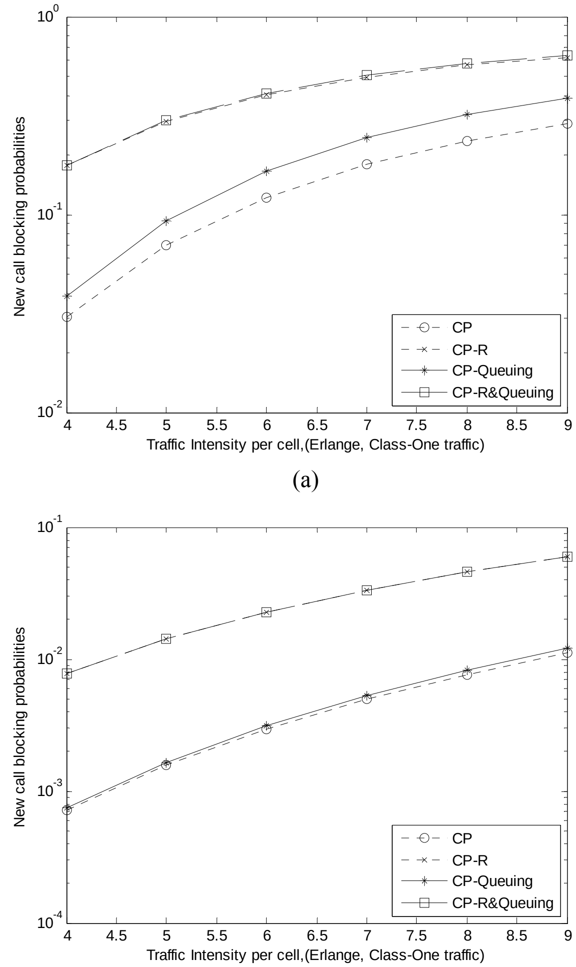
$$P_0 = \left\{ \sum_{j=0}^{C_k-C_{hk}} \left[\frac{\lambda_k^j}{j!\,\mu_k^j}\right] + \sum_{j=C_k-C_{hk}}^{C_k} \left[\frac{\lambda_k^{C_k-C_{hk}}\,\lambda_{hk}^{j-(C_k-C_{hk})}}{j!\,\mu_k^j}\right] + \sum_{j=C_k+1}^{C_k+L} \left[\frac{\lambda_k^{C_k}\,\lambda_{hk}^{j-C_k}}{C_k!\,\mu_k^{C_k}\,\prod_{i=0}^{j-C_k}[C_k\mu_k + i(\mu_k+\mu_w)]}\right] \right\}^{-1} \tag{21}$$

Class-k new call arrivals are blocked when (C_k-C_{hk}) channels are in use. Therefore, the steady state blocking probability for the class-k new call (P_{bk}) can be expressed as:

$$P_{bk} = \sum_{j=C_k-C_{hk}}^{C_k+L} P_j \tag{22}$$

Similar to the previous scheme, the class-k handover failure probability can be computed as (15).

Using (18) and (19), P_{dk} and P_{usk} can then be computed, respectively.



(a)

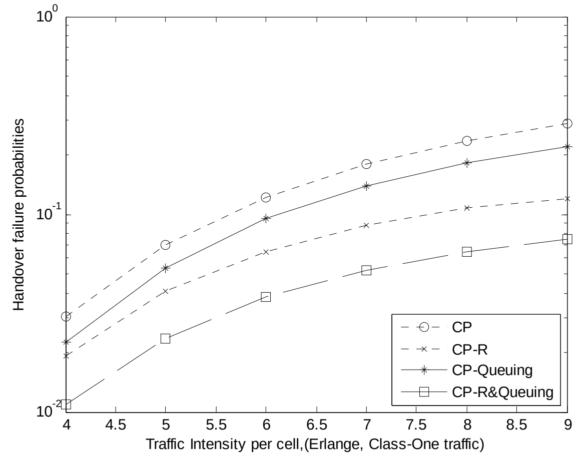
(b)

Figure 4. Analytical results for new call blocking probabilities as function of class-one traffic intensity of CP policy with different handover priority schemes.
(a) Class-One traffic. (b) Class-Two traffic.

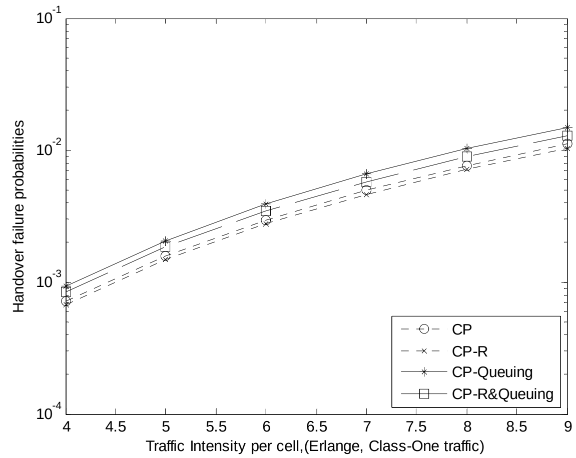
V. ANALYTICAL RESULT

In this section, we analyze the analytical results of the CP policy for multi-class traffic with the handover request queuing priority (named as CP-Queuing) scheme and the CP policy with the combination of guard channel and handover request queuing priority (named as CP-R&Queuing) scheme, which have been presented in section IV.

In the following, we consider from K-class of traffic in the cell two different class of traffic with the following parameter values: the total number of channel assigned for class-k traffic (C_1 = 8, C_2 = 4), reserved 25% of the total channel of each class for handover (C_{h1} = 2, C_{h2} = 1), the average duration time of class-k calls (T_{d1} = 180, T_{d2} = 540), the handover request queue length for class-k traffic are (L_1 = 4, L_2 = 2) and the traffic intensity of class-two traffic is 0.1 of the traffic intensity of class-one traffic.

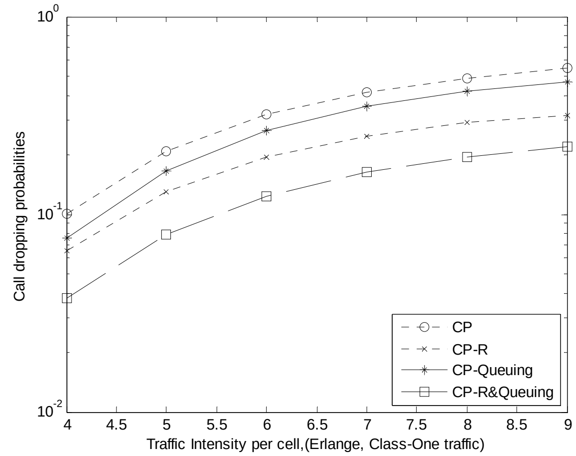


(a)

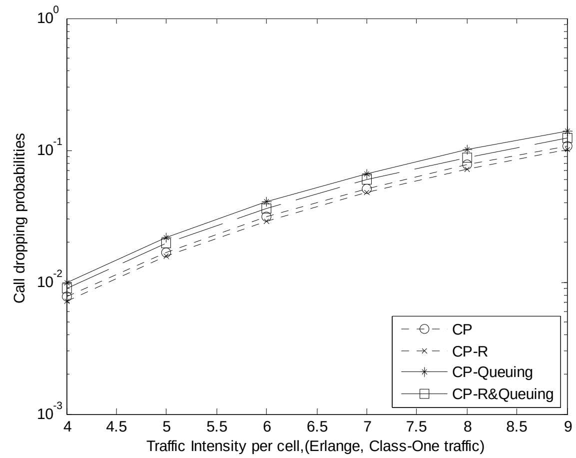


(b)

Figure 5. Analytical results for handover failure probabilities as function of class-one traffic intensity of CP policy with different handover priority schemes.
(a) Class-One traffic. (b) Class-Two traffic.



(a)



(b)

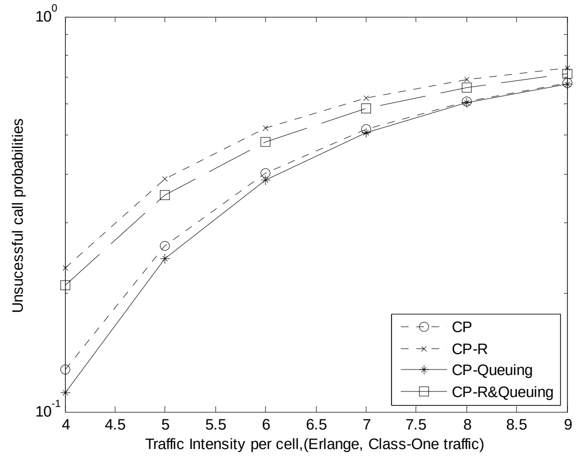
Fig. 6. Analytical results for call dropping probabilities as function of class-one traffic intensity of CP policy with different handover priority schemes.
(a) Class-One traffic. (b) Class-Two traffic.

Figures 4-7 shows analytical results of CP policy under different handover priority schemes in terms of P_{bk}, P_{fk}, P_{dk} and P_{usk} respectively. In these graphs, the behavior of CP with no priority (named as CP) and CP with fixed channel reservation (guard channel) priority (named as CP-R) scheme examined in [7] have been also considered.

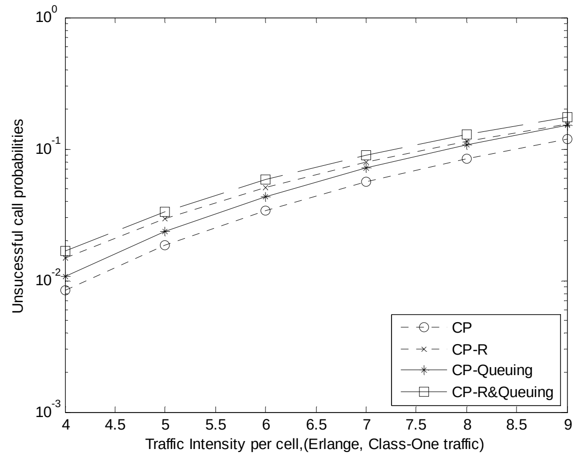
In Figures 4(a) and 4(b), the analytical results for class-k new call blocking probability show that the handover queuing (CP-Queuing) priority scheme achieves a better performance than the handover queuing with guard channel combination (CP-R&Queuing) priority scheme for class-one and class-two traffic respectively. However, for class-two traffic the CP-Queuing scheme is very close in performance to non-prioritized CP scheme, it is slightly higher for class-one traffic. The difference between the two schemes is duo to that the handover call requests which wait in a queue will occupy the channel as soon as the condition of channel varies from busy to free. Therefore, the new calls have smaller opportunity of occupying channel than the handover calls.

From the Figures 5(a) and 6(a), we can see that the combination (CP-R&Queuing) priority scheme for class-one traffic in terms of handover failure probability (P_{fk}, see Figure 5(a)) and also of call dropping probability (P_{dk}, see Figure 6(a)) is the best among all other different priority schemes, and the performance difference between it and other schemes increase as the class-one traffic intensity increased. However, for class-two traffic the non-prioritized CP scheme and CP-R scheme attain better results than our schemes as shown in Figures 5(b), 6(b).

From the performance of unsuccessful call probability (P_{usk}, i.e. 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) of class-one and class-two traffic shown in Figures 7(a), 7(b) respectively, the handover queuing (CP-Queuing) priority scheme and non-prioritized CP scheme have a good response over other priority schemes. In Figure 7(a), the CP-Queuing scheme is less than non-prioritized CP scheme in

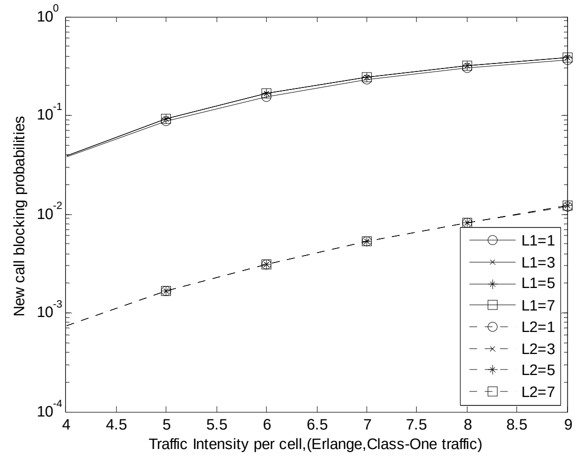


(a)

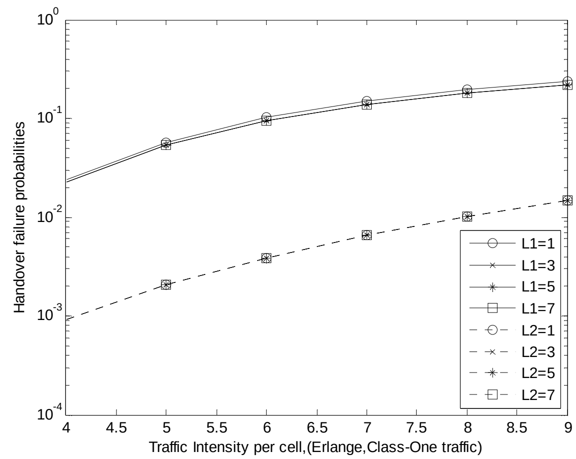


(b)

Figure 7. Analytical results for unsuccessful call probabilities as function of class-one traffic intensity of CP policy with different handover priority schemes.
(a) Class-One traffic. (b) Class-Two traffic.



(a)



(b)

Figure 8. The effect of the handover request queue length (L_k) on the class-one and class-two traffic:

a)New Call Blocking Probability b)Handover Failure Probability

terms of P_{usk} at low traffic intensity. And as the class-one traffic intensity increase the performance begin to close to each other till be the same. However, for class-two traffic the non-prioritized CP scheme is the best performance.

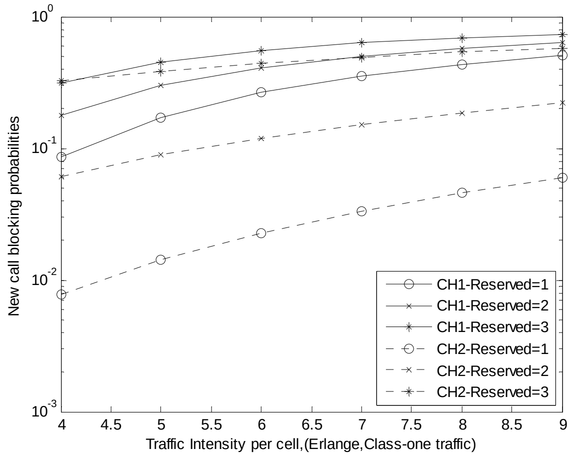
For CP-Queuing priority scheme and as we can see in Figure 8, the increasing of handover request queuing length (L_k) has a approximately the same effect on the performance of new call blocking probability (Figure 8(a)) and handover failure probability (Figure 8(b)) for both class of traffic.

In the CP-R&Queuing priority scheme, the new call blocking probability increases significantly as the number of channel reservation increase as shown in Figure 9(a). The performance difference for class-two traffic is significantly higher than the class-one traffic; this is due to the small number of channel assigned for this class. This increase in P_{bk} results with a decrease in the handover failure probability as can be seen in Figure 9(b). However, for class-two traffic as the reserved channel increase it adopt with a little decrease in P_{fk}.

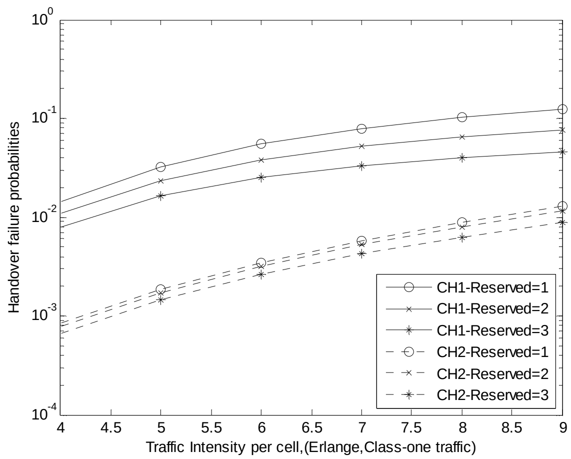
In conclusion, at low traffic intensity, the CP policy with queuing of handover requests scheme for class-one traffic effectively reduce the $P_{bk}$and P_{usk} at the expense of a little increase in the P_{fk} and P_{dk} than did the combination of handover request queuing with guard channel priority scheme. However, as traffic intensity increase, the performance difference in terms of $P_{bk}$and P_{usk}decrease to be very close and for $P_{fk}$and $P_{dk}$is increased. For class-two traffic, the non-prioritized CP priority scheme attains good result in all performance parameters.

VI. CONCLUSION

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



(a)



(b)

Figure 9. The effect of the number of reserved channel for handover on the class-one and class-two traffic :
a) New Call Blocking Probability b) Handover Failure Probability.

Analytical results have shown that: for class-one traffic, the CP policy with queuing of handover requests scheme provides a good result at low traffic intensity. However at high traffic intensity, it is recommended to use the combination of handover request queuing with guard channel priority scheme. For class-two traffic, we have seen that the CP policy with no priority scheme attains the best performance results.

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