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Performance Analysis of Priority-Based Multi-class Traffic Channel Reservation Scheme in LEO-MSS

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Abstract. This paper proposes a channel reservation scheme for handovers which efficiently supports multi-class traffic in low earth orbit mobile satellite systems (LEO-MSS). Analytical methods are developed for evaluating the performance of priority-based multi-class traffic channel reservation scheme (PMCR). The new call blocking probability and handover failure probability of PMCR for each traffic are deduced. The simulation results verify the correctness and accuracy of the proposed scheme and show that the new call blocking probability of the system is lower than fixed channel reservation (FCR) and handover call performance of services of high levels can be improved by the introduction of priorities.

Keywords: low earth orbit (LEO), multi-class traffic, priority, handover, channel reservation.

1. Introduction

Low earth orbit mobile satellite systems (LEO-MSS) are anticipated to serve mixed populations of users in the future due to advantages such as global coverage, low transmission loss and short transmission delay. Owing to fast movement of satellites with respect to the earth's surface, handover occurs frequently during a call's lifetime. From users' point of view, blocking a handover call is generally considered less desirable than blocking a new call. Thus, handover calls should be prioritized rather than new calls. In actual communication systems, more than one class of service are considered. Obviously, high priority service such as military service, business service should obtain a better quality of service (QoS), while low priority service has to tolerate and sacrifice.

Up to now, various channel assignment schemes have investigated the reservation of channels for handover calls. The GH scheme [1] envisages a high-quality service named GH service and guarantees the success of it. In [2], two FCR schemes with or without queue are studied. However, single traffic is considered in these papers. Although there have been publications discussing multi-traffic in LEO-MSS (e.g. [3]-[5]), to the best of our knowledge, FCR scheme with multi-class traffic of different priorities has not been researched. The contribution of this paper is to introduce multi-class traffic into channel reservation scheme and set different admission thresholds according to different priorities of services and call types.

2. Channel Reservation Procedure for Multi-class Services

The proposed procedure is based on a street of coverage, which consists of a set of contiguous cells. Fig. 1 illustrates the mobility model which consists of N rectangular bounded cells, modeled in [1], [6]-[8]. The speed and direction of the mobile terminal (MT) can be neglected compared to the LEO satellite, thus the MT can be thought of crossing the network with a relatively constant speed of sub-satellite point V_{trk}, but in the

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opposite direction. The target cell for a handover call is the subsequent cell along the direction of the MT's motion.

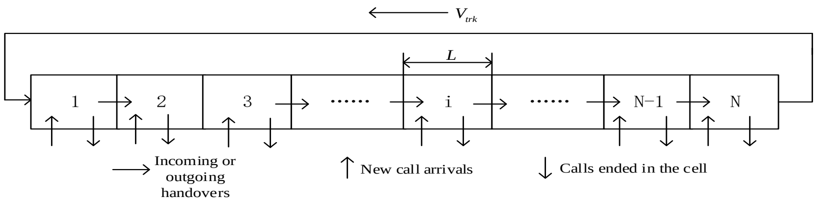

Fig. 1: Rectangular cell system model for the LEO-MSS network.

In order to be consistent with other previous publications (e.g. [1], [5], [9]-[11]), some assumptions are adopted in this paper. The new and handover call arrival processes are independent Poisson processes; the call duration time and the channel holding time are exponentially distributed; the average call origination rate is independent of the number of calls in progress; a uniform traffic per cell is considered.

The system model parameters are defined: L denotes the length of each cell; $\lambda_n^{(i)}$ and $\lambda_h^{(i)}$ denote the mean new call arrival rate and the mean handover call arrival rate per cell for class *i* service respectively; C denotes the total number of channels assigned to each cell; for $co = \{co_1, co_2, ..., co_m\}$, co_i denotes the proportion of class *i* service of whole input traffic. The well-known QoS performance parameters are investigated: $P_b^{(i)}$, blocking probability of new call attempts of class *i* service; $P_f^{(i)}$, handover failure probability of class *i* service.

In PMCR scheme, *m*-classes services are considered, new calls of all classes have the same priority, while handovers of class of a bigger order are superior to ones of a lower order. Besides, handovers have higher priority than new calls. A set of parameters $K = \{k_0, k_1, ..., k_m\}$ is used as thresholds to distinguish the priorities among different services and call types, and to determine whether a new or handover call of some class should be accepted according to the condition of channel usage in the target cell. Among them, k_0 denotes the admission threshold of new calls of all classes of service, k_i denotes the admission threshold of handover calls of class *i* service. The thresholds are satisfied with the relation $k_0 \le k_1 \le ... \le k_m$, and k_m generally takes value of *C*. Fig. 2 shows the set of thresholds applied into the channel reservation scheme.

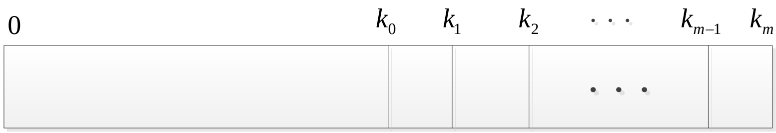

Fig. 2: (*m*+1) thresholds of channel reservation.

The procedure of PMCR scheme is as follows:

- When a new call generates, if the number of occupied channels of the original cell is less than k_0, a channel is allocated and the new call is admitted. If not, the call is blocked at set up.
- When a handover occurs, the call is judged by its class. If it belongs to class *i* service and the number of occupied channels is less than k_i, a channel is allocated and the handover is admitted. If not, the handover is terminated.

3. The Analytical Approach Used for Performance Evaluation

Analysis of the Mobility Model and Traffic. Constellation mobility is characterized by a dimensionless parameter γ defined as the ratio between the mean call duration time T_{call} and the user sojourn time T_{cell} in a cell [1], [10]

$$\gamma = T_{call} / T_{cell}, \tag{1}$$

where T_{cell} is given by L / V_{trk}. The handover probabilities in source/transit cell P_{h1} / P_{h2} can be expressed as [12].

$$P_{h1} = \gamma(1-e^{-1/\gamma}) \qquad P_{h2} = e^{-1/\gamma}. \tag{2}$$

The handover requests are subjected to the condition of flux equilibrium in a cell between incoming and outgoing handovers. This equilibrium condition will be separately applied for each class of service. Therefore, the handover call arrival rates of each class of service are reached as

$$\lambda_h^{(i)} = \lambda_n^{(i)} \frac{P_{h1}(1-P_b^{(i)})}{1-P_{h2}(1-P_f^{(i)})} \quad i = 1, 2, ..., m, \tag{3}$$

and the total call arrival rate in a cell includes both new calls and handovers of all classes of service. The channel holding time in a cell follows an exponential distribution with average rate μ. Since a channel can be occupied by a new call or a handover of any class of service, expected channel holding time in each situation is weighted with its occurrence probability. These products add up together to the mean channel holding time $1/\mu$. For all classes of service, expected value of channel holding time in the source cell and transit cells are $E[T_{H1}]$ and $E[T_{H2}]$ respectively. So the mean channel holding time is given by

$$\frac{1}{\mu} = P_1 E[T_{H1}] + P_2 E[T_{H2}], \tag{4}$$

where P_1/P_2 indicates the probability that a channel is occupied by a new call or a handover, including all classes of service. The expressions of P_1, P_2 and $E[T_{Hi}]$ are given by

$$P_1 = \frac{\sum_{i=1}^{m} \lambda_n^{(i)}(1-P_b^{(i)})}{\Lambda} \quad P_2 = \frac{\sum_{i=1}^{m} \lambda_h^{(i)}(1-P_f^{(i)})}{\Lambda}, \tag{5}$$

$$E[T_{Hi}] = T_{call}(1-P_{hi}) \quad i = 1, 2, \tag{6}$$

where Λ represents the traffic accepted by the cell, given by

$$\Lambda = \sum_{i=1}^{m} \lambda_n^{(i)}(1-P_b^{(i)}) + \sum_{i=1}^{m} \lambda_h^{(i)}(1-P_f^{(i)}). \tag{7}$$

A Markov Chain Approach. Each cell can be modeled as an M/M/C/C system with non-homogeneous arrival rates. The state of this system is defined as the sum of the number of calls in service. The Markov chain model associated with each cell is shown in Fig. 3.

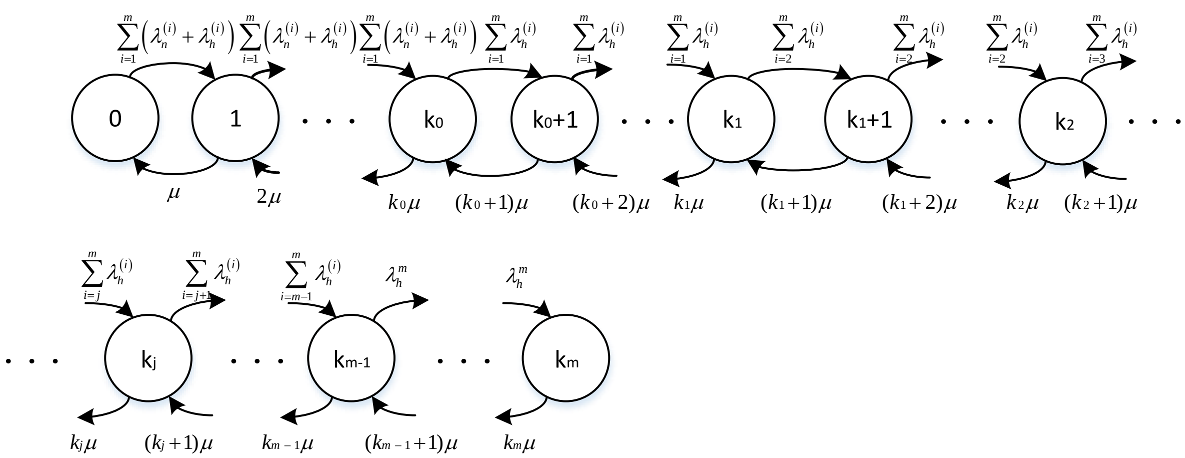

Fig. 3: Markov chain model for PMCR.

Let *j* be the state number, thus *j* is between 0 and C. If *j* is between 0 and k_0-1, new and handover calls of all classes of service are admitted, so the arrival rate is $\sum_{i=1}^{m} \lambda_n^{(i)} + \lambda_h^{(i)}$. If *j* is between k_0 and k_1-1, new calls are all blocked while handover calls are all admitted, so the arrival rate is $\sum_{i=1}^{m}\lambda_h^{(i)}$. If j is between k_1 and k_2-1, only handover calls of class 2 to m will be admitted, so the arrival rate is $\sum_{i=2}^{m}\lambda_h^{(i)}$. In this way we derive that if j is between k_{t-1} and k_t-1, only handovers of class t to m will be admitted, so the arrival rate is $\sum_{i=t}^{m}\lambda_h^{(i)}$, where t ranges from 1 to m. Let π_j be the steady state probability of state j, the "rate-up = rate-down" equations for all of the states are as follows:

$$\begin{cases}(\sum_{i=1}^{m}\lambda_n^{(i)}+\sum_{i=1}^{m}\lambda_h^{(i)})\pi_0=\mu\pi_1 & j=0\\ (\sum_{i=1}^{m}\lambda_n^{(i)}+\sum_{i=1}^{m}\lambda_h^{(i)}+j\mu)\pi_j=(\sum_{i=1}^{m}\lambda_n^{(i)}+\sum_{i=1}^{m}\lambda_h^{(i)})\pi_{j-1}+(j+1)\mu\pi_{j+1} & 1\le j<k_0\\ (\sum_{i=1}^{m}\lambda_h^{(i)}+k_0\mu)\pi_{k_0}=(\sum_{i=1}^{m}\lambda_n^{(i)}+\sum_{i=1}^{m}\lambda_h^{(i)})\pi_{k_0-1}+(k_0+1)\mu\pi_{k_0+1} & j=k_0\\ (\sum_{i=t}^{m}\lambda_h^{(i)}+j\mu)\pi_j=\sum_{i=t}^{m}\lambda_h^{(i)}\pi_{j-1}+(j+1)\mu\pi_{j+1} & k_{t-1}<j<k_t, t=1,2,...,m\\ (\sum_{i=t+1}^{m}\lambda_h^{(i)}+j\mu)\pi_j=\sum_{i=t}^{m}\lambda_h^{(i)}\pi_{j-1}+(j+1)\mu\pi_{j+1} & j=k_t, t=1,2,...,m-1\\ k_m\mu\pi_{k_m}=\lambda_h^{(m)}\pi_{k_m-1} & j=k_m\end{cases} \quad (8)$$

Using the above equations, along with the normalization condition

$$\sum_{j=0}^{C}\pi_j=1, \quad (9)$$

thus

$$\begin{aligned}\pi_0=[1&+\sum_{j=1}^{k_0}\frac{(\sum_{i=1}^{m}\lambda_n^{(i)}+\sum_{i=1}^{m}\lambda_h^{(i)})^j}{j!\mu^j}+\sum_{j=k_0+1}^{k_1}\frac{(\sum_{i=1}^{m}\lambda_n^{(i)}+\sum_{i=1}^{m}\lambda_h^{(i)})^{k_0}(\sum_{i=1}^{m}\lambda_h^{(i)})^{j-k_0}}{j!\mu^j}+...\\ &+\sum_{j=k_{t-1}+1}^{k_t}\frac{(\sum_{i=1}^{m}\lambda_n^{(i)}+\sum_{i=1}^{m}\lambda_h^{(i)})^{k_0}(\sum_{i=1}^{m}\lambda_h^{(i)})^{k_1-k_0}...(\sum_{i=t-1}^{m}\lambda_h^{(i)})^{k_{t-1}-k_{t-2}}(\sum_{i=t}^{m}\lambda_h^{(i)})^{j-k_{t-1}}}{j!\mu^j}+... ,\\ &+\sum_{j=k_{m-1}+1}^{k_m}\frac{(\sum_{i=1}^{m}\lambda_n^{(i)}+\sum_{i=1}^{m}\lambda_h^{(i)})^{k_0}(\sum_{i=1}^{m}\lambda_h^{(i)})^{k_1-k_0}...(\sum_{i=m-1}^{m}\lambda_h^{(i)})^{k_{m-1}-k_{m-2}}(\sum_{i=m}^{m}\lambda_h^{(i)})^{j-k_{m-1}}}{j!\mu^j}]^{-1}\end{aligned}$$

$$\pi_j=\begin{cases}\dfrac{(\sum_{i=1}^{m}\lambda_n^{(i)}+\sum_{i=1}^{m}\lambda_h^{(i)})^j}{j!\mu^j}\pi_0 & 1\le j\le k_0\\ \dfrac{(\sum_{i=1}^{m}\lambda_n^{(i)}+\sum_{i=1}^{m}\lambda_h^{(i)})^{k_0}(\sum_{i=1}^{m}\lambda_h^{(i)})^{k_1-k_0}...(\sum_{i=t-1}^{m}\lambda_h^{(i)})^{k_{t-1}-k_{t-2}}(\sum_{i=t}^{m}\lambda_h^{(i)})^{j-k_{t-1}}}{j!\mu^j}\pi_0 & k_{t-1}<j\le k_t\end{cases}. \quad (10)$$

The new call blocking probability for each class of service is the sum of the probabilities that the state number is no less than k_0, given by

$$P_b^{(i)} = P_b = \sum_{j=k_0}^{C} \pi_j \quad i = 1, 2, ..., m. \tag{11}$$

The probability of failure for handover call of class *i* service depends on its own handover threshold k_i, which is defined as the sum of probabilities that the state number is no less than k_i, given by

$$P_f^{(i)} = \sum_{j=k_i}^{C} \pi_j \quad i = 1, 2, ..., m. \tag{12}$$

The QoS parameter channel utilization to reflect the system performance is given by

$$\eta = \frac{1}{C} \sum_{j=0}^{C} j\pi_j. \tag{13}$$

A recursive approach is needed to compute $P_b^{(i)}$ and $P_f^{(i)}$, because $\lambda_h^{(i)}$ and μ depend on $P_b^{(i)}$ and $P_f^{(i)}$ through Eq. 3-5. The system parameters are: K, C, $\rho_n^{(i)}$, T_{call} and γ. We start with the iterations with $P_b^{(i)}=0$ and $P_f^{(i)}=0$, compute μ and steady-state probabilities according to Eq. 10, then obtain new $P_b^{(i)}$ and $P_f^{(i)}$ according to Eq. 11 and Eq. 12 respectively. These values are averaged with their counterparts at the previous step. A new iteration starts with these averaged value of $P_b^{(i)}$ and $P_f^{(i)}$. The iterative method is stopped when the relative differences between the $P_b^{(i)}$ and $P_f^{(i)}$ computed in two subsequent steps are both below 10^{-3} for each class of service.

4. Simulation Results and Comparisons

The system parameters used in simulation are:

1) All the cells have rectangular shape and a length L of 425 kilometers. V_{trk} is fixed to about 7.41km/s.
2) The call holding times are exponentially distributed with average call duration T_{call} =3min.
3) Twenty channels per cell are available with FCA.
4) Three different classes of service are considered, so *m*=3 and $K = \{k_0, k_1, k_2, k_3\}$.
5) The proportions are considered the same for each class of service, for the convenience of calculation, i.e. $co^{(i)} = 1/3$, $\rho_n^{(i)} = 1/3 \times \rho_n$, *i*=1,2,3.

In the FCR scheme, C_h channels are reserved for handover calls and no priority is considered. Actually, FCR is a particular situation of PMCR with the same number of total channels C, where $k_0 = C - C_h$ and $k_1 = k_2 = ... = k_m = C$. Let us denote PMCR with threshold K as $PMCR(k_0, k_1, ..., k_m)$ and hence FCR with C total channels and $C - k_0$ reserved channels is the same as $PMCR(k_0, C, ..., C)$, which we denote as $FCR(k_0, C)$ for short. The physical meaning of $FCR(k_0, C)$ can be thought of as *m* classes of service with the same priority, thus *m* handover thresholds take the same value C.

From the view of the system, $PMCR(k_0, k_1, ..., C)$ and $FCR(k_0, C)$ are comparable because of the same number of total channels and reserved channels. Two performance metrics are considered, i.e. channel utilization and new call blocking probability. When the state gets to k_0, the PMCR scheme will accept handovers according to priorities. More precisely, the PMCR will refuse handovers whose class order is smaller than or equal to *j* after the state arrives at k_j even if there's no handovers of senior service in the cell. While the FCR scheme won't refuse a handover until the state reaches C. Therefore, the PMCR leads to a little poorer channel utilization than the FCR. We denote $CS(C)$ as the complete sharing scheme with C total channels. Fig. 4 shows the comparison in channel utilization between the PMCR and the FCR scheme, and the CS scheme is used as an assistant reference.

When the state is below k_0, the PMCR and the FCR perform the same logic and have similar steady-state probability expression $\pi_j = \frac{(\sum_{i=1}^{m} \lambda_n^{(i)} + \sum_{i=1}^{m} \lambda_h^{(i)})^j}{j!\mu^j} \pi_0$. However, when the state exceeds k_0, different logics to admit the handovers are performed, causing differences in the steady-probabilities of every states. Fig. 5 illustrates the comparison in new call blocking probability between the PMCR and the FCR scheme. In given traffic limit ($\rho_n \leq 10erl$) or in the QoS limit ($P_b < 0.24$), the new call blocking probability of the PMCR is lower than that of the FCR, which indicates an advantage of the introduction of priorities.

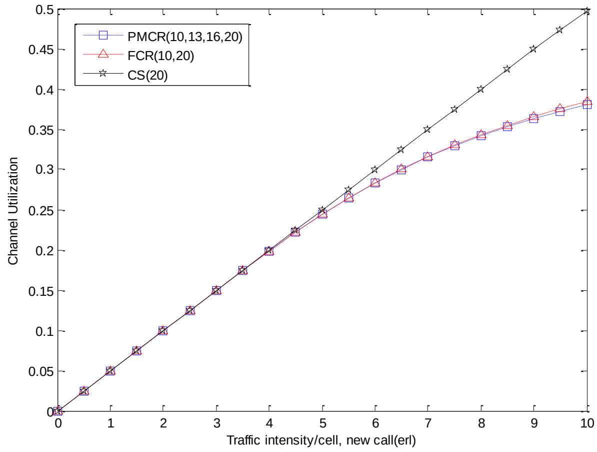

Fig. 4: Channel utilization for PMCR, FCR and CS.

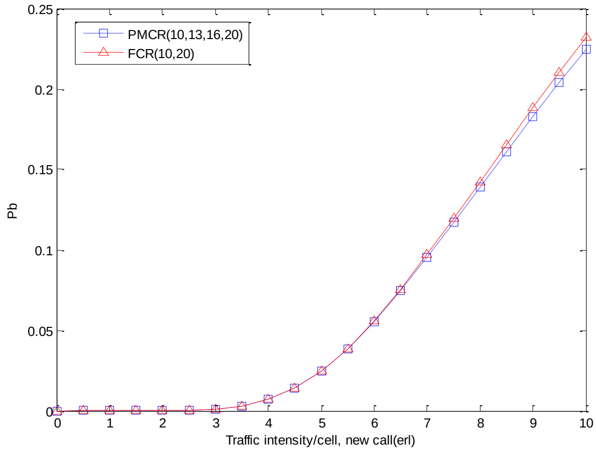

Fig. 5: New call blocking probability for PMCR and FCR.

From the view of specific class of service, the performance metric of handover call failure probability of its own is considered, which reveals its priority. Service with a higher priority must be offered a stricter ensurance to handovers by reserving more channels. Fig. 6 to Fig. 8 show the comparison of handover failure probability of the same class of service for the PMCR and the FCR scheme. Services with the same number of public channels and reserved channels are regarded as the same class of service, for they have the same thresholds for new calls and handovers.

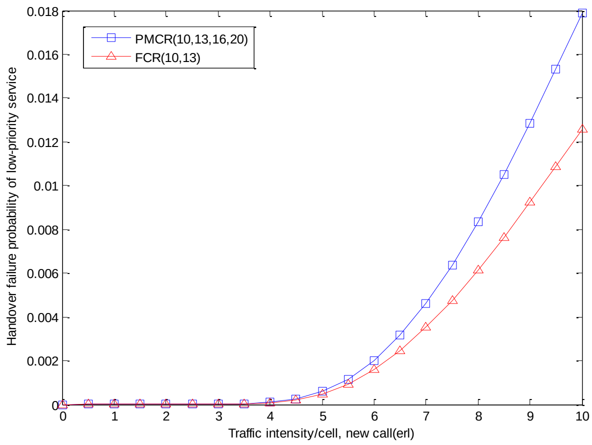

Fig. 6: Handover failure probability of low-priority service.

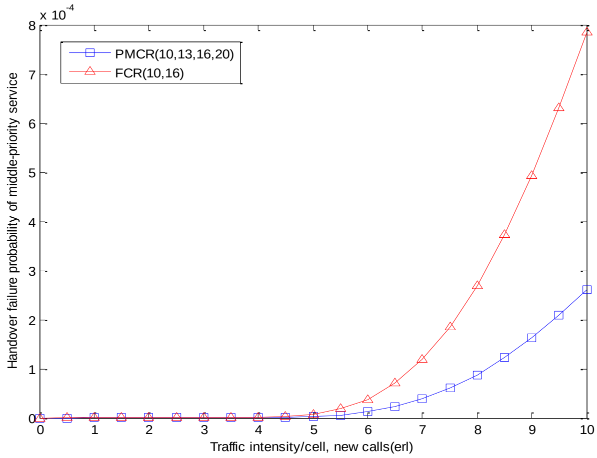

Fig. 7: Handover failure probability of middle-priority service.

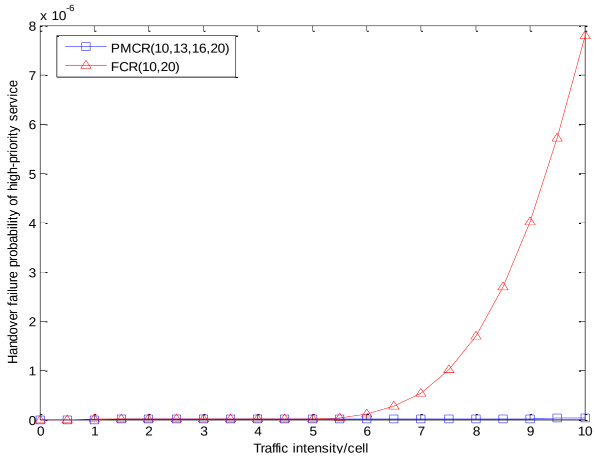

Fig. 8: Handover failure probability of high-priority service.

Firstly compared among different classes of service, with the promotion of priority, the handover failure probability can be greatly decreased, no matter for the PMCR or the FCR. Then handover failure probability of the same service adopting the PMCR and the corresponding FCR is compared. If the service is of low priority (See Fig. 6), its handover failure probability of PMCR is higher than that of FCR. However, if the service is of high priority (See Fig. 7 and Fig. 8), its handover failure probability of PMCR is lower than that of FCR. This means service with a high priority is guaranteed of a better QoS compared PMCR with FCR, and this is in accord with priorities assigned to each class of service.

5. Summary

This paper has introduced priorities into channel reservation scheme for LEO-MSS, and proved that the new call blocking probability and the handover failure probability of the high priority service of the PMCR scheme are both lower than those of the FCR scheme. In the next step, a comprehensive performance metric will be formulated and the impact of the variation of K on this metric will be studied to obtain the best performance of the PMCR scheme.

6. Acknowledgements

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7. References

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