Call Admissibility for Multiservice Traffics in Low-Earth Orbit (LEO) Satellite Networks*

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Abstract

In a LEO system, a user's call may be handed over constantly from one satellite to another due to visibility changes caused by satellites' movements. The resultant system performance will degrade if handover calls occur frequently but few are transferred successfully. This paper considered a multiservice LEO system that allows different bandwidth/channel allocations (so-called multirate) on-demand for different calls. We proposed a novel call admission control (CAC) strategy called guard-channel policy over SMDP that applies SMDP theory to find optimal channel reservation and reserves appropriate channels for various types of handover calls. The study manifested that this SMDP-based guard-channel policy performed better than general ones like coordinate-convex type and ordinary SMDP, on the premise of CoS guarantee to handover calls, under various traffic conditions.

Ⅰ. Introduction

The International Mobile Telecommunications (IMT)-2000, proposed by International Telecommunication Union (ITU), is considered to be the standard for the future personal communication system. One of the essential issues in IMT-2000 is how the terrestrial cellular network and the mobile satellite system are integrated in order to support multirate communications and global roaming [1]. Satellite communications can be a great auxiliary for the areas that terrestrial mobile system cannot be easily constructed. Moreover, it also partake the traffic of terrestrial networks on the Earth. In terms of attenuation, propagation delay, and installation cost, a Low-Earth Orbit (LEO) satellite system deployed at an altitude from 500 km to 2000 km has becoming an attractive solution. Examples are Iridium, Globestar, Teledesic, and M-star [2].

The satellite movements (i.e., circulating around the Earth by moving along their predetermined orbit) aroused the problems of both mobility management and admission control in a LEO satellite network. In the Iridium system, for example, the satellites moving speed approaches to 26,000 km/hr or equivalently 8 km/sec. This speed is much faster than the mobility of a ground user. Under such circumstance, the footprint of a satellite, defined as an effective region covered by satellite transceivers' radio, also shifts quickly. This may interrupt or even disconnect an in-processing call. To avoid the service interruption, all in-progress calls have to be taken care by a succeeding satellite that covers the original footprint, as the user C in Figure 1. Such transferring a call from one satellite to another is called *satellite handover.* Consequently, several user calls would be served by a number of satellites before completion.

Many admission control policies were proposed and have been applied to multiservice

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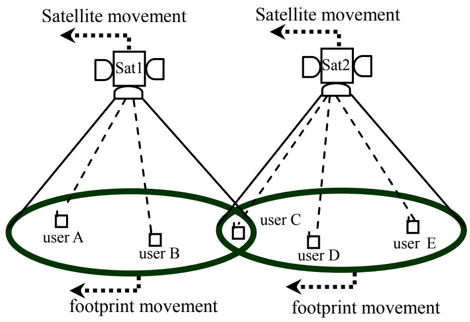

Figure 1. Concept of satellite handover.

environments. They can be classified as two types: coordinate convex (CC) and non-coordinate convex. Some major CC policies are explained as follows: (1) Complete sharing (CS) policy: it always grants access to an arriving call as long as the residual channel is available; (2) Complete partitioning (CP) policy: it partitions the total channels for each type of traffics for exclusive use; (3) Threshold-type policy (TH): it blocks an arriving call only when the acceptable number of calls of the same type is greater than a predefined maximum amount. Although the CC policies are easier to be analyzed, they turns out can obtain optimum result only under some specific conditions.

The most popular noncoordinate convex type policy is using the S*emi-Markov Decision Process* (SMDP) approach [3]. In the SMDP, making a decision from various options for a state will gain different rewards, and the optimal policy that give the maximum average reward can be found via different formulations. In [4], the authors proposed a genetic method to obtain a near-optimal CAC for multimedia wireless networks and showed some numerical results to illustrate the concept. Reference [5] also applied SMDP formulation to find the optimal CAC for multicell model. One can extend the results for wireless networks to LEO scenarios, but they did not guarantee the class of service (CoS) for handover calls, neither the multirate and broadband environments. Thus, there reveals the opportunity of adding resource reservation scheme to improve the CAC performance. In this paper, a high performance CAC policy for multiservice broadband LEO satellite networks is proposed. We consider a multirate broadband LEO system and derive a guard-channel policy that reserves an appropriate amount of channels to assure CoS of handover calls. The optimal reservation value is found by applying SMDP linear programming formulation under certain CoS constraints.

The remaining sections of this paper are organized as follows: Section II described network model and relative product-form solution. Section III illustrated the SMDP formulation and explained the SMDP-based guard-channel policy for multiservice networks. Numerical results and discussion are given in Section IV. Finally, we conclude our discussion in Section V.

Ⅱ. Network Model

We consider a LEO satellite system supporting multirate traffics and model the effective footprint of a satellite as a hexagon (called a cell) inscribed into the footprint, as shown in Figure 2. Each satellite has a total *C* channel units available. We assume that new call arrivals in a cell follow a Poisson process. Both call session time (the time a mobile unit experienced until it finished) and call dwell time (the time a mobile stays in a cell before being handed over) are exponentially distributed and are independent from cells to cells. Using the single-cell approximation in [6], where the authors assumed that the handover calls also follow the same model as the new calls but with a rate equal to the average of the handover rates of all states. By doing that, we only need single-cell information and find the CAC policy on per-cell basis.

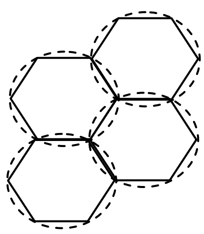

Figure 2. LEO satellite footprint equivalent cell.

Suppose that each cell has total C channels and supports K different types of calls. Each type of calls demands c_i unit of channels, where $1 \le i \le K$ and $c_1 \le c_2 \le \cdots \le c_K$. The call admission problem in a cell can be modeled by a Markov process with state vector $\mathbf{x} = [n_1, n_2, \ldots, n_k]$, where n_i is the number of type-i calls in processing. Assume that the arrival rate of new type-i calls is $\lambda_{i,n}$, and the arrival rate of handover calls is $\lambda_{i,h}$, then the total arrival rate of type-i call is $\lambda_i = \lambda_{i,n} + \lambda_{i,h}$. The mean session time of type-i calls is $1/\mu_{i,s}$, and the mean dwell time of type-i calls is $1/\mu_{i,h}$, resulting in the mean holding time of a type-i call to be $1/\mu_i = 1/(\mu_{i,s} + \mu_{i,h})$.

The action of the system takes in a particular state upon a call arrival is called a decision. If the decision in all states are specified, they collectively are called the admission policy of the system. We assume that there is no queuing facility for the call, and thus a rejected call will leave the system without affecting the calls in progress.

III. Multiservice CAC Policy

A. Ordinary SMDP-based call admission policy

With the traffic characteristics described in Section 2, we first model the call admission problem in a cell as a SMDP, then apply data transformation technique (uniformization) to convert the SMDP model into a discrete-time MDP in which for a stationary process the average reward per unit time keep unchanged [3]. A SMDP state of the system is given by the vector $\mathbf{x} = [n_1, n_2, \ldots, n_k]$,and at a decision epoch, the action space $\mathbf{A}$ containing all possible decisions upon arrival is

$$\mathbf{A} = \{(a_{1,n}, a_{2,n}, \ldots, a_{K,n}, a_{1,h}, a_{2,h}, \ldots, a_{K,h}) : a_{i,\delta} \in \{0,1\}, i = 1,2,\ldots,K\} \quad (1)$$

where

$a_{i,n}$ = 0 (or 1) : reject (or accept) the type-i new call, and

$a_{i,h}$ = 0 (or 1) : reject (or accept) the type-i handover call.

Also, we define the following parameters:

- The action space of state $\mathbf{x}$, $\mathbf{A_x}$:

$$\mathbf{A_x} = \{a \in \mathbf{A} : \ a_i = 0 \ \ if \ \ \mathbf{x}_i^+ \notin \Omega\}, \quad (2)$$

where Ω is the set of containing all admissible states and

$$\Omega = \left\{ \mathbf{x} \middle| \ \sum_{i=1}^{K} n_i \cdot c_i \le C \ \text{ and } \ n_i \ge 0 \right\}. \quad (3)$$

- The average sojourn time in state $\mathbf{x}$ when action a is chosen:

$$\tau(\mathbf{x},a) = \left[\sum_{i=1}^{K} n_i(\mu_{i,s} + \mu_{i,h}) + \sum_{i=1}^{K} \lambda_{i,n} a_{i,n} + \sum_{i=1}^{K} \lambda_{i,h} a_{i,h} \right]^{-1}. \quad (4)$$

- The transition probability that at next decision epoch the system will be in state $\mathbf{y}$ given that the action a is chosen by the current state $\mathbf{x}$ is

$$P(\mathbf{y}|\mathbf{x},a) = \begin{cases} (a_{i,n}\lambda_{i,n} + a_{i,h}\lambda_{i,h})\tau(\mathbf{x},a), & \mathbf{y} = \mathbf{x}_i^+, \ i = 1,\ldots,K \\ n_i(\mu_{i,s} + \mu_{i,h})\tau(\mathbf{x},a), & \mathbf{y} = \mathbf{x}_i^-, \ i = 1,\ldots,K \\ 0, & otherwise \end{cases} . \quad (5)$$

- The expected reward obtained until the next decision epoch given that the action a is chosen by the current state $\mathbf{x}$ is

$$r(\mathbf{x}, a) = \sum_{i=1}^{K} n_i c_i. \quad (6)$$

We define decision variable $u(\mathbf{x},a)$ as the long-run fraction of time at which the state $\mathbf{x}$ making action a, and the set of $u(\mathbf{x},a)$ collectively determines the policy. Searching for the optimal policy is equivalent to finding those decision variables for all states. This can be done by solving the following SMDP linear programming (LP) formulation with the objective on maximizing long-run network reward:

Maximize:

$$U = \sum_{\mathbf{x}\in\Omega} \sum_{a\in\mathbf{A_x}} r(\mathbf{x},a)\tau(\mathbf{x},a)u(\mathbf{x},a) \quad (7)$$

subject to:

$$\sum_{a\in \mathbf{A}_y} u(\mathbf{y},a) - \sum_{\mathbf{x}\in\Omega}\sum_{a\in \mathbf{A}_x} P(\mathbf{y}|\mathbf{x},a)u(\mathbf{x},a) = 0, \quad \mathbf{y}\in\Omega \tag{8}$$

$$\sum_{\mathbf{x}\in\Omega}\sum_{a\in \mathbf{A}_x} \tau(\mathbf{x},a)u(\mathbf{x},a) = 1 \tag{9}$$

$$\sum_{\substack{\mathbf{x}\in\Omega \\ a\in\{a_{1,h},\ldots,a_{k,h}\}}} \tau(\mathbf{x},a)u(\mathbf{x},a) \le P_{BH} \tag{10}$$

$$u(\mathbf{x},a) \ge 0, \quad \mathbf{x}\in\Omega, a\in \mathbf{A}_{\mathbf{x}}. \tag{11}$$

The term $\tau(\mathbf{x},a)u(\mathbf{x},a)$ can be interpreted as the long-run fraction of decision epochs at which the system is in state $\mathbf{x}$ and action a is chosen. Thus, the objective function U is the utilization rate. Equation (8) is the balance equation from the long-run viewpoint. Equation (9) is the normalization condition. In addition, Equation (10) and (11) give the constraints on blocking probability and decision variables, respectively. The P_{BH} in Equation (10) limits the highest blocking probability of handover calls to ensure their CoS. The optimal feasible solutions $u(\mathbf{x},a)^*$ to the Equation (7) gives the optimal CAC policy.

B. Guard-channel Policy over SMDP

The guard-channel policy over SMDP is the main idea of the paper. The policy partitions the total channels into "regular channels" for all calls and "reserved channel" (denoted as G) only for various type of handover calls. It starts to give out the reserved channels only when the regular channels are all occupied. The corresponding state space for the guard-channel policy can be represented by

$$\Omega_{GC} = \left\{ \mathbf{x} \,\middle|\, \begin{matrix} 0 \le \sum_{i=1}^{K} n_i c_i \le G, & \lambda_{\bar{\mathbf{x}}\mathbf{x}} = \lambda_{i,n}+\lambda_{i,h} \\ G < \sum_{i=1}^{K} n_i c_i \le C, & \lambda_{\bar{\mathbf{x}}\mathbf{x}} = \lambda_{i,h} \end{matrix}, \; n_i \ge 0, \; G<C \right\}. \tag{12}$$

To clarify the idea, we show a state transition diagram based on guard-channel policy in Figure 3.

For a multirate network, the difficulty is how to find the best partitions such that an optimal system performance resulted and the CoS of

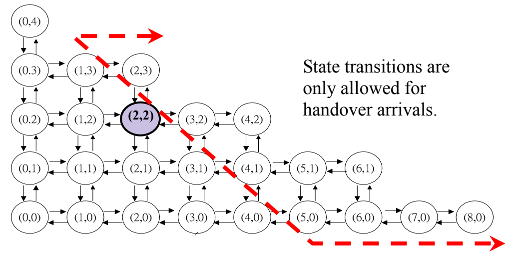

Figure 3. Example of guard-channel policy: regular channel = reserved channel = 4, for C=8, c_1=1 and c_2=2.

handover calls can be assured. This can be done via SMDP LP formulation but with some modifications. First, in order to satisfy the CoS of each type of handover calls, the maximum acceptable blocking probability for handover calls in Equation (10) needs to be refined as

$$\sum_{\substack{\mathbf{x}\in\Omega \\ a\in\{a_{i,h}\}}} \tau(\mathbf{x},a)u(\mathbf{x},a) \le P_{BHi}, \quad 1\le i\le K. \tag{13}$$

Next, Equation (4) and (5) should be modified for the states with channel occupancy greater than G,

$$\tau(\mathbf{x},a) = \left[\sum_{i=1}^{K} n_i(\mu_{i,s}+\mu_{i,h}) + \sum_{i=1}^{K}\lambda_{i,h}a_{i,h}\right]^{-1}, \tag{14}$$

$$P(\mathbf{y}|\mathbf{x},a) = \begin{cases} a_{i,h}\lambda_{i,h}\tau(\mathbf{x},a), & \mathbf{y}=\mathbf{x}_i^+, \; i=1,\ldots,K \\ n_i(\mu_{i,s}+\mu_{i,h})\tau(\mathbf{x},a), & \mathbf{y}=\mathbf{x}_i^-, \; i=1,\ldots,K \\ 0, & otherwise \end{cases}. \tag{15}$$

Another possibility is to find the guard states for each type of traffics. While this manner is similar to the threshold-type policy, the procedure of searching for guard states is too complicated to be implemented, comparing to the method described previously.

IV. Numerical Results

We will present several computation results in this section to exemplify the CAC performance of the proposed policy by comparing the utilization of an ordinary SMDP-based CAC (denoted SMDP) [3] and the guard-channel policy over SMDP (denoted SMDP_GC). Both policies are found by using SMDP linear programming formulation with the same objective function of maximizing network reward (It is actually the utilization as described in Equation (6) in Section 3). Although the ordinary SMDP-based CAC policy also considered the CoS guarantee for handover calls, there is still a room to improve the performance, especially if the reservation channels is appropriately chosen in applying our proposed guard-channel policy over SMDP. This can be seen from the several examples under various traffic conditions, and we will discuss the performance improvement of the guard-channel policy over SMDP in which the improvement is measuring the utilization ratio from $[(\text{SMDP\_GC} - \text{SMDP})/\text{SMDP}] \times 100\%$.

Assuming that a satellite network supports two types of traffics, and each requires low (narrowband) and high (wideband) number of channels, respectively. Without loss of generality, the channels required by each traffic type are normalized by the channel of the lowest requirement. The offered load to the satellite network by each traffic type is ρ_i and $\rho_i = \lambda_i / \mu_i$. To ease the discussion, we use the total normalized offered load *L,* defined as $L = \sum_{i=1}^{K} \rho_i c_i / C$. Other key parameters used in this section are as follows: Total Channels in each satellite cell C = 50; Type-1 (narrowband) channel requirement $c_1 = 1$ and type-2 (wideband) channel requirement $c_2 = 5$. The maximum acceptable blocking probability for narrowband handover traffics is $P_{BH1} = 0.01$ and that for wideband traffics is $P_{BH2} = 0.05$ (We tolerate higher blocking to wideband handover traffics since they ask for more channels and potentially encounter higher blocking.). The arrival rate ratio of new calls to handover calls are: $\lambda_{1,n} / \lambda_{1,h}$ = 2 and $\lambda_{2,n} / \lambda_{2,h}$ = 2.

The investigation is first done by fixing the normalized offered load at 1.5 (a heavy-load condition) and change the arrival rates of calls with respect to various ratios of mean session time μ_1 / μ_2. Figure 4 to Figure 6 show the utilization under the traffic conditions stated above except for μ_1 / μ_2 = 1, 10, and 20, respectively. It is observed that the guard channel policy over SMDP always gets better utilization than a regular SMDP policy does. A few results presenting the utilization improvement are summarized in Table 1. Figure 7 illustrates the robustness of the policy by changing normalized offered load. In this test, the complete sharing (CS) policy is also examined. From those numerical results, we can observe the SMDP_GC will have better performance than that of SMDP and CS, especially when the system is under heavily-loaded or overloaded traffic condition.

Table 1. Utilization improvement under various traffic conditions.

	$\mu_1 / \mu_2 = 1$	$\mu_1 / \mu_2 = 10$	$\mu_1 / \mu_2 = 20$
$\lambda_1 / \lambda_2 = 20$	18.6%	10%	9.6%
$\lambda_1 / \lambda_2 = 10$	17.9%	9.06%	11.3%
$\lambda_1 / \lambda_2 = 5$	16.6%	10.4%	13.8%
Improvement ratio = $[(\text{SMDP\_GC} - \text{SMDP})/\text{SMDP}] \times 100\%$			

V. Conclusions

In this paper, we have presented an SMDP-based guard-channel policy for call admission and channel allocation in a LEO satellite network. We showed that the system performance could be improved in terms of revenue if we reserve some channels for handover traffics for exclusive use. The reservation channel under a given handover CoS constraint was found via SMDP's linear programming formulation and resulted in an optimal decision for each state. Intensive numerical results reveal that the guard-channel policy over SMDP can also increase the utilization with a guarantee on the low blocking to all handover calls.

References

1. E. Del Re, et al., "Characterization of user

mobility in Low Earth Orbit mobile satellite system," *Wireless Networks*, Vol. 6, No. 3, pp.165-179, 2000.

2. URL: http//www.ee.surrey.ac.uk/Personal/L.Wood/
3. Henk C. Tijms, *Stochastic Models: An Algorithmic Approach*. John Wiley & Sons, 1994.
4. Y. Xiao, C.L.P. Chen, and Y. Wang, "A Near Optimal Call Admission Control with Genetic Algorithm for Multimedia Services in Wireless/Mobile Networks," *IEEE NAECON 2000*, pp.787-792, Oct. 2000.
5. J. Choi, et al., "Call Admission Control for Multimedia Services in Mobile Cellular Networks: A Markov Decision Approach," *IEEE ISCC2000*, pp.594-599, July 2000.
6. C.-J. Ho and C.-T. Lea, "Improving call admission policies in wireless networks," *Wireless Networks*, Vol. 5, No. 4, pp.257-265, 1999.
7. K. W. Ross and D. H. K. Tsang, "Optimal Circuit Access Policies in an ISDN Environment: A Markov Decision Approach," *IEEE Trans. on Communications*, Vol. 37, No. 9, pp.934-939, Sept. 1989.
8. C.-T. Lea and K.-W. Ke, "Quantization, state reduction and cost-based admission and routing," *Computer Communications*, Vol. 19, Issue 13, pp.1051-1064, 1996.

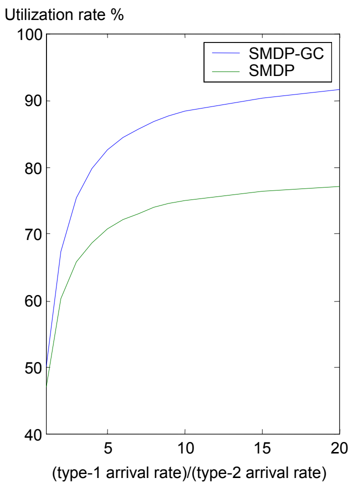

Figure 4. Utilization rate vs λ_1 / λ_2: $\mu_1 / \mu_2 = 1$, $L = 1.5$.

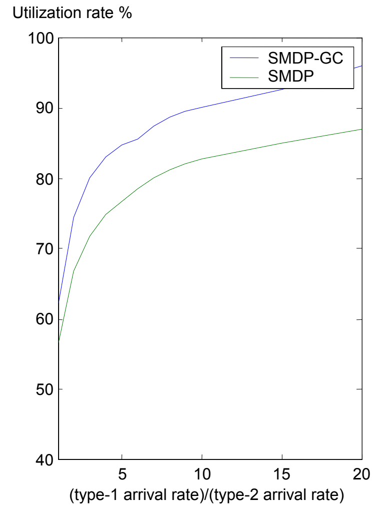

Figure 5. Utilization rate vs. λ_1 / λ_2: $\mu_1 / \mu_2 = 10$, $L = 1.5$.

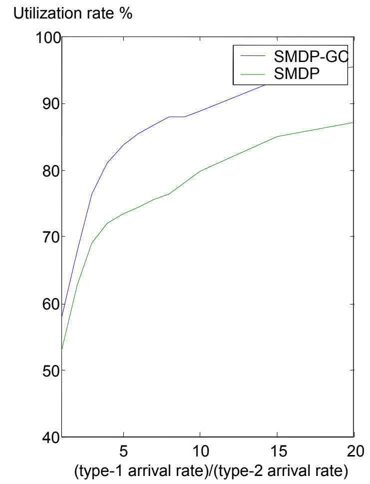

Figure 6. Utilization rate vs. λ_1 / λ_2: $\mu_1 / \mu_2 = 20$, $L = 1.5$.

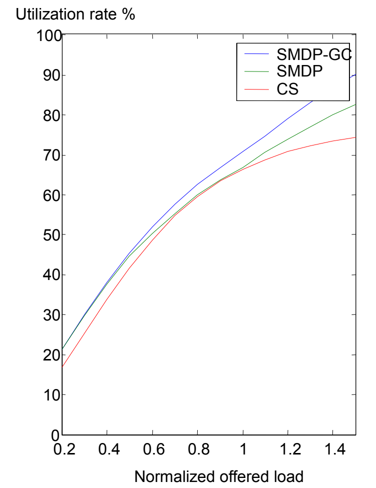

Figure 7. Utilization rate vs. normalized offered load: $\mu_1 / \mu_2 = 20$, $\lambda_1 / \lambda_2 = 10$.