A New Spotbeam Handover Management Technique for LEO Satellite Networks

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Abstract— **The geographical connection admission control (GCAC) algorithm is introduced for low earth orbit (LEO) satellite networks. The GCAC scheme estimates the future handover blocking probability of a new call attempt based on the user location database, in order to decrease the handover blocking. By simulation, it is shown that the proposed GCAC scheme guarantees the handover blocking probability to a predefined target level. Since GCAC algorithm utilizes the user location information, performance evaluation shows that this technique also guarantees the target level of handover blocking probability in the nonuniform traffic pattern.**

Keywords— **LEO Satellite Networks, Connection Admission Control, Channel Allocation, Handover Management**

I. Introduction

In *low earth orbit* (LEO) satellite networks, the spotbeam handover is the most frequently encountered network function because of the relatively small spotbeam areas of LEO satellite networks and the relatively high speed of the satellites [1]. Frequent spotbeam handovers would cause handover blocking if no resource (or channel) is available in the destination spotbeam. Blocking a handover call is generally considered less desirable from user's point of view than blocking a new call request since dropping a call in progress breaches *quality of service* (QoS) requirements [9]. The priority can be assigned via different treatments of new and handover calls to decrease the handover call blocking. Handover calls can experience a more favorable blocking probability than new calls by prioritizing channel allocation during call admission phase.

One noticeable prioritization scheme is *handover with queueing* (HQ) technique [10]. This scheme utilizes the overlapped area between two spotbeams where the handover takes place. When a user terminal is in the overlapped area, the handover process is initiated. If a channel is available in the new spotbeam, it is allocated to the user terminal; otherwise, the handover request is queued. When a channel becomes available, one of the calls in the queue is served. HQ scheme reduces the handover call blocking; however, its performance depends on the new call arrival rate and the size of the overlapped area. In the worst case, high call arrival rates or small overlapped areas would result in a high value of handover call blocking probability.

Another prioritization technique proposed is *handover with guard channel* (HG) scheme [5]. In this scheme, guard channels are used to ensure that certain number of channels are reserved for handover calls even when the new call arrival rate is high. In a system with guard channels, new call attempts are rejected if the number of busy channels is greater than a certain threshold. The difference between the system capacity in the number of channels and the threshold value is equal to the number of guard channels. The handover call blocking probability could be reduced by increasing the number of guard channels. Reservation of certain channels for handover calls, however, increases the blocking probability for new arrivals. Hence, we need a trade-off between the handover call blocking and new call blocking.

With the above techniques, various solutions have been proposed to lower the blocking probabilities in wireless networks [11]. Most of these studies focus on the notion of channel allocation algorithms. They try to maximize the channel utilization efficiency. This approach, however, does not provide connection-level quality of service (QoS) [9]. Due to scarcity of resources, *connection admission control* (CAC) policies are important for a network's capability to guarantee connection-level quality of service (QoS).

Recently, several connection admission control (CAC) techniques in wireless networks have been proposed [8], [9], [12]. In [12], the overload probability metric is restricted to simple one dimensional model. Hence, this assumption does not fit into the realistic situations. The technique proposed in [9] considers only fixed channel allocation (FCA) scheme. This scheme may lower the channel utilization efficiency. Moreover, only geographically uniform traffic patterns are investigated. In particular, the above two techniques cannot be directly applied to our problem because of the differences between the LEO satellite networks and the terrestrial wireless networks. Also, a connection admission control (CAC) technique in Non-GEO satellite networks has been proposed in [8]. In this scheme, admission decision is based upon so-called *mobility reservation status* which provides the information about the current bandwidth requirement of all the active connections in a specific spotbeam in addition to the possible bandwidth requirements of mobile users currently connected to the neighboring spotbeams. However, this scheme has the problem of determining threshold point and does not take the QoS issues into account.

In this paper, we propose a new connection admission control scheme called a *geographical connection admission control* (GCAC) algorithm in LEO satellite networks. The GCAC algorithm estimates the future handover blocking

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performance of the new call attempts based on the user location database. In this scheme, the user location database is updated by using global positioning system (GPS) receivers [4].

The remaining of the paper is organized as follows. In section II, we propose a new connection admission control algorithm, *geographical connection admission control.* In section III, we describe the mobility model and simulation assumptions in the analysis. We then compare the proposed GCAC algorithm with other techniques described in [5], [10], [11]. Then, the paper concludes with section IV.

II. Geographical Connection Admission Control

The spotbeams of LEO satellites move along known trajectories on the Earth surface with an approximately constant speed. Moreover, the user locations can be estimated using global positioning system (GPS) receivers [4] with limited estimation error. Both the deterministic spotbeam movement and the user location information provide the handover patterns of the user terminals to the system, i.e., the future handover behavior of a user terminal can be determined.

In general, admission control function has to check the availability of the resource by channel allocation technique which can be roughly divided into fixed, dynamic, or the combination of both. In the previous study [3], we provide a solution using adaptive dynamic channel allocation (ADCA) scheme. For the channel availability test of the proposed GCAC, the ADCA scheme is used.

The acceptance of a new connection request can increase the handover blocking probability in an area swept by the spotbeam that serves the new user. This area is referred to as a *contention area.* Let Λ be the set of user terminals in the contention area. The GCAC algorithm guarantees that the handover blocking probability is less than a target handover blocking probability, P_{QoS}. The newly arriving call is admitted to the network if the following two conditions are satisfied:

- **C1**: The target handover call blocking probability is guaranteed for the newly arriving call.
- **C2**: The handover blocking probability of the existing calls does not exceed the target handover blocking probability.

In our assumption, the spotbeam movement can be taken into account as relative user arrival and departure in a fixed spotbeam. Hence, the GCAC algorithm simulates the user arrival and departure in each spotbeam for a test call. During the lifetime of the test call, it could be handed over to other spotbeams. If the admission decision process decides that the above conditions **C1** and **C2** are not satisfied, the test call is rejected.

While the test call is in the *origination spotbeam,* other active calls can arrive and depart. This number of active calls should be taken into consideration in estimating blocking probabilities since accepting the test call could breach the target handover blocking probabilities of the other calls. Moreover, during the lifetime of the test call in the origination spotbeam, other active calls in the same spotbeam could be terminated due to call release. We use analytical expressions to estimate the number of active calls in spotbeams.

The test call could be handed over to other neighboring spotbeam referred to as *transit spotbeam.* In this handover event, it needs to estimate the number of other active calls again since this number will change in the new spotbeam. As in the origination spotbeam, the number of other calls should be updated in every handover event (handover arrival or handover departure) of the other calls, while the test call is in the transit spotbeams.

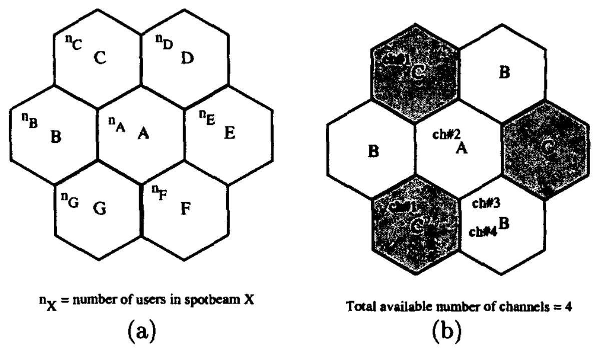

Fig. 1. Cellular architecture: (a) example of dynamic channel allocation (DCA) in spotbeams; (b) derivation of the blocking probability in DCA scheme.

The *handover blocking probability*, P_b, is defined by

$$P_b \triangleq \frac{E_b}{E_h} \tag{1}$$

where E_b is the expected number of blocked handover arrivals and E_h is the expected number of handover arrivals. E_h is given by

$$E_h = \sum_{i \in \Lambda} p_a(i) \tag{2}$$

where $p_a(i)$ is the probability that call i is active at the handover instant.

Likewise, E_b is given by

$$E_b = \sum_{i \in \Lambda} p_{b,i}\, p_a(i) \tag{3}$$

where $p_{b,i}$ is handover blocking probability of call i at the handover instant given that it is active at this instant.

Since the *call duration*, T_h, is assumed to be exponentially distributed with mean $1/\mu_i$, then

$$\begin{aligned} p_a(i) &= P[T < T_h] \\ &= e^{-\mu_i T} \end{aligned} \tag{4}$$

where T is the system time.

Fig. 1 (a) shows a spotbeam pattern on the ground. Define the state vector $\vec{n} \triangleq (n_A, n_B, n_C, n_D, n_E, n_F, n_G)$ where random variable n_X is the number of users in spotbeam $X \in \{A, B, C, D, E, F, G\}$. In order to determine blocking probability, maximum packing (MP) policy is considered. MP is a scheme that accepts every call to which a channel can be allocated regardless of the number of possible reassignments if reuse constraint is satisfied [6].

A state vector $p(\vec{n})$ is said to be *admissible* if there exists a channel allocation to spotbeams such that no channel is

$$p_{b,i} = P[\{n_A+n_B+n_C \geq C\} \cup \{n_A+n_C+n_D \geq C\} \cup \{n_A+n_D+n_E \geq C\} \cup \{n_A+n_E+n_F \geq C\} \cup \{n_A+n_F+n_G \geq C\} \cup \{n_A+n_B+n_G \geq C\}] = 1 - \sum_{n_A=0}^{C-1} \sum_{n_B=0}^{C-n_A-1} \sum_{n_C=0}^{C-n_A-n_B-1} \sum_{n_D=0}^{C-n_A-n_C-1} \sum_{n_E=0}^{C-n_A-n_D-1} \sum_{n_F=0}^{C-n_A-n_E-1} \sum_{n_G=0}^{C-n_A-n_F-n_B-1} p(\vec{n}) \quad (7)$$

used in each of two adjacent spotbeams [6]. A state vector $p(\vec{n})$ is admissible if and only if the following condition is met [6]:

$$n_A + n_B + n_C < C \quad (5)$$

for all (n_A, n_B, n_C) in Fig. 1 (b) where C is the maximum number of channels when exploiting DCA technique.

This test can be carried out at the six vertices of hexagonal spotbeam A in Fig. 1 (b). For example, the channel # 2 can be allocated to spotbeam A since the sum of active calls is less than 4 at each vertex of spotbeam A.

In summary, a call can be accepted in the spotbeam A in Fig. 1 (a) if

$$(n_A+n_B+n_C < C) \cap (n_A+n_C+n_D < C) \cap (n_A+n_D+n_E < C) \cap (n_A+n_E+n_F < C) \cap (n_A+n_F+n_G < C) \cap (n_A+n_B+n_G < C) \quad (6)$$

where the channel reuse distance is assumed to be 2, i.e., a channel can be reused in every other spotbeam.

Then, the blocking probability of call i can be expressed as shown in (7). Note the state vector $\vec{n}$ is generally not Markov. However, our statistical assumptions (Poisson arrival pattern and exponential call duration) ensure that the number of users in each spotbeam forms a Markov process. Accordingly, the state vector $\vec{n}$ forms a multi-dimensional Markov chain. This type of chain is usually difficult to analyze than the one-dimensional Markov chain, but in many interesting special cases we can obtain a closed-form solution for the stationary distribution $p(\vec{n})$ [2]. If we deal with this problem using Jackson network [2], as shown in Fig. 2, we can find a closed-form solution. First, we assume that there are K queues (or spotbeams), and each queueing system has m_i servers, where $i \in \{A, B, C, D, E, F, G\}$. In our case, $K = 7$. Second, we assume the external arrival process to the i-th queue is Poisson with rate λ_i. Third, service times at the queue i are assumed to be exponentially distributed with mean of $1/\mu_i$. Since the call duration is assumed to be exponentially distributed, the residual call duration in a spotbeam after a handover is also exponentially distributed with the same mean (memoryless property). For each user, the service times at each queue are mutually independent and independent of the arrival process at the queue. Let denote probability that a user departs queue i and then joins queue j by $h_{i,j}$ where $i, j \in \{A, B, C, D, E, F, G\}$. Thus, an actual arrival rate to the queue i is $\gamma_i = \lambda_i + \sum_{j\in\{A,B,C,D,E,F,G\}} \gamma_j h_{j,i}$. Furthermore, we assume $\sum_{i\in\{A,B,C,D,E,F,G\}} h_{j,i} < 1$, where $h_{j,0} = 1 - \sum_{i\in\{A,B,C,D,E,F,G\}} h_{j,i}$ is a probability a user leaves the system after served at the queue j. In other words, mobile user will leave the system with probability one. Finally, the system is assumed to be stable, i.e., $\rho_i = m_i\gamma_i/\mu_i < 1, \forall i \in \{A,B,C,D,E,F,G\}$. This is true since the queueing network is a loss system [2].

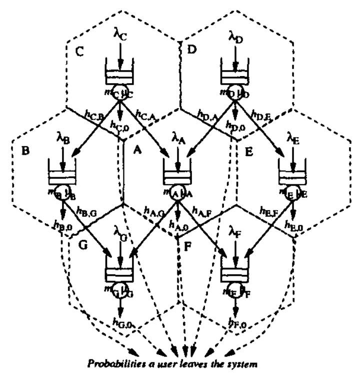

Fig. 2. Queueing Network model for spotbeams.

Based on the above assumptions, the multidimensional Markov chain (MC) is reversible in steady state, and thus the equilibrium distribution of the state vector $p(\vec{n})$ can be expressed as product form [2]:

$$p(\vec{n}) = \prod_{X\in\{A,B,C,D,E,F,G\}} p(n_X) \quad (8)$$

where $p(n_X)$ is the stationary distribution of the number of active calls in the spotbeam $X \in \{A, B, C, D, E, F, G\}$. Whenever the test call is handed over to the next spotbeam, it is initialized by

$$p(n_X = i) = \begin{cases} 1.0, & i = M_X \\ 0.0, & i \neq M_X \end{cases} \quad (9)$$

where M_X is the number of user terminals located in the spotbeam X, and M_X is incremented by one for handover arrival and decremented by one for handover departure.

The GCAC algorithm operates similar to an event-driven simulation. Upon a new call arrival, the spotbeams hypothetically move along their respective trajectories. During the spotbeam movement, handover arrival and departure events occur. System statistics are updated for every handover events. At event epochs, analytical expressions are used to estimate the system state and the handover blocking probability. The time interval between successive events is referred to as the handover event gap, Δ. Between the gap, a number of calls would have been terminated by the users. Thus, at each event epoch, the system state, which is represented by the number of active calls in the spotbeam, is updated to handle call terminations. This is followed by the update of the system state according to the handover event.

If the handover call is still active upon a handover arrival, there should be a transition from state $(i-1)$ to i for $i = 1, 2, \ldots, M_X + 1$. Therefore, when a handover arrives, stationary distribution $p(n_X = i)$ can be updated as follows:

$$p(n_X = i) \;=\; p_a(i)p(n_X = i-1) + (1 - p_a(i))p(n_X = i) \quad \text{for } i = 1, 2, \ldots, M_X + 1 \qquad (10)$$

where $p_a(i)$ is computed in (4), and $p(n_X = i)$ is initialized as in (9).

If the handover call is still active upon a handover departure, only the transition from state $(i+1)$ to i is possible for $i = 0, 1, \ldots, (M_X - 1)$. Hence, when a handover departs, $p(n_X = i)$ can be determined by

$$p(n_X = i) \;=\; \frac{i+1}{M_X}p(n_X = i+1) + (1 - \frac{i}{M_X})p(n_X = i) \quad \text{for } i = 0, 1, 2, \ldots, M_X - 1 \qquad (11)$$

Departures from the system result only from the call terminations. Since the call duration of the users are assumed to be identically distributed, the conditional probability that the call is still active given that there are i active calls in the spotbeam only depends on the number of active calls and the number of users located in the spotbeam tested. Since only call terminations could occur between handover events (handover arrivals or departures), i.e., only downward transitions are possible in the time interval $(T, T+\Delta)$, the stationary distribution $p(n_X = i)$ can be updated as follows:

$$p(n_X = i) = \sum_{j=i}^{M_X} P_{ji}(\Delta)p(n_X = j) \qquad (12)$$

for $i = 0, 1, \ldots, M_X$ where

$$P_{ji}(\Delta) = \binom{j}{j-i} (e^{-\mu\Delta})^i (1 - e^{-\mu\Delta})^{j-i} \qquad (13)$$

which is the probability that out of j active calls, $(j-i)$ calls terminated in a time interval of length Δ, and i active calls remained.

If the condition

$$P_b = \frac{E_b}{E_h} \leq P_{QoS} \qquad (14)$$

is satisfied, the call is admitted to the network. Otherwise, it will be rejected.

III. Performance Evaluation

A. Assumptions

In the simulation, mobile users are assumed to cross the cellular network with a constant relative velocity orthogonal to the side of the spotbeams. The call duration T_h is assumed to be exponentially distributed with average holding time of 3 minutes. The call arrival process is assumed to be Poisson in all spotbeams. In our experiments, orbital satellite velocity is assumed to be 26,600 km/h, and we assume the radius of the circle inscribed in the hexagonal spotbeam to be 212.5 km [10]. In particular, an edge effect is taken into account, i.e., results have been collected only from the central spotbeams.

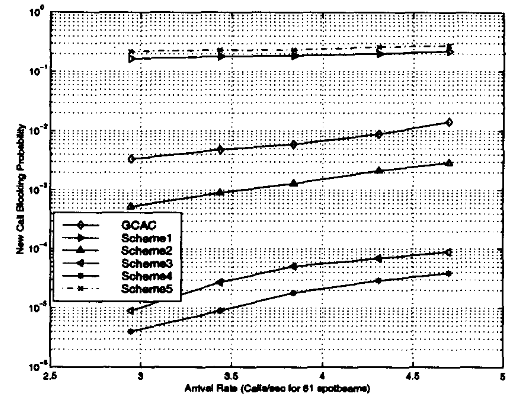

Fig. 3. New call blocking probabilities (no. of channels = 285 in 19 spotbeams).

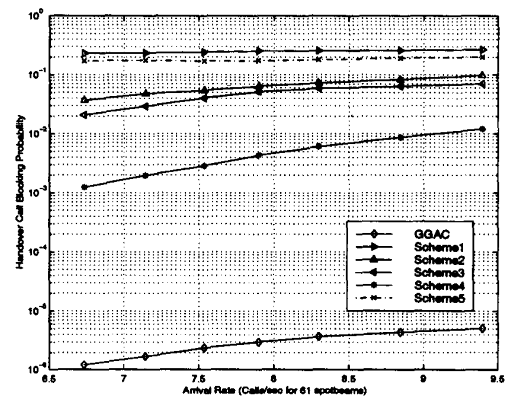

Fig. 4. Handover call blocking probabilities (no. of channels = 285 in 19 spotbeams).

For performance comparison, we developed a simulation tool containing following spotbeam handover schemes:

Scheme 1: Fixed Channel Allocation (FCA) [5]
Scheme 2: Dynamic Channel Allocation (DCA) [10]
Scheme 3: Dynamic Channel Allocation 2 (DCA2) [10]
Scheme 4: Handover with queueing [10] using DCA2 scheme (DCA2-HQ)
Scheme 5: Handover with one guard channel (HG) [5]

B. Performance Evaluation of the GCAC Algorithm

Fig. 3 and Fig. 4 show simulation results of the GCAC algorithm when the number of channels per spotbeam is 15, i.e., 285 channels are available in the common pool for 19 spotbeams in the DCA schemes. Performance evaluation shows that the GCAC significantly lowers handover blocking probabilities compared to other schemes as shown in Fig. 4 (the gain is 33.72 dB compared with DCA2-HQ scheme at 9.4 calls/sec). Throughout the simulation experiments, the GCAC algorithm guarantees the target handover blocking probability ($P_{QoS} = 10^{-5}$).

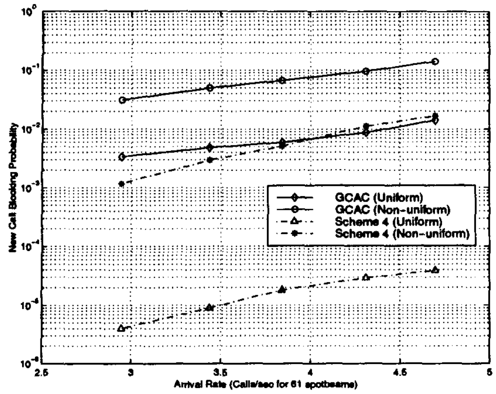

Fig. 5. New call blocking probabilities (traffic pattern comparison).

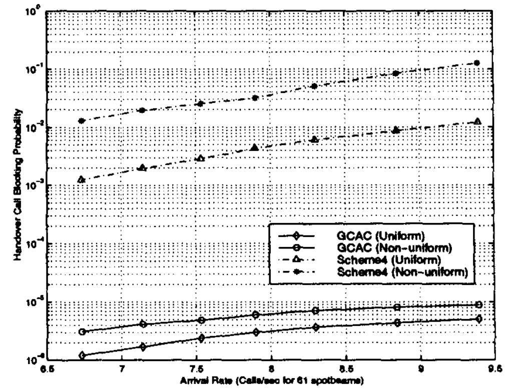

Fig. 6. Handover call blocking probabilities (traffic pattern comparison).

In terms of the new call blocking probability, the DCA2 technique (Scheme 3) [10] and DCA2-HQ technique (Scheme 4) [10] perform better than the GCAC as shown in Fig. 3 with the gain of 22 and 25.6 dB, respectively. In some points with heavy load, however, these techniques could breach the target handover blocking probability (see Fig. 4). Handover with guard channel scheme (Scheme 5) [5] does not show good performance compared to the GCAC algorithm in terms of new and handover blocking probability because of the over-estimation of guard channels.

C. *Effect of Nonuniform User Distribution*

In most of previous studies [5], [10], uniform distribution for user location has been assumed. However, in reality, the distribution of user terminals over the Earth surface cannot be uniform, e.g., spotbeams of LEO satellites may cover a number of crowded cities as well as lightly populated areas such as ocean and mountains. The performance of the GCAC algorithm is investigated using both uniform and nonuniform traffic distribution in the coverage area. In case of uniform distribution, every spotbeam generates the call with the same arrival rate. However, in case of the nonuniform distribution, the traffic generation is state-dependent, i.e., a certain spotbeam does not generate any traffic at some time period but it could be overloaded sometime later. In the simulation model, we model the non-uniformity as only some spotbeams generate traffic, while the others do nothing except accepting handover traffic from adjacent spotbeams.

As shown in Fig. 5 and Fig. 6, simulation results show that the blocking probabilities increase in case of nonuniform traffic. We also compared these effects with DCA2-HQ technique (Scheme 4). Performance evaluation shows that the GCAC algorithm is less affected by the traffic uniformity than the DCA2-HQ technique. In other words, the difference of uniformity and non-uniformity is higher in DCA2-HQ technique than the GCAC algorithm. This shows that GCAC technique estimates well the user population distribution.

IV. Conclusions

The geographical connection admission control (GCAC) algorithm has been proposed in order to limit handover blocking probability in low earth orbit (LEO) satellite networks. By simulation, we have shown that the proposed GCAC scheme limits the handover blocking probabilities to a predefined target level (QoS). Performance study also shows that the GCAC technique provides better handover blocking probability over the DCA-2HQ scheme in nonuniform traffic environment.

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