Adaptive Dynamic Channel Allocation Scheme for Spotbeam Handover in LEO Satellite Networks*

Sungrae Cho

Broadband and Wireless Networking Laboratory
School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, GA 30332

Tel: (404) 894-6616; Fax: (404) 894-7883
Email: srcho@ece.gatech.edu

Abstract

Among satellite systems, low earth orbit (LEO) satellite system will make an important role in new future communication services, because of its less propagation delay, less power consumption in the user terminal and the satellites, and efficient spectrum utilization using smaller coverage area for each satellite than geostationary (GEO) counterpart. However, a number of mobility problems that did not exist in GEO satellite systems should be solved. One noticeable mobility problem is the spotbeam handover which occurs most frequently in LEO satellite systems. The frequent spotbeam handover requires a technique to decrease handover blocking probability. In this paper, an adaptive dynamic channel allocation (ADCA) scheme is introduced for LEO satellite networks. The ADCA scheme estimates the future number of handover events based on the user location database, and reserves corresponding number of channels in order to decrease the overall handover blocking probabilities. Performance evaluation shows that the handover blocking probabilities of ADCA technique substantially decrease in comparison with the other channel allocation schemes.

Keywords—LEO Satellite Network, Channel Allocation, Blocking Probability

1. Introduction

Terrestrial wireless networks provide mobile communication services with limited geographic coverage since they are economically infeasible due to rough terrain or insufficient user population. In order to provide global information access, a number of satellite systems have been proposed [9]. The satellite networks are well suited for worldwide communication services and to complement the terrestrial wireless networks because they can support not only the areas with terrestrial wireless networks but also the areas in lack of any wireless infrastructure. Among the satellite systems, *low earth orbit* (LEO) satellite system will make an important role in near future communication services, because of its less propagation delay, less power requirement in the user terminal and the satellites, and efficient spectrum utilization using smaller coverage area for each satellite than geostationary (GEO) satellite systems. Moreover, it is possible to route a connection using inter-satellite links (ISL) without relying on terrestrial resources. However, a number of mobility problems that did not exist for GEO satellite systems should be solved in order to have feasible implementations of the LEO systems.

Low earth orbit (LEO) satellites located at low earth orbits move with respect to a fixed observer on the Earth surface. The service area called *footprint* of a single LEO satellite is a circular area on the Earth's surface, as shown in Figure 1. The footprints are cov-

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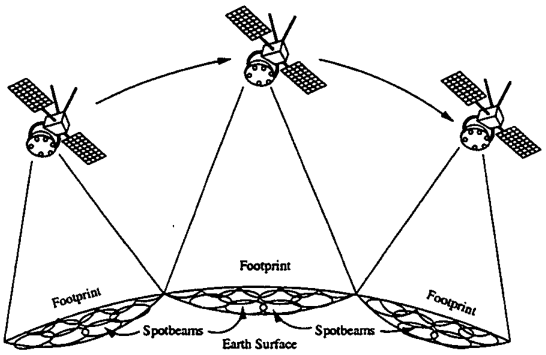

Figure 1. Spotbeams of the LEO Satellite

ered by smaller cells or *spotbeams* to achieve frequency reuse inside the footprint. Identical frequencies can be reused in different spotbeams if the spotbeams are geographically separated to limit the interference.

In the LEO satellite networks, spotbeam handover is the most frequently encountered because of the relative small spotbeam areas and the relative high speed of the satellites. Frequent spotbeam handovers would cause more handover blockings. Blocking a handover call is generally considered less desirable from user's point of view than blocking a new call [15]. The priority can be given via different treatments of new and handover calls to decrease the handover call blocking. Many solutions have been proposed to achieve this goal for terrestrial wireless networks [5, 13, 15].

One noticeable prioritization scheme is *handover with queueing* (HQ) technique [12]. This scheme utilizes the overlapped area between two spotbeams where the handover takes place. When a user terminal is in an 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. A handover call is blocked if no channel is allocated for the call in the new spotbeam when the power level received from the current spotbeam falls below the minimum power level that is required for a successful data transfer. The 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.

However, these techniques cannot be directly applied to our problem because of the differences between the LEO satellite networks and the terrestrial wireless networks. One distinct disparity is their mobility patterns. In terrestrial wireless networks, user mobility is generally unknown in advance, and is difficult to analyze. Hence, the choice of cell side that a user will depart through is assumed to be equally-likely [11]. On the other hand, the spotbeams of LEO satellites move along almost known trajectories on the Earth surface with an approximately constant speed. Moreover, user is approximately fixed from the view of the satellite since the satellite moves very fast than user. Hence, the mobility pattern in LEO satellite network is rather deterministic [12].

Relative few solutions have been proposed for LEO satellite networks [10, 12]. However, these techniques try to solve the problem using the same techniques as in the terrestrial wireless counterpart. Therefore, the channel utilization efficiency is suboptimal in the sense that the deterministic mobility pattern in LEO satellite network is not exploited.

In this paper, an adaptive dynamic channel allocation (ADCA) scheme is introduced for LEO satellite networks. The technique estimates the future handover events based on the user location database, and dynamically reserves channels for future handover requests. This paper is organized as follows. In section 2, proposed adaptive dynamic channel allocation technique is described. Performance evaluation is given in section 3, then, this paper concludes with section 4.

2. Adaptive Dynamic Channel Allocation Technique

In trunk reservation techniques [4, 5], the fixed number of guard channels are reserved for handover calls to reduce handover blocking probability. Excessive reservation of guard channels for handover calls increases the new call blocking probabilities. Also, small number of guard channels would cause increased handover blocking probabilities.

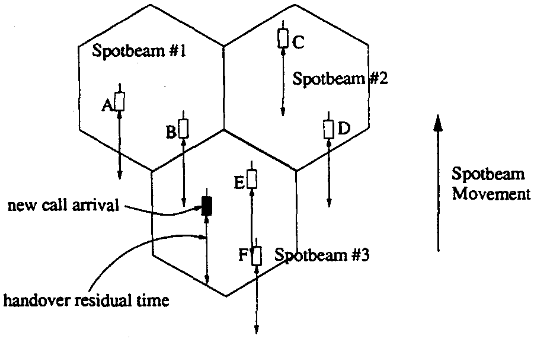

Figure 2. Illustration of ADCA Scheme

Our new channel allocation scheme called ADCA scheme, which is based on the dynamic channel allocation (DCA) scheme [15], utilizes the concept of *guard channel* but adapts it dynamically according to the user location information in the adjacent spotbeams. The ADCA technique finds the optimal number of guard channels for future handovers.

When a new call arrives in a spotbeam, the ADCA scheme considers two possible handover events in the spotbeam occurring before the hypothetical handover departure of the new call: (1) handover arrivals from the other spotbeams; and (2) handover departures from the spotbeam where the new call is being tested for the admission.

Let define the *handover residual time* τ as the time interval between acceptance and handover departure of a new call. This interval τ can be easily computed according to the user location information. From the example in Figure 2, users A, D, and F are handed over to other spotbeams, and users C and E remain in their spotbeams. Thus, a possible handover arrival to spotbeam # 3 during τ, would be from the user B. Likewise, a possible user terminal to be handed over from spotbeam # 3 would be the user F.

Denote radius of the circle inscribed in the hexagonal spotbeam by R as shown in Figure 3. Then, the handover residual time τ from the location (a, b) can be easily obtained by

$$\tau = \frac{\sqrt{3}}{3}(2R - |b|) - a \qquad (1)$$

where $|b| < R$, if $|a| < \frac{\sqrt{3}}{3}R$; $|b| < 2R - \sqrt{3}|a|$, if $\frac{\sqrt{3}}{3}R \leq |a| < \frac{2\sqrt{3}}{3}R$; otherwise, $b = 0$.

Some calls of possible users may be terminated during τ. Hence, the probability of call termination should be taken into consideration for determining the number of channels to be reserved. If we assume the distribution of call holding time to be exponential with mean $1/\mu$, the probability that a user is active during τ, λ, can be obtained by

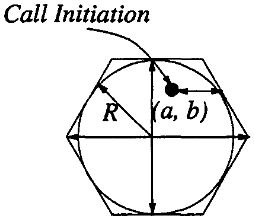

Figure 3. The Computation of Handover Residual Time τ

$$\lambda = e^{-\mu\tau} \qquad (2)$$

When a call request arrives, the ADCA algorithm performs the following steps:

1. If the call is a handover call request, go to step 9; otherwise go to step 2.
2. Determine τ based on the location of the call request.
3. Obtain the number of possible users to handover by searching the neighboring spotbeams.
4. Calculate λ from (2).
5. Compute the expected number of channels γ to be reserved.
6. Find the available number of channel C in the test spotbeam.
7. If $C > \gamma$, accept the call and exit the procedure.
8. If $C < \gamma$, reject the call and exit the procedure.
9. Find the available number of channel C in the test spotbeam.
10. If $C > 0$, accept the call and exit the procedure.
11. If $C < 0$, reject the call and exit the procedure.

3. Performance Evaluation

3.1. Assumptions

The mobility model in the simulation is assumed to be as follows:

- Mobile users cross the cellular network with a constant relative velocity orthogonal to the side of the spotbeams.

- When a handover occurs, the destination spotbeam is the neighboring spotbeam in the direction of the relative satellite-user motion.
- The call duration is exponentially distributed with average holding time of 3 minutes.
- The call arrival process is Poisson in all spotbeams.
- The cellular layout is regular hexagonal.
- The same channel can be assigned in different spotbeams at the same time provided that these spotbeams are sufficiently separated in space (reuse distance).

For the performance evaluation of the proposed algorithm, discrete-event simulation technique is utilized. With this technique, the simulation clock is initialized to zero and the times of occurrence of future events are determined. Then, the simulation clock is advanced to the time of the most imminent event, the state of the system is updated, and future event times are determined. These series of clock advances are continued until the pre-specified ending condition reaches. The user location perceived by the spotbeam is continuously moving; however, in our simulation, all state periods of inactivity are skipped over by jumping the simulation clock from event time to event time. When a new call is accepted to one of 61 spotbeams, its call duration is set according to exponential distribution. This time is stored in the event list and used for a future call release event. Depending upon the user location, the handover time of the new call is determined, which is used for a next handover event.

In our experiments, we consider the Iridium system [9, 12] which uses 66 satellites over six polar circular orbits at about 780 km of altitude, and orbital satellite velocity of approximately 26,600 km/h [12]. We assume the radius of the spotbeam to be 212.5 km. In particular, an edge effect is taken into account, i.e., results have been collected only from the central spotbeams.

For performance comparison, we developed a simulation tool containing following channel allocation schemes:

- Handover with queueing (HQ) [12]
- Fixed Trunk Reservation (FTR) with one guard channel [5]
- Fixed Trunk Reservation (FTR) with two guard channels [5]

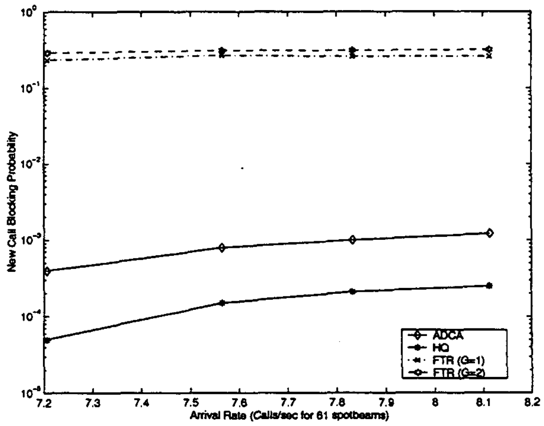

Figure 4. New Call Blocking Probabilities (No. of Channels = 380 in 19 Spotbeams)

In the HQ algorithm [12], channel allocation is performed on-demand based on the evaluation of a cost function defined for each available channel. The HQ incorporates handover queueing technique. This scheme substantially reduces the handover blocking probability. In FTR [5] scheme, the fixed number of guard channels are used to ensure certain number of channels are reserved for handover calls. Particularly, in this scheme, we use FCA technique as a channel allocation strategy.

3.2. Performance Evaluation of the ADCA Algorithm

Figure 4 and 5 show the new call and handover call blocking probabilities, respectively, when the traffic is generated uniformly, and the number of channel is 20 per spotbeams (i.e., 380 channels are used in the common pool for 19 spotbeams in the DCA techniques). In terms of new call blocking probability, the HQ technique performs better than the others as shown in Figure 4. In fixed trunk reservation schemes, the new call blocking probability is very high because of inappropriate number of guard channels in both cases of (Guard Channel = 1) and (Guard Channel = 2). As illustrated in Figure 5, the ADCA scheme substantially decreases handover blocking probabilities at the expense of slight increase of new call blocking probabilities.

4. Conclusions

In this paper, an adaptive dynamic channel allocation (ADCA) scheme has been introduced. The per-

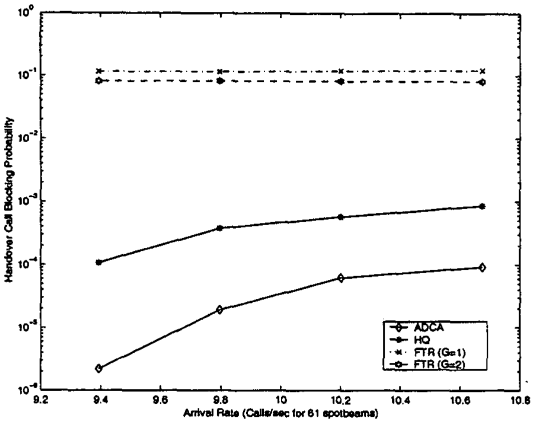

Figure 5. Handover Call Blocking Probabilities (No. of Channels = 380 in 19 Spotbeams)

formance evaluation shows that the ADCA technique outperforms the other channel allocation schemes in terms of handover blocking probability.

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