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LEO SATELLITE COMMUNICATION SYSTEM HANDOVER TECHNOLOGY AND CHANNEL ALLOCATION STRATEGY

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Abstract. *Satellite handover happens frequently in Low Earth Orbit (LEO) satellite network due to satellite's high mobility. In this paper, we propose a novel call admission control scheme which utilizes both the geographical information and the distance between the new call's position and the preparing handover user's position in the previous plot beam to intelligently decide whether to block a new call to help avoid possible handover failure. An approximate analytical model is derived to estimate the new call blocking performance of the new scheme, which is verified by simulation results. Research results show that the new scheme can improve the new call blocking probability significantly while maintaining a zero handover call dropping probability seen with the time-based channel reservation algorithm (TCRA).*
Keywords: LEO satellite system, Handover, Channel reservation, Preemptive occupy

1. **Introduction.** In response to the increasing demand for truly global seamless coverage needed by personal communication services (PCS), a new generation of mobile satellite networks was proposed in the literature [1]. In LEO satellite networks, handover management differs significantly from terrestrial networks, as handovers occur frequently due to the movement of satellites. Moreover, due to the deployment of multi-spot-beam antennas on satellites, inter-beam handovers are the most common type handovers experienced in LEO satellite systems [2], and also the main issue of this paper. As we have known, ongoing call dropping is less desirable than new call blocking from user's viewpoint. So, priority should be placed on handover connections over new requests.

In the context of mobile satellite networks, one popular and effective scheme is GC (Guaranteed Channel) scheme which achieves low handover dropping rate by reserving resources in the cells to be crossed by users. However, GC scheme suffers from relatively high connection blocking probability (CBP) since it guarantees handover connections too much at the expense of blocking new connection requests. Several algorithms were proposed to improve GC scheme and control the extent of priority placed on handover connections [3,4]. All of them provided solutions to delay the bandwidth reservation in the next candidate cell by a calculated time, and trade-off the handover guarantee to a certain extent. Boukhatem et al. proposed a Time-based Channel Reservation Algorithm (TCRA), in which the satellite trajectory and subscriber locations were utilized to maintain a zero handover dropping probability [5]. Ding et al. proposed a threshold-based handover prioritization (TBHP) resource management scheme for LEO satellite networks which decreases the new call blocking probability by deferring the channel locking time in the guaranteed handover (GH) algorithm [6]. A mobile IP based handover algorithm is proposed in [7,8]. The method for satellite handovers proposed in [9], reserves resources in the next cell/satellite when the handover occurs for both classes of users. Dynamic Doppler-based handover prioritization (DDBHP) scheme provided solutions to delay the channel locking in the next candidate cell by calculated time [10].

The main contribution of this work is to propose a novel call admission and handover management scheme. Based on the predictable and deterministic feature of mobile users' movement, it takes user location and connection characteristics into consideration, thus reserving resources more accurately and maximizing the number of connections admitted into the system while providing users with satisfactory quality of service (QoS). Extensive simulation results show that compared with GC scheme, the new scheme greatly reduces new connection blocking probability while its handover failure probability is relatively low. It also achieves results comparable with TCRA, and outperforms TCRA under heavy traffic conditions, thus achieving a better utilization of bandwidth under bursty traffic conditions.

2. Theoretical Analysis.

2.1. **Model analysis.** LEO satellite moves quickly relative to the ground terminal; therefore, the speed of the ground mobile terminal can be ignored. In earlier works on LEO satellites visibility, general expressions for the single satellite visibility time are provided [11,12]. In Iridium system, by using multi-beam antenna, satellite motion direction is fixed, and the coverage cell of each spot beam is round or oval. So to ground users, satellite motion direction is certain and through the whole beam under the star time is basically the same. According to the moving relatively, we can assume the satellite cell is fixed, and all of the mobile terminals move in the same fixed speed along the same direction. So handover service can only be generated by the last cell, that is, the handover call arrival probability of the cell is only related to the state of last cell. The new call origination cell is called "current cell", the cell which the new call will enter to is called "target cell", and the cell which the users will be switched into the current cell is called "previous cell". In order to analyze simply, as shown in Figure 1, we select the connected cell as the algorithm model, L is the length of cell, the dotted line in Figure 1 is two adjacent cell for the overlap regions, and ΔS_{AB} means the distance between user A and user B in two adjacent cells.

Combined with the practical application of satellite networks, assume that each beam coverage cell has C channels, in which C_R channels are reserved by communication systems for handovers, the remaining $C - C_R$ channels are provided to handover calls and new calls which use these channels are according to the principle of first come first served. When a handover arrived, the corresponding free channel is distributed to handover if C channels of the cell are not fully occupied; otherwise using the overlap region between the two spot

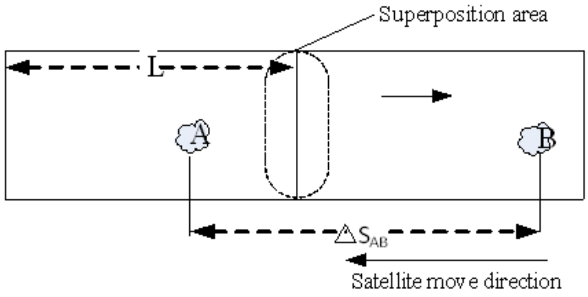

FIGURE 1. System motion model

beams to queue handover requests. If any channel of the target spot beam is releasing, the handover call in the first of the queue will automatically get the channel, and the queue refreshes in turn. If it still fails to be assigned channel which will be removed from the handover buffer, this handover call requests will be forced to discard. When a new call user issues the requirement of using the cell channel to system, the free channel will be distributed to this new call if the channel used by the common competition is not all occupied; If the channel used by the common competition is all occupied, judging the remaining amount number of the reserved channels, the call will be blocked if the reserved channel is all occupied; If surplus m channels are reserved to switch, the new call users will be compared the relative position with the first m handover users in the last cell. If among the distances between the new call and the first m handover users in last cell at least there is a length which is longer than the length of the cell, then the new call will seize a reserved channel, which will be released and recover to the original state when the new call in this cell ends the call or switches to the next cell; If among the distances between the new call and the first m handover users in the last cell there is no one length which is longer than the length of the cell, then do not perform seizing strategy, and block the new call.

2.2. **Mathematical analysis.** Each cell can be regarded as an M/M/C/S queuing system model. Each cell has total C channels, the maximum queue length is C, has total $(2C+1)$ states which are defined as the sum of the number of calls on the call and the number of the handover request waiting for service in the queue. The system state transfer rate is shown in Figure 2.

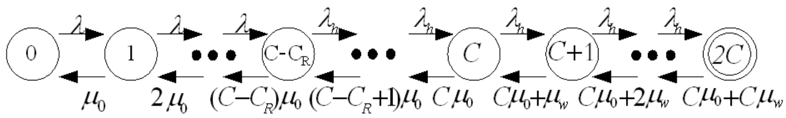

FIGURE 2. System state transfer diagram

Set T_m as the average call duration, the new call arrival and handover request arrival are two mutually independent Poisson process, set λ_n as new call arrival probability, λ_h as the handover request arrival probability, users obey $[0, L]$ uniform distribution in the cell, p_b is the new call blocking probability, and p_h is handover dropping probability. $E[t_w] = L_0/v_{sat}$ is the maximum waiting in line, where L_0 is the width of the overlapping cell. Therefore, the state of the model has no memory as Figure 2. The channel occupancy time of the new call and handover call channel in each cell can approximately obey $1/\mu_0$ negative exponential distribution, p_i $(i \in [0, 2C])$ is the probability of system in certain state.

The queuing process is a birth-death process, and the state balance equation is as follows:

$$p_i = \begin{cases} \frac{\lambda}{i\mu_0} p_{i-1}, & 1 \le i \le C - C_R \\ \frac{\lambda_h}{i\mu_0} p_{i-1}, & C - C_R + 1 \le i \le C \\ \frac{\lambda_h}{C\mu_0 + (i+C)\mu_w} p_{i-1}, & C + 1 \le i \le 2C \end{cases} \tag{1}$$

State by the above recursive equation and combined with the normalization condition: $\sum_{i=0}^{2C} p_i = 1$, it can get the probability distribution $\{p_i\}$:

$$p_0 = \left[\sum_{j=0}^{C-C_R} \frac{\lambda^j}{j!\mu_0^j} + \sum_{j=C-C_R+1}^{C} \frac{\lambda^{C-C_R}\lambda_h^{j-(C-C_R)}}{j!\mu_0^j} + \sum_{j=C+1}^{2C} \frac{\lambda^{C-C_R}\lambda_h^{j-(C-C_R)}}{C!\mu_0 \prod_{k=1}^{j-C} (C\mu_0 + k\mu_w)} \right]^{-1} \tag{2}$$

$$p_i = \begin{cases} \frac{\lambda^i}{i!\mu_0^i} p_0, & 1 \le i \le C - C_R \\ \frac{\lambda^{(C-C_R)}\lambda^{i-(C-C_R)}}{i!\mu_0^i} p_0, & C - C_R \le i \le C \\ \frac{\lambda^{(C-C_R)}\lambda_h^{i-(C-C_R)}}{C!\mu_0 \prod_{j=1}^{i-C} (C\mu_0 + j\mu_w)}, & C+1 \le i \le 2C \end{cases} \tag{3}$$

When the channels used by the common competition in a cell are all to be used and the reservation channels to handover still have free ones, supposing the new call request access, set the position of the new call origination from the start to the handover boundary as s_1, because the new arrival probability of each cell obeys the parameters λ_n Poisson stream, and users in each cell obey uniform distribution. Supposing j users are communicating in the previous cell, which is that channel using state in the previous cell is j state. The channels which the common competition in the current cell are used, the current cell is i state, there are $(C-i)$ remaining free reserved channels, and then according to the distance between the new call in the current and j users in the previous cell calculate the probability of the occupied channels. When the number of free reserved channels in this cell is larger than the number of communicating users in previous cell, this means there are plenty of reserved channels for handover users to use, then it can directly seize a reserved channel to communicate; If the number of communicating users in previous cell is larger than the number of fixed reserved switching channels in this cell, then it must be according to the users' position to judge whether to occupy the reservation channels. If at least a user of the first j waiting handover users in previous cell will switch into this cell after this new call leaves this cell, the new call can occupy the original switch reservation channels; otherwise the new call is blocked; the occupied probability can be expressed as:

$$p(i,j) = \begin{cases} 1 & j < C - i,\ i \in (C - C_R, C) \\ 1 - \left(\frac{s_1}{L}\right)^j & j \ge C - i,\ i \in (C - C_R, C),\ j \in [C_R, C],\ s_1 \in (0, L) \end{cases} \tag{4}$$

where $p_{(n-1)j}$ is the probability of the $(n-1)$ cell using state in j state, that is the probability of j channels used in $(n-1)$ cell (the cell is: the source cell for n, the previous cell for $(n-1)$).

So according to position to judge whether it can implement the occupied channels strategy, which can be implemented to reduce the new call blocking probability, the new call blocking probability p_b is:

$$p_b = \begin{cases} \sum_{i=C-C_R+1}^{C} p_{ni} - \sum_{i=C-C_R+1}^{C} \left[p_{ni} \cdot \sum_{j=0}^{C_R-1} p_{(n-1)j} \right] \\ \sum_{i=C-C_R+1}^{C} p_{ni} - \sum_{i=C-C_R+1}^{C} \left\{ p_{ni} \cdot \sum_{j=C_R}^{C} \left[p_{(n-1)j} \cdot \left[1 - \left(\frac{s_1}{L}\right)^j \right] \right] \right\} \end{cases} \tag{5}$$

For FIFO queuing mechanism, if the current system state $i < C$, the switch request can be satisfied immediately, that is the handover calls can be serviced immediately without queuing. Conversely, if the current system state $i \ge C$, the handover request enters the queue and the handover request will be cleared only during the waiting time. Therefore, the dropping probability of handover calls can be expressed as follows: According to the proposed method [13], it can be pushed to get:

$$P_h = \sum_{k=1}^{C-1} \left\{ 1 - \prod_{i=1}^{k} \left[1 - \frac{\mu_w}{(C\mu_o + \mu_w)2^i} \right] \frac{C\mu_o}{C\mu_o + \mu_w} \right\} P_{C+k+1} + \frac{\mu_w}{C\mu_o + \mu_w} P_{C+1} \quad (6)$$

3. **Simulation Performance Analysis.** In this paper based on the fixed reserve channel, using queuing switch strategy and occupied reserved channel strategy, we made the simulation comparison with time-based channel reservation algorithm (TCRA) and fixed channel reservation strategy. Corresponding to different total traffic loads, compare the handover dropping probability, new call blocking probability, channel utilization probability. The class of service (GoS) is an important index to reflect the QoS, to ensure that the new strategy has better QoS requiring GoS of the new strategy lower. Combined with the definition of GoS, $Gos = p_b + k \cdot p_f$, the balance factor is 10.

Using MATLAB to simulate, simulation parameters are set as follows:

1) Suppose there are 7 connected beam cells, the cell length is 250km; satellite mobile speed is 27000km/h;
2) Using fixed channel distribution among the cell, the number of average distributed channels is 20 in each cell and reserve 3 fixed channels to switch in each cell;
3) User call duration obeys negative exponential distribution, and the average of call duration $Tm = 180$s;
4) Adopt uniform business model and total traffic load is variable, the new call arrival process in cell is Poisson process with the same arrival probability.

In Figure 3, it is shown that the new call blocking probability of the new strategy compares with GC and TCRA with the cell total traffic load changing. As it can be seen from Figure 3, the number of system service call is gradually increasing as the call arrival probability becomes larger, but the number of channels used to new call reducing, coming block and the blocking probability is gradually increasing, the strategy of TCRA guarantee the handover determining the performance of its new call gradually becomes worse as increasing volume of business. In order to balance performance of handover and the new call, this paper implemented the occupied reservation channels based on the distance between new call and the preparing handover user's in the previous cell, which effectively increases the number of new call access. Compared with the GC strategy, new call blocking probability is greatly reduced and resolved by the reservation caused part of channel idle problem as the total traffic load becomes larger; the new strategy is especially suitable for the numerous users request access to relieve the problem of call blocking.

Figure 4 shows the comparison of the handover dropping probability of the three strategies in the case of different total traffic loads. From Figure 3 can be seen TCRA does not produce handover dropping in different total traffic loads. With cell total traffic load increasing, the channels of reserved by fixed reserve strategy to switch are fixed, the number of the preparing handover users is increasing and the handover performance declined. This paper strategy based on preparing handover user's position in the previous cell ensured the handover performance from the previous cell to this cell, but the users occupied the reservation channels in this cell will common compete the next channel resources with this cell users, so inevitably cause that the handover performance from this cell to the next cell declined, that is the switching dropping probability is only 0.0023 even when the total traffic load is 12, so that the handover dropping probability will be within the system allowable range.

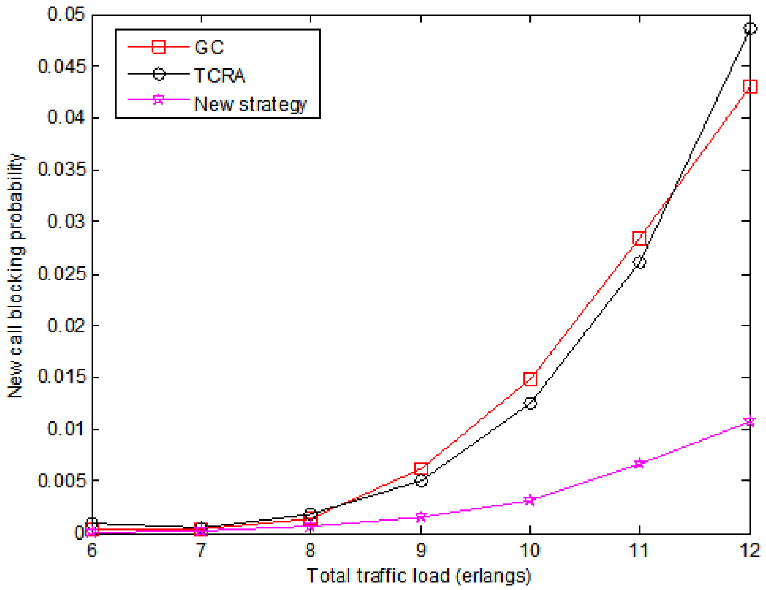

FIGURE 3. New call blocking probability

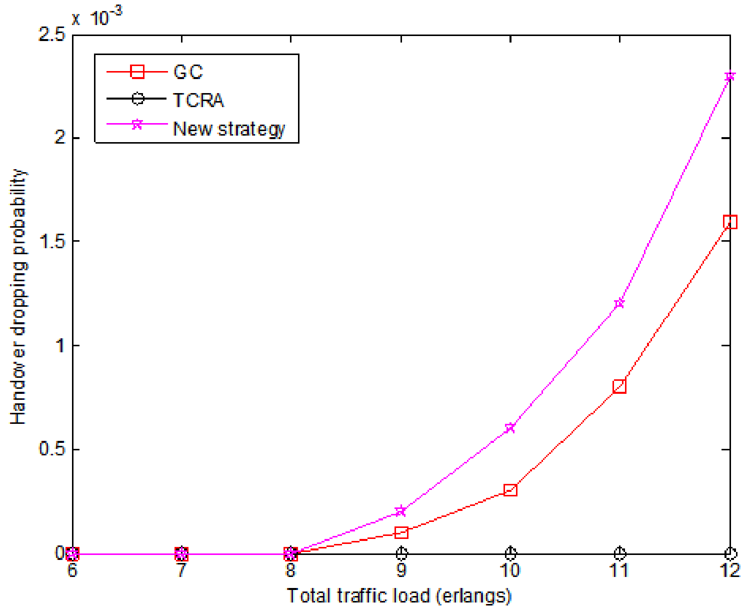

FIGURE 4. Handover dropping probability

Figure 5 shows the comparison of several strategies in GoS, the proposed new strategy has the lowest GoS in selected different total traffic loads, that is it has the best overall performance. Followed by TCRA, GoS of the reserve strategy reserved 3 channels is the highest. GoS as an evaluation strategy meets the measure of the degree of user, which reflects the better feasibility of the strategy.

Figure 6 shows the channel utilization probability of several strategies, and we can see the channel utilization probability of the proposed new strategy higher than the fixed channel reserve strategy in different total traffic loads. Simulation results show that the advantages of the channel utilization probability of the proposed new strategy is not

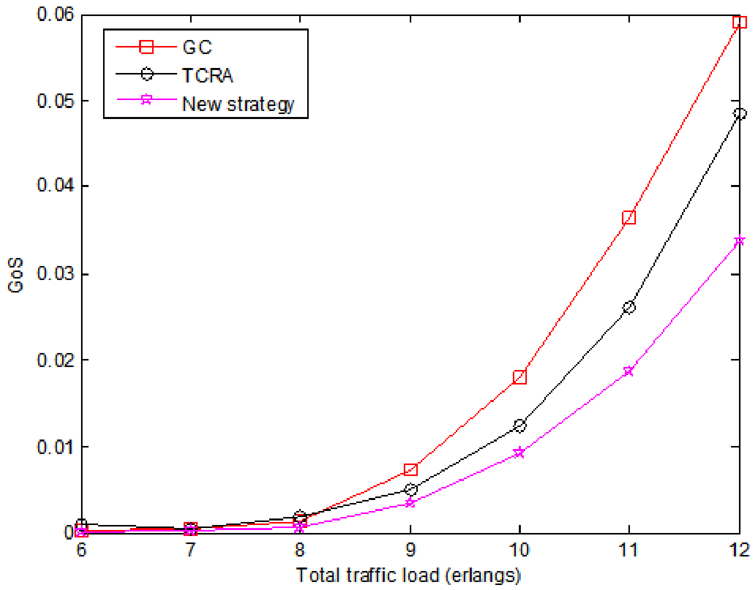

FIGURE 5. GoS of several strategies

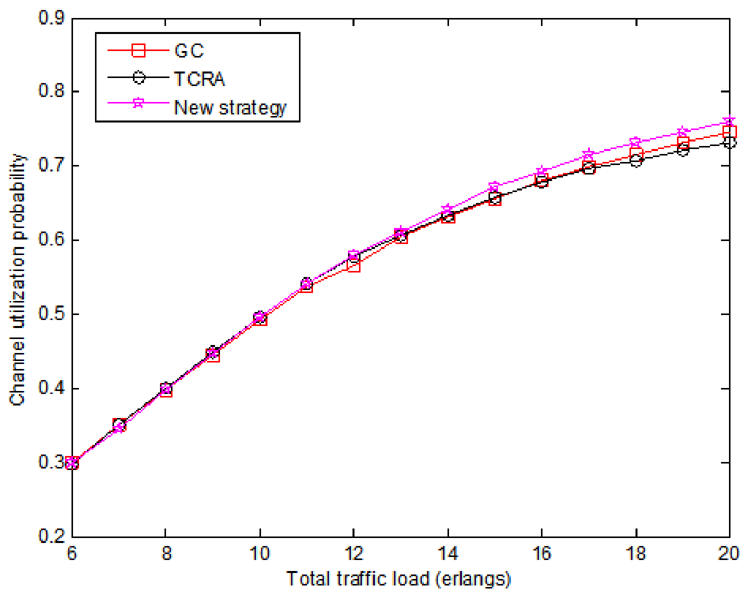

FIGURE 6. Channel utilization probability

obvious when the lower numbers of channels demanded by call users; but the new strategy obviously shows the advantage of the channel utilization probability as the greater total traffic load of cell.

In summary, the new strategy significantly improved the new call performance and the channel utilization probability compared with the fixed channel reserve strategy and TCRA, and then better used the channel resources. The new strategy increases the handover dropping probability, but it is significant using tiny handover dropping probability in exchange for the higher performance of channel utilization probability.

4. **Conclusions.** In view of the spot beam satellite communication system has frequently handover between spot beams. In the premise of the fixed reserved channel for handover users and the queuing switching users, this paper proposed the occupied strategy to the new call according to the distance between the new call's position and the preparing handover user's position in the previous plot beam when total public channels are all used and still have free reserved channels. The new strategy effectively reduces the new call blocking probability and increases the channel utilization probability.

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