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A Sub-cell Based Channel Reservation Method for MEO Network

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Abstract. Medium Earth Orbit (MEO) satellite networks must be capable of handle the handover problem of users between different spot-beam cells. In this paper, a Sub-cell based Handover Scheme (SHS) is proposed to decrease the resource reservation time reasonably in the Dynamic Doppler-Based Handover Prioritization (DDBHP) scheme. In this way, we decrease the new call blocking probability effectively while keeping very small of the forced termination probability for the handover user, which greatly increases the resource utility. Simulation results verify the correctness of the proposed approach.

Keywords: MEO satellite networks; handover management; time-based reservation.

1. Introduction

Handover scheme for satellite networks has been thoroughly researched nowadays. Most of them are based on the way of resource reservation, that is, the resources are reserved in advance for users to guarantee the success of handover. Guarantee Handover (GH) method [1], as the pioneer of resource reservation schemes, tries to reserve a channel in the cell next to the one the user is entering. However, GH is somewhat selfish for its over conservative behaviour, in which locked channel cannot be used by other users, even though the owner does not use it currently. That is why the DDBHP scheme [2]–[4] is proposed to lock the resources only for their expected handover time of use for a better channel utilization. By anticipating the user motion and reserving resources, DDBHP estimates the residence time of the user in each cell to be crossed and reserves a resource during the corresponding residence time interval. Similarly, other solutions have been provided to delay the channel locking in the next candidate cell and trade-off the handover guarantee to a certain extent: The Elastic Channel Locking scheme [5], Time-based Channel Reservation Algorithm method [6][7], Threshold-Based Handover Prioritization scheme [8], Channel Status based Reservation Strategy [9], Dynamic Channel Reservation scheme based on Priorities [10], and a geographical information based resource reservation algorithm [11].

State-of-the-art methods are devoted in delaying the reservation request moment as much as possible while ensuring the QoS of the UT. Nevertheless, they usually set the time reserved in the next spot-beam cell for the UT as the channel duration of a spot-beam cell. This kind of resource reservation methods has a certain applicability in LEO networks with short channel duration of the spot-beam cell. However, the channel duration of the spot-beam cell is longer in MEO network. To clarify this problem, assume that the constellation of a satellite network is composed of five MEO satellites, with the height of 10390km and 0° inclination, which meets the seamless communication requirement for low latitude area. The duration of a spot-beam cell is about 10 minutes, while a typical voice call usually lasts about 3 minutes. With the state-of-the-art methods applied, 10 minutes channel resource would be reserved for the UT whose average demand is just 3 minutes. Apparently, there is a significant waste of resources in these methods. In this paper, we propose a Sub-cell based Handover Scheme (SHS) based on DDBHP to provide a better resource utilization

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of the MEO system. In this scheme, the duration of channels locked is equal to the expected communication time of the UT. This methodology allows to perform more accurate reservations in order to increase the number of admitted users in the system.

The remaining of this paper is organized as follows: In section 2, we briefly descript the DDBHP handover scheme and shows how our proposed SHS method improves the DDBHP performance. An analytical approach is developed in Section 3 to evaluate the performance of SHS algorithm. In Section 4, simulation experiments are derived to validate the results obtained analytically. Finally, the conclusions are reported in Section 5.

2. Resource Reservation Based Handover Problem in MEO Satellite Network

In this paper, we focus on the Satellite-Fixed Cells (SFC) and Fixed Channel Allocation (FCA) scheme [2]. To clarify the differences between SHS and DDBHP scheme, the user relative mobility models of DDBHP and SHS are illustrated in Fig. 1 and Fig. 2 respectively.

In the DDBHP scheme, T_{cell} denotes the duration of a spot-beam cell, the time threshold t_{TH} indicates the moment when the reservation request is sent. The properly choosing t_{TH} allows DDBHP to achieve different levels of forced termination probability P_f or even eliminate it, because whether or not a new call is admitted in the network depends on the position of the UT at the call setup:

- If the UT is located in region A, an available channel only in the present spot-beam cell is required;
- If in region B, available channels both in the present and the next spot-beam cell are required.

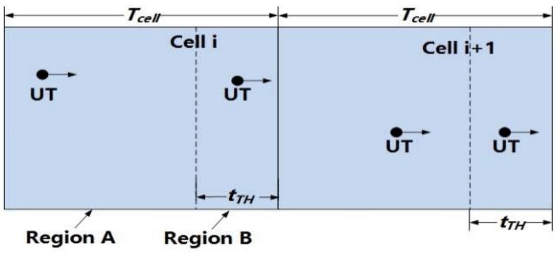

Fig. 1: User relative mobility model in DDBHP

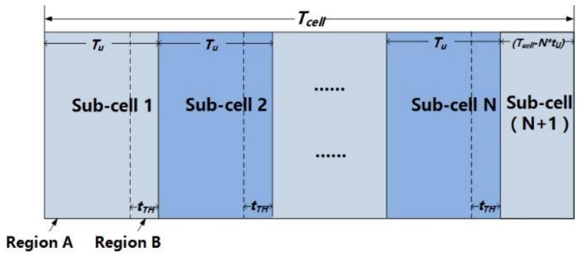

Fig. 2: The sub-cell model of spot-beam cell

However, there are two main differences between SHS and DDBHP scheme: the channel reserved time for the UT and the time threshold t_{TH}. Since the channel duration T_{cell} of the spot-beam cell is much longer than the average communication time T_u of the UT in MEO networks. As shown in Figure 2, the spot-beam cell is divided into multiple sub-cells to avoid the excessive resource reservation in SHS. Because of the non-integer of $\frac{T_{cell}}{T_u}$, the channel duration of the $(N+1)_{th}$ sub-cell is $(T_{cell} - N * T_u)$, where $N = \lfloor\frac{T_{cell}}{T_u}\rfloor$. Thus, the resource reservation time for the UT is the channel duration t_R^i of the i_{th} sub-cell in SHS, instead of the channel duration of a whole spot-beam cell T_{cell} in DDBHP. In addition, different from DDBHP scheme, the time threshold t_{TH} divides a sub-cell into region A and region B in SHS. If the UT is located in region A of a sub-cell, an available channel only in the present sub-cell is required. If the UT is located in region B of a sub-cell, available channels both in the present and in the next sub-cell are required. In both case, similar to DDBHP, if the next sub-cell has an available channel, it is locked for the UT immediately. Otherwise, the reservation request is queued for a time interval. If a channel is not found during the time t_{TH}, the communication of the UT is forced into termination. If the communication is terminated before the handover occurrence, the reserved channel or the queued request are also cleared.

3. Analytical Approach for SHS

In this process, we analyze the performances of forced termination probability P_{fs} and blocking probability P_{bs} in a sub-cell firstly. Then the mathematical analysis of P_f and P_b are extended. We consider the following basic assumptions, also as usually made in the literature [1], [2], [5], [10]:

- The new call and handover arrival processes of UTs are independent Poisson processes;
- The distribution of UTs in spot-beam cells are uniform;
- The communication times of UTs are exponentially distributed, with mean value T_u.

3.1. The performance analysis in a sub-cell

According to equilibrium condition [12], the equilibrium equation in region A and B of a sub-cell can be derived as

$$\lambda_r = \lambda_h P_{h2-A} + \lambda_{n-A}(1 - P_{bs})P_{h1-A} \quad (1)$$

$$\lambda_r(1 - P_{fs})P_{h2-B} + \lambda_{n-B}(1 - P_{bs})^2 P_{h1-B} = \lambda_h \quad (2)$$

where λ_h denotes the arrival rate of handover calls, λ_r is the rate of handover requests, and λ_{n-A}, λ_{n-B} represent the arrival rate of new calls in regions A and B. Similar to literature [2], $P_{h1-A} = \alpha_A(1 - e^{-\frac{1}{\alpha_A}})$, $P_{h1-B} = \alpha_B(1 - e^{-\frac{1}{\alpha_B}})$ denote the first handover in region A and B, $P_{h2-A} = e^{-\frac{1}{\alpha_A}}$, $P_{h2-B} = e^{-\frac{1}{\alpha_B}}$ denote the subsequent handover in region A and B, where dimensionless parameters $\alpha_A = \frac{T_u}{t_R - t_{TH}}$, $\alpha_B = \frac{T_u}{t_{TH}}$, and traffic parameters $\lambda_{n-A} = \frac{\lambda_n}{\alpha_A}$, $\lambda_{n-B} = \frac{\lambda_n}{\alpha_B}$.

There are four kinds of UTs who occupying resources in current sub-cell: 1) In the current sub-cell, the new arrival UTs generated in region A; 2) In the current sub-cell, the new arrival UTs generated in region B; 3) In the previous sub-cell, the new arrival UTs generated in region B need reservation in the current sub-cell; 4) In the previous sub-cell, the UTs reaching the boundary t_{TH} of region A and B need resource reservation in the current sub-cell.

Similar with literature [2], the derivation of the average channel holding time $\frac{1}{\mu} = \sum_{n=1}^{4} P_n E[T_H^n]$ for UTs in a sub-cell consists of four situations above, each of which represents a different case of call. When the number of occupied channels in the sub-cell is less than C, all these four kinds of UTs above can occupy channels, and the channel occupancy rate of the sub-cell λ_{sp} is

$$\lambda_{sp} = \lambda_{n-A} + \lambda_{n-B}(1 - P_{bs}) + \lambda_{n-B}(1 - P_{bs}) + \lambda_r \quad (3)$$

Thus, the Markov chain model for SHS can be depicted in Fig. 3. Each state represents the sum of the channel in service and reservation request in the waiting queue. For $k \in [0, C-1]$, the transition rate from state k to $k+1$ is given by λ_{sp} in (3). However, for $k \in [C, 2C-1]$, because all channels are busy, the arriving new calls would be discarded immediately and only the fourth kind of UTs above (who requesting resource reservation) would be queued to wait for a chance, so the transition rate from state k to $k+1$ is λ_r. The parameter μ_{ut} is the average departure rate of UTs, which meets $\mu_{ut} = \frac{1}{T_u}$.

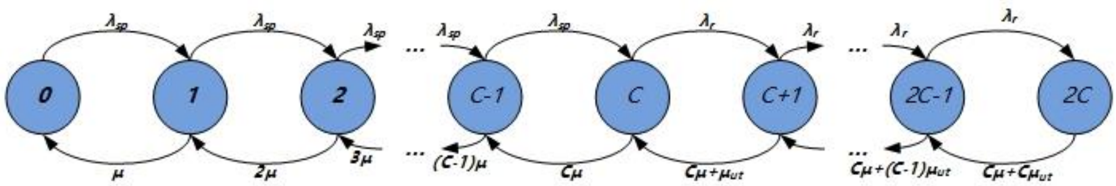

Fig. 3: Markov chain model for SHS

Similar with DDBHP scheme [4], $P_s(k)$ (the steady-state probability of state k) is derived

$$P_s(k) = \begin{cases} \frac{(\lambda_{sp})^k}{k!\mu^k} P_s(0), & 0 \le k < C \\ \frac{(\lambda_{sp})^C (\lambda_{rq})^{(k-C)}}{C!\mu^C \prod_{j=1}^{k-C}(C\mu + j\mu_{ut})} P_s(0), & C \le k \le 2C \end{cases} \quad (4)$$

where the channel idle probability $P_s(0)$ is given by

$$P_s(0) = \left\{ \sum_{s=0}^{C-1} \frac{(\lambda_{sp})^k}{k!\mu^k} + \sum_{s=C}^{2C} \frac{(\lambda_{sp})^C (\lambda_{rq})^{(k-C)}}{C!\mu^C \prod_{j=1}^{k-C}(C\mu + j\mu_{ut})} \right\}^{-1} \quad (5)$$

Therefore, the block probability P_{bs} and forced termination probability P_{fs} of a sub-cell can be derived as

$$P_{bs} = \sum_{k=C}^{2C} P_s(k) \quad (6)$$

$$P_{fs} = \sum_{k=C}^{2C} P_s(k)\, Pr\{t_q \geq t_{TH}\} = P_{ns} e^{(\lambda_{rq} - C\mu)t_{TH}} \quad (7)$$

3.2. The performance analysis in a spot-beam cell

As the sub-cell is divided from a spot-beam cell (Fig. 2), we set t_R^i be the channel duration of i_{th} sub-cell, and P_{bs}^i ,P_{fs}^i be the block probability and forced termination probability respectively. The block probability P_b and forces termination probability P_f of a spot-beam cell can be deduced as

$$P_b = \sum_{i=1}^{N+1} \frac{t_R^i}{T_{cell}} P_{bs}^i \quad (8)$$

$$P_f = \sum_{m=1}^{\infty} (1 - \left(1 - P_{fs}\right)^m) P\{(m-1)T_u < t_u < mT_u\}) = \sum_{m=1}^{\infty} \left(1 - \left(1 - P_{fs}\right)^m\right) \frac{e-1}{e^m} = \frac{eP_{fs}}{e-(1-P_{fs})} \quad (9)$$

Based on the analysis provided in this section, with the help of recursive approach, t_{TH} can be calculated for meeting the required performance in terms of $P_b$and P_f.

4. Simulation and Analytic Results

The purpose of this section is to verify the validity of SHS method by comparing the simulation results with DDBHP scheme. In obtaining our simulation, we use the mobility model shown in Section 2. Each spot-beam cell has 10 channels. The channel duration of a spot-beam cell T_{cell} equals to 360 seconds, which is calculated according to the satellite altitude and the cell size of ICO system [13]. In this system, we implemented a Poisson procedure for arriving traffic by using a number of UTs $N_{UTs} = 1000 \gg C$ and the traffic load ranging from 6 to 24 Erlang. 1200 UTs were uniformly distributed in each spot-beam cell, and the communication time t_u of the UT is exponentially distributed with the mean value set to $T_u = 180s$. Queuing policy for channel resource reservation request is First In First Out (FIFO). Thus, the number of sub-cells for a spot-beam cell is 2 in SHS, and the channel duration of a sub-cell $t_R = 180s$.

When the cell load is 24 Erlang in system, the Blocking probability P_b and forced termination probability P_f versus threshold t_{TH} in SHS is shown in Fig. 4. Apparently, P_f in SHS is actually zero when $t_{TH} \geq 0.4t_R$, and the P_b would increase with the higher of t_{TH}. Therefore, on the basis of satisfying the QoS demand of the UT on P_f, we should decrease the value of t_{TH} as much as possible to improve the system resource utilization.

The comparison on the blocking probability P_b and forced termination P_f of SHS and DDBHP method is shown in Fig. 5, where the cell load still be 24 Erlang. Because the reservation time for UTs are determined by the average duration of communication T_u in SHS, rather than the channel duration T_{cell} of a spot-beam cell in DDBHP, the wasted reserved resources which cannot be used by other users is significantly reduced in SHS. Thus, the P_b in SHS keeps obviously lower than that of DDBHP. However, because the resource reservation time T_u in SHS algorithm is shorter than that of DDBHP (which is T_{cell}), the UT with a communication time longer than T_u has to handover again in SHS scheme, which increases the number of handover in SHS. As a result, the performance on P_f is slightly worse in SHS than that of DDBHP scheme. Nevertheless, if we choose the t_{TH} appropriately and keep the P_f in very small value in SHS, the negative effect of worse performance on P_f can be eliminated.

Fig. 6 shows the blocking probabilities P_b of SHS and DDBHP under different cell load versus reservation threshold t_{TH} , and Fig. 7 depicts the blocking probabilities P_b of SHS and DDBHP under different reservation threshold t_{TH} versus cell load. Both of them demonstrated the validity that the proposed SHS method can inherit the advantage of DDBHP method, while making a better resource utilization in MEO satellite networks.

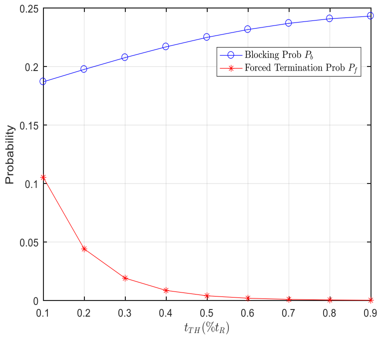

Fig. 4: Blocking probability and forced termination probability versus threshold in SHS

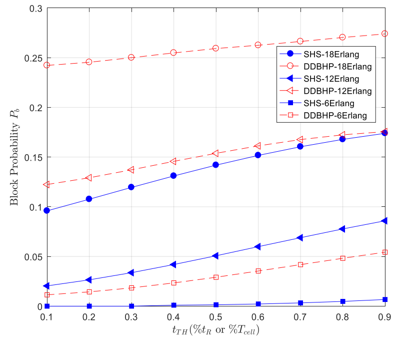

Fig. 6: Blocking probability of SHS and DDBHP under different cell load versus threshold

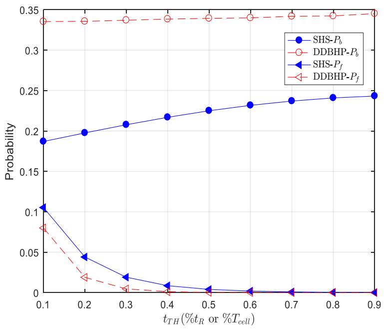

Fig.5: Blocking probability and forced termination probability of SHS and DDBHP versus threshold

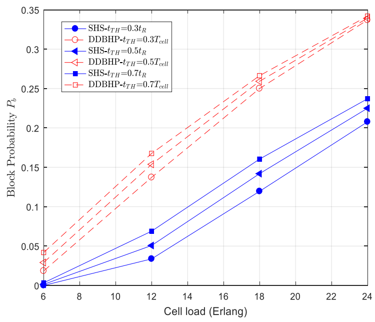

Fig.7: Blocking probability of SHS and DDBHP under different threshold versus cell load

5. Conclusions

In this paper, we point out the problem of over-reservation in the resource reservation based handover methods, which has never been addressed so far in contributions. And a sub-cell based handover scheme was proposed, which takes the advantage of the statistical communication time of the traffic, to solve the over-reservation problem for a better resource utilization. Simulation results show that the proposed method can satisfy QoS demands of users on the forced termination probability while achieving better blocking probabilities.

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7. References

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