Research on Dynamic Timeslot Reservation Handover Algorithm Based on Remaining Time in Beam Hopping System

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Abstract. Recently, beam hopping (BH) technology has been considered as the key technology of the next generation High Throughput Satellite (HTS) system for its flexibility. In order to ensure the communication continuity of the terminal in the beam hopping satellite system, it is particularly important to study efficient beam handover technology. This paper proposes a dynamic timeslot reservation handover algorithm based on remaining time. Firstly, the terminal obtains remaining time of terminal in the current beam position. Then this paper simulates load imbalance through Poisson random distribution, and then clusters the beam positions to calculate the probability density function of the timeslot occupied in the cluster. Finally the algorithm dynamically reserves timeslot resources for the terminal. The simulation results show that, compared with the traditional handover algorithm, when the timeslot resources are insufficient, the algorithm can dynamically reserve timeslot resources to reduce the handover failure probability, and improve QoS.

Keywords: High Throughput Satellite · Beam Hopping (BH) · Beam handover · Timeslot reservation

1 Introduction

The core concept of beam hopping [1] is to employ time-slicing method: not all beams are illuminated at the same time, only part of them are activated on demand. Compared with the traditional multi-beam satellite system, the beam hopping technology is more able to meet the scenarios with unbalanced traffic requirements [2–5]. On the basis of this technology, in order to ensure the continuity of the communication of high-speed mobile terminals between beam positions, it is particularly important to study beam handover technology.

Many scholars have done a lot of research on beam handover algorithm. Literature [6] proposed a hard handover algorithm, which is based on the received signal strength

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and the speed of the mobile terminal. The algorithm does not take into account the current geographical location the terminal, and hard handover is more likely to cause communication interruption. A conventional handover algorithm was proposed in literature [7], which is based on the distance between the terminal and the center of each beam position. This algorithm does not consider the speed of the mobile terminal and follows the first-come first-served principle, which has great limitations. A handover algorithm was proposed based on remaining time [8, 9]. This algorithm takes into account information about geographic location and terminal speed to obtain remaining time at the current beam position, which solves the urgency problem. Mul-priority channel reservation allocation strategy was proposed in literature [10]. This algorithm classifies call types and reserves channels for handover calls to reduce handover failure probability. The beam handover strategy should be a multi-factor integration problem, so literature [11] proposes a handover algorithm based on fuzzy logic, combining multiple variables into a cost function for judgment. All the above algorithms are based in multi-beam satellite system. In beam hopping satellite system, the success of handover mainly depends on the occupancy of timeslot resources.

In view of the lack of research on beam hopping handover algorithm, with the goal of optimizing handover failure probability and improve the quality of service, this paper focuses on minimizing the failure of handover calls by reserving timeslot resources in the case of random distribution. Firstly, the terminal obtains the remaining time of terminals at the current beam position. Secondly, the beam positions are clustered. This paper simulates load imbalance through random distribution and the probability density function of the occupied timeslots is obtained. Finally, according to the handover failure probability, the timeslot resources are dynamically reserved for handover call terminals: when the handover failure probability is greater than the threshold, increase the number of timeslot reservations, otherwise the number of timeslot reservations remains unchanged. The simulation results show that under high arrival rate, the dynamic timeslot reservation handover algorithm based on remaining time has a lower handover failure probability, and improves QoS.

The rest of this paper is arranged as follows: Sect. 2 gives the beam hopping system model; Sect. 3 mainly explains the handover algorithm and handover process; Sect. 4 analyzes the simulation results; This paper is summarized in Sect. 5.

2 Beam Hopping System Model

The beam hopping model is shown in Fig. 1. The core concept of beam hopping is to employ time-slicing method: not all beams are illuminated at the same time, only part of them are activated on demand. Each cluster has timeslot period tables, and the beam positions are illuminated according to the timeslot period table. When the gateway receives the handover request, according to the usage of timeslot resources, beam is switched by the beam hopping controller on the satellite to ensure the continuity of mobile terminal communication.

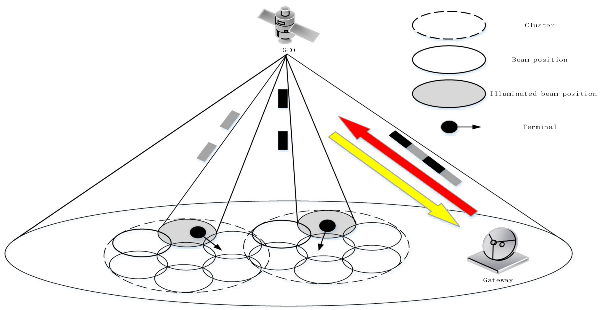

Fig. 1. Beam hopping system model

For ease of analysis, we assume that the system is a single beam hopping satellite system. Firstly, the beam positions are clustered. N_b beam positions form a cluster. Mobile terminals are randomly distributed in the cluster. At the same time, at most one beam position in each cluster is illuminated, and the number of timeslots in each cycle is the same, and the window length is W. Assuming that each terminal needs at least one timeslot for access, at most W mobile terminals are allowed to access at the same time in a cluster. In practice, the experience of handover failure is worse than waiting for new connection request access, so this paper sets the priority of handover request higher than new connection request. K timeslots are reserved for initialization, and the reserved timeslots are only allocated to the terminal that handover request. The remaining (W-K) timeslots are called by the handover and the new connection calls compete together.

3 Handover Algorithm and Analysis Model

3.1 Handover Mechanism

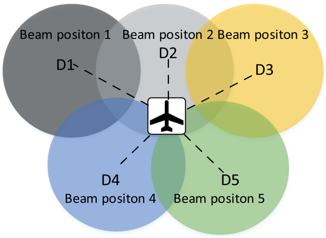

Fig. 2. Schematic diagram of the movement of the terminal in the multi-beam

Handover Mechanism Based on Location. In the handover mechanism [7, 8] based on location, the location of the terminal is used as a condition for triggering handover. As shown in Fig. 2, **D**1–**D**5 are the distance between the mobile terminal and the beam position center respectively. Assuming that the current beam position No. 2 is serving the mobile terminal, the terminal periodically calculates the distance D1–D5 from the center of each beam position. Then D1–D5 compare with D2. The distance difference $\mathbf{para} = \boldsymbol{D_i} - \boldsymbol{D_2}$. We set the terminal's mobility management requirement to 0, and the terminal sends the position information to the gateway via satellite. When para < 0, the handover request is met, the gateway prepares timeslot resources for the terminal on the target beam position. If the occupied time window is smaller than the timeslot window W, then the gateway execute handover. If the timeslot window is occupied, the terminal enters the waiting timeslot resource state, and continuously send the current location information within the overlap range until it leaves the overlap area.

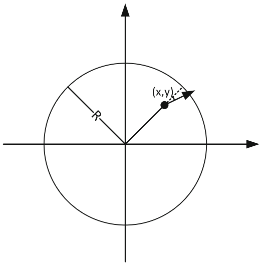

Fig. 3. The mobile station in the beam residence time calculation chart

Handover Mechanism Based on Remaining Time. Under the same satellite system, high-speed terminals such as airplanes and trains compete for the same channel or time slot resources. Assuming that in a overlap area, terminals with different speeds and different trajectories make handover requests to the gateway. According to the Mechanism in 3.1.1, the gateway will handle the handover requests according to the first-come first-served principle. For systems that include terminals of different speeds, this Mechanism has great limitations. This section proposes the handover mechanism [4, 7] based on remaining time that takes the remaining time of the terminal in the current beam position as the decision factor for handover. As shown in Fig. 3, the current position of the terminal is (x, y), the distance from the center of the beam position is $\mathbf{d} = \sqrt{\boldsymbol{x}^2 + \boldsymbol{y}^2}$. Assuming that the angle is $\boldsymbol{\theta}$, the remaining distance in the current beam position is $\boldsymbol{D} = \sqrt{\boldsymbol{R}^2 - \boldsymbol{d}^2\mathbf{sin}^2\boldsymbol{\theta}} - \boldsymbol{d}\mathbf{cos}\boldsymbol{\theta}$. The remaining time in the current beam position is $\mathbf{T} = \mathbf{D}/\mathbf{V}$. When it is less than the remaining time threshold, all mobile terminal handover requests will be queued according to the remaining time, and the gateway will give priority to the terminal with the least remaining time to allocate timeslot resources. It can be seen that under this handover mechanism, some urgent terminals can be processed preferentially, which reduces the handover failure probability.

3.2 Analysis Model

For a general connection, the channel holding time of the spot beam can be derived from [12]:

$$T_{hold} = \{T_{res}, T_{un}\} \tag{1}$$

Where T_{res} is the time interval between the moment of reaching the beam position and the moment of reaching the boundary of the adjacent beam position. T_{un} is the unencumbered connection duration. For these two types of terminals, airplanes(i = a) and trains(i = t), we assume that T_{un} is an exponentially distributed random variable with parameter τ. When deriving the T_{hold} [13], the position where the terminal enters the beam position cannot be ignored, that is, T_{hold} is related to the original position of the terminal [7, 14].

The terminals are always randomly distributed within the beam position, and then average channel holding times are derived from [9]:

$$E\left[T_{hold,i}^{new}\right] = \frac{1}{\tau}\left(1 - \frac{1-e^{-\tau R_{max,i}}}{\tau R_{max,i}}\right) \tag{2}$$

$$E\left[T_{hold,i}^{handover}\right] = \frac{1}{\tau}\left(1 - e^{-\tau R_{max,i}}\right) \tag{3}$$

Where $R_{max,i}$ is the time required for the terminal to cross the beam position. $E\left[T_{hold,i}^{new}\right]$ is average channel holding time of the terminal in original beam position. $E\left[T_{hold,i}^{handover}\right]$ is average channel holding time of the terminal in handover beam position.

The new connection arrival rate and handover request arrival rate of different terminals are independent Poisson processes, and arrival rates are $\lambda_{new,i}$ and $\lambda_{handover,i}$ respectively. Their relationship is [9]:

$$\lambda_{handover,i} = \frac{\lambda_{new,i}(1-P_{nb})P_{new,i}}{1-\left(1-P_{hf}\right)P_{handover,i}} \tag{4}$$

where P_{nb} is new connections blocking probability. P_{hf} is handover failure probability. $P_{new,i}$ is the probability that a certain terminal needs to switch in the original beam position. $P_{handover,i}$ is the probability that a certain terminal needs to switch in the handover beam position. In order to simplify our analysis, a traditional approximation is made to the above formulas.

The average connection time of the terminal $\frac{1}{\tau_i}$ is derived from the above formula [9]:

$$\begin{aligned} \frac{1}{\tau_i} = & \frac{\lambda_{new,i}(1-P_{nb})}{\lambda_{n,i}(1-P_{nb}) + \lambda_{h,i}\left(1-P_{hf}\right)} E\left[t_{hold,i}^{new}\right] \\ & + \frac{\lambda_{handover,i}\left(1-P_{hf}\right)}{\lambda_{new,i}(1-P_{nb}) + \lambda_{handover,i}\left(1-P_{hf}\right)} E\left[t_{hold,i}^{handover}\right] \end{aligned} \tag{5}$$

The number of occupied timeslots in the cluster is C, and the probability density function $f_C(z)$ of variable C is derived through the algorithm proposed in [15], and $z = 1, 2, 3, 4 \ldots W$:

$$f_C(z) = \frac{1}{z}\sum_{j=1}^{4}\frac{\lambda_j}{\tau_j}f_C(z-1)\Delta_j(z-1) \tag{6}$$

$$\Delta_j(z) = \begin{cases} 1 & z \le threshold_j - 1 \\ 0 & otherwise \end{cases} \tag{7}$$

Where $threshold_j$ is the threshold of each connection type. $j = 1, 2, 3, 4$ are the new connection request of train, the new connection request of airplane, the handover request of the train and the handover request of airplane respectively. Since trains and airplanes share the same timeslot resources, only the type of connection is distinguished, not the type of terminal. Then $\Delta_{new}(j = 1, 2)$, $\Delta_{handover}(j = 3, 4)$, $threshold_{\mathrm{new}}(j = 1, 2)$, $threshold_{\mathrm{handover}}(j = 3, 4)$ will be considered below.

After normalizing $f_C(z)$, the new connection blocking probability is derived from [9]:

$$P_{nb} = 1 - \sum_{z=0}^{W} f_C(z-1)\Delta_{new}(z-1) \tag{8}$$

According to $f_C(z)$, the probability P_{all} that all timeslots are occupied is derived:

$$P_{all} = 1 - \sum_{z=0}^{W} f_C(z-1)\Delta_{handover}(z-1) \tag{9}$$

Equation (9) does not consider the queuing strategy. For this reason, we assume that the maximum queuing time of the *i-th* terminal is an exponentially distributed random variable with parameter τ_i^P. At the same time, the results given in (9) are extended to a single type of terminal:

$$P_{hf} = P_{all}\left(\sum_{i=a,t} P_i P_i^{active} P_i^{occupied}\right) \tag{10}$$

Where P_i is the probability that the terminal requesting handover is the *i-th* type of terminal, P_i^{active} is the probability that the terminal remains connected in the overlapping area and $P_i^{active} = \frac{\tau_i^P}{\tau_i + \tau_i^P}.P_i^{occupied}$ is the probability that the timeslot is not released within the maximum queuing time, and $P_i^{occupied} = \frac{\tau_i^P}{\tau_a Com_{\frac{a}{tot}} + \tau_t Com_{\frac{t}{tot}} + \tau_i^P}$,$Com_{\frac{a}{tot}}$ and $Com_{\frac{t}{tot}}$ respectively are the ratio of the number of timeslots occupied by planes and trains, and $Com_{\frac{a}{tot}} + Com_{\frac{t}{tot}} \le 1$. This method allows us to implement the handover mechanism by changing the τ_i^P value: Under the mechanism based location, $\frac{1}{\tau_t^P} = \frac{1}{\tau_a^P} = 550$ s, and under the mechanism based remaining time, $\frac{1}{\tau_t^P} = 275$ s, $\frac{1}{\tau_a^P} = 80$ s.

For a certain beam position, the interval between two adjacent illuminations cannot be too long [16]. Otherwise, the transmission delay will be too long and the communication will be interrupted. A condition is needed here:

$$min t_{slot} \geq 10\,ms$$

Where $t_{slot} = T_{slot} \times N.t_{slot}$ is the total timeslot duration of a certain beam position, T_{slot} is duration of one timeslot. N is the number of timeslots allocated to a certain beam position.

3.3 Dynamic Timeslot Reservation Handover

For beam hopping system, users in the same cluster are served by the same beam, and do not need to switch at network layer. At the same time, the handover signaling overhead is low, but it puts forward high requirements on resource allocation: the corresponding timeslots need to be allocated when the terminals arrive and are released when the terminals leave. For multi-beam system, each beam resource is relatively fixed, there are many handover signaling interactions, and beam handover often involves network layer protocols.

The handover failure probability P_{hf} derived in the previous section is a handover algorithm based on static timeslot reservation, and does not reflect the superiority of the handover algorithm based on dynamic timeslot reservation. The handover algorithm based on dynamic timeslot reservation proposed in this paper, which based on static timeslot reservation, the number of timeslot reservations is dynamically adjusted according to the handover failure probability: when the handover failure probability is greater than the threshold, increase the number of timeslot reservations, otherwise the number of timeslot reservations remains unchanged. Dynamic timeslot reservation is shown in Fig. 4:

1. Initialize the terminal arrival rate λ_1, λ_2.
2. Initialization. For different types of terminals, $P_{hf} = P_{nb} = P_{all} = 0$, and the number of remaining timeslots in the cluster is W, then $f_C(0) = 1$.
3. According to the arrival rates of airplanes and trains λ_1, λ_2, the handover arrival rates of airplanes and trains λ_3, λ_4 are derived.
4. According to (5), the average connection time $\frac{1}{\tau_i}$ of a certain terminal is derived.
5. The probability density function $f_C(z)$ of the number of occupied timeslots in the cluster is derived through (6), and then normalized.
6. Select the handover mechanism, get different τ_i^P, and derive $NewP_{hf}$, $NewP_{nb}$, $NewP_{all}$.
7. If $NewP_{hf}$ is greater than the $threshold_{Phf}$, the number of timeslot reservations is increased by one, and repeat 5.
8. If $min t_{slot}$ is greater than 10 ms and $\sum_{k} |NewP - P| < \alpha$, output handover failure probability P_{hf} and new connection blocking probability P_{nb}, otherwise, repeat 3.

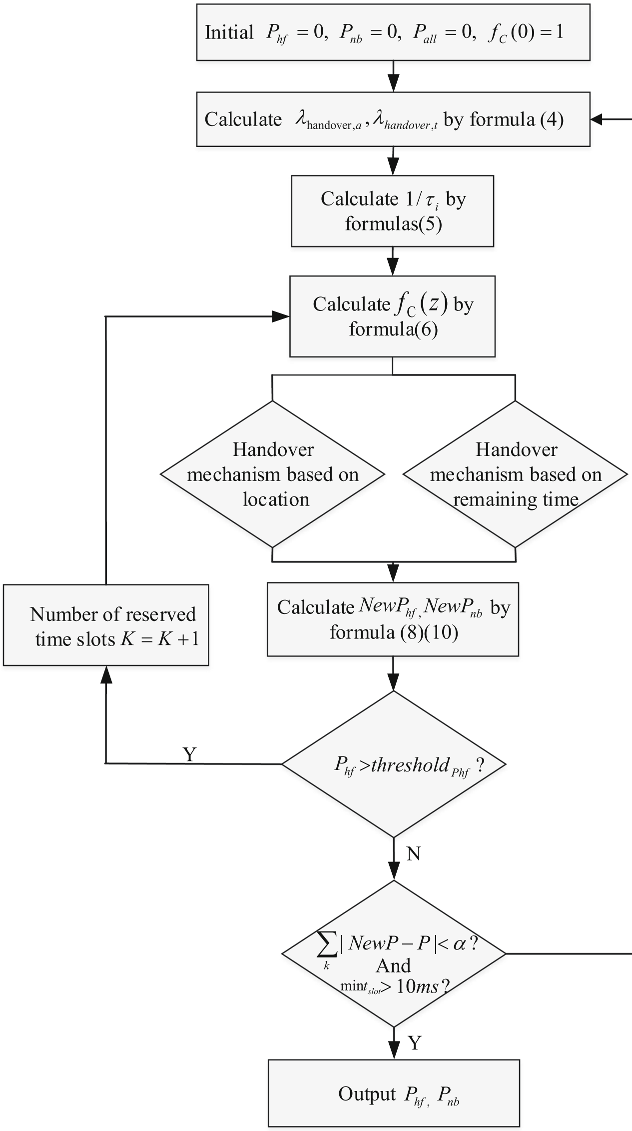

Fig. 4. Dynamic reservation handover flow chart

4 Simulation and Analysis

The simulation parameters are shown in Table 1. In addition, in order to better compare the simulation results, P_{hf}, P_{nb}, and QoS are used as indicators, and QoS is defined as:

Table 1. Simulation parameters

Parameters	Value
Beam hopping period	W = 140 T_{slot}
Number of beam positions per cluster	$N_b = 7$
Arrival rate of terminal	λ from 1 to 20
Average connection time	$\tau = 1$ h
Duration of one timeslot	$T_{slot} = 2$ ms
Importance of handover failure probability	$\alpha_{hf} = 0.8$
Importance of new connection blocking probability	$\alpha_{nb} = 0.2$
Number of initial timeslot reservations	K = 7
Handover failure probability threshold	$threshold_{Phf} = 0.01$
Convergence threshold	$\alpha = 0.01$

$$QoS = 1 - \left(0.7 \sum_{i=a,i=t} \alpha_{hf} P_{hf} + 0.3 \sum_{i=a,i=t} \alpha_{nb} P_{nb}\right) \tag{11}$$

The weight of P_{hf} is higher than the weight of P_{nb}, because the success of the terminal handover can affect the user experience more. The greater the QoS, the better the experience in this paper.

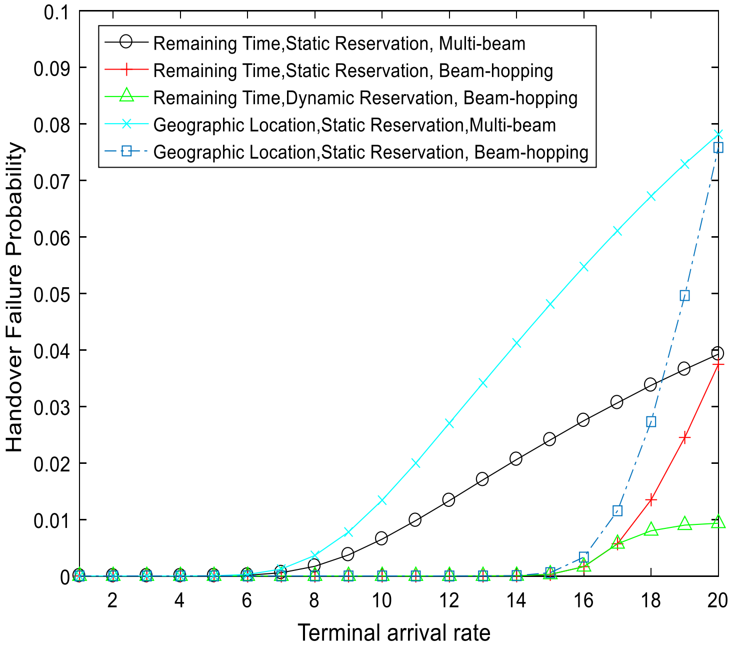

Fig. 5. The comparison of handover failure probability

As shown in Fig. 5, in the same scenario, it can be seen that the higher the arrival rate, the timeslot reservation handover algorithm based on remaining time has a significant improvement in handover failure probability. Under the same handover algorithm, there is a lower handover failure probability in beam hopping. Because beam hopping has more flexibility in timeslot allocation. This paper proposes a dynamic timeslot reservation handover algorithm based on remaining time. When the arrival rate is large enough, more timeslot resources need to be reserved to ensure that handover failure probability is within $threshold_{Phf}$.

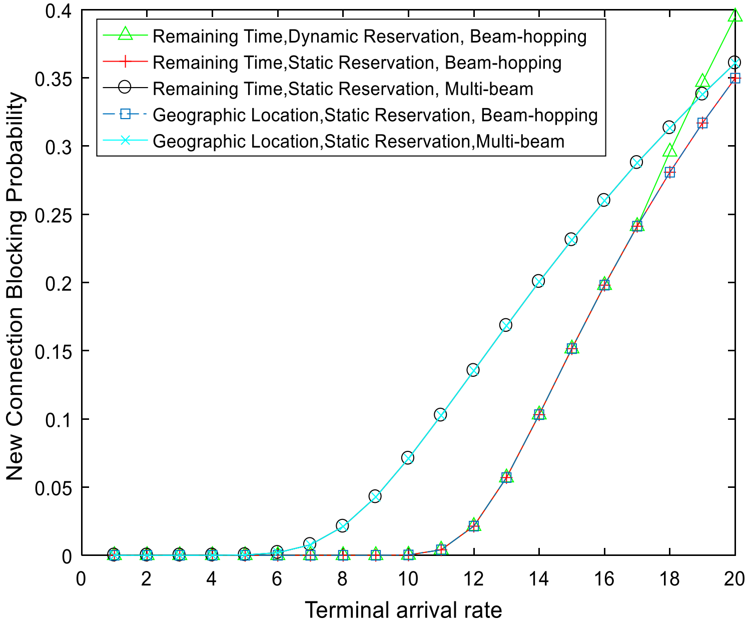

Fig. 6. The comparison of new connection blocking probability

As shown in Fig. 6, in the same scenario, the static timeslot reservation handover algorithm based on location and the static timeslot reservation handover algorithm based on remaining time have the same new connection blocking probability, indicating that the difference between the two handover mechanisms is not the new connection access, so different handover mechanisms have little effect on the new connection blocking probability. Under the same handover mechanism, there is a lower new connection blocking probability in the beam hopping, because beam hopping has more flexibility in timeslot allocation. This paper proposes a dynamic timeslot reservation handover algorithm based on remaining time. As handover failure probability approaches $threshold_{Phf}$, more timeslots are reserved for handover calls, which increases the new connection blocking probability.

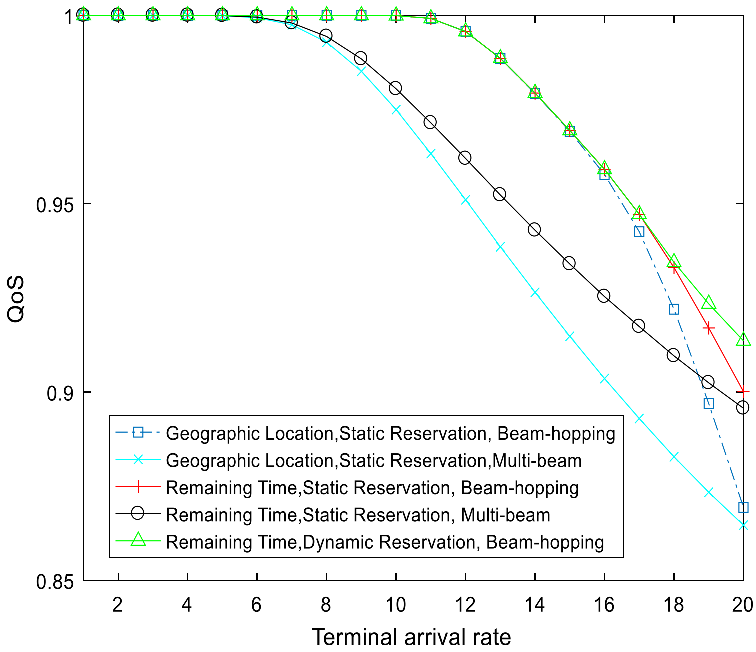

Fig. 7. The comparison of QoS

Successful handover can improve the user experience more, so the handover success probability is far more important than the new connection success probability. As shown in Fig. 7, in the same scenario, the QoS of the timeslot reservation handover algorithm based on remaining time goes down more slowly. For the same handover algorithm, the QoS goes down more slowly in beam hopping. In the case of high arrival rate or insufficient resources, the beam hopping technology uses can effectively reduce the handover failure probability for its flexibility. The dynamic timeslot reservation handover algorithm based on remaining time proposed in this paper reserves more timeslots to ensure the handover success probability. So that the QoS goes down the slowest.

5 Conclusion

In this paper, random distribution is used to simulate load imbalance. In order to reduce the handover failure probability of the system, a dynamic timeslot reservation handover algorithm based on remaining time is proposed: when the handover failure probability is greater than the threshold, increase the number of timeslot reservations, otherwise the number of timeslot reservations remains unchanged. The simulation results show that the algorithm can update the number of timeslot reservations according to the handover failure probability, which effectively guarantees the high-priority call service in the case of insufficient timeslot resources, and improves the user's quality of service.

References

1. Tang, J., Li, G., Bian, D., Hu, J.: Review on resource allocation for beam-hopping satellite. Mob. Commun. **43**(05), 26–31 (2019)
2. Yi, K., Li, Y., Sun, C., Nan, C.: Recent development and its prospect of satellite communications. J. Commun. **36**(06), 161–176 (2015)
3. Zhao, X., Zhang, C., Zhang, G.: Summary of beam-hopping technology of broadband satellite communication system. In: The 15th Annual Satellite Communication Conference, p. 7 (2019)
4. Feng, S., Tang, H., Xu, Z., Li, H.: The development and standardization process of broadband multimedia satellite system. Space Int. **12**, 20–25 (2012)
5. Chen, T., Liu, H., Wang, D., Hao, X.: Research on airborne satellite communication technology based on Ka high-throughput satellite communication system. Sci. Technol. Vis. (21), 219–221+143 (2019)
6. Song, L., Liu, A., Tian, X., Xi, G.: Dynamic handoff algorithm for GEO mobile satellite system. J. Syst. Simul. **21**(11), 3411–3415 (2009)
7. Liu, M., Shi, Y., Cheng, Z.: Performance analysis of beam handover mechanism in high throughput satellite communication system. Electron. Des. Eng. **27**(02), 154–159+165 (2019)
8. Deng, Z., Long, B., Lin, W., Wang, J.: GEO satellite communications system soft handover algorithm based on residence time. In: 3rd International Conference on Computer Science and Network Technology, Dalian, pp. 12–13, October (2013)
9. Lattanzi, F.,Acar, G., Evans, B.: Performance study of a lightweight DVB- RCS handover scheme for vehicular GEO networks. In: IEEE International Workshop on Satellite and Space Communications, Toulouse (2008)
10. Gui, Y., Zhu, L.: Multi-priority channel reservation allocation strategy for satellite airborne terminals. Radio Commun. Technol. **45**(01), 62–67 (2019)
11. Wang, J., Yu, H.: Research of Spotbeam handoff strategy based on fuzzy logic for GEO Multibeam satellite mobile communication system. Commun. Technol. **50**(10), 2266–2273 (2017)
12. Lin, Y., Chang, L., Noerpel, A.: Modeling hierarchical microcell/Macrocell PCS architecture. In: IEEE International Conference, vol. 1, pp. 405–409 (1995)
13. Del Re, E., Fantacci, R.: Different queuing policies for handover requests in low earth orbit mobile satellite systems. IEEE Trans. Veh. Technol. **48**(2), 448–458 (1999)
14. Tani, S., Uchida, S., Okamura, A.: Overlapping clustering for beam-hopping systems. In: 36th International Communications Satellite Systems Conference. Niagara Falls, pp. 14–18, October (2018)
15. Kyrgiazos, A., Evans, B., Thompson, P.: Smart gateways designs with time switched feeders and beam hopping user links. In: Advanced Satellite Multimedia Systems Conference and the Signal Processing for Space Communications Workshop, pp. 1–6 (2016)
16. Zhang, C., Zhang, G., Wang, X.: Design of next generation high throughtput satellite communication system based on beam-hopping. J. Commun. **41**(07), 59–72 (2020)