Research on Multi-beam Handover Invitation Technology for GEO Mobile Satellite System

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Abstract. Different from the terrestrial cellular system, the GEO mobile satellite system has its own characteristics, such as the extremely large beams, the long propagation delay and the diversity of the MS (Mobile Station) velocity. Based on these characteristics, a cooperative beam-cluster is constructed, and a handover invitation technology based on the coordinated multi-beam is proposed in the paper. Using the sending mechanism of handover invitation by a variable sliding window, the technology can avoid the occurrence of the phenomenon of "ping pong" handover to realize seamless handover, and make the handover quick, efficient and reliable. Simulation results show that the algorithm significantly increases the handover success rate, prevents the unnecessary handoff and has a favourable adaptability to the high velocity MS.

1. Introduction
As the development of the next generation satellite mobile communication system towards higher throughput and transmission rate, the multi-beam system architecture is widely used, providing various services for terminals in the coverage area. When a communications user moves from one beam to another beam coverage area, beam handover management is required to ensure the continuity of communication [1]-[2].

Because it does not involve the issue of satellite selection, the current research on beam handover focuses on the allocation of channel resources and the handover guarantee strategy. For example: Literature [3] proposed that only when there are available channels in the current beam and the next switching beam, the call request can be accessed, and the call request can be queued according to the FIFO (First In First Out) principle; Literature [4] combines the handover guarantee algorithm with the LUI (Last Useful Instant) criterion, and queues according to the handover retention time to ensure that the most "critical" handover request is ranked first.

In recent years, a handover method based on inter-beam cooperation has also been proposed. Through negotiation between the current beam and candidate adjacent beams, the user terminal to be handed over is allocated random access channel resources in the adjacent beams. At this time, the terminal is maintaining the current beam, using the allocated channel resources to measure the link quality of the area, and finally determine the adjacent area that meets the handover requirements. Subsequently, the current beam initiates a handover request to the target beam for the user terminal that has obtained the synchronous information of adjacent beams. If the target beam accepts the request, the response information is returned to the current beam, and the current beam transmits the
information to the user through the handover command. Overall, the multi-beam cooperative handover technology has improved stability and reliability.

This paper introduces a handover invitation strategy based on multi-beam cooperation, which can increase the handover success rate.

2. Principle of multi-beam handover invitation Technology

Compared with the traditional handover method, which has limitations such as high handover failure rate, signaling loss and ping-pong handover, the invitation strategy allows the target beam to actively send handover invitations to mobile terminals with handover intentions in advance, changing the handover mechanism to passive be proactive, simplify the process of signal measurement and signal judgment, increase the switching speed, and reduce user service data interruption.

To implement the handover invitation strategy, it is necessary to first solve how the target beam sends a handover invitation to the communication user, including the sending time, sending method, and sending content. In addition, it is also important for communication user to solve the problem of how to deal with and answer the invitation.

2.1. Handover invitation sending mechanism based on sliding window

In order to achieve handover and automatic adaptation of the moving range, the window of sending the invitation is variable [5]. The window width $W$ represents the number of beams in the window. As shown in figure 1.

![Handover invitation based on sliding window](image)

Figure 1. Handover invitation based on sliding window.

Each time a handover invitation is sent, the service beam (the main-beam) where the user is located, must always remain within the sending window and be at the upper edge of the window to ensure that the main beam signal reaches the user terminal first, effectively reducing the occurrence of "ping-pong handover". According to the sliding mechanism of the window, the order in which the aide-beams send invitations is determined by the signal quality that they reach the user.

Take $W=2$ as an example. When sending for the first time, the sending order is the main-beam and aide-beam 1 with the best signal quality; for the second sending, the main beam at the upper edge of
the window remains unchanged, and aide-beam 2 with the second best quality is taken at the lower edge of the window. That is, the aide beam slides forward by one position, and the previously ranked aide-beam 1 moves to the end of the cooperative cluster. According to whether the user can correctly receive the handover invitation, it is determined whether the third or fourth transmission is required. The transmission order of the aide-beams is still arranged according to the previous sliding principle, until each beam in the cluster is traversed. Generally, when W=3, the actual effect is the best.

2.2. Multi-beam cooperation sends handover invitation
Determining a reasonable sending area can effectively improve the effectiveness of sending handover invitations [6]-[7]. Therefore, in this paper, according to the communication user's moving direction, the service beam and the position information of adjacent beams, the current beam and its adjacent beams are formed into a cooperative cluster [8]-[12]. Establish a handover invitation mechanism based on multi-beam cooperation.

The flow chart of multi-beam cooperation sending handover invitation to the user terminal is shown in Figure 2.

![Figure 2. The flow chart of multi-beam cooperation sending handover invitation.](image)

Step 1: Establish a cooperative cell, and the current beam of the communication user and the two adjacent beams form a cooperative relationship;
Step 2: According to the current movement trajectory of the communication user and estimate the reference position of the target beam to send the handover invitation;
Step 3: Combine the reference position for sending the invitation and half of the maximum overlap coverage distance of adjacent beam signals to predict the exact time for sending the handover invitation;
Step 4: According to the user’s speed and the center position of the target beam, decide whether to adjust the time for sending the invitation, and finally determine the adjusted time as the time for sending the invitation;

Step 5: Start beam handover.

In the above process, the crucial issue is to estimate the reference location and reference time. The ideal time for the target beam to send the handover invitation is called the reference time, and the position of the MS at this time is the reference location. It is generally believed that the position where the coverage signal strength of the target beam and the current beam is equal is the reference location. The reference time can be obtained by the reference position and the moving speed of the MS.

Therefore, the communication environment model based on the handover invitation strategy of multi-beam cooperation is first established\(^{[13]}^{[14]}\), as shown in Figure 3.

![Figure 3. The communication environment model.](image)

Estimate the RSS (Received Signal Strength) of MS (Mobile Station) according to the COST231-Hata loss prediction model.

When the MS moves away from the center of the Main-beam, the RSS gradually decreases in the form of a log-normal distribution. Assuming that distance between the center of main-beam and aide-beam 1 is \(D\) kilometres, the predicted moving direction of the MS is to move from the main-beam to the aide-beam 1. During the movement, the MS is \(d\) kilometres away from the center of the main-beam (current serving beam). At this time, the RSS from the current beam is denoted as \(R_0(d)\), the RSS from aide-beam 1 and aide-beam 2 are \(R_1(d)\) and \(R_2(d)\). The received signal is averaged through an exponential filter window to eliminate Rayleigh fading. The impulse response of the filter is \(f(d)\) and the average window width \(d_0\). Then the expression of the received signal is:

\[
\bar{R}(d) = f(d) * R(d) = 1/d_0 \cdot \int_0^{d_0} \exp(-x/d_0) z \cdot R(d - x) dx
\]

Among them, the shadow fading components in the received signal are mutually independent zero-mean Gaussian random components. The variance is \(\sigma^2\). \(\bar{R}_0(d)\) and \(\bar{R}_1(d)\) obey normal distribution. When \(\bar{R}_0(d) = \bar{R}_1(d)\), the RSS by the MS from the main-beam and the aide-beam 1 is the same. It is considered that the MS is at the reference position of the aide-beam 1 (target beam) for sending the handover invitation \((X_h, Y_h)\).

Use GPS to determine the current position \((X, Y)\) of MS. The Doppler Shift is estimated according to the statistics of LCR (level crossing rates) or ZCR (zero crossing rates), thereby obtaining the approximate moving speed \(V\) of the MS.

Therefore, the reference time for sending the handover invitation can be expressed as:

\[
T = \sqrt{(X - X_h)^2 + (Y - Y_h)^2}/V
\]

In order to improve the success rate of beam handover, the time for sending the handover invitation can be advanced for a period of time. The target beam starts to send the handover invitation once MS passes through the signal overlap area. Set the lead time \(T_0 = L/V\), Where \(L\) is half the distance of
the beam signal overlap area, and the final time for the target beam to send the handover invitation is:

\[ t = T - T_0 \]  

(3)

3. Results and discussion

Figure 4 is a comparison of the simulation curves of the handover success rate of the two handover algorithms at different operating speeds. It can be seen from the figure that the handover success rate of the handover invitation algorithm is higher than that of the traditional handover algorithm. The handover success rate of the traditional handover algorithm has a significant downward trend, but the invitation algorithm declines more slowly.

Assuming that the distance between the center of the two beams \( D = 3500 \text{km} \), the shadow fading variance \( \sigma = 5 \text{dB} \), the sampling interval \( T_0 = 0.5 \text{s} \), and the link fading threshold \( \Delta = -95 \text{dB} \).

![Comparison of simulation curves of handover success rate at different operating speeds.](image)

**Figure 4.** Comparison of simulation curves of handover success rate at different operating speeds.

4. Conclusion

Based on the current common beam handover technology research, this paper proposes a handover invitation mechanism based on inter-beam cooperation, and introduces the invitation sending mechanism based on sliding window and Multi-beam cooperation sends handover invitation in detail. MATLAB Simulation results prove the effectiveness of the technology. However, this technology needs to be established on the premise that the trajectory of MS is predictable. An interesting future step will be to solve how the target beam chooses an accurate invitation sending time when the trajectory is difficult to predict.

Acknowledgments

This work was supported by the National Natural Science Foundation of China under Grant 61771128.

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