Performance Evaluation of Location-based Conditional Handover Scheme using LEO Satellites

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***Abstract*—The high velocity of LEO satellites can result in frequent handover (HO) in non-terrestrial networks (NTN). In a satellite environment, due to the high altitude, the signal strength variation between the cell center and the cell edge is very small. As a result, when using the signal strength-based HO, there are challenges in selecting an appropriate cell during HO. To address this issue, we proposed a location-based conditional HO (CHO) approach instead of the signal strength-based method. This approach uses the distance between the reference location of the cell and the user equipment (UE) to make HO decisions. This allows the UE to choose a suitable cell. Additionally, through an analysis based on the variation of signal strength with the UE's position within the cell and the distance change between the UE and the cell center, the distance offset is determined. Simulation results demonstrate that the proposed approach, when compared to the conventional method, can reduce radio link failure (RLF) and HO failure (HOF).**

***Index Terms*—non-terrestrial networks, LEO satellites, handover, mobility**

I. INTRODUCTION

Recently, mobile communications have been growing interest in non-terrestrial network (NTN) scenarios, in which satellites provide global communication coverage. Operating at lower altitudes (i.e., between 500 km and 2,000 km), low-Earth orbit (LEO) satellites offer advantages over geostationary Earth orbit (GEO) satellites, including shorter propagation delays and round-trip times. However, due to the higher altitude of LEO satellites compared to terrestrial networks (TN), signal strength variation in cell center and edge region is very small. For the reason, based on signal strength handover (HO) approaches encounter difficulties in choosing suitable cells.

To address these issues for non-terrestrial networks (NTN), conditional HO (CHO) is introduced and various triggering events is proposed [1]. Additionally, authors of [2] have presented triggering events based on signal strength, distance, elevation angle, and time. However, they did not mention specific method for selecting the offset. Authors of [3] proposed location-based triggering events for the HO and CHO. However, they use distance only as an offset in the signal strength method. For this reason, there is a current need for research on location-based HO methods that distance utilization.

In this paper, we propose the location-based CHO approach in LEO satellite-based NTN. The proposed method utilizes the UE's position and the reference location. The reference location is the center point of the satellite cell to determine HO based on distance variation. Furthermore, the distance offset is determined for using in the location-based triggering event. This is obtained by continuously analyzing the signal strength variations and the variations in distance from the reference location based on the location of the UE. Simulation is conducted to compare the HO performance of the proposed location-based CHO and the conventional signal strength-based CHO according to various offset values.

The remainder of this paper is organized as follows. In Session II, we explain the proposed location-based HO triggering event and method for obtaining distance offset. In Session III, we present the distance offset and analyze the performance of the proposed location-based CHO. Finally, in Session IV, we conclude this paper.

II. LOCATION-BASED HO METHOD

In Session II, we explain the proposed location-based HO triggering event method and describe the process and method for obtaining distance offsets.

A. Location-based HO triggering event

The location-based triggering event is determined based on the distance between the reference location and the UE's position. The proposed location-based HO triggering condition is defined as follows:

$$D_s > D_t + offset_m, \tag{1}$$

where D_s and D_t represent the distances, in meters, between the UE's position and the reference locations of the serving cell and the target cell respectively; $offset_m$, in meters, refers to the distance offset value. Therefore, to satisfy the HO condition, D_s must be greater than the sum of the distance from D_t and the $offset_m$.

B. Method for obtaining distance offset

We configure the positions of UEs and analyze the signal strength and distance variation. Fig. 1 shows the method for calculating the positions of UEs. The X_p represents the extent to which the UE's position deviates from the reference line. The reference line refers to the line connecting the reference locations of two cells. So, the X_p indicates how far the UE is located from the line connecting the reference locations of two cells. The X_t represents the UE's position in time

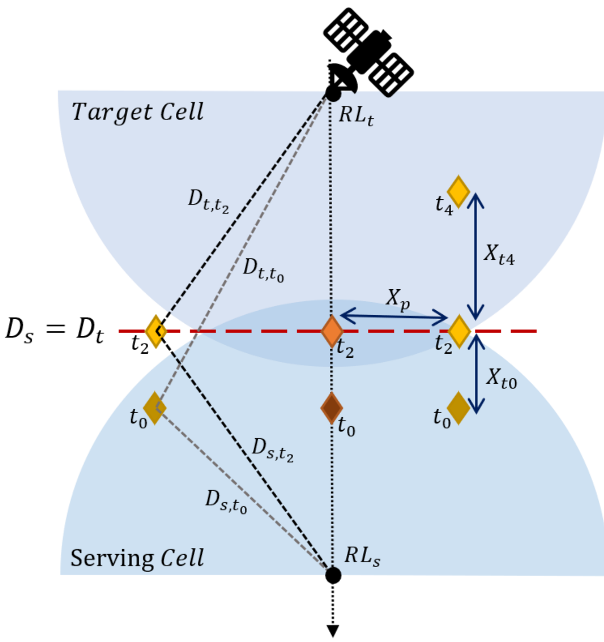

Fig. 1. Method for obtaining distance offsets considers the UE's position

due to the satellite's movement. Using the X_p and X_t, the distances between the serving cell's reference location and the target cell's reference location can be defined as D_s and D_t, respectively. These distances can be expressed using the equation as follows:

$$D_s = \sqrt{X_p^2 + (ISD/2 + X_t)^2}, \quad (2)$$

$$D_t = \sqrt{(ISD - \sqrt{D_s^2 - X_p^2})^2 + X_p^2}, \quad (3)$$

The inter-site distance (ISD) refers to the distance between the center points of cells.

The positions of UEs are generated based on the parameters X_p and X_t. The antenna gain values can be calculated by the angles at each cell for every UE position. This allows us to calculate the signal strength about each cells. For each generated UE position, the signal strengths, D_s, and D_t are determined. These values are configuration set [5]. At specific UE positions, the signal strength variation between the serving cell and the target cell is obtained to match the criteria. Also, the distance variation value ($D_s - D_t$) is then calculated at this point. The calculated distance variation values are then chosen as $offset_m$ values.

III. Performance Evaluation

In Session III, we explain system model demonstrate the results of the $offset_m$ obtain for location-based HO. Additionally, the simulations results show a performance comparison between the conventional method and proposed method.

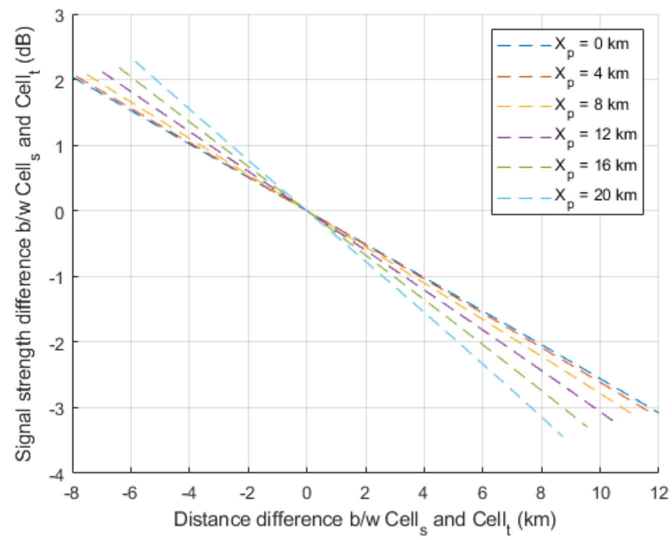

Fig. 2. Results of signal strength and distance variation based on X_p

A. System model

In this scenario, one of satellite is deployed at an altitude of 600 km with a velocity of 7.56 km/s. It consists of a total of 61 beams, and among them, UEs are only positioned within the 19 beams. We positioned UEs, one per beam, within 7 beam out of the 19 beams. The footprint diameter of each cell is 50 km, and the ISD is 43.3 km due to overlapping of beams. The system model is implemented based on the parameters from system-level simulation (SLS) study case 9 in [1] and the satellite channel model from [4]. The channel model in a rural environment was used. The satellite's antenna pattern is referenced from [4]. Carrier frequency is S-band, and handheld-type UEs are placed. In the system model, UEs have global navigation satellite system (GNSS) capabilities. It is assumed that UEs know the coordinates of the center points of all satellite cells and calculate the distances to these points during each signal measurement period.

B. Results of distance offset

In Fig. 1, the X_p values were set in intervals of 4 km within the range of 0 km to 20 km, resulting in a total of 6 sets. The range of X_t is defined as a continuous sequence of UE positions with a 10 m interval. This sequence range from -4 km to 6 km in the direction from the serving cell to the target cell, using the point where D_s and D_t are equal as the reference.

The continuous variations in signal strength and distance corresponding to each X_p are demonstrated in Fig. 2. And the results for distance variation values $offset_m$ according to the signal strength variation criteria is presented in Table 1. As the value of X_p increases (i.e., how far the UE is located from the reference line), we observed varying distance offset values. Calculating the $offset_m$ as the average value, the $offset_m$ values corresponding to signal strength variations of 1 dB, 2

TABLE I
RESULTS OF $offset_m$ ACCORDING TO X_p

X_p	Signal strength variation criteria		
	1 dB	2 dB	3 dB
0 km	3,940 m	7,840 m	11,700 m
4 km	3,854 m	7,666 m	11,430 m
8 km	3,638 m	7,229 m	10,763 m
12 km	3,321 m	6,594 m	9,804 m
16 km	2,957 m	5,883 m	8,733 m
20 km	2,598 m	5,154 m	7,656 m
AVG	3,385 m	6,728 m	10,014 m

TABLE II
OFFSET OF A3 AND DISTANCE EVENT USED IN THE SIMULATION

Set Number	0	1	2	3
A3 event	0 dB	1 dB	2 dB	3 dB
Distance	0 m	3,385 m	6,728 m	10,014 m

dB, and 3 dB [5] are determined as 3,385 m, 6,728 m, and 10,014 m respectively.

C. Performance of proposed method

Using the Riverbed Modeler's long-term evaluation (LTE) model, a comparative analysis was conducted between the conventional signal strength-based CHO A3 event and the proposed location-based CHO. The offsets for each event were configured from Table 2. The time-to-trigger (TTT) value, as increasing it leads to additional delay, was set to 0 for all cases. The same event method and offsets were used for both the preparation and execution event in the CHO process.

In the simulation, the evaluation of results involved using the number of radio link failure (RLF) per second per UE and HO failure (HOF) rates. In Fig. 3, the performance evaluation for each simulation set is demonstrated. The x-axis represents the simulation set number in Table 2, while (a) and (b) represent the results for RLF and HOF, respectively. Simulation results for RLF in the conventional signal strength-based method show respective outcomes of 0.032, 0.069, 0.152, and 0.242 for each simulation set. In contrast, the proposed location-based method resulted in outcomes of 0.012, 0.029, 0.067, and 0.156. Additionally, for HOF, the conventional signal strength-based method resulted in percentages of 10.94%, 30.57%, 65.78%, and 93.26%, while the proposed location-based method show percentages of 6.11%, 12.69%, 33.40%, and 66.88%.

These results indicate that the location-based method is better than the conventional method in terms of overall RLF and HOF rates. Due to the significant distance between the satellite and UE, signal strength variation between the cell center and the cell edge is very low. Therefore, choosing cells for HO based only consider on signal strength in cell edge regions presents difficulties. However, the proposed method makes it easier to identify cells that are closer to the UE. As a result, the location-based CHO method enhances the reliability of HO decisions, thereby ensuring more stable HO compared to conventional signal strength method.

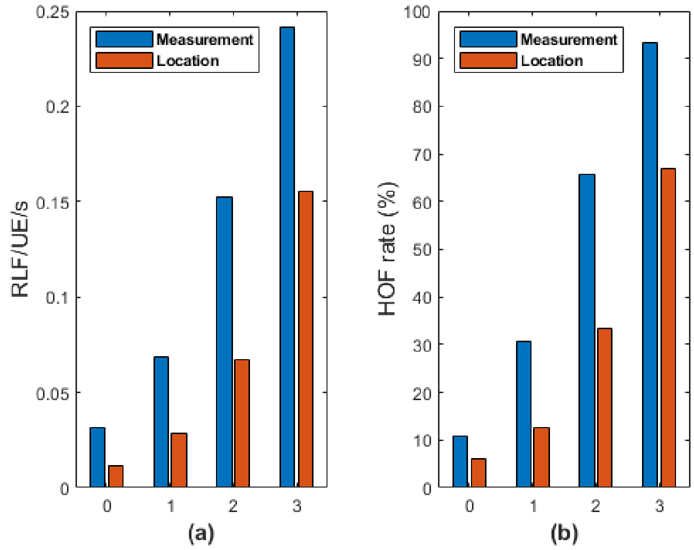

Fig. 3. Simulation results of A3 and distance event: (a) RLF (b) HOF

IV. CONCLUSION

In this paper, we proposed a location-based CHO method to ensure seamless connectivity in satellite networks. The proposed method utilizes the distance between the UE and the reference location. It can be enable the UE to choose a more suitable cell for the HO. Simulation results show that the RLF and HOF of proposed method outperforms that of conventional method.

In future work, we plan to investigate the method of dynamically assigning optimal distance offsets for each UE's position.

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