

Resource-Efficient Group Handover for Disaggregated gNB-Based Non-Terrestrial Networks

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Abstract—In low Earth orbit (LEO)-based non-terrestrial networks (NTNs), the movement of satellite beams may cause multiple user equipment (UE) devices to enter the same handover (HO) region within a short time interval. When each UE performs an individual HO procedure in such multi-UE HO scenarios, repeated control signaling occurs over the F1 interface between the central unit (CU) and distributed units (DUs), thereby increasing the network control load. In this paper, we propose a boundary-margin-based non-uniform UE grouping method that forms UE groups according to the remaining distance to the serving beam boundary and performs group-level HO only when RLF-safe conditions are satisfied. Simulation results show that the proposed method reduces the number of F1 signaling messages from 400 to approximately 240 with 100 valid HO candidate UEs, corresponding to about a 40.0% reduction, while effectively suppressing RLF occurrence. These results demonstrate that the proposed grouping method enables RLF-safe group-level HO while reducing F1 signaling overhead in same-CU-based NTN HO environments.

Index Terms—Non-Terrestrial Networks, LEO Satellite, Group Handover, Disaggregated gNB

I. INTRODUCTION

Recently, non-terrestrial networks (NTNs) have been actively discussed by the Third Generation Partnership Project (3GPP) to support fifth-generation (5G) and beyond-5G systems, and satellite-based networks have been considered a key technology for extending coverage beyond terrestrial networks [1], [2]. In addition, open radio access network (O-RAN) and disaggregated radio access network (RAN) architectures have been studied to improve network flexibility, and 3GPP has considered a disaggregated NTN architecture in which a ground central unit (CU) controls satellite-associated distributed units (DUs) [2]–[4].

However, in LEO-based NTNs, satellite beam coverage continuously changes due to satellite and beam movement [6], [9]. As a result, multiple user equipments (UEs) may approach the serving beam boundary and trigger handover (HO) toward a target beam within a short time interval. In a disaggregated NTN architecture, these HO-related control procedures are processed through the F1 interface between the CU and DUs [5], [9]. Therefore, individual per-UE HO can cause repeated F1 control signaling and increase control-plane overhead, especially in multi-UE HO scenarios.

To mitigate frequent HO signaling in LEO-based NTNs, previous studies have investigated conditional HO, mobility

prediction, HO delay reduction, and group-based HO [10]–[13]. Although group-based HO can reduce repeated HO procedures by processing multiple UEs together [12], existing approaches do not jointly consider UE-specific radio link failure (RLF) risk and F1 signaling overhead in a disaggregated CU-DU architecture. Moreover, studies on O-RAN-based or disaggregated NTN architectures have shown that functional split choices affect HO delay, control signaling, and RLF performance, but they do not directly address UE grouping for reducing F1 signaling overhead [13], [14]. Therefore, a grouping method is required to reduce repeated F1 signaling while avoiding RLF caused by excessive waiting time in group-level HO.

In this paper, we propose a boundary-margin-based non-uniform UE grouping method for group-level HO in LEO-based NTN environments. The proposed method uses the boundary margin, defined as the remaining distance from a UE to the serving beam boundary at the HO trigger time, to adjust group formation according to RLF risk. Specifically, beam-edge UEs with smaller boundary margins are grouped conservatively, whereas UEs with larger boundary margins can be included in larger groups when the RLF-safe condition is satisfied. Through this design, the proposed method reduces F1 signaling overhead while supporting RLF-safe group-level HO in disaggregated NTN environments.

II. SYSTEM MODEL

Fig. 1 illustrates the considered same-CU LEO-based NTN HO architecture. We consider a LEO-based NTN system consisting of a ground CU and satellite-associated DUs, where each DU forms moving cells on the ground and is centrally controlled by the CU through the F1 interface [4], [5]. The serving DU and the target DU are assumed to be connected to the same CU, and the HO control procedures between them are processed through the CU-DU F1 interface [4], [5]. Each satellite is assumed to employ a 19-beam layout, but the performance evaluation focuses on one active adjacent serving-target beam pair to clearly evaluate the effect of the proposed UE grouping method on F1 signaling overhead and RLF safety.

The large-scale propagation characteristics of the satellite-to-UE link are modeled based on the NTN path loss model. The basic path loss between a satellite and a ground UE is expressed as [2], [6]

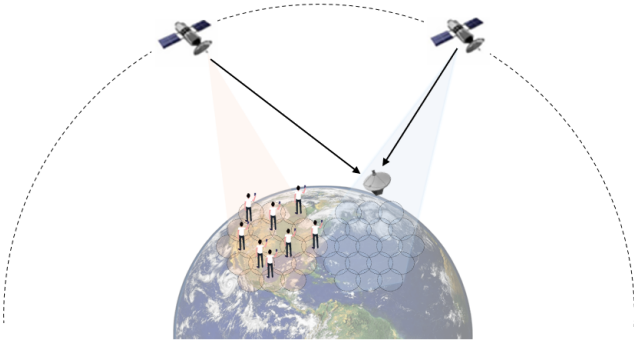


Fig. 1. System model of same-CU HO in LEO-based NTN.

$$PL_b = FSPL(d, f_c) + SF + CL(\alpha, f_c), \quad (1)$$

$$FSPL(d, f_c) = 32.45 + 20 \log_{10}(f_c) + 20 \log_{10}(d), \quad (2)$$

where PL_b denotes the basic path loss, $FSPL(d, f_c)$ is the free-space path loss, d is the distance between the satellite and UE, and f_c is the carrier frequency. In addition, SF and $CL(\alpha, f_c)$ represent shadow fading and clutter loss, respectively, where α denotes the elevation angle. These path loss components follow the large-scale channel model for NTN scenarios [2], [6]. In this paper, an S-band carrier frequency of 2 GHz and a rural deployment environment are assumed. Since the considered frequency is below 6 GHz, atmospheric absorption and rain attenuation are assumed to have limited impact compared with the geometric path loss variation caused by satellite and beam movement [6].

III. PROPOSED BOUNDARY-MARGIN-BASED GROUP HANDOVER

The proposed method performs group-level HO based on the boundary margin and the RLF safety margin to reduce repeated F1 signaling while avoiding RLF caused by excessive grouping delay. Unlike conventional per-UE HO, which is RLF-safe but inefficient in terms of F1 signaling, and purely geographic grouping, which may delay early-triggered UEs without considering their remaining RLF margin, the proposed method makes grouping decisions jointly with the remaining HO time budget. Specifically, the boundary margin is used as a spatial risk indicator, and the RLF safety margin is used as a feasibility condition for determining whether each UE can be included in the current group.

For valid HO candidate selection, UEs are first filtered based on the Q_{in} condition, which represents the in-sync threshold for maintaining the serving link in radio link monitoring [7], [8]. UEs that do not satisfy this condition are excluded from the valid HO candidate set, so that the proposed grouping procedure only considers UEs with sufficient link quality to perform HO.

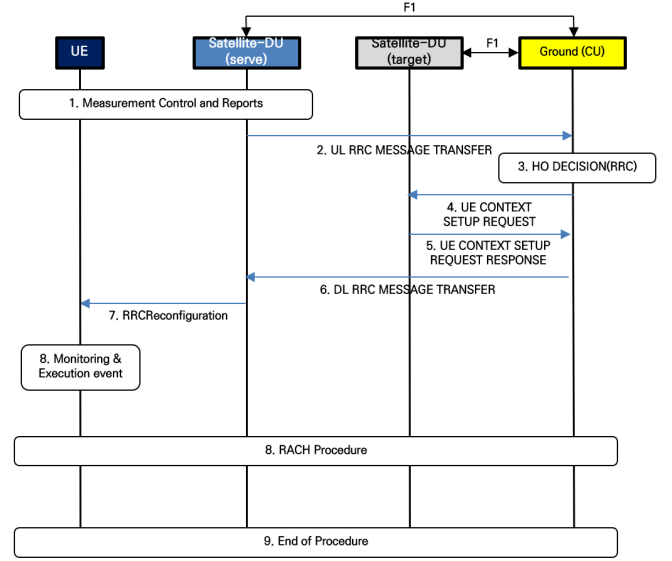


Fig. 2. Same-CU HO control procedure through the F1 interface.

Accordingly, the total node-to-node delay during the same-CU HO procedure is expressed as

$$Delay_{Total} = T_{UE,serDU} + T_{serDU,CU} + T_{CU,tarDU} + T_{tarDU,CU} + T_{CU,serDU} + T_{serDU,UE}. \quad (3)$$

where $T_{UE,serDU}$ is the time for the measurement report to be delivered from the UE to the serving DU, $T_{serDU,CU}$ is the time for the uplink RRC message to be transferred from the serving DU to the CU, $T_{CU,tarDU}$ and $T_{tarDU,CU}$ are the message exchange times between the CU and the target DU, and $T_{CU,serDU}$ and $T_{serDU,UE}$ represent the downlink transfer times from the CU to the serving DU and from the serving DU to the UE, respectively.

When the delay of each node-to-node link is modeled by propagation time, the total same-CU HO delay is expressed as

$$Delay_{Total} = \sum_{(i,j) \in AllLinks} \frac{r_{i,j}}{c}, \quad (4)$$

where $AllLinks$ denotes the set of node-to-node links involved in the same-CU HO procedure, $r_{i,j}$ is the distance between nodes i and j , and c is the speed of light.

To reflect this signaling delay in the distance-based HO condition, the delay compensation offset is obtained by converting the total same-CU HO delay into the corresponding cell movement distance:

$$\Delta_{offset} = V_{cell} Delay_{Total}, \quad (5)$$

where V_{cell} is the cell movement speed on the ground.

Let $d_{s,i}(t)$ and $d_{t,i}(t)$ denote the distances from UE i to the serving and target beam centers at time t , respectively. In the conventional distance-based HO condition, the UE compares the distance to the serving cell and the distance to the target cell with a predefined HO offset O_{HO} [9].

Using the delay compensation offset, the delay-aware HO trigger condition for UE i is expressed as

$$d_{s,i}(t) + O_{\text{HO}} + \Delta_{\text{offset}} > d_{t,i}(t). \quad (6)$$

The HO trigger time of UE i is defined as the first time instant at which the delay-aware HO condition is satisfied:

$$t_i^{\text{trig}} = \min \{t \mid d_{s,i}(t) + O_{\text{HO}} + \Delta_{\text{offset}} > d_{t,i}(t)\}. \quad (7)$$

The delay compensation offset converts the expected signaling delay into the corresponding cell movement distance and is given by

$$\Delta_{\text{offset}} = V_{\text{cell}} \sum_{(i,j) \in \text{AllLinks}} \frac{r_{i,j}}{c}, \quad (8)$$

where V_{cell} is the cell movement speed on the ground, $r_{i,j}$ is the distance between nodes i and j , and c is the speed of light.

The RLF time budget after the HO trigger is defined as

$$D_i = t_i^{\text{RLF}} - t_i^{\text{trig}}, \quad (9)$$

where t_i^{RLF} is the time when UE i reaches the RLF boundary. The boundary margin of UE i is defined as

$$m_i = R_{\text{beam}} - d_{s,i}(t_i^{\text{trig}}), \quad (10)$$

where R_{beam} is the serving beam radius. A smaller m_i indicates that the UE is closer to the serving beam edge and has a higher RLF risk, whereas a larger m_i indicates that the UE can tolerate a longer grouping delay. Therefore, m_i is used to classify UEs according to their remaining HO time budget.

After valid HO candidate UEs are determined, they are classified into non-uniform boundary-margin zones. Let the zone edges be defined as

$$\mathbf{b} = [b_0, b_1, \dots, b_Z], \quad (11)$$

where Z is the number of boundary-margin zones. UE i is assigned to zone z according to

$$z_i = z \quad \text{if} \quad b_{z-1} \leq m_i < b_z. \quad (12)$$

The zone edges are adaptively determined based on the boundary-margin distribution and the available RLF time budgets of valid HO candidate UEs. Then, the final groups are formed only when the grouping waiting time and propagation delay satisfy the RLF-safe condition for all UEs in the group.

Within each zone, UEs are sorted in ascending order of their HO trigger times:

$$t_1^{\text{trig}} \leq t_2^{\text{trig}} \leq \dots \leq t_{N_z}^{\text{trig}}, \quad (13)$$

where N_z is the number of UEs in zone z . For group-level HO, multiple valid HO candidate UEs can be released together after their HO trigger times. For a group G , the group release time and the waiting time of UE i are defined as

$$t_G^{\text{rel}} = \max_{j \in G} t_j^{\text{trig}}, \quad (14)$$

$$W_i = t_G^{\text{rel}} - t_i^{\text{trig}}. \quad (15)$$

TABLE I
SIMULATION PARAMETERS

Parameters	Values
Number of satellites	2
Ground CU	1
Number of beams per satellite	19
Satellite altitude	600 km
Inclination	43°
Minimum elevation angle, $\theta_{\min}$	10°
Inter-site distance	50 km
Beam center spacing	43.3 km
Carrier frequency	2 GHz
Number of valid HO candidate UEs	100
Straight-line partitions, L	2, 30, 50, 70
Satellite transmit antenna gain, G_{tx}	30 dBi
UE receive antenna gain, G_{rx}	0 dBi
EIRP density, $EIRP_{\text{den}}$	34 dBW/MHz
Channel environment	Rural

To evaluate whether group-level HO can be completed without RLF, the RLF safety margin of UE i is defined as

$$M_i = D_i - W_i - T_{\text{prop},i} - T_{\text{guard}}, \quad (16)$$

where $T_{\text{prop},i}$ is the same-CU propagation delay and T_{guard} is the guard time. A group-level HO is regarded as RLF-safe only when

$$M_i \geq 0, \quad \forall i \in G. \quad (17)$$

For the current group G_k , when a new UE u is considered, a temporary group is given by

$$G_k^+ = G_k \cup \{u\}. \quad (18)$$

The UE u is appended to G_k only when all UEs in G_k^+ satisfy the RLF-safe condition:

$$M_i(G_k^+) \geq 0, \quad \forall i \in G_k^+. \quad (19)$$

Accordingly, the group update rule is expressed as

$$\begin{cases} G_k \leftarrow G_k^+, & \text{if } M_i(G_k^+) \geq 0, \forall i \in G_k^+, \\ \text{finalize}(G_k), \quad G_{k+1} \leftarrow \{u\}, & \text{otherwise.} \end{cases} \quad (20)$$

Thus, the proposed method forms the largest possible group within the RLF-safe constraint, rather than blindly maximizing the group size. This sequential grouping rule is applied independently within each boundary-margin zone, so UEs with different RLF risk levels are not forced into the same group only because they are geographically close. This prevents beam-edge UEs from being delayed by inner-beam UEs with larger time budgets, while still allowing group-level HO gain for UEs that can safely wait.

For comparison, a fixed straight-line partitioning baseline is considered. In this baseline, valid HO candidate UEs are ordered along the ground-track direction of the moving cell and divided into L consecutive segments:

$$\mathcal{P} = \{P_1, P_2, \dots, P_L\}. \quad (21)$$

Unlike the proposed method, this baseline does not check $M_i \geq 0$ when forming groups. Therefore, small L can reduce

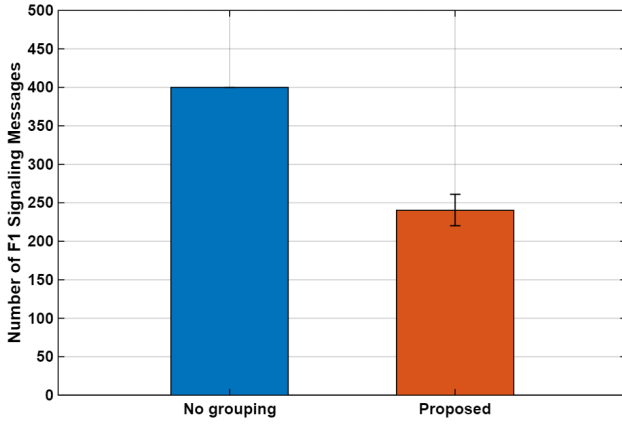


Fig. 3. F1 signaling reduction by the proposed group-level HO.

F1 signaling but may increase RLF risk, whereas large L can reduce RLF risk but limits the group-level HO gain.

IV. PERFORMANCE EVALUATION

A. Simulation Setup

The proposed method is evaluated in a same-CU LEO-based NTN HO scenario, and the main simulation parameters are summarized in Table I. Two satellites are considered, each with 19 beams, and the evaluation focuses on one adjacent serving-target beam pair. The beam diameter is 50 km, the beam radius is 25 km, and the beam center spacing is 43.3 km. A total of 100 valid HO candidate UEs are used.

The straight-line partitioning baseline divides the valid HO candidate UEs into L consecutive segments along the ground-track direction of the moving serving cell. In this evaluation, $L = 2, 30, 50$, and 70 are considered to compare fixed partitioning with the proposed RLF-aware grouping method.

B. Performance Metrics

The performance is evaluated using three metrics: the number of F1 signaling messages, the RLF safety margin, and the deterministic RLF probability. The number of F1 signaling messages is used to measure the control signaling overhead caused by HO-related F1AP procedures between the CU and DUs [4], [5]. The RLF safety margin evaluates whether each UE can complete group-level HO before reaching the RLF boundary, considering grouping waiting time and same-CU propagation delay [7], [8]. A positive margin indicates RLF-safe HO completion, whereas a negative margin indicates possible RLF before HO completion. The deterministic RLF probability is defined as the percentage of UEs whose RLF safety margin becomes negative after grouping.

C. Results and Discussion

Fig. 3 compares the F1 signaling overhead of individual per-UE HO and the proposed group-level HO. In the individual HO case, 100 UEs generate 400 F1 signaling messages because each UE performs a separate HO control procedure through the F1 interface. In contrast, across repeated

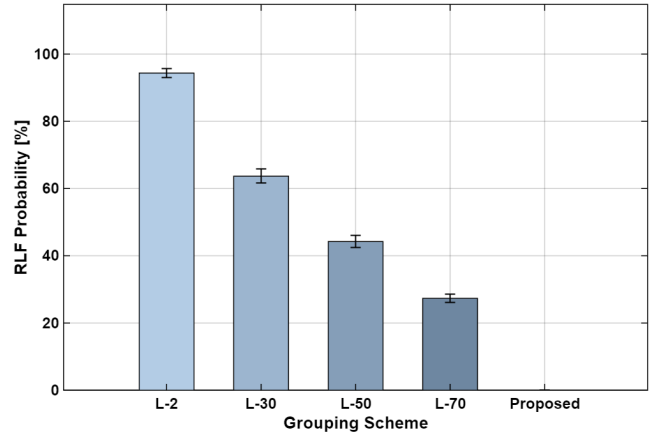


Fig. 4. RLF safety margin distribution according to boundary-margin zones.

simulation trials, the proposed method reduces the number of F1 signaling messages from 400 to a range of 220–260, with an average of approximately 240. This corresponds to an average reduction of about 160 messages and a 40.0% decrease compared with individual per-UE HO. This reduction occurs because multiple UEs with compatible HO timing and sufficient RLF safety margins share a single group-level HO control procedure. Therefore, the proposed method suppresses redundant F1 signaling and reduces the control-plane load in multi-UE HO scenarios.

Fig. 4 compares the RLF probability of the fixed straight-line partitioning baseline and the proposed RLF-aware grouping method. In the fixed partitioning baseline, valid HO candidate UEs are divided into a predefined number of segments L along the ground-track direction of the moving cell. As L increases from 2 to 70, the RLF probability decreases from 94.0% to 28.0% because finer segmentation reduces the waiting time of early-triggered UEs. However, even with $L = 70$, the baseline still shows a considerable RLF probability because it does not explicitly check whether each UE has sufficient RLF margin before group release. In contrast, the proposed method dynamically determines whether a UE can be included in the current group by checking the RLF safety margin. As a result, the proposed method maintains RLF-safe group-level HO in the considered scenario, reducing the RLF probability by 94.0 percentage points compared with $L = 2$ and by 28.0 percentage points compared with $L = 70$. This result indicates that RLF-aware dynamic grouping is more effective than simply increasing the number of fixed partitions.

Fig. 5 compares the generated groups of the fixed partitioning baseline and the proposed method, and also shows the UE group-size distribution of the proposed method. Fig. 5(a) shows the number of generated groups according to the grouping scheme. In the fixed straight-line partitioning baseline, valid HO candidate UEs are divided into a predefined number of segments L along the ground-track direction of the moving cell. In contrast, the proposed method generates approximately 13 groups by dynamically checking the RLF safety margin

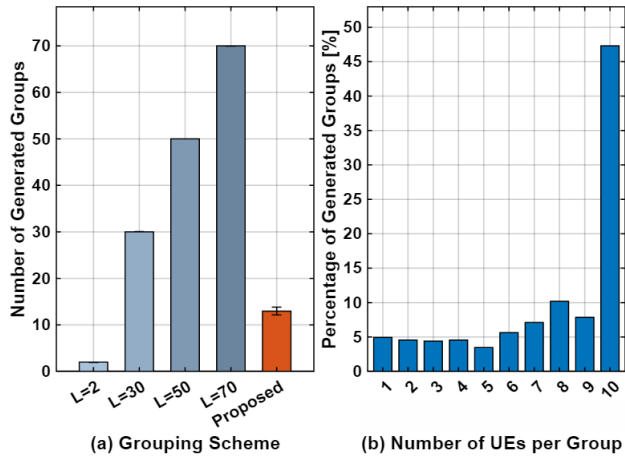


Fig. 5. Generated groups and UE group-size distribution.

during group formation. This result indicates that the proposed method does not rely on a fixed partition number, but adaptively determines whether each UE can be included in the current group without violating the RLF-safe condition. Fig. 5(b) shows the distribution of the number of UEs per group in the proposed method. Groups containing 10 UEs account for the largest portion, about 47% of the generated groups. This means that the proposed method can form large groups when sufficient RLF margins are available. At the same time, smaller groups are generated when the available RLF margin is limited. Therefore, the proposed method adaptively balances F1 signaling reduction and RLF-safe group-level HO execution. Overall, these results show that the proposed RLF-aware grouping method reduces F1 signaling overhead while lowering RLF risk more effectively than fixed partitioning.

V. CONCLUSION AND FUTURE WORK

In this paper, we proposed a boundary-margin-based non-uniform UE grouping method for same-CU group-level HO in LEO-based NTN environments. The proposed method classifies UEs according to their boundary margin and forms groups only when the RLF-safe condition is satisfied. A delay compensation offset is also included in the HO condition to reflect node-to-node delay in the disaggregated gNB architecture. Simulation results with 100 valid HO candidate UEs showed that the proposed method reduced the average number of F1 signaling messages from 400 to approximately 240, corresponding to about a 40.0% average reduction, while maintaining positive RLF safety margins across all boundary-margin zones. Compared with the straight-line partitioning baseline, the proposed method reduces RLF risk without relying on excessive fixed partitioning. Future work will consider more realistic UE mobility, dynamic beam movement, inter-CU HO scenarios, and multi-beam interference effects.

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