Performance Evaluation of Handover using A4 Event in LEO Satellites Network

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***Abstract*—Low earth orbit (LEO) satellites have fast mobility, which causes frequent handover (HO) problems. Solving the matters of HO is very important for a seamless and stable service connection. Therefore, in this paper, to overcome the HO issues in LEO we used A4 event which is discussing in 3rd generation partnership project (3GPP). Unlike the terrestrial network, in non-terrestrial network (NTN), the difference between reference signal received power (RSRP) of cell edge and RSRP of cell center is very small. For this reason, 3GPP has been discussing the method comparing the RSRP of cells with an absolute threshold rather than comparing the RSRP of the serving cell and the neighboring cell in HO events. In addition, we compare the HO performance of A3 event based HO and A4 event based HO according to L3 filter K value. The simulation results indicate that radio link failure (RLF) and handover failure (HOF) perform better in A4 event based HO than A3 event based HO. In addition, the performance of RLF and HOF performs significantly better when L3 filter K value is 0 than 6, and 13.**

***Index Terms*—Mobility management, Low earth orbit (LEO), Satellite communications, Handover**

I. Introduction

Recently, with the developments of satellite technology, a performance of satellites has been improved and the uses of satellites have been diversified [1]. Among them, low earth orbit (LEO) satellites are attracting attention. In LEO satellites, the development cost is reduced due to the miniaturization of the satellite, and the launching cost is reduced by reusing the launch vehicle. Furthermore, LEO satellites are replacing geostationary orbit (GEO) satellites with advantages of low propagation delay time [2], [3].

In comparison to GEO satellites, LEO satellites have the characteristic of frequent handover (HO) occurrences. These largely affect mobility management in LEO satellite networks. Recently, several mobility management methods for efficient HO of networks have been proposed in [4] - [9]. The authors of [4] proposed HO-independent mobility management scheme. They suggested cell-free on-demand coverage to overcome the cost-ineffectiveness of conventional cellular architecture. The authors of [5] proposed a low cost area based mobility management (ABMM) by using global positioning system (GPS) in LEO satellite network. LEO satellites have higher speed than terrestrial mobile networks, therefore it have lower quality of service. Also, they have high mobility management cost. The suggested algorithm overcame these problems. In [6], the authors proposed LEO-based non-terrestrial network (NTN) deployment with new mobility solutions. They also compare the performance with urban macro scenario and high-speed train scenario. Also, to address the excessive HO issues in moving beams, the authors of [7] designed and analyzed the fixed duration for LEO earth fixed scenario. In [8], the authors proposed learning-based auction HO. They considered received signal strength and service time. The authors of [9] proposed a mobility core network architecture that loads the mobility management function of the core network on the satellite. The proposed method can improve the flexibility of management and control of satellite-terrestrial Integrated Network (STIN). They improve the flexibility of the satellite next-generation nodeB (Sat-gNB) networking by proposed algorithm.

Mobility management is one of the most important issues to ensure service continuity and high performance in HO. However, even thought [11] discussed mobility management challenges in NTN, the previous papers didn't consider the various parameters for HO mobility managements in NTN. Moreover, there are features and studies about A4 event in measurement report. The serving cell's signal strength isn't getting low largely because of NTN environments [10]. In NTN, HO based on A4 event will perform better than A3 event. However, to the best of our knowledge, there are no papers in past literature considered both of A3 event and A4 event for HO. In this paper we considered A4 event for HO trigger, and HO parameters to guarantee reliable HO. Using the proposed algorithm, we analyze the HO performance according to the event A4 threshold and the L3 filter K value, which is HO parameter. Simulation results show the difference results according to the key performance indicators (KPIs).

The remainder of this paper is organized as follows. In section II, we present the system model. III section is described with HO process in cellular. In section IV, we present the simulation design. Section V shows performance evaluation. Finally, VI concludes this paper.

II. System Model

In section II, we describe the system model. We use the system level simulation (SLS) environment of [11] and the channel model of [12]. Fig. 1 depicts the system model used in our work. It is consisted of 1 LEO satellite and 61 beams. The LEO satellite is moving at a speed of 7.56 km/s and it only operates 19 beams. Two Additional tiers of beams are arranged outside the 19-beam layout. This is to prevent an

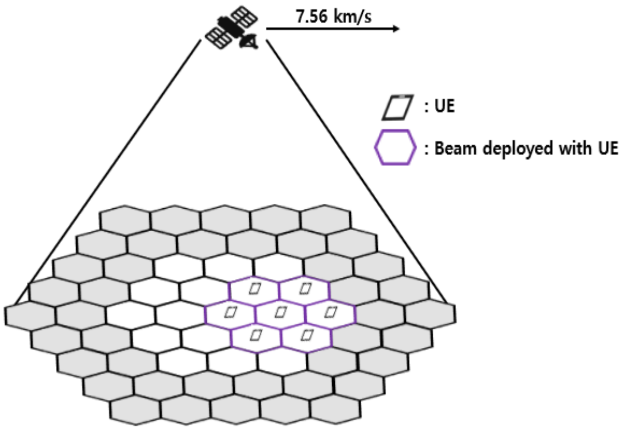

Fig. 1. System model.

increase in interference ratio due to decrease in the number of adjacent beams when the user equipment (UE) is connected to the edge beam of the satellite. Therefore, the UE is not handover to external 2-tier beams.

A. Scenario

We consider NTN reference scenario based on the SLS study case 9 of technical report (TR) 38.821 [11]. We assume D2 scenario which uses regenerative satellite and moving beam. UE is randomly placed on the 7 beams which are surrounded by purple color, and the remaining beams establish an interference environment.

B. Satellite Channel Model

The satellite channel model in this paper is based on the large scale model of TR 38.811 [12]. The path loss between LEO satellite and UE is defined as follows:

$$PL = PL_b + PL_g + PL_s + PL_e, \tag{1}$$

where PL is the total path loss, PL_b is the basic path loss, PL_g is the attenuation due to atmospheric gasses, PL_s is the attenuation due to either ionospheric or tropospheric scintillation, and PL_e is the building entry loss in dB. However, among these, the system of SLS channel model of [12] only considered PL_b. Therefore, we only calculate the PL_b. The PL_b is calculated as follows:

$$PL_b = FSPL(d, f_c) + SF + CL(\alpha, f_c), \tag{2}$$

where $FSPL$ denotes the free space path loss, SF is the shadow fading loss which modeled by a log-normal distribution, and CL is the clutter loss. The $FSPL$ can be calculated as follows:

$$FSPL(d, f_c) = 32.45 + 20log_{10}(f_c) + 20log_{10}(d), \tag{3}$$

where d is the distance between LEO satellite and UE in meter and f_c is the carrier frequency in GHz. The d can be calculated as follows:

$$d = \sqrt{R_E^2 \sin^2\alpha + h_0^2 + 2h_0 R_E} - R_E \sin\alpha, \tag{4}$$

TABLE I
SF AND CL ACCORDING TO ELEVATION ANGLE [12]

Elevation	LOS	NLOS	
	σ_{SF}(dB)	σ_{SF}(dB)	CL(dB)
10°	1.79	8.93	19.52
20°	1.14	9.08	18.17
30°	1.14	8.78	18.42
40°	0.92	10.25	18.28
50°	1.42	10.56	18.63
60°	1.56	10.74	17.68
70°	0.85	10.17	16.50
80°	0.72	11.52	16.30
90°	0.72	11.52	16.30

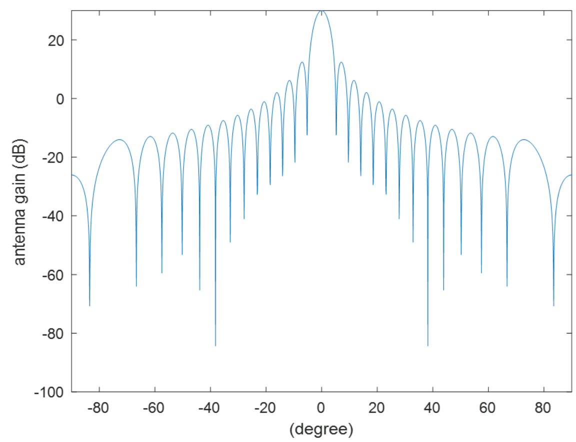

Fig. 2. Satellite antenna gain pattern.

where R_E denotes the Earth radius, α is the elevation angle and h_0 is the altitude of satellite. As we considered suburban scenarios, the SF and CL are followed by Table I. The signal-to-interference-plus-noise ratio (SINR) is based on [13]. SINR is calculated as follows:

$$SINR[dB] = -10log_{10}(10^{-0.1SNR} + 10^{-0.1SIR}), \tag{5}$$

where SNR is signal-to-noise ratio and SIR is signal-to-interference ratio. SNR can be calculated as follows:

$$\begin{aligned} SNR[dB] = EIRP[dBW] - PL[dB] - k[dBW/K/Hz] \\ +G/T[dB] - 10log_{10}(BW[Hz]/K_{FR}). \end{aligned} \tag{6}$$

Here, $EIRP$ is equivalent isotropic radiated power, k is Boltzmann constant, G/T is the received antenna gain-to-thermal noise ratio, BW is bandwidth, and K_{FR} is the bandwidth factor based on the selected frequency reuse scheme. SIR is calculated as follows:

$$SIR[dB] = S[dB] - I[dB], \tag{7}$$

where S is the signal strength and I is the interference strength. I is calculated as follows:

$$I[dB] = 10log_{10}(\sum 10^{0.1I_i[dB]}), \tag{8}$$

where I_i is the interference of i-th beam.

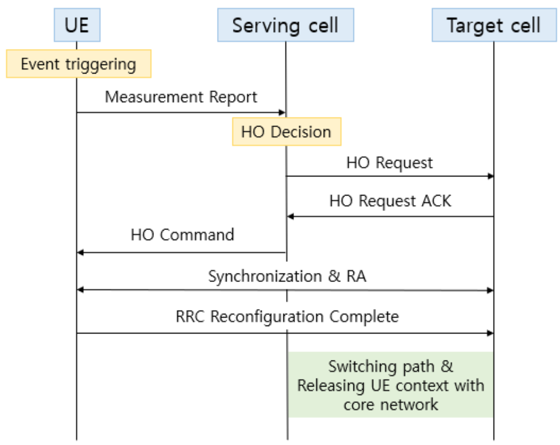

Fig. 3. Baseline HO procedure.

C. Antenna Pattern

The antenna pattern of LEO satellite using (9) is shown in Fig. 2.

$$\begin{cases} 1 & for\ \theta = 0^\circ \\ 4\left|\frac{J_1(k_w a_{sat} sin\theta_{b,u})}{k_w a_{sat} sin\theta_{b,u}}\right|^2 & for\ 0^\circ < |\theta| \leq 90^\circ, \end{cases} \tag{9}$$

where J_1 is Bessel function of the first kind and first order with argument x. k_w is the number of wave which calculated by $2\pi f/c$, a_{sat} is the aperture radius of antenna. $\theta_{b,u}$ is the angle between the boresight of the antenna and UE. The f is the carrier frequency, and the c is the speed of light.

III. HO Process in Cellular Network

The HO mechanism is a technology that enables seamless service between a base station and a base station. Therefore, UE can freely use the service while moving. At this section, we describe about the HO process in cellular network.

A. HO Procedure

The baseline HO procedure is shown in Fig. 3. It consists of three steps: preparation, execution, and completion. If the certain event condition is satisfied for time-to-trigger (TTT) duration, then the UE sends the measurement report to the serving cell. When the serving cell receives the measurement report, it decides HO. These procedures belong to the HO preparation step. After serving cell decides to initiate HO, it exchanges HO request and HO request acknowledge (ACK) message (msg) with target cell. Then the HO execution step starts. In the HO execution process, the serving cell sends the HO command msg to the UE. Then the UE disconnects the serving cell and executes the connection process with the target cell with synchronization and random access (RA) process. At the HO completion step, the UE announces HO complete to the target cell and the core network initiates resource release on the serving cell. After that, it switches the path to the target cell. Then the HO procedure complete.

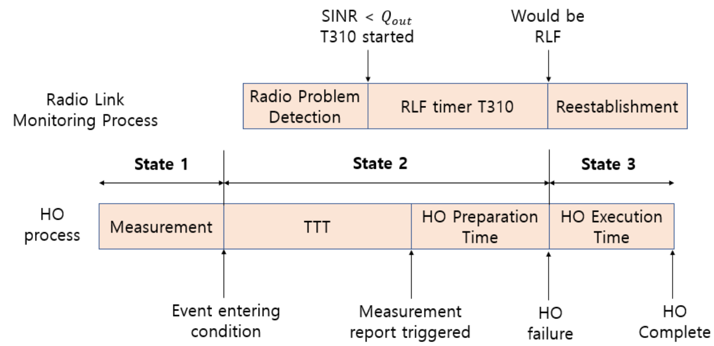

Fig. 4. HO state definition.

TABLE II
Parameters of State

Parameter	Value	Parameter	Value
Q_{out}	-8 dB	Max HARQ re-transmission	7
Q_{in}	-6 dB	Max RLC re-transmission	3
T310	1 s	Max Preamble /Msg 3 re-transmission	4
N310	1	RA response timer	5 subframes
N311	1	Contention resolution timer	40 subframes
Frequency band	S-band	Satellite altitude	600 km
Cell diameter	50 km	Satellite EIRP density	34 dBW/MHz
UE G/T	-33.6 dB/K	UE antenna pattern	Omni directional
Off	0 dB	A3 event HO offset	0 dB

B. Measurement Event

3rd generation partnership project (3GPP) defined measurement report mechanisms called event to be executed by UEs. In 5G, there are 6 events for intra-radio access technology (RAT) measurements and 2 events for inter-RAT measurements [14]. The most useful event is A3, but there have been many discussions with using which event in NTN. In TN, the reference signal received power (RSRP) between the cells is large enough to compare. However in NTN, the RSRP levels of cells may be similar and unpredictable [10]. Furthermore, 3GPP discussed using the event that compares the RSRP with absolute threshold. For that reason, we use A4 event for measurement report in our paper. If the neighbour cell's RSRP is offset better than the threshold, the A4 event is triggered. The A4 event triggering condition is as follows:

$$M_n + Off > \zeta. \tag{10}$$

The M_n is the measurement result of the neighboring cell, and the Off is the measurement specific offset for the A4 event. The ζ is the threshold value for the A4 event.

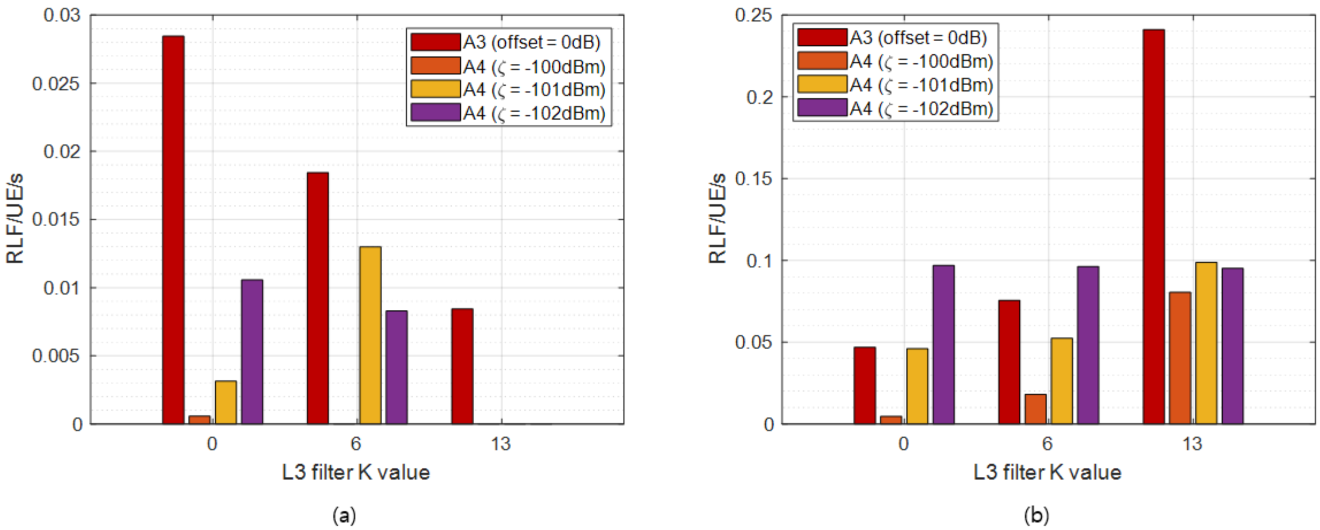

Fig. 5. Number of RLF times per UE over time [RLF/UE/s] (a) In state 1, (b) In state 2.

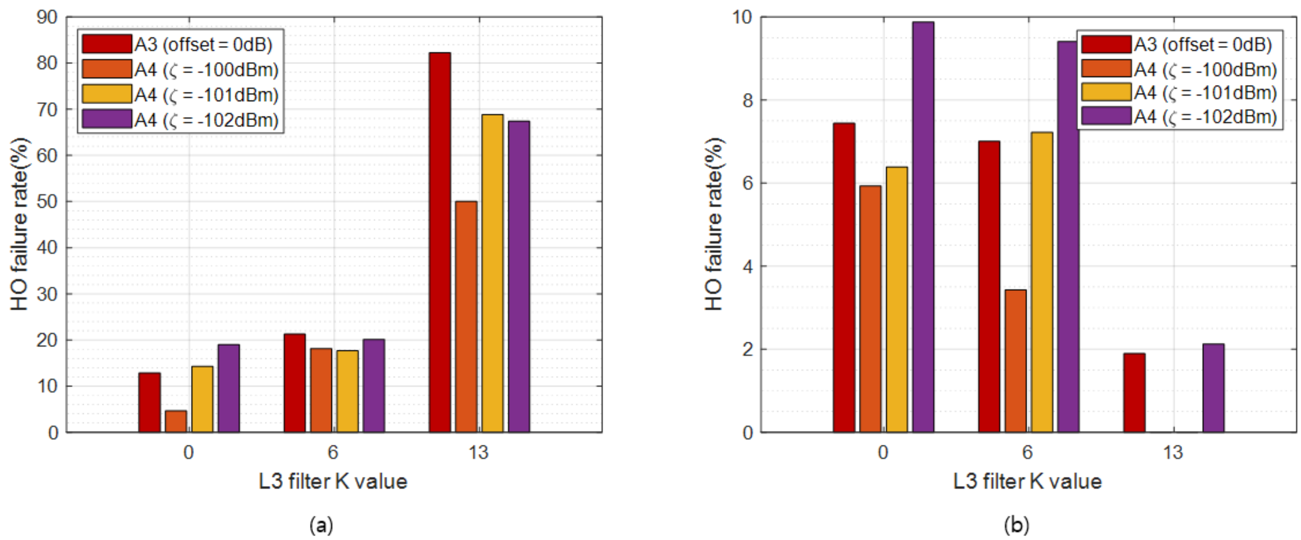

Fig. 6. HOF rate (a) In state 2, (b) In state 3.

IV. Simulation Design

A. Key Performance Indicators

The following key peformance indicators (KPIs) have been collected to evaluate the mobility performance in NTN. Fig. 4 depicts HO states in detail. The UE's HO process is analyzed in 3 states. State 1 defined until the event entering condition is satisfied. From the end of state 1 until the HO command msg is successfully transmitted from the serving cell to the UE is called state 2. Lastly, state 3 defined from the end of state 2 to the HO complete.

1) Radio Link Failure (RLF)
When the measured SINR is lower than Q_{out}, out-of-sync indication occurs. If the number of out-of-sync indication is more than N310, then the T310 timer starts. After that, if the SINR gets higher than Q_{in}, in-syn indication occurs. If the number of in-sync indication is more than N311 before the T310 expires, there is no RLF. On the other hand, if the T310 expired, the RLF occurs. The number of RLF events are defined per UE over time.

2) Handover failure (HOF)
If the UE does not HO to another cell despite the weak RSRP of the serving cell, the UE experiences RLF and HO fails. Also, when HO to target cell with low RSRP due to incorrect HO parameter setting, the UE fails the HO. In state 2, HOF includes RLF in state 2. Also, it includes the case where timer T310 is running when the HO command message is received by UE. State 3 HOF occurs when the RA doesn't success in HO execution

step.

B. Simulation Setup

For performance analysis, we use Riverbed Modeler's LTE model in this paper. ζ is set to -100, -101, and -102 dBm. L3 filter K value is set to 0, 6, and 13. We assume that simulation time for 10 seconds. In this paper, we consider a single satellite scenario. The adjacent beam spacing is 0.0068 on UV plane [15], which is about 50 km in our simulation. The frequency reuse factor of satellite beam is option 1. The type of UE is handheld. Other parameters are shown in Table II. Hybrid automatic repeat and request (HARQ) re-transmission and radio link control (RLC) re-transmission number is set by 7 times and 3 times, respectively. The deployment scenario assumes a suburban area. The environment of UE is 100% outdoor environment. Simulation conducted based on changing ζ of A4 event and L3 filter K value. L3 filter K value is the factor that determines how much ratio the previously measured RSRP of the cell is reflected. It is required to ensure unwanted HO does not triggered due to low or high measurement report.

V. Performance Evaluation

In this section, we analyze simulation results based on the simulation design. Fig. 5 shows the average RLF for an UE per second. RLF in state 1 is generated when the Q_{out} is indicated before the event entering condition occurs and the Q_{in} is not received within the timer T310. Conversely, RLF in state 2 occurs after the serving cell receives the measurement report. In other words, RLF happens when the above situation occurs by comparing the RSRP with the serving cell. As a result of the simulation, when the threshold of A4 event is set to -100 and -101 dBm, it shows better performance than A3 event regardless of the L3 filter K value. This confirms that the performance of the A4 event is better than that of the A3 event because the difference in RSRP between the serving cell and the target cell is no large enough for comparison. In addition, if the L3 filter K value is 0, it can be confirmed that the number of RLF times is lower than when it is set to 6 or 13 because the RSRP value of the previously measured serving cell is not reflected. However, if the threshold value is set as low as -102 dBm, the number of RLF times is slightly higher. This is because the lower the threshold value for the A4 event, the closer the HO is to the neighboring cell, so the HO procedure starts late.

The HOF rate is shown in Fig. 6. HOF generally occurs a lot in state 2. The HOF occurring in state 2 means the HOF in the serving cell. This mainly happens because the HO command msg is not received. On the contrary, HOF in state 3 occurs before approaching the target cell, therefore a failure occurs in the process of RA procedure to the target cell. When the threshold of A4 event is set to -100 and -101dBm, it can be seen that, like RLF, it generally shows better performance than A3 event. We are able to confirm through this work that it is better to check the RSRP difference between the target cell and the threshold value than to compare the insignificant RSRP difference between the serving cell and the target cell.

VI. Conclusion and Future Work

In this paper, we have performed HO simulation based on A4 event and L3 filter K value. We considered system model with satellite in 600 km altitude which operating 19 beams. Simulation used the baseline HO procedure. The RLF and HOF of A4 event based handover show better performance than A3 event based handover. In addition, we performed both of handover with L3 filter K value. The results show that when the L3 filter K value is low, the RLF and HOF get low, either. When we run our simulation by setting the measurement event as A4 event, we can see that the HO performance is better than the one with the A3 event. Therefore, performing handover with the A4 event which compares the RSRP of the target cell and the threshold is more advantageous than the A3 event which compares the RSRP of the serving cell and the target cell. In future work, we will conduct research for the optimal threshold for A4 event, and optimize the handover parameters to reduce the HOF and RLF.

Acknowledgment

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