Conditional Handover for Non-Terrestrial Networks

Mehmet Izzet Saglam
Research and Development
Turkcell Teknoloji
Istanbul, Turkiye
izzet.saglam@turkcell.com.tr

***Abstract*—The 3rd Generation Partnership Project (3GPP) Release 17 (Rel-17) standardizes Non-Terrestrial Networks (NTNs). The 3GPP 5th Generation (5G) Advanced and 6th Generation (6G) technologies aim to enable reliable, environment-friendly, cost-efficient and secure NTNs. Integrating Terrestrial Networks (TNs) and NTNs can introduce ubiquitous coverage for Mobile Network Operators (MNOs). While NTNs have many coverage advantages, the operation of NTNs has several challenges, like mobility functionalities. Even the stationary MNO subscribers have to make HandOver (HO) due to Non-Geostationary Satellite Orbit (NGSO) satellites' trajectories. Conditional HO (CHO) is designed in 3GPP Rel-16 for TNs. It cannot be directly applied to NTNs for fixing mobility challenges. Hence, new necessary enhancements need to be designed. This paper presents an overview of CHO and signaling challenges related to NTN coverage and mobility functionalities, along with their potential solutions.**

***Index Terms*—3GPP, Non-terrestrial network, conditional handover, signaling overhead, signaling storm**

I. Introduction

Wireless communication research topics have shifted to 5G Advanced and 6G systems that are expected to make a giant jump in standardization studies. Nationwide 5G commercial networks have been available since 2019 with the Korea Telecom launch. The new rollouts of 5G networks continue in different parts of the world. The 3GPP 5G Advanced and 6G technologies try to solve the digital divide by providing reliable, environment-friendly, cost-efficient and secure access for all in urban and remote areas based on United Nations Sustainable Development Goals (SDGs) [1]. The goal of extending broadband connectivity in rural and extreme coverage regions will be achieved by integrating NTNs with TNs. TNs connected with satellites can provide resilient access for MNOs subscribers [2].

MNOs search for innovation in NTN and partner with verticals like automotive, logistics and agriculture for future use cases [3]. Besides new use cases, 5G Advanced and 6G can offer a reliable solution acting in emergencies and disasters with NTNs. During natural catastrophes, such as tsunamis or earthquakes, the infrastructures of MNOs are often destroyed or damaged, which makes it difficult for first responders and subscribers inside a disaster to communicate.

Ubiquitous, resilient and secure service must be advanced such that 6G networks are fully trusted by subscribers, verticals, regulators and MNOs. A Radio Access Network (RAN) can support subscribers' requirements under all circumstances with NTNs. MNOs can adapt and use 6G technologies for different purposes to serve their Internet of Things (IoT) and New Radio (NR) subscribers in urban, rural, suburban and even extreme coverage conditions. NTN NR and IoT can be cost-efficient solutions in the aspects of the network architecture. Deserts, oceans, or regions unfeasible for the OPerational Expenditure (OPEX) or CAPEX perspective of MNOs can be covered by NTN NR and IoT. MNOs expect mega-constellations of NGSO satellites like Low Earth Orbit (LEO) will be a connectivity alternative in 3GPP 5G Advanced and 6G RANs. NGSO NTNs can give limitless connectivity to MNO subscribers everywhere [4]. In the future digital world, NTN NR and IoT connectivity are strategic assets for MNOs' resilience. It closes the digital divide between the different parts of the same country, like cities and rural or between continents like Africa and Europe.

In the standardization efforts toward 5G Advanced and 6G, there is still much to be done to activate IoT and NR functionalities in NTNs fully. The roadmap of 3GPP NTN activities is defined for Rel-18. The first step of the 3GPP NTN normative studies started with Rel-15 in March 2017. The 3GPP Rel-15 study is related to the deployment scenarios, and characterization of propagation channels [5]. The next step is to adapt 5G NR support in Rel-16. The 3GPP finalized the Study Item (SI) in Rel-16. NTN NarrowBand IoT (NB-IoT) and Long-Term Evolution (LTE) for Machine-type communication (LTE-M) feasibility have been completed during the Rel-17. 3GPP starts a Work Item (WI) for NTN NR [6] and NTN IoT [7] in Rel-17 to complete the normative specifications. Rel-17 and 5G Advanced, specified under Rel-18, will represent major 5G evolutions and support the continuous coverage of verticals, deployments, and new use cases for MNOs. The 3GPP Rel-18 enhances the basic NTN functionalities developed in the previous releases by supporting several new features. The main new features of NTN are the extension of connectivity to remote areas or those not covered by TNs. These features can support better coverage, system performance, reliability and efficiency by integrating NTNs and TNs.

3GPP Rel-15 5G NR was designed to target terrestrial communications without considering NTN and its features. 3GPP NTN activities on space-borne include NGSO and Geostationary Earth Orbit (GEO) satellites. A more detailed review of the 3GPP NTN activities is shared in [8] and [9].

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The fundamental functionalities are enabled in 3GPP Rel-17 to support NTN satellite access with suboptimal performance. Most of the 5G NR features are out of scope in Rel-17 for NTN satellite access in the 5G NR and IoT due to time limitations and Covid-19 effects on 3GPP standard development organization. Integrating TNs and NTNs will be tighter in 5G Advanced, and 6G networks. This tight coordination, essential to achieve global coverage in 5G Advanced and 6G between TNs and NTNs, provides seamless mobility inside and between each network.

TN handover mechanism requires a large amount of signaling interaction among User Equipment (UE), source next generation Node B (gNB), and target gNB. For NTN, the high-speed movement of the satellites (e.g., LEO) due to their orbits will lead to frequent handover in a short time. For example, a 600 km LEO satellite with a 7.56 km/s speed for a 50 km cell diameter needs a handover of 6.61 seconds [9]. The coverage of NTNs is much broader than TNs', resulting in a considerable number of UEs in a single NTN cell having to make a handover even if they are stationary. These mandatory cell changes make the handover procedure more difficult due to the high signaling overhead or signaling storm. These mandatory frequent handovers also negatively impact the performance and Quality of Service (QoS) of the MNO subscribers [10]. Examples of handover control in various network scenarios are explored, like reinforcement learning and game theory. In [11], system-level simulations are evaluated for the 5G NR mobility performance in the NTN LEO satellites. It shows that NTNs have ten times worse than TN handover performance in terms of handover failure rate. It highlights the new mobility solutions necessities to address the challenges introduced by NTNs. In [12], a cell-free massive multiple-input multiple-output (MIMO) based architecture for LEO satellites is proposed. The proposed MIMO techniques require less handover with the synchronization of multiple satellites instead of a single one. The paper does not present a solution to the NTN LEO satellite HO problem. A learning-based auction HO with the service time and the consideration of received signal strength is proposed in [13]. It does not mention the suitability of the deep learning-based second-price auction algorithm to the 3GPP NTN HO algorithm.

This paper proposes a new 3GPP-compatible NTN active mode mobility algorithm based on CHO. Specifically, we discuss NGSO satellite mobility and coverage problem based on signaling overhead and signaling storm challenges in NTN. We try to solve multi-objective problems of HO decision processes and signaling load. MNO subscribers' throughput is enhanced, and their signaling overhead is minimized while considering their different QoS requirements based on the proposed 3GPP-compatible NTN CHO architecture. For this purpose, different simulations are worked to evaluate the performance of the proposed active mode mobility technique. The performance of conventional CHO and the proposed 3GPP-compatible enhanced NTN CHO are compared.

The main contributions of this paper are shared below.

- It is introduced a 3GPP compatible NTN to NTN active mode mobility algorithm that uses a dynamic CHO approach.
- The proposed CHO approach uses two different techniques to prevent signaling overhead and signaling storm during NTN to NTN mobility.

The remainder of this paper is structured as follows: Section II introduces the 3GPP baseline handover procedure and the proposed NTN CHO. Section III describes the simulation setup and results for the proposed CHO approach. Section IV covers conclusions with future works.

II. Handover Procedure

Mobility management of NTN and TN RANs includes User Equipments (UEs) in idle mode and UEs in active mode. Paging, cell tracking, cell selection and re-selection are related to idle mode mobility management. The active mode mobility is HO processes. When a UE is active, the network controls mobility, assisted by the UE. When the current service link is degraded, the UE transmits measurement reports, or a better neighbour is founded [14]. The measurement reports can trigger HO from the source cell to the target cell for a UE so that the UE will get better radio conditions while guaranteeing service connectivity without noticeable service interruption.

We need to make necessary changes to mobility management procedures in NTNs. The TN cells do not change their location, while NTN ones are mobile based on their orbit trajectories like LEO. Earth-moving cells can cover a fixed area for only a few seconds. This duration can increase to minutes for quasi-earth fixed cells.

A. Baseline Conditional Handover

Conditional HO sends multiple candidate target HO cells to the source cell, while the legacy HO use limited number of target cells. These multiple candidate cells' information is sent to the source cell during the HO preparation phase, which means that the source cell's radio condition is not degraded too much. The source cell cannot receive the target cell information in the legacy HO when radio conditions worsen [14].

Different CHO enhancements are proposed for TNs. Self-organizing network optimization based on source cell quality for CHO and its triggers improves performance significantly without increased signaling [15]. CHO triggers a handover command with a condition for a UE. The UE keeps the HO command and executes it when the condition is satisfied. After UE execution, the CHO connects the UE to the target cell. Enhanced CHO (ECHO) in [16] predicts the trajectory of the users to prepare the base stations along the user's path to reduce the handover rate. In [17], AI-assisted CHO focuses on signal overhead reduction. All these enhancements are based on terrestrial requirements and unsuitable for non-terrestrial ones. The signaling flow of baseline TN CHO [18] is shown in Fig. 1 below.

The Access and Mobility Management Function (AMF) is responsible for mobility management. User Plane Function (UPF) is the function that does all of the work to connect

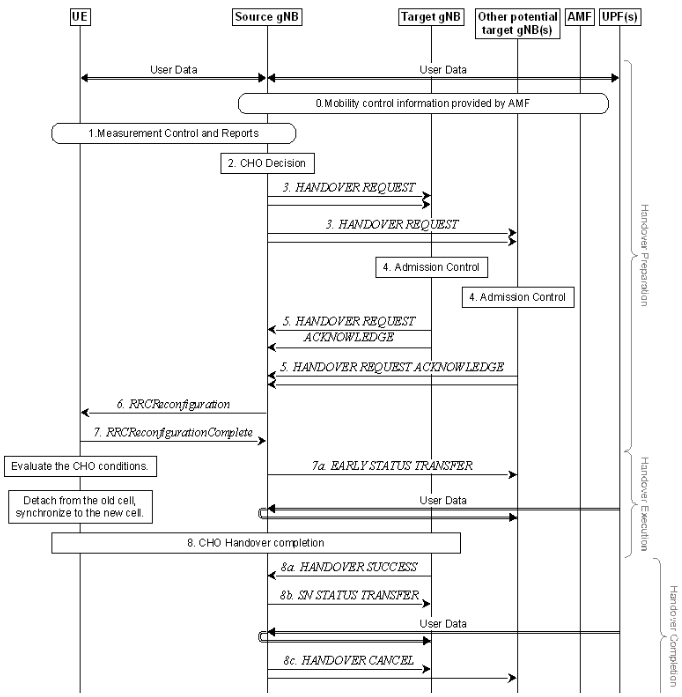

Fig. 1. The signaling flow of the baseline CHO.

the actual data coming over RAN to the internet in active mode. Firstly, the UE sends its measurement report to the serving cell when the triggering conditions are satisfied, like the serving cell radio condition is worse than a threshold or a new neighbour cell with a better radio condition detected. Secondly, CHO usage is decided by the source cell. The source gNB sends a CHO request message to all candidate cells. Admission control is needed to be completed in step 4. The configuration information of CHO candidate cells is sent to the target cell. The CHO response message is sent for each candidate cell. Then, the source cell shares this information with the UE to update it for the candidate CHO configuration and execution conditions. A radio resource control message is sent to the source gNB by UE. Early data forwarding is completed in the next step, step 7. The UE evaluate the CHO candidate cell execution conditions while it keeps the source gNB connection. The UE releases the source gNB connection when the target CHO cell execution conditions are satisfied. The UE follows this target cell's stored configuration and completes the synchronization. This is the last step of the UE in the RRC HO procedure. The target gNB informs the source gNB that the HO procedure is successfully completed. After that, the source gNB transfer the secondary node status transfer message. The source gNB informs the other CHO candidates to cancel the ongoing CHO process.

CHO can increase the HO success rate by using multiple candidate cells at the same time. Nevertheless, each of these multiple cells needs to reserve a radio resource. The potential CHO target cell should be carefully selected for a UE to save UE and gNB radio resources. Furthermore, the UE needs to reserve radio resources for potential CHO candidates, even if one becomes a successful CHO target. This becomes more problematic during peak hours or a network is congested in NTNs.

B. Proposed Conditional Handover

In the TN environment, the serving cell of an active state UE may decide to configure conditional handover for the UE according to measurement control and the measurement report of the UE. Most handover required for a UE is caused by UE mobility in TNs. When an NTN serving cell is moving away from the location of the UE, it performs the handover for an active UE based on its non-geosynchronous satellite trajectory.

More tailored handover conditions are needed in the NGSO NTN RAN, as described in [9]. UEs can easily trigger measurement reports based on a clear Reference Signal Receive Power (RSRP) difference between the cell edge and center in TNs. The RSRP difference between the NTN cell edge and center is negligible compared to the TNs. Only RSRP-based HO triggering has a problem in the execution part for NTNs. The location of UE, satellite ephemeris data and service time of NGSO satellites can be used to enhance HO in NTNs.

NTN mobility could be further optimized considering the inevitable signaling overhead and signaling storm caused by a large number of UE handovers almost at the same time. Frequent handover and intensive signalings for handover configuration in NTN can affect UE's data throughput and key performance indicators. In our proposed CHO algorithm, dynamic time-based and/or location-based execution triggering for the same candidate cell is used to enhance CHO performance in NTNs besides the baseline parameters like RSRP and Reference Signal Receive Quality (RSRQ). We think the time-based CHO is more efficient than the location-based CHO for the quasi-earth fixed cells because the new cell will cover the same area as the previous one. We choose the location-based CHO for the GEO cells because the satellite serves the same area continuously. The location-based CHO can be used for earth-moving cells in our proposed algorithm to track the movement of the coverage because the earth-moving cell does not provide a fixed coverage to a specific location during a long dedicated duration. The coverage moves with the LEO satellites. There is such a case that location- and time-based CHO must simultaneously trigger both for a quasi-fixed cell. If the UE is located at the cell edge and is likely to move out of the coverage proactively before the serving cell stops serving the area, it can configure both time-based CHO and location-based CHO for the same UE.

In our proposed location-based CHO algorithm for NTN, gNB uses two new reference location triggers and one time trigger. 1stlocationtrigger is the location that shows the distance between the source cell center and the UE. 2ndlocationtrigger is between the candidate target cell center and the UE. The location-based CHO occurs when 1stlocationtrigger becomes larger than the absolute value and the 2ndlocationtrigger becomes shorter than the absolute value. The time-based CHO uses a timetrigger. Timetrigger shows how much of the serving cell availability duration is left. MNOs can configure these absolute values of the location and time-based triggers. An example scenario is shown in Fig. 2 below for the proposed location and time-based CHO.

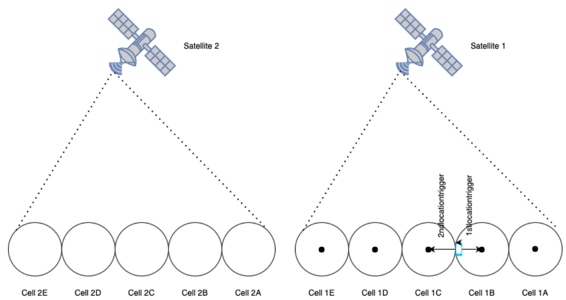

Fig. 2. The proposed CHO approach.

The second challenge in NTNs is the signaling overhead and signaling storm due to all UEs in NTN cells needing CHO for a short time. NTN cells have larger footprints than TN ones. The first proposed method to prevent the signaling overhead is to use the CHO configurations of the second and third tiers with the next CHO candidate. In NTNs, a satellite can serve more than one NTN cell. When UEs get service from a new cell, UEs can report that their configuration supports second or third tiers of CHO candidate cells beside the next one. For example, the UE in Fig. 2 can get the configuration of Cell 1D and Cell 1E besides Cell 1C. Cell 1D is the second tier of Cell 1B, while Cell 1E is the third tier of Cell 1B. The second proposed method to prevent signaling storms in earth-fixed cells is to use group HO instead of individual ones. The cell coverage is finalized roughly simultaneously in the earth-fixed cell. Before the finalization of the NTN cell, the proposed time-based CHO was triggered for a group of UEs. The proposed time-based CHOs are based on the serving cell's service availability duration, timetrigger. There is shown only one UE in Cell 1B. If we assume more than one UE in Cell 1B, all UEs in Cell 1B can get the same CHO command. These chosen UEs are informed in advance and can be sorted by the source cell to prevent signaling storms. The sorting mechanism can be based on the location, randomness or division of the UEs' data payload. The proposed NTN CHO simplified approach is summarized below.

- The proposed CHO approach chooses the additional parameters based on the NTN cell type:
  - If the NGSO satellite supports earth-moving cells, the proposed NTN CHO approach adds location-based triggers, 1stlocationtrigger, and 2ndlocationtrigger in addition to RSRP and RSRQ.
  - If the NGSO satellite supports quasi-earth fixed cells, the proposed NTN CHO approach adds a time-based trigger in addition to RSRP and RSRQ.
  - If the GEO satellite supports earth fixed cells, the proposed NTN CHO approach adds location-based and/or time-based triggers, timetrigger, 1stlocationtrigger, and 2ndlocationtrigger, in addition to RSRP and RSRQ.
- After the additional parameter decision, the signaling overhead and signaling storm prevention work as follows:
  - If the NTN cell type is the quasi-earth fixed cell, the CHO command activated group based instead of individual UEs to prevent signaling storm.
    * Groups are defined according to UE's locations or random manner.
    * Groups are defined according to UE's data payload.
  - The dynamic NTN CHO approach uses 2nd and 3rd tier of CHO candidates to decrease signaling overhead for all types of satellite cells.

III. Simulation Results

In 5G Advanced RAN, simulations are essential for understanding the mutual interactions between UE and gNB. We use a system-level simulator in an object-oriented programming environment based on [9] requirements. Our simulations assume all UEs have global navigation satellite system (GNSS) sensors. The UEs can get the NTN-specific parameters for the source and its neighbor cells from SIB19. The UEs can determine the serving, target CHO cell, or satellite position and velocity. Simulations with traffic models in [5] are provided to assess the CHO performance under typical traffic and load conditions. UE's positions and mobility paths are kept identical to compare our simulations' baseline and conditional CHO scenarios. The simulation parameters are shared in Table 1.

TABLE I
Simulation Parameters

Parameter Name	**NTN Scenarios**		
	GEO 35,786	***LEO 600***	***LEO 1200***
Altitude (km)	35,786	600	1200
Orbit Type	GSO	NGSO	NGSO
Payload	Transparent	Transparent	Transparent
Carrier Frequency (GHz)	2 (S-band),	2 (S-band)	2 (S-band)
Bandwidth (MHz)	20	20	20
Elevation Angle (degrees)	12.5	30	30
Shadowing margin (dB)	3	3	3
Additional loss (dB)	0	0	0
EIRP density (dBW/MHz)	59	34	40
Antenna aperture (m)	22	2	2
Tx max Gain (dBi)	51	30	30
Beam diameter (km)	250	50	90
Scheduler	Round Robin	Round Robin	Round Robin
Number of UEs per Cell	10	10	10
Satellite Speed (km/s)	Negligible	7.56	7.56
UE Tx Power (dBm)	23	23	23
UE Speed (km/s)	Negligible	Negligible	Negligible
Traffic Model	Full Buffer	Full Buffer	Full Buffer

The proposed CHO is evaluated with multiple simulation runs. We compare its performance with the baseline HO and CHO, considering key performance indicators signaling overhead reduction, ping pong and HO failure rates. HO failures are calculated by dividing the total number of HO failures by the total number of HO attempts. Ping Pong HO rate is counted when the UE returns the source cell within ping pong time. The ping pong and handover failure rates of the proposed and baseline methods can be seen in Table 2.

TABLE II
SIMULATION RESULTS

Key Performance Indicator[a]	**Simulation Scenarios**		
	HO	***CHO***	***Proposed CHO***
Ping Pong Rate LEO	0.00%	46.39%	2.47%
HO Failure Rate LEO	70.66%	0.00%	0.00%
Signaling Reduction LEO	–	–	33.34%

[a] Key performance indicators evaluated for 600 km LEOs.

The proposed CHO approaches have superior performance than the baseline HO in terms of HO failure rate because of its dynamic location- and time-based triggers. Furthermore, the proposed CHO approach prevents ping pong handovers using 2nd and 3rd-tier target cells with a signaling overhead reduction of up to 33.34%. The baseline HO and CHO can only use RSRP and RSRQ thresholds.

IV. CONCLUSIONS

The proposed CHO uses two new techniques to prevent signaling overhead and signaling storms during the mobility of the UEs from one NTN cell to another. The proposed mobility approach addresses the similar RSRP level at the edge and middle of the NTN cell with a dynamic, customized CHO method. An NTN-to-NTN mobility method is studied with simulations and compared against the baseline HO and CHO. The NTN to NTN handover is considered with the same altitude value.

For future work, some system information could be transmitted to UEs by dedicated signaling during conditional handover to reduce signaling overhead. Handover signaling common to all the UEs would be broadcasted. Therefore, signaling storms could be reduced further. Additionally, we could check the feasibility of the possible common system information and signaling parameters as a future study.

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