# Terminal-Oriented Handover in Small Cell Wireless Systems: A Multi-Layered Recovery Method in Surrounding Cells

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***Abstract*—This study introduces a terminal-oriented handover method as an alternative to the conventional backhaul-oriented handover in cellular mobile networks. Our method allows mobile terminals to prepare for synchronization with surrounding cell before leaving the serving base station. This approach facilitates handovers even in small cell systems where overlap areas are insufficient. Unlike conventional handovers that require overlapping cells, the entire cell of the target base station becomes a handover section, providing ample time for handover, even at high speeds. Additionally, using Passive Optical Network for the backhaul enables pre-storage of downlink communication data at potential target base stations. This eliminates the need to transfer data from the serving to the target base station during handover, allowing immediate transmission of pending data upon request. By integrating these methods in a multi-layered manner at surrounding cells, the recovery of the mobile terminal's wireless connection is accelerated, resulting in more flexible handover.**

***Keywords— high-speed hand over, small cells, PON backhaul, terminal-oriented hand over.***

## I. Introduction

Wireless systems like Beyond 5G (fifth-generation mobile communication systems) play a crucial role as essential infrastructure in today's information society. Among them, the realization of large capacity and high reliability is an important technical challenge [1]. Meanwhile, in cellular networks, the spatial locality of cells, which are the radio coverage areas of ground base stations (hereafter BS), is utilized to improve the overall wireless capacity of the system by reusing the same frequency bands at different BSs across regions. In cellular mobile networks, before a mobile terminal (hereafter MT) moves out of the cell of the serving BS (Serving BS; hereafter SBS), it switches the radio section to the cell of the target BS (Target BS; hereafter TBS) to handover (hereafter HO) [2]. In conventional cellular mobile networks, the initiation of HO is instructed by the mobility management device (hereafter SW), such as the switch of the ground network or the AMF (Access and Mobility Management Function) of the 5G core network, to the MT. This is referred to as backhaul-oriented handover (hereafter BoHO) in this paper. In BoHO, the SW instructs the MT to HO through the cell radio section of the SBS. Moreover, if the MT is outside the cell of the TBS at the completion of HO, the radio section communication is interrupted, so it is necessary to BoHO while the MT is within the common area of the SBS and TBS cells. Therefore, this BoHO approach has unavoidable problems in principle:

- The cells of the SBS and TBS need to overlap to some extent, requiring a common area as the HO section.
- If the HO procedure is not completed within the HO section, the MT communication is interrupted, necessitating a fast HO procedure to support high-speed moving MTs.

Using small cells reduces the number of MTs within a cell compared to large cells with a radius of several kilometers, increasing the radio section bandwidth per MT. However, the common area for BoHO must maintain the same area as macrocells to support high-speed moving MTs. This illustrates one of the technical issues in configuring small cell cellular mobile networks.

Furthermore, in the millimeter-wave bands expected to be used in 5G, factors such as spatial fading and obstacles increase signal propagation losses. Achieving large-scale cell coverage becomes more difficult compared to the existing microwave bands. While most previous studies have assumed large cells as the control plane (C-plane), here we consider a different approach, configuring cellular mobile networks consisting only of small cells.

In this study, we propose terminal-oriented handover (hereafter ToHO) as a fundamental solution to address these problems caused by BoHO. ToHO reduces the dependence on the ground network for HO procedures and provides a means for the MT to independently initiate HO procedures.

Against this background, the purpose of this study is to discuss the feasibility and effectiveness of the ToHO approach. We analyze the technical aspects and significance of implementing ToHO as a means to improve the HO procedures of cellular mobile networks. By reducing the dependence on the ground network for the initiation of HO, ToHO is expected to overcome existing limitations and enhance the overall efficiency and reliability of the wireless systems.

In the following sections of this paper, we discuss the detailed methodology while focusing on the proposed ToHO approach and its potential advantages. Section two introduces the ongoing related research works. Section three proposes our ideas to implement ToHO in the context of implementations of 5G. Section four discusses the qualitative evaluation methods for our proposal. Section five is the conclusion section.

## II. Current Research Works

A2-A4-RSRQ (Reference Signal Received Quality) HO [3] is one of the HO procedures within LTE networks based on RSRQ. RSRQ is the average value of the ratio of RSRP (Reference Signal Received Power) to RSSI (Received Signal Strength Indicator). First, the occurrence of an A2 event trigger, which starts when the RSRQ of the SBS falls below a set threshold, initiates the measurement of RSRQ of neighboring base stations. Then, an A4 event trigger occurs when the RSRQ of one of the neighboring base stations exceeds another threshold, and HO is executed with that neighboring base station as the TBS. In HO procedures triggered by events such as RSRQ, RSRP, and SINR (Signal-to-Interference-plus-Noise Ratio), these values can be directly measured by the receiver of the MT, and there is no need to acquire information about base station deployment, MT location, or information held by the ground network SW separately.

It is also conceivable to perform HO using the location information and predicted movement direction of the MT. This makes it easy to predict the optimal TBS and HO timing in advance, efficiently allocate resources of the ground network, and perform HO seamlessly. For this, accurate location information of the MT and BS is required.

The 3GPP HST (High-Speed Train) scenario [4,5] defines the high-speed train use case for 5G NR (New Radio). Using event-triggered HO for high-speed trains exceeding 300 kilometers per hour can lead to a rapid deterioration in the reception quality of the SBS and a high possibility of HO failure. In the HST scenario, it is considered to use the train's location information to perform HO between the ground base station and the BS inside the high-speed train, or to maintain communication by beam scanning from the ground base station to the BS inside the high-speed train.

Reference [6] has realized an ultra-high-speed and switchable Wavelength Division Multiplexing (WDM) fiber-radio backhaul system in the W-band. By arranging a number of ground RAUs (Remote Antenna Units) that realize RoF (Radio-over-fiber) along the HST trackside and assigning specific optical wavelengths to each, it is possible to maintain uninterrupted downlink communication from the ground network's CS (Central Station) to the BS on the HST by switching the downlink optical wave-length to match the HST movement in less than 10 microseconds using a wave-length-tunable laser. The uplink communication from the BS to the CS is received at the CS as a separate wavelength signal for each receiving RAU, so it can be received without loss if demodulated.

The possibility of configuring a high-speed HO or HO-less wireless backhaul system in the HST scenario is based on the assumption that the location information and predicted movement direction of the HST are known, and that there are not multiple HSTs within the SBS. Therefore, it is difficult to apply these system concepts directly to the realization of high-speed HO in general cellular mobile networks. In this study, we consider high-speed HO that does not depend on the location information of the MT.

## III. Proposed Method

When an MT is activated from a cold startup or in the event of an HO failure, there are usually no measures that can be taken by the ground network. Currently, the MT restores radio section communication with the nearest BS through Random Access Procedure. In the case of HO failure, it is unlikely that the MT will immediately move to a different region due to its geographical locality. Therefore, it is considered that some procedures can be omitted more easily when recovering from an HO failure compared to the MT startup. For example, if preparations for the synchronization procedure for MTs that have failed HO are made in advance around the cells of the SBS, it is believed that synchronization between the MT and BS can be achieved much more easily than at MT startup. After synchronization is complete, it is also possible to resend the downlink data through the normal HO procedure of SBS-TBS transfer. Furthermore, if there is surplus capacity in the BS resources, it is possible to broadcast the downlink data in advance and resend the same data to the MT immediately upon determination of the TBS [7]. In this way, if the various steps of HO are advanced to a certain point at the BS where the MT is likely to be in the area after an HO failure, the MT side can resume HO simply by performing the synchronization procedure with the nearest BS. In this study, we consider implementing ToHO by making advance preparations on the ground network side for such HO failure recovery, specifically, synchronization preparation and broadcasting of downlink data.

### A. Synchronization Preparation

In LTE or 5G NR, there are mainly two types of BS access procedures on the control plane: CFRA (Contention-Free Random Access), which is used for HO and similar processes, and CBRA (Contention-Based Random Access), which is used for initial access and resynchronization, among others [2]. The latter, CBRA, is executed through a four-step message communication process:

1. The MT selects a RAP (Random Access Preamble) randomly from the shared sub-frame and transmits it to the TBS via the RACH (Random Access Channel).
2. If there is no collision with the RAP, the TBS assigns a TC-RNTI (Temporary Cell Radio Network Temporary Identifier) and uplink/downlink channel resources and replies to the MT with a RAR (Random Access Response) via the DL-SCH (Down-link Shared Channel). The RAR includes the RAP identifier, UL Grant (Uplink Grant), and TA (Timing Advance).
3. The MT sends a MSG3 (Message 3) to the TBS via the UL-SCH (Uplink Shared Channel), which includes the MT's ID, connection request, RAP identifier, and, if already assigned, the C-RNTI (Cell Radio Network Temporary Identifier).
4. The TBS notifies the MT of the connection establishment by sending a MSG4 (Message 4) via the DL-SCH, which includes the TA, SRB (Signaling Radio Bearer), and MAC main configuration settings.

If multiple MTs without a C-RNTI choose the same RAP, a collision occurs, and the MT waits to receive the CCCH SDU (Common Control Channel Service Data Unit) and for the resolution of the conflict to be transmitted by the PDCCH (Physical Downlink Control Channel). If the PDCCH is not received or a timeout occurs, the CBRA procedure must be repeated.

Unlike CBRA, CFRA ensures that different MTs use different preambles by the BS assigning a dedicated RAP in advance. In a normal HO, the MT receives the RAP assigned by the TBS in the HO section and performs CFRA to synchronize with the TBS.

If we apply the idea of this study to the control plane in LTE or 5G NR, it would be sufficient to secure the resources needed for the RAR reply in step 2 of CBRA in the neighboring cells of the SBS that could become the next TBS, and then transmit the RAP to the MT in advance. This is referred to here as "synchronization preparation on the control plane." As a result, the MT can connect to one of the neighboring cells of the SBS that will become the TBS at any timing and request an HO. The ground network SW only needs to execute the remaining steps of the HO in response to the HO request from the MT. Some of the surplus resources prepared in the surrounding cells will become unnecessary with the success of ToHO and must be released. This will be discussed in the later section on virtual mosaic macrocells.

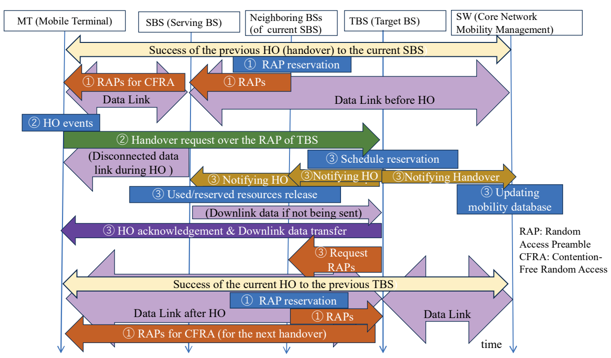


Fig. 1. The time diagram of the proposed handover procedure at control plane.

Figure 1 shows the time diagram of proposed handover procedure. The followings are the simple three steps from ① to ③ compared to the current backhaul-oriented handover:

Step ①: **Preparation for Synchronization.** The Serving Base Station (SBS) sends a Random Access Preamble (RAP) for Contention-Free Random Access (CFRA) to the Mobile Terminal (MT) from the neighboring cells' Base Stations (BSs) after they make a reservation of BS communication resources corresponding to the RAPs. This step prepares for synchronization on the control plane before the handover in advance.

Step ②: **Handover Request.** The MT requests handover to the Target BS (TBS) based on existing handover events such as A2-A4-RSRQ. The MT selects one of the neighboring cells' BS as the TBS and initiates the handover request communication using the stored RAP of the TBS via radio interface.

Note: This step can be executed even if the MT deviates from the overlapping cell area, that is, the cell of SBS. In the time diagram, the radio link between SBS and MT is denoted as " (Disconnected data link during HO)" after the handover request. Thus, the proposed handover procedure expands the handover area from the overlapping cell area to the group of neighboring cells' BSs.

Step ③ : **Processing by the Selected TBS for Notification to the Network Facilities** The selected TBS processes the handover. The TBS notifies the Core Network Mobility Management (SW) of the successful handover to update the mobility database. The TBS also notifies the old SBS and neighboring cells' BSs to release the used resources including the reserved RAP resources if unnecessary. After receiving the stored downlink data at the old SBS, if it exists, the TBS resumes data transfer with the MT over a newly scheduled radio channel assignment. We will propose our novel idea to prevent the downlink transfer from SBS to TBS in the following section.

The TBS requests the neighboring cells' BSs of the previous TBS, the new SBS, to notify the MT of the RAP resources for the next handover procedure.

### *B. Downlink Data Multicasting*

In the HO procedure, after the MT has synchronized with the TBS, the critical task is the transfer of downlink data that has been residing at the SBS to the MT through the TBS. In 5G NR, if the SBS and TBS are directly connected via the Xn interface, the SBS transfers the data to the TBS through that interface; otherwise, the SBS transfers the data to the core network's UPF (User Plane Function), which then transfers it to the TBS.

Reference [8] is a real-world experiment accommodating 5G small cells with a 50G TDM (Time-Division Multiplexing)-PON (Passive Optical Network). While the previous XGS (Ten Gigabit Symmetric)-PON is not suitable for high-speed communication in small cells in many usage scenarios, the 50G TDM-PON prototype has reported download speeds of approximately 800 Mbps (bits per second) to 1000 Mbps.

A characteristic of PON is that it is a downstream broadcast-type network where the laser light from the upstream device, the OLT (Optical Line Terminal), is split by a passive element, the prism, and delivered to all the downstream devices, the ONUs (Optical Network Units). Just as the radio waves from the BS reach all MTs within a cell, using PON in the configuration of the ground network allows broadcasting of downlink communication from the UPF to all subordinate BSs. In other words, by coordinating a group of small cells, it is possible to broadcast downlink communication as if it were a large cell, allowing immediate transfer of downlink communication from the TBS to the MT after synchronization in ToHO. Here, we will call this method "downlink data multicasting on the U-plane." When the neighboring cell becomes the SBS, it is necessary to always store the downlink communication data for MTs outside the area in a buffer. To clear the data in the buffer, the SBS can multicast the ACK (Acknowledgment) of the ARQ (Automatic Repeat-Request) directly sent from the MT through the PUCCH (Physical Uplink Control Channel) to other BSs within the same PON.

It should be noted that among the data residing during HO, the uplink data is stored only in the MT, so in principle, no special measures are needed. After the recovery of radio section communication, the MT can immediately transmit the uplink data.

### *C. Virtual Mosaic Macrocell*

In this study, by performing two types of synchronization preparations in advance in neighboring cells that could become the TBS, it becomes possible for the MT to make an HO request towards the TBS. The realization of synchronization preparation on the control plane is not just a matter of assigning a numerical RAP to the MT; it requires scheduling of the air interface to ensure that the RAP can actually be used and reserving radio section communication. On the other hand, using the broadcasting feature of PON, downlink data multicasting can be performed simply by providing buffers at each BS, eliminating the need to transfer residual data from the SBS to the TBS via the Xn interface or UPF. To achieve this, it is necessary to have a system for transferring and managing the downlink data received by the BS to the buffer, as well as semiconductor memory to construct the buffer. Considering the situation where the former prepares extra resources for ToHO, which are finite resources like radio waves, while the latter does not, it seems that the former's preparations should be made in as narrow a range as possible, and the latter can be implemented in as wide a range as possible within the limits of computational resources such as buffer capacity and buffer management.

Therefore, the two ground network support methods proposed for ToHO in this study seem rational in the following three-tier combination model:

- 1st tier BSs: Neighboring BSs of the SBS. Sending CFRA RAP to the MT and holding downlink data.
- 2nd tier BSs: Neighboring BSs of the 1st tier BSs. Holding downlink data without RAP preparations.
- 3rd tier BSs: Neighboring BSs of the 2nd tier BSs. Neither RAP nor downlink data, but prepared for capturing HO-failed MTs.

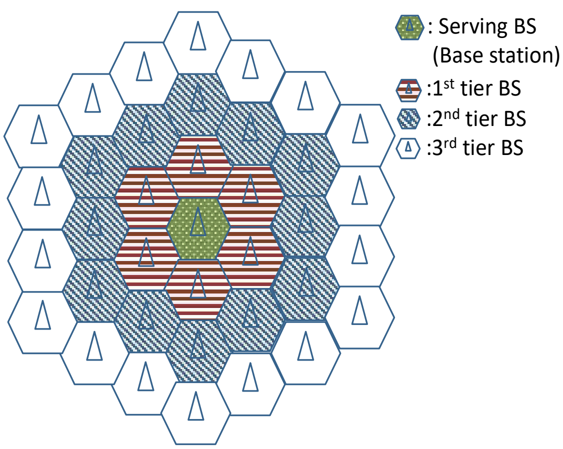


Fig. 2. The example of geographical arrangement of three tier types of BSs model.

Figure 2 shows an example of the geographical cell arrangement of a typical three-tier BS group centered on the SBS. Centered on the SBS, the BSs of the cells adjacent to the SBS are the 1st tier BSs, the ones of the cells adjacent to the 1st tier BSs are the 2nd tier BSs, and the ones of the cells adjacent to the 2nd tier BSs are the 3rd tier BSs. This is expected to function as if combining small cells to form a virtual large cell with an area many times that of a small cell. Since each cell uses different radio channels and their readiness for ToHO also varies, this study refers to such a geographical cell arrangement of the three-tier BS group as a "Virtual Mosaic Macrocell."

In the 1st tier BSs, synchronization preparation is made, and downlink data broadcasting is also performed, so the MT can immediately communicate with the TBS using the RAP received in advance, and if the HO procedure is completed while in the area of the TBS, it is a successful HO. Thus, the following advantages are expected from ToHO by these methods:

There is no need for the cells of the SBS and TBS to overlap, and the entire TBS can become the HO section. This makes high-speed HO easier in a large-capacity cell system consisting only of small cells.

The 2nd tier BSs should be the next 1st tier BSs when an MT-initiated HO request is made to the adjacent 1st tier BSs and one of them becomes the TBS. Therefore, it is necessary to prepare the RAP and send it to the MT through the TBS. If there is a temporary delay in completing the HO for some reason, and the transmission of residual downlink data is not completed within the TBS area, the original 2nd tier BS can still hold the residual downlink data and immediately transmit it to the MT without having to transfer it from the SBS in the next ToHO. This is the advantage of preparing the 2nd tier BS. This can be summarized as follows:

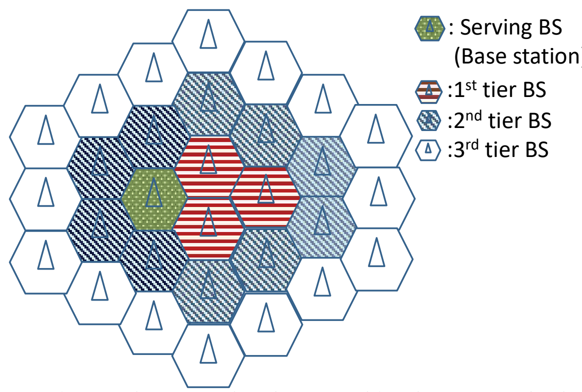


Fig. 3. The example of geographic placement of 3 layers of BS at high-speed movement to the right of the terminal.

In the TBS that becomes the HO section, if the 2nd tier BSs are prepared to become the 1st tier BS, it is possible to maintain radio section communication. It is sufficient if the transfer of residual downlink data is completed while the MT is moving at high speed to the previous 2nd tier BSs.

In cases where there is a bias in the destination of the MT's movement, such as railway tracks or highways, it is also conceivable to deform the Virtual Mosaic Macrocell according to the possibility of movement. Figure 3 shows a case where the 1st tier BS in the upward, downward, and leftward directions are omitted, and additional 1st tier BSs are added in the rightward direction when the MT is observed to be moving at high speed to the right.

On the ground network side, the ACK of the ARQ (Automatic Repeat Request) from the MT is multicast to the cell group to release resources, and if the BS that has successfully completed the synchronization procedure from the MT is considered as the TBS by the SW, then the HO is complete.

## IV. Discussions

### A. Comparison among Related Work

In 5G, Cell Reselection [2] is a terminal-driven cell switching process that does not depend on BS or SW. This occurs when the MT is in idle mode and neither the BS nor SW is monitoring the MT's location or event triggers, and the MT switches from the SBS to the TBS. This takes place in the overlapping area of the SBS and TBS cells, just like a regular HO. Therefore, it is not the same as the HO performed by the MT when active, as we studied here, and it is not a method capable of handling reduced HO sections in a cellular mobile network configuration consisting only of small cells.

Reference [9] proposes a study to reduce the downlink data transfer overhead that occurs during X2/Xn HO in LTE/5G NR by moving the radio section data not to individual BSs but to a central database accessible from a group of BSs, called the "Radio Shared Data Layer (RSDL)." By allowing third-party applications to access this central database, it is possible to understand the situation of the wireless network and contribute to the improvement of network performance. If one tries to broadcast downlink data without using a broadcasting medium like PON, a system configuration similar to RSDL seems to be a candidate.

Reference [10] proposes a connection cell switching method that uses the relative relationship between the MT's movement direction and the BS position of the cell in a heterogeneous wireless environment in the 5G wireless access network, which assumes the use of cells with different frequency bands and radio bandwidths, or wireless systems other than cellular networks, such as wireless LANs, in the multilayer cell configuration for inter-radio system HO. This seems to be a research result that can help in configuring and transforming the Virtual Mosaic Macrocell for cell groups with more complex shapes.

In the IEEE 802.11 series of wireless LANs, clients corresponding to wireless LAN devices can switch access points (APs), which correspond to parent devices. This is called roaming. Roaming is similar to the ToHO proposed in this study, where the device switches APs and performs a connection procedure and authentication called association. IEEE 802.11r [11] allows for Fast BSS Transition (or FT; Fast Transition), which omits some of the client authentication procedures required after association to speed up the process by performing a handshake with the roaming destination AP over the wired Distribution System (DS) and sharing a cryptographic key called PMK (Pairwise Master Key) in advance. In FT, the PKM defined in IEEE 802.11i [12] is split into two, with PKM-R0 shared within the mobility domain and PKM-R1 generated at each AP. The PMK cache function saves the PMK of an AP that has successfully associated once in the device and uses the cached PMK to omit client authentication and speed up reconnection. To implement the 'synchronization preparation' of this study using the mechanism of IEEE 802.11r, it is conceivable to obtain the PMK-R1 of surrounding APs in advance over the DS and cache the PMK.

### B. Resources Required for our Method

When parallel processes use multiple types of resources simultaneously and exclusively, there is a concern for deadlocks and starvation due to the order in which resources are acquired or the method of mutual exclusion, especially in the field of Operating Systems (OS). Therefore, this section will discuss these concerns. In our ToHO preparation at the data place, we multicast downlink data to both 1st tier BSs and 2nd tier BSs, independently store the data in each BS, and release the data after successful transfer to the MT as notified by acknowledgment from the MT in each BS. This means that no mutual exclusion is required for our ToHO preparation at the data plane.

In our ToHO preparation at the data place, MTs will acquire wireless resources from each 1st tier BS as indicated by the RAP for CFRA. However, each resource and RAP for CFRA is independent for each BS, so there is no need for mutual exclusion either. If a BS is out of resources for RAP when requested, it should not wait for the release of the wireless resources that act as the root cause of deadlock but should reject the request. This only leads to a demotion from the 1st tier BS to the 2nd tier one, avoiding deadlock.

In our method, all MTs are involved in acquiring wireless resources from each BS as indicated by the RAP for CFRA, which are the 1st tier BS resources. However, MTs do not actually use all of these resources, so it means unnecessarily reserving temporarily unused resources for MTs in preparation for HO, which is wasteful. While it may seem that stationary MTs are always excessively reserving resources from the 1st tier BS during their stay, for MTs moving at high speeds, each cell transition involves the release of resources from the BS behind and the acquisition of resources from the BS ahead, which becomes the new 1st tier BS. Therefore, the movement speed of the MT does not significantly affect the overall surplus reservation of 1st tier BS resources in the wireless system.

If we model the arrangement of small wireless cells as a dense planar hexagonal pattern, there are six 1st tier BSs surrounding an SBS. Consequently, the resources reserved in excess are six times what is normally required for an HO. Thus, the total amount of resources for the adjacent cells is a fixed number, and no matter how densely the cells are arranged, the total amount of resources excessively reserved by all MTs is at most a linear quantity proportional to the number of MTs. Therefore, it is not conceivable for the system as a whole to diverge by consuming resources in a polynomial amount. Adaptively controlling the candidate for SBS, the 1st tier BSs by direction prediction or geographical locations obtained from the strength of radio waves from the SBS, for example, might improve the problem of unnecessarily reserving temporarily unused resources for MTs in preparation for our ToHO.

### C. Dynamic Adaptation Strategies for Small Cells in High-speed MT Environments

For efficient communication between the BS and the MT, it is not sufficient to merely prepare wireless resources on the BS side through RAR. It is also essential to send a Timing Advance command from the BS to the MT to adjust the MT's transmission timing for the MT's PUCCH/PUSCH (Physical Uplink Shared Channel). Assuming the use of a small cell with a radius of 100 meters, it is advisable to allocate a longer time slot for the initial handover request from the MT and consider the possibility of omitting it. The time taken for light/radio waves to travel 100 meters is approximately 333 nanoseconds, which is a very short duration, about 10000/3 of the LTE frame length of 10 milliseconds. Moreover, if communication persists in the certain SBS, it is possible to communicate with more precise time slots by implementing the Timing Advance command if the MT movement speed is slow.

For an MT traveling at 500 km/h, such as on the Linear Shinkansen, it would take 1.44 seconds to traverse a small cell with a diameter of 200 meters. Meanwhile, the radio interval schedule for LTE with a long Extended Cyclic Prefix is 20 ms, so it is possible to perform about 720 radio interval schedules within the same cell. During this period, it is considered that there is ample opportunity and time to handle the HO on the backbone network side and prepare for the next virtual mosaic macrocell addition while performing normal uplink/downlink communication for the data link.

The frequency variation ratio due to the Doppler effect caused by the MT's movement at 500 km/h is about $4.6\times10^{5}$. In the 1.5 GHz band, this results in a maximum frequency shift of ±7 kHz, which is sufficiently small and manageable at the time of reception.

## V. CONCLUSIONS

In this study, we proposed a terminal-driven HO method. With this method, the MT performs synchronization preparations with surrounding base stations before HO, allowing it to accommodate small cells and high-speed movement. Additionally, by using PON, downlink communication data can be prestored, enabling immediate transmission when switching base stations. By applying this method in a multi-layered manner, we can achieve fast and flexible HO. Furthermore, we proposed a configuration of a Virtual Mosaic Macrocell that covers the SBS by combining control plane synchronization preparation with user plane downlink data broadcasting for HO recovery support. The HO in this study is different from Cell Reselection in 5G or roaming in the IEEE802.11 series of wireless LANs. The 'synchronization preparation' of this study can be realized using the mechanism of IEEE 802.11r's Fast BSS Transition. The HO of this study has the potential to accommodate heterogeneous wireless environments and complex cell shapes.

Future tasks include formalizing the HO procedure for 5G NR, and verifying methods and effects of transforming the Virtual Mosaic Macrocell according to the direction and speed of MT movement. Additionally, it is essential to:

- Develop and implement simulation models to evaluate the performance and reliability of the proposed ToHO method under various network conditions and MT movement patterns.
- Investigate the impact of different synchronization preparation strategies on the overall network efficiency and resource utilization.
- Explore the integration of machine learning algorithms to predict MT movement and optimize the allocation of resources dynamically.
- Conduct real-world experiments to validate the theoretical findings and refine the proposed methods based on empirical data.
- Examine the scalability of the Virtual Mosaic Macrocell approach in larger and more complex network environments, including urban and rural settings.
- Assess the security implications of the proposed ToHO method and develop robust mechanisms to protect against potential threats and vulnerabilities.

By addressing these tasks, we aim to enhance the feasibility and effectiveness of terminal-driven HO in future wireless communication systems.

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## REFERENCES

[1] N. Zohar, "Beyond 5G: Reducing the handover rate for high mobility communications," in Journal of Communications and Networks, 24, 2, 154-165, Apr. 2022. doi: 10.23919/JCN.2022.000001.

[2] A. Haghrah, M. P. Abdollahi, H. Azarhava, and J. M. Niya, "A survey on the handover management in 5G-NR cellular networks: aspects, approaches and challenges," EURASIP J. Wirel. Commun. Netw. 2023, 1 Jul. 2023. doi: 10.1186/s13638-023-02261-4.

[3] 3GPP TS 28.658: "Telecommunication management; Configuration Management (CM); Evolved Universal Terrestrial Radio Access Network (E-UTRAN) network resources Integration Reference Point (IRP): Network Resource Model (NRM)", 2019.

[4] F. Hasegawa *et al*., "High-Speed Train Communications Standardization in 3GPP 5G NR," in IEEE Communications Standards Magazine, 2, 1, 44-52, Mar. 2018. doi: 10.1109/MCOMSTD.2018.1700064.

[5] G. Noh, B. Hui, and I. Kim, "High Speed Train Communications in 5G: Design Elements to Mitigate the Impact of Very High Mobility," in IEEE Wireless Communications, 27, 6, 98-106, Dec. 2020. doi: 10.1109/MWC.001.2000034.

[6] P. T. Dat, A. Kanno, K. Inagaki, F. Rottenberg, N. Yamamoto, and T. Kawanishi, "High-Speed and Uninterrupted Communication for High-Speed Trains by Ultrafast WDM Fiber–Wireless Backhaul System," in Journal of Lightwave Technology, 37, 1, 205-217, 1 Jan.1, 2019. doi: 10.1109/JLT.2018.2885548.

[7] T. Yamada and T. Nishimura, "Covering from Spot to Belt: Virtual Single Cell Network for the 3rd Wireless Access Means," WTC 2014; World Telecommunications Congress 2014, Berlin, Germany, 1-6, 2014.

[8] N. Wang *et al*., "A Field Trial of 50G TDM-PON Based 5G Small Cell Backhaul," 2022 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, 1-3, 2022.

[9] S. K. Tangudu, N. Nanavaty, R. Banda, S. Chandrashekar, R. Krishnamurthy, and S. Bandi, "5G RAN optimizations through radio shared data layer (RSDL)," 2017 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS), Bhubaneswar, India, 1-4, 2017.doi: 10.1109/ANTS.2017.8384091.

[10] A. Kishida, H. Morihiro, T. Asai,Y. Okumura, "A Study of Handover Reduction considering Moving Direction of UE for 5G Multi-layered Networks with Overlay Structure," IEICE (Institute of Electronics, Information and Communication Engineers) Technical Report, 116, 508, MoNA2016-42, 223-228, 2017.

[11] IEEE Std 802.11r-2008, "IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications - Amendment 2: Fast Basic Service Set (BSS) Transition," IEEE, Piscataway, NJ, USA, 2008.

[12] IEEE Std 802.11i-2004, "IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications - Amendment 6: Medium Access Control (MAC) Security Enhancements, " IEEE, Piscataway, NJ, USA, 2004.