Study on Improvement of Handover in Relay Communication Systems using UAV

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***Abstract*— High frequency bands such as millimeter wave and terahertz wave are utilized to enable the use of wide band capable of large data communication. However, the throughput of the uplink tends to deteriorate more than that of the downlink. Therefore, we think that the throughput improvement of the uplink can be carried out by relaying UAV (Unmanned Aerial Vehicle) with the relay communication function. When performing relay communication, it is necessary to switch UAVs for relay communication and base stations for communication by handover (HO) in accordance with the movement of user terminals (UEs). In the conventional method, the system capacity and UE throughput may decrease since HO decision is performed with only RSRP (Reference Signal Received Power). Therefore, we have proposed a new HO method using not only RSRP but also system capacity and UE throughput and show the results of computer simulation.**

Keywords— UAV, Millimeter-wave Communication, Uplink, Hand Over

I. Introduction

Wireless communication using high-frequency bands such as millimeter waves is being implemented in the 5th generation mobile communication system [1, 2]. In the 6th generation mobile communication system, which is considered as the successor, it is expected to become more integrated into our daily lives, economy, and industries, enabling us to experience it more directly. For example, digital twins that collect data from the real world and present it as if it exists in a virtual space, and 3D holograms that project images as if objects are in front of you [3] are expected as use cases. These use cases require large amounts of data, and high-speed, high-capacity transmission is required. Therefore, communication systems using the wide bandwidth of high-frequency bands are necessary.

However, high-frequency band communication, such as millimeter waves, has a characteristic of being highly direct and easily affected by obstacles compared to the conventional microwave communication. This leads to signal attenuation and the creation of dead zones where communication is impossible. Therefore, coverage enhancement in the high frequency band communication is a critical issue.

One solution to reduce dead zones is to densely install base stations to reduce dead zones, but this is not realistic in terms of installation cost and energy consumption. Another solution is to use high-gain antennas and high-power equipment that can increase the radiated power. This is applicable to base stations, but it is difficult to apply to user equipment (UE) considering the portability of UE. Consequently, the uplink tends to have poorer communication performance compared to the downlink, and there is a method to aim for high-speed uplink by providing a relay station (RS) on a drone-like UAV [4]. The optimal position of the UAV changes according to the movement of the UE, and the UAV moves to that position. Therefore, when the distance from the connected UAV increases or when an obstacle occurs, the UE needs to perform a handover (HO) to another UAV or base station.

In the conventional HO method of the cellular systems, whether HO is to be performed or not is determined using RSRP (Reference Signal Received Power) [5]. Recently, the HO methods for the RS assisted cellular systems has been studied [6-9]. In [6], the location of UE and UAV is predicted by using deep learning, and the execution of HO is judged based on the future location of them. In [7], the parameters of HO are adjusted by using RSRP. In [8], the Q-learning algorithm with SINR and BS-UAV distance as parameters is used to determine whether HO is performed or not. In [9], the position of the UE is learned by machine learning using the collected RSRP, and execution of HO is judged according to the position of the UE.

However, using these methods [6-9] for HO decision-making can potentially lead to a decrease in system capacity and UE throughput due to interference from other UEs or RS and resource scheduling after HO execution. Therefore, this paper proposes a novel HO method that considers not only RSRP or location information but also system capacity and UE throughput after HO. In our proposed HO method, there are three steps to decide whether to perform HO. The first step, similar to the conventional method, uses RSRP to determine the trigger for executing HO. In the second step, the system capacity is estimated with and without HO, and HO is executed if the system capacity increases. Finally, the throughput of the UE after HO is estimated, and when the throughput of the UE is lower than a threshold value, HO is additionally performed to another RS where the throughput reaches or exceeds the threshold value.

This paper is organized as follows. In Chapter 2, we describe the system model to be targeted. In Chapter 3, we explain the conventional method, and in Chapter 4, we explain the method proposed in this paper to consider the system capacity and UE throughput. In Chapter 5, we show the results of computer simulations, and in Chapter 6, we summarize this paper.

II. System Model

In this paper, we discuss the uplink communication from UE to RS or base station (BS) in a system composed of one BS, K RS mounted on UAVs, and U UEs, as shown in Figure 1. We assume that the RS is equipped with two antenna arrays, one is for communicating with the UE and another is for communicating with the BS. Each antenna is a uniform rectangular array (URA) with T-by-T antenna element for beamforming and the number of ports is p. UE has an omni-directional antenna.

When the signal transmitted by mth UE is x_m, the received signal y_m received at the BS/RS is expressed as

$$y_m = \sqrt{\frac{P_{tx\_m}}{L_m}} \mathbf{W}_{rx\_m} \mathbf{W}_{bf\_m} \mathbf{H}_m x_m, \tag{1}$$

where P_{tx_m} is the transmission power of mth UE, L_m is the propagation loss of the signal transmitted from mth UE, $\mathbf{W}_{rx\_m}$ is the 1-by-p MMSE (Minimum Mean Square Error) weight matrix for reception, $\mathbf{W}_{bf\_m}$ is the p-by-T^2 reception beamforming weight matrix, and $\mathbf{H}_m$ is the T^2-by-1 propagation channel information between the BS/RS and mth UE. The signal power P_m of the received signal y_m is converted by the following equation as

$$P_m = E[\|y_m\|^2]. \tag{2}$$

Also, a scheduling algorithm is applied to the timing of each UE's transmission. When we assume that sth UE is desired UE and $\boldsymbol{I}_s$ is the set of UEs that are allocated resources and transmitting signals which are interference signals to sth UE at a certain time. The SINR (Signal to Interference plus Noise Ratio) of sth UE, SINRs, is expressed by the following equation.

$$SINR_s = \frac{P_s}{\sum_{i\in \boldsymbol{I}_s} P_{s\_i} + N}, \tag{3}$$

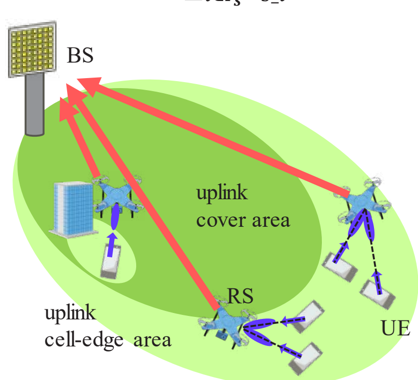

Fig. 1. System model

where N represents the noise power and P_{s_i} is the interference from ith UE to sth UE. Ps_i can be expressed as

$$P_{s\_i} = E\left[\left\|\sqrt{\frac{P_{tx_i}}{L_i}} \mathbf{W}_{rx\_s} \mathbf{W}_{bf\_s} \mathbf{H}_i x_i\right\|^2\right]. \tag{4}$$

At this time, the throughput TPUTs [bps] of the communication from sth UE to BS/RS is calculated by the following equation.

$$TPUT_s = W \log_2(SINR_s + 1), \tag{5}$$

where W is the bandwidth [Hz] used for communication. The system capacity [bps], CA, is defined as the time-averaged value of the sum of the uplink throughputs of UEs included in the set S. CA is expressed as

$$CA = E\left[\sum_{s\in \boldsymbol{S}} TPUT_s\right], \tag{6}$$

where $\boldsymbol{S}$ is the set of all UEs.

In this study, it is assumed that the throughput expressed by equation (5) can be ideally calculated for future time, and the system capacity, which is the sum of the uplink throughputs from each user terminal, can also be ideally calculated.

III. Conventional Method

This section explains the conventional method. The conventional method involves a power-based handover (HO) decision. This decision involves setting parameters for the continuation time dt[ms] and power margin M[dB].

The UE terminal making the HO decision has a received signal power, RSRP, of the reference signal transmitted by the connected BS/RS, denoted as $P_{serving}$, and the RSRP value of the reference signal transmitted by the candidate BS or RS for the HO decision, denoted as P_{target}. The UE detects that HO should be performed when the $P_{serving}$ and P_{target} are satisfied as

$$P_{target} > P_{serving} + M, \tag{7}$$

from the current time t to the past dt time.

If several BS or RS are satisfied the equation (7), the destination of HO is the BS/RS that has the highest P_{target}.

IV. Proposed Method

Generally, it is not known whether the system capacity will improve with a conventional HO using only RSRP. Therefore, we proposed a new HO method. Our proposed method consists of three step HO. First step is making a normal power-based HO, described in Chapter 3. In second stage, a system capacity-based HO is made to consider system capacity. The last step is performed as additional HO to improve the throughput

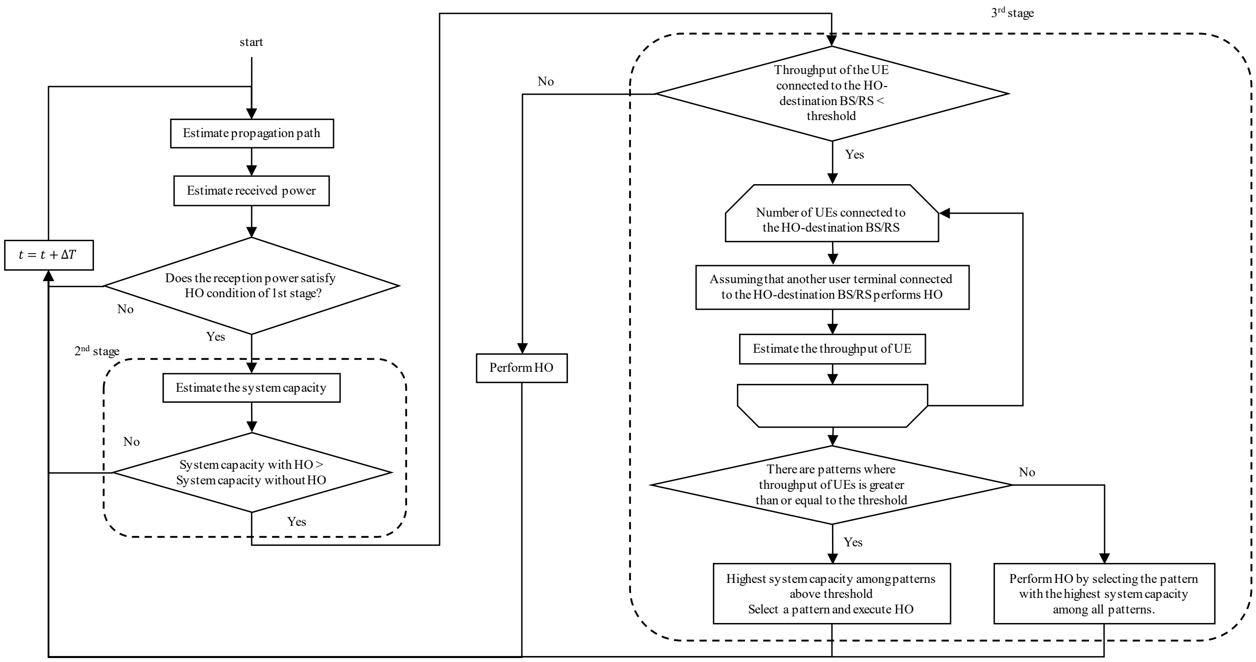

Fig. 2. Flow chart of our proposed HO method

of each UE that extremely degraded in second stage. Figure 2 shows the flow chart of our proposed HO method. Our proposed three-stage HO process is explained below.

(a) First Stage

The first stage HO decision is based on the conventional method described in Chapter 3. In the first stage, HO decision is performed when the equation (6) is satisfied continuously for past *dt* time.

(b) Second Stage

The second stage HO decision is explained. This decision involves setting parameters for the HO processing continuation time T and the system capacity estimation period multiplier α. The HO processing continuation time T is defined as the time from the last time when data communication is possible with the BS/RS before switching the connection to the first time when data communication is possible with the BS/RS after switching. The UE cannot communicate during the HO processing continuation time T, and the throughput becomes 0.

Since future throughput estimation is necessary for making a HO decision, but it is not possible to set the estimation period to infinite future, a system capacity estimation period multiplier α is set, and the length of αT is set as the future system capacity estimation period. In order to make a HO decision considering both the throughput during HO and the throughput after HO completion, the system capacity estimation period needs to be set longer than the HO processing continuation time, so α is a value greater than or equal to 1. Therefore, the system capacity estimation period for making a HO decision is the period from the current time t to t + αT. If the system capacity estimated for the system capacity estimation period when HO is performed exceeds the system capacity when HO is not performed, the second stage HO condition is satisfied. The reason for using system capacity as the decision criterion is that even if the throughput of the UE that performed HO is improved, the system capacity when viewed from the entire system may not improve when HO is performed.

(c) Third Stage

When system capacity is used as a HO criterion, some UEs may experience severely degraded throughput, leading to potential unfairness among UEs. To address this, a method is proposed to enhance the throughput of UEs with extremely low throughput by performing additional HO.

This proposed method operates after the second stage HO determination. First, after deciding to perform an HO, it checks if any UE, among those performing the HO and those originally connected to the target BS/RS, has a throughput below a predefined threshold during the system capacity estimation period. If no such UE exists, the process ends. Otherwise, it proceeds to the next step.

The method then considers an additional HO scenario where a UE originally connected to the HO destination performs a further HO to the BS/RS with the highest Received Signal Strength Indicator (RSRP) among all BS/RS except the currently connected one. For both the original HO and this additional HO pattern, the throughput during the system capacity estimation period and the system capacity are estimated. It then determines if the estimated throughput falls below the threshold for all UEs involved in both HO stages and those connected to the target BS/RS.

Assuming that each UE initially connected to a BS/RS is additionally connected to the BS/RS with the highest RSRP among all BS/RSs excluding the connected BS/RS, estimate the throughput during the system capacity estimation period and calculate the system capacity for each pattern. Additionally, for the UEs that perform HO to other BS/RSs in all stages of our proposed HO method, and for the UEs connected to the target BS/RS of the HO, we determine whether the estimated throughput is below the threshold. We perform the same processing for the pattern where either first and second stage of our proposed method is performed and third stage is not performed, and determine whether the estimated throughput is below the threshold for all terminals in the pattern where no HO is performed.

If there are the patterns in which there is no UE whose throughput is lower than the threshold, the pattern with the largest system capacity among the patterns is selected. If there is no pattern in which there is the throughput of each UE is lower than the threshold, the pattern with the largest system capacity among all patterns is selected. Based on the selected pattern, it is determined whether to perform the first HO and additional HO, and the HO operation is performed accordingly.

V. Simulation Evaluation

The effect of the proposed HO method was evaluated by computer simulation. UEs were placed within the area of the base station randomly, and we assumed in which the RS moved linearly above it, and the uplink throughput and system capacity from the UEs to the RS/BS were evaluated. The simulation conditions are shown in Table 1. This evaluation focused on UE-to-RS/BS communication; RS-to-BS communication was assumed to be lossless. The user scheduling of BS/RS was performed by proportional fairness scheduling, the maximum spatial multiplexing number was 2, and MMSE (Minimum Mean Square Error) equalizer for MIMO (Multi-Input Multi-Output) was assumed. The threshold value for the throughput of the UE used in the proposed method was 15 Mbps, the time T when data communication cannot be performed due to HO was 60 [ms], and the system capacity estimation period ratio α was 8. The antenna spacing was $\lambda/2$, where λ was the wavelength.

Figure 3 shows the computer simulation results of the system capacity in the section where the proposed method was applied. From these results, the averaged system capacity of our proposed method and conventional method is 2144.6 Mbps and 1951 Mbps, respectively. We can see that the averaged system capacity of our proposed method is higher by about 9.9% than that of conventional method. Our proposed method can select the HO pattern with the highest system capacity by considering both RSRP and system capacity during the HO decision process. On the other hand, in conventional HO method, HO decision is performed with only RSRP. Therefore, our proposed method can achieve higher system capacity.

Next, we show the computer simulation result with each UE's throughput to evaluate the effectiveness of third stage of our proposed method. Since the probability of occurrence is low in cases where the throughput of UE significantly degrades, such as when the terminal transitions to the third stage of our proposed method, this evaluation focuses only on the performance of cases where such events occur, rather than presenting average characteristics. Table 2 shows the throughput of each UE. The conventional method only considers RSRP. Therefore, it cannot detect UEs whose throughput falls below the threshold. However, our proposed method utilizes system capacity and the UE throughput threshold for HO judgment. Consequently, in the conventional method, the throughput of UE 1 was 10.95 Mbps after performing HO, which was below the threshold, whereas in our proposed method, it improved to 314.52 Mbps, which was above the threshold. This improvement is attributed to our proposed method's ability to estimate the throughput of each UE and select the connection pattern that maximizes system capacity while ensuring that each UE's throughput exceeds the threshold.

VI. Conclusion

In this paper, we proposed a new HO method to improve the system capacity and throughput of UEs with extremely degraded throughput by performing multiple handovers simultaneously in a high-frequency band mobile wireless communication system using a moving relay communication terminal such as a UAV. By computer simulation, we confirmed that our proposed method can improve the system capacity and ensure the fairness of UEs.

Acknowledgments

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TABLE 1. Simulation parameters

Simulation area	200 (m) ×200 (m)
Carrier frequency	28 (GHz)
Band width	400 (MHz)
Subcarrier space	120 (kHz)
Maximum Modulation	256QAM
Simulation duration	3 (s)
No. of UEs	12
No. of RSs	3
Height	UE: 1.5 (m) BS: 10 (m) RS: 30 (m)
No. of antennas	UE: 1x1 BS: 4x4 RS: 4x4
Noise Figure	UE: 9 (dB) RS: 9 (dB) BS: 5 (dB)
Power margin M	0
dt	80 (ms)
T	60 (ms)
α	8
Threshold of UE throughput	15 (Mbps)
Pathloss model	3GPP UMi Street Canyon [6]
Transmit power	UE: 24 (dBm) BS: 30 (dBm) RS: 30 (dBm)

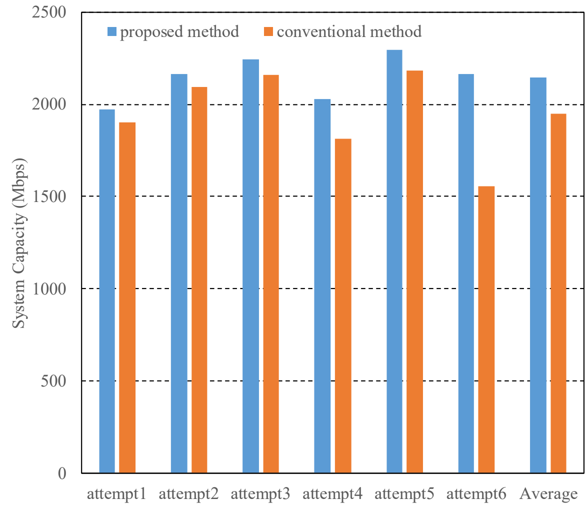

Fig. 3. System capacity comparison between our proposed HO method and conventional HO method

TABLE 2. UE throughput comparison between our proposed HO method and conventional HO method

	Throughput of conventional method (Mbps)	Throughput of proposed method (Mbps)
UE 1	10.917	314.52
UE 2	303.15	395.4
UE 3	446.75	284.57
UE 4	119.41	147.94
UE 5	213.66	241.48
UE 6	95.792	79.333
UE 7	127.44	75.028
UE 8	103.11	88.647
UE 9	111.32	92.182
UE 10	335.14	260.83
UE 11	161.1	106.26
UE 12	130.17	156.82
System Capacity	2157.959	2243.01