A Study on Non-Orthogonal Multiple Access with Stored Device-to-Device Communication in Cellular Systems

1st Masahiro Mizuno
Shinahu University
Nagano, Japan
23w2090d@shinshu-u.ac.jp

2nd Osamu Takyu
Shinahu University
Nagano, Japan
takyu@shinshu-u.ac.jp

***Abstract*—In recent years, wireless communication traffic has exploded. Therefore, non-orthogonal multiple access (NOMA), which expands communication capacity to accommodate the growing wireless communication traffic, is attracting attention. In addition, relay transmission by the cell-center user communication is a promising solution to solve the inequality of communication capacity among terminals (users) in cellular systems. However, there is a problem in that throughput per unit time decreases due to the expansion of communication time required for relaying. In this study, we investigated a method of combining NOMA and Device-to-Device communication (D2D) in the downlink of a cellular system, where D2D uses transmission in the millimeter wave band to reduce the transmission time required for relaying by increasing the capacity. On the other hand, to overcome the large difference in throughput between D2D and D2D communication from a base station to user, the transmission bandwidth of the millimeter wave band used for transmission is maximized by storing data at the users as a relay station. This is called store-and-forward relaying. Computer simulations have confirmed that the proposed system achieves higher throughput when compared to the case where stored relaying is not used. It was also found that there is an appropriate number of information storage at cell-edge users to achieve high throughput.**

***Index Terms*—NOMA, stored D2D, mmwave**

I. INTRODUCTION

In recent years, video distribution services and games have been used on mobile users such as smartphones, and high-speed, large-capacity data communications via wireless communications are in constant use. There is an urgent need to increase throughput to accommodate the growing wireless communication traffic. [1].

To expand the throughput of limited frequency resources, it is important to improve frequency utilization efficiency [2]. Therefore, non-orthogonal multiple access (NOMA) has been attracting attention as a technology that contributes to improved frequency utilization efficiency. With recent improvements in user-side processing power, NOMA's complex signal separation can now be applied by users, and it is attracting attention as a wireless standard for 5th-generation mobile communications (5G), Beyond5G, and 6G.

In a cellular system, users located at the cell edge achieve low and stagnant throughput due to low received power and co-frequency interference from other cells. On the other hand, cell-center users achieve high throughput due to high received power and low same-frequency interference. This difference in throughput between users is a problem of poor fairness. Therefore, methods to improve fairness between cell-center users and cell-edge users using Device-to-Device (D2D) are being considered [4]. Specifically, a user near a cell acquires the information about a cell-edge user and transfers it to the cell-edge user using D2D. In this case, millimeter wave bands are used for D2D to enable broadband transmission of D2D [7]. This enables the base station and cell-edge users to achieve high-quality reception of information from the cell edge with high signal power, and the time required for relaying by users in the cell vicinity can be reduced by the wideband transmission of D2D using the millimeter wave band. As a result, the throughput of cell-edge users can be improved, and fairness can be overcome. However, if the throughput from the base station to the cell-center user is smaller than the D2D throughput, less information can be transferred and the wide bandwidth of D2D cannot be fully utilized.

In this study, we propose a non-orthogonal multiple access with stored relaying in a cellular system. Stored relaying is a relaying method in which the user stores information to be transmitted for a certain period and then transfers the stored data together in a single D2D access. Stored relaying reduces the number of transfers compared to normal relaying, and thus reduces the time required for relaying and contributes to increasing the throughput of cell-edge users.

Furthermore, when NOMA is used for access from a base station to users, the information of other users is demodulated by signal separation during demodulation, so that information on other users can be acquired without additional processing. Therefore, without increasing the complexity of the users, it is possible to acquire information on cell-center users to be used for transmission. Evaluation of computer simulation shows that the throughput expansion of cell-edge users is achieved. In addition, there is a delay in data arrival corresponding to the number of data accumulated. Therefore, we clarified the effect of throughput expansion when the data delay is constrained.

979-8-3503-3094-6/24/$31.00 ©2024 IEEE

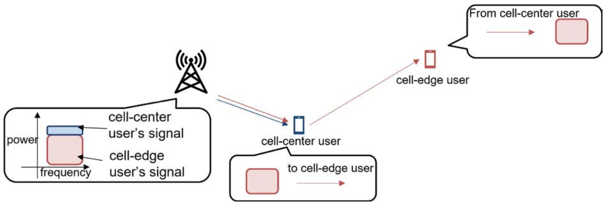

Fig. 1. System model

II. PROPOSED SYSTEM

In this study, we propose a receiver system using D2D based on downlink NOMA with Sequential Interference Cancellation (SIC). The system model is shown in Figure 1.

A. Downlink NOMA with SIC

In downlink NOMA with SIC, the base station transmits multiplexed signals with power differences [2]. In NOMA downlink, the signal power of the cell-edge user is higher than that of the cell-neighbor. As a result, the cell-center user demodulates the multiplexed signal of the cell-edge user with higher signal power to regenerate the interference replica. Then, by subtracting the interference signal from the received signal, the desired signal can be extracted. On the other hand, since the desired signal has more power than the interfering signal at the cell-edge user, the desired signal is demodulated directly. However, the signals of the cell-neighbor users become same-frequency interference, and communication performance is degraded. It is generally known that the decoding order of SIC is better for demodulating signals addressed to users with poor channel conditions first [2]. The throughput of each user in the downlink NOMA with SIC in the 2 users' case is given by the following equation.

$$C_1 = W_1 \log_2 \left(\frac{1 + P_1|h_1|}{N} \right) \tag{1}$$

$$C_2 = W_2 \log_2 \left(\frac{1 + P_2|h_2|}{P_1|h_2| + N} \right) \tag{2}$$

C_1 is the throughput for users with good channel conditions and C_2 is the throughput for users with bad channel conditions. Since good and bad channel conditions are basically determined by the distance from the base station, the channel conditions of the cell-center user are used as the channel conditions are worse than those of cell-edge users. W_1 is the bandwidth of the cell-center user and W_2 is the bandwidth of the cell-edge user. P_1 is the base station transmit power of the signal destined for the cell-center user, and P_2 is the base station transmit power of the signal destined for the cell-edge user. h_1 is the channel matrix between the user near the cell and the base station, and h_2 is the channel matrix between the cell-center user and the base station. N is the noise power.

In actual SIC, interference replica playback may not be possible due to demodulation errors. This condition is referred to as an outage. In the outage case, same frequency interference is generated multiplexed signals. The communication capacity at that time becomes the following equation.

$$C_1 = W_1 \log_2 \left(\frac{1 + P_1|h_1|}{P_2|h_1| + N} \right) \tag{3}$$

$$C_2 = W_2 \log_2 \left(\frac{1 + P_2|h_2|}{P_1|h_2| + N} \right) \tag{4}$$

When an outage occurs, C_1 is expected to decrease significantly because the large non-power desired signal power becomes the interference power. To avoid this outage, it is necessary to ensure power balance and noise tolerance among users that determine the same frequency interference. From the latter perspective, the outage is easily avoided in cell-edge users because a high signal power-to-noise ratio can be ensured.

B. Stored Device-to-Device

In this section, we use data transfer by Device-to-Device (D2D) communication. In downlink NOMA, it assumes that cell-center user transfer information to users at the edge of the cell because they can obtain high received power. The millimeter wave band is assumed to be the most suitable for the D2D communication. Millimeter wave band can be transmitted with higher throughput than microwave band. As a result, if the user responsible for relaying transfers data sequentially, the transmission capacity available for transmission in D2D cannot be fully used. Therefore, we consider stored relaying. This is a relaying method in which data to be relayed by cell-center user is accumulated to a certain degree and transmitted to cell-edge users in a single transmission. If the D2D transmission bandwidth is large compared to the transmission bandwidth from the base station to the users, the transmission bandwidth between users can be used to the maximum extent. In addition, the number of radio accesses during transmission is reduced, leading to a reduction in the time required for transmission. The throughput at the cell-edge user is defined by the following equation.

$$C = \frac{\alpha}{\alpha + 1} \left(W_{BSUE} \log_2 \left(1 + SINR_{BSUE} \right) \right) \tag{5}$$

$$C_{BSUE} = W_{BSUE} \log_2 (1 + SINR_{BSUE}) \tag{6}$$

$$C_{UEUE} = W_{UEUE} \log_2 (1 + SINR_{UEUE}) \tag{7}$$

$$\alpha = \left\lfloor \frac{C_{UEUE}}{C_{BSUE}} \right\rfloor \tag{8}$$

Where C_{BSUE} is the throughput between the base station and the cell-center user, and C_{UEUE} is the throughput between the cell-center user and the cell-edge user. W_{BSUE} is the bandwidth between the base station and the cell-center user, and W_{UEUE} is the bandwidth between the cell-center user and the cell-edge user. $SINR_{BSUE}$ is the SINR between the base station and the cell-center user, and $SINR_{UEUE}$ is the SINR between the cell-center user and the cell-edge user. Here, α is set as the value accumulated to the maximum value that does

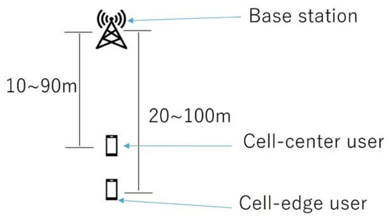

Fig. 2. Simulation environment

not exceed the transmission bandwidth of millimeter wave, assuming that the other user's information notified from the base station to the relay users is transmitted in one millimeter wave access.

Thus, as the transmission capacity C_{UEUE} between D2D expands, the information capacity that can be stored expands, and $alpha$, which indicates the number of storages, expands. Therefore, since many information can be transferred with a single access, the communication capacity of the cell-edge user shown in Equation (5) expands. However, in store-and-forward relaying, the latency increases due to the transfer waiting time caused by storage. If the data arrival time is limited, the delay time due to accumulate can be suppressed by setting it to an integer value less than α calculated by the above formula. However, the effective transmission capacity will be reduced because the number of D2D accesses will increase.

C. Access Method of the Proposed System

In the proposed system, cell-center users communicate directly with the base station, and cell-edge users do not communicate directly with the base station but communicate only with the cell-center users. In D2D, the cell-center users take advantage of the fact that the cell-center users regenerates signals destined for the cell-edge user, and the cell-center users forwards only the regenerated signals to the cell-edge user. Exceptionally, when an outage occurs, direct communication with the base station is performed because the user near the cell cannot regenerate the signal for the cell-edge user.

III. SIMULATION

The environment for the simulation is shown in Figure 2. The number of base stations is 1 and the number of users is 2, and the users and base stations are placed on a straight line. In this environment, cell-center user is considered as cell-center users, and users far from the base station are considered as cell-edge users, and simulation is performed to receive the data using the proposed system. The users are placed at any two of the ten points at distances of 10, 20, 30, . . . , 100m from the base station. In this simulation, the power ratio of the base station transmit power per user is set to 1:1 to simplify the analysis.

A. Shadowing Effect

The millimeter wave shadowing model used was the model in Ref [6]. In this paper, millimeter wave is transmitted and received by placing transmitting and receiving antennas at both ends of a busy boulevard, and the received power is observed and recognized as shadowing when it falls below a certain threshold value. Figure 3 shows the transition diagram between unshaded and shaded states. In Figure 3, P_{shad} is the probability of transition from the unshaded state to the shaded state. P_{unshad} is the probability of transitioning from the shadowed state to the unshaded state.

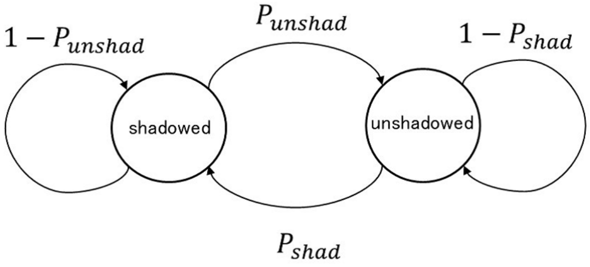

Fig. 3. Transition diagram of unshadowed and shadowed states

TABLE I
SIMULATION PARAMETERS

parameter	value
BS transmission power	40dBm
BS frequency	3GHz
BS bandwidth	10MHz
number of BS antenna	2
UE transmission power	24dBm
UE frequency	44.45GHz
UE bandwidth	100MHz
number of UE antenna	1

Probability-based state transitions are incorporated into the simulation using the transition probabilities and average decays obtained from the experimental results of this paper.

B. Simulation Parameters

The simulation parameters are shown in Table I below. The base station and user transmit power were taken from Ref [2]. The path loss model and cell-center user frequency were taken from Ref [5].

IV. SIMULATION RESULTS

A. Comparison of NOMA and Proposed System

A comparison of the NOMA-only system and the proposed system is made using the results when the distance between the base station and the cell-center user is 50 m and the distance between the base station and the cell-edge user is 60 m. We chose this environment for the comparison between the NOMA-only system and the proposed system for two reasons: first, it would be impractical if the distance between base stations and users were too close or too far; second, the communication between cell-center users and cell-edge users uses millimeter waves, so a large user-to-user distance may not be appropriate. The second reason is that the shadowing model adopted in this study may not be appropriate if the distance between users is too large because the communication

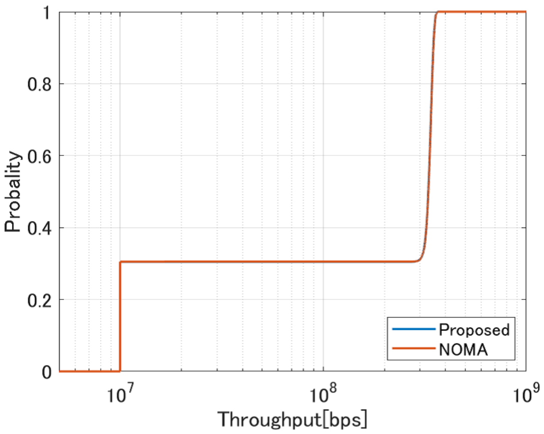

Fig. 4. CDF of throughput of cell-center user

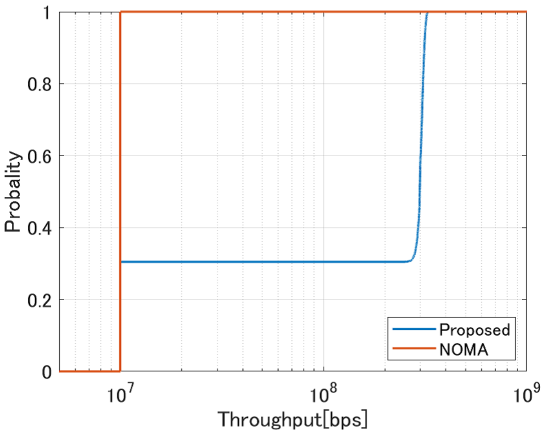

Fig. 5. CDF of cell-edge user throughput

between cell-edge users and cell-edge users uses millimeter waves. Simulation results for cell-center users in the NOMA-only system and the proposed system are shown in Figure 4. Simulation results for cell-edge users are shown in Figure 5. The vertical axis of the figure is the cumulative distribution function (CDF). Figure 4 shows that the conventional method (NOMA) and the proposed method (NOMA and D2D) yield the same results for cell-center users. The difference between NOMA and the proposed method is the presence or absence of D2D, and since cell-edge users do not use D2D, there is no difference in the characteristics. It is assumed that the access between the base station and the cell-center users and the D2D between the cell-center users and the cell-edge users are on different frequencies and that they are independently accessible. Figure 5 shows that the proposed system tends to have higher throughput for cell-edge users; the 50% point values for the NOMA-only system and the proposed system are approximately 1.0×10^7[bps] and 3.0×10^8[bps], respectively. This improvement is attributed to the following reasons. First, since the power ratio of the base station transmit power per user is set to 1:1, when the transmit power is constant, the signal power of other users accounts for half of the total power, resulting in a significant decrease in the desired power for cell-edge users who do not perform SIC in NOMA. On the other hand, in the proposed system, cell-edge users transmit only interference-regenerated signals, so cell-edge users receive signals with no interference power. Therefore, the proposed system is considered to have improved performance compared to the proposed system and the NOMA-only system.

B. Relationship Between the Number of Accumulations and Throughput in the Proposed System

Figure 6 below shows a scatter diagram of the relationship between the number of accumulations and throughput for each of the 45 configurations created by selecting 2 user locations from 10 locations. Figure 6 shows that high throughput is easily achieved when the number of storages is 5, 6, or 7, while throughput tends to be low when the number of storages is larger than that. This result indicates that there is an appropriate number of accumulations that can easily achieve high throughput. This is directly related to the variation in D2D throughput from received signal power variation due to shielding effects in the millimeter wave band. Hence, when D2D throughput is low and stagnant, the number of accumulations is reduced and adaptively transmitted.

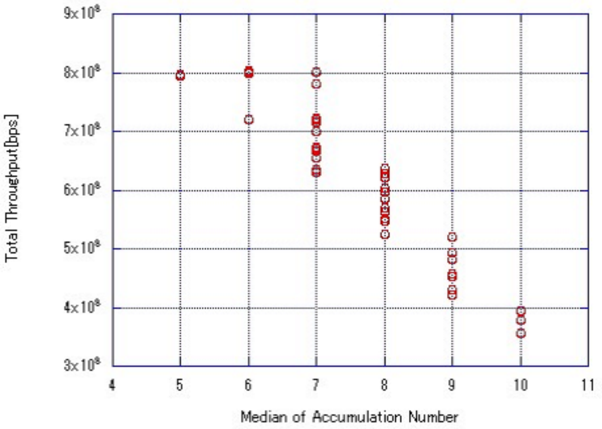

Fig. 6. Relationship between median number of accumulations and throughput

C. Delay Control

Figure 7 shows the relationship between delay and throughput for each of the 45 possible placements created by selecting 2 users from 10 locations. Throughput increases logarithmically with the increase in the upper limit of the number of accumulations. Therefore, it is considered that there is a good trade-off between the amount of increase in delay and the amount of increase in throughput when the number of accumulations is low 1-3.

V. SUMMARY

This paper proposes a system that contributes to improving the inequality of wireless communication traffic and the

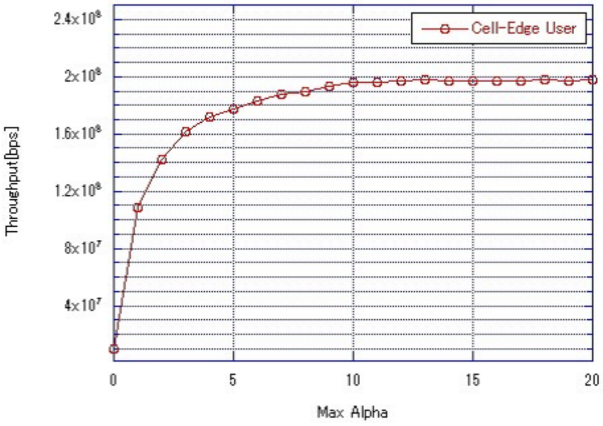

Fig. 7. Relationship between latency and throughput

capacity of each user in a cellular system. The proposed system is a combination of NOMA, D2D, and stored relay, as described in Chapter 2. Computer simulations show that the proposed system achieves higher throughput than the NOMA-only system. It was also found that there is an appropriate number of information to be stored to achieve high throughput. It was also found that the throughput of the proposed system decreases when low-latency communication is attempted.

Future prospects are to study the method of user group formation for reception by the proposed system in an environment with a large number of users.

REFERENCES

[1] Ministry of Internal Affairs and Communications, “Information and communications in japan,” http://www.soumu.go.jp/johotsusintokei/whitepaper/index.html

[2] K. Higuchi, ”Fundamentals of Digital Wireless Communications Focusing on multiple connections and scheduling”, The Institute of Electronics, Information and Communication Engineers, Communication Society.

[3] X. Liu, X. Wang, and Y. Liu, “Power allocation and performance analysis of the collaborative noma assisted relaying systems in 5g,” China Communications, vol. 14, no. 1, pp. 50–60, 2017.

[4] S. M. R. Islam, N. Avazov, O. A. Dobre and K. -s. Kwak, ”Power-Domain Non-Orthogonal Multiple Access (NOMA) in 5G Systems: Potentials and Challenges,” in IEEE Communications Surveys and Tutorials, vol. 19, no. 2, pp. 721-742, Secondquarter 2017, doi: 10.1109/COMST.2016.2621116.

[5] H. Sawada, K Ishizu, “Study on propagation models for advanced application of millimeter and terahertz waves,” https://www.nict.go.jp/publication/shuppan/kihoujournal/houkoku-vol63-2/K2017W-02-03.pdf, vol. 63, 2017. 4

[6] G. R. MacCartney, T. S. Rappaport, and S. Rangan, “Rapid fading due to human blockage in pedestrian crowds at 5g millimeter-wave frequencies,” in GLOBECOM 2017 - 2017 IEEE Global Communications Conference, 2017, pp. 1–7. DOI: 10.1109/GLOCOM.2017. 8254900.

[7] A. Abdelreheem, O. A. Omer, H. Esmaiel and U. S. Mohamed, ”Deep Learning-Based Relay Selection In D2D Millimeter Wave Communications,” 2019 International Conference on Computer and Information Sciences (ICCIS), Sakaka, Saudi Arabia, 2019, pp. 1-5, doi: 10.1109/ICCISci.2019.8716458.

[8] M. Mizuno and O. Takyu, ”[Short Paper] A Study on Non-Orthogonal Multipoint Access with Store-and-Forward Relaying in Cellular Systems”, IEICE Technical Report, vol. 123, no. 19, SR2023-9, pp. 50-54, 2023.