Cooperative Beam Selection based on Fingerprint Database using User Types in Unmanned Aerial Vehicle Supported Systems

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***Abstract*— Unmanned aerial vehicles (UAVs) are attracting attention in the New Radio (NR) system due to their high altitude and mobility features, but high altitude UAVs can be greatly affected by interference between different cells with high line-of-sight (LOS) probabilities. Therefore, in this paper, we propose an algorithm to select the optimal beam to reduce the effect of interference and maximize the transmission efficiency. The proposed algorithm is divided into a process of constructing a user position-based fingerprint database that stores the necessary information and a cooperative beam selection process. As a performance analysis indicator, the Signal-to-Interference-plus-Noise Ratio Cumulative Distribution Function (SINR CDF) was used.**

Keywords— cellular-connected system; cumulative distribution function; coordinated beam selection; fingerprint database; signal-to-interference-plus-noise ratio; unmanned aerial vehicle.

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) are attracting attention in the new radio (NR) system due to their high altitude and mobility characteristics. Recently, UAVs are being utilized in various situations due to their characteristics of flexibility and mobility [1]. However, high altitude UAVs can be greatly affected by interference between different cells with high line-of-sight (LOS) probabilities. Accordingly, in order to reduce the influence of interference, a beam selection algorithm to maximize transmission efficiency is being studied. Therefore, in this paper, we propose an algorithm to select the optimal beam for the user type presented in this paper using the fingerprint database according to the user's position in a UAV-enabled cellular cooperative system.

II. SYSTEM MODEL AND CHANNEL MODEL

A. Cellular downlink systems

In this paper, we consider NR downlink systems in which terrestrial-base stations (T-BSs) support terrestrial-user equipment (T-UE) and unmanned aerial vehicle-user equipment (UAV-UE) in multi-cell environments [2]. As you can see the system model in Fig. 1, one T-BS is placed in the center of each cell and supports multiple T-UE and UAV-UE [3]-[5].

B. Channel Model

In this paper, a 3GPP-based UAV channel model is applied, and a spatial channel model (SCM) is applied between T-BS and UE [3], [5]. When utilizing the SCM model, channel parameters must be set according to the scenario, and the UMa-AV scenario is considered in this paper. Detailed model descriptions are omitted in this paper as they are provided in the 3GPP bibliography [3], [5].

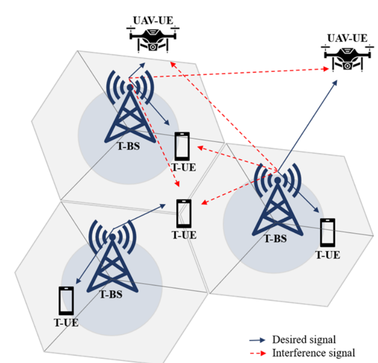

Fig. 1. Cellular downlink system model.

TABLE I.
EXAMPLE OF FINGERPRINT DATABASE.

UAV-UE								T-UE							
cell-center			cell-edge					cell-center			cell-edge				
P_1	…	P_A	P_{A+1}		…	P_{A+n}		p_1	…	p_B	p_{B+1}		…	p_{B+T}	
B_1^{opt}	…	B_A^{opt}	B_{A+1}^{opt}		…	B_{A+n}^{opt}		b_1^{opt}	…	b_B^{opt}	b_{B+1}^{opt}		…	b_{B+T}^{opt}	
			$\tilde{C}_{A+1}^{I\_1}$	$\tilde{B}_{A+1}^{I\_1}$	…	$\tilde{C}_{A+n}^{I\_1}$	$\tilde{B}_{A+n}^{I\_1}$				$\tilde{c}_{B+1}^{I\_1}$	$\tilde{b}_{B+1}^{I\_1}$	…	$\tilde{c}_{B+T}^{I\_1}$	$\tilde{b}_{B+T}^{I\_1}$
			$\tilde{C}_{A+1}^{I\_2}$	$\tilde{B}_{A+1}^{I\_2}$	…	$\tilde{C}_{A+n}^{I\_2}$	$\tilde{B}_{A+n}^{I\_2}$				$\tilde{c}_{B+1}^{I\_2}$	$\tilde{b}_{B+1}^{I\_2}$	…	$\tilde{c}_{B+T}^{I\_2}$	$\tilde{b}_{B+T}^{I\_2}$

III. COORDINATED BEAM SELECTION ALGORITHM USING POSITION-BASED FINGERPRINT DB

In this paper, we propose an algorithm to select the optimal beam while the UE can be less affected by interference from other cells.

A. Position-based fingerprint DB

The algorithm proposed in this paper is largely divided into two stages.

First, the UE is divided into a user on the ground, T-UE, and a user on the air, UAV-UE. A space within the critical radius is classified as cell-center space and an outer space is classified as cell-edge space, based on the critical radius in which the area ratio of the center part and edge part of the cell is 1:1. Therefore, the UE in each space is classified into a cell-center UE and a cell-edge UE, respectively like Fig. 2. In this case, cell-edge UE is greatly affected by interference, so not only optimal beam-related information but also interference-related information is stored when constructing a fingerprint database. An example of a fingerprint database is shown in Table I.

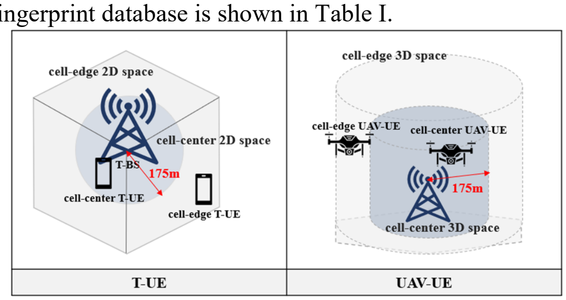

Fig. 2. Classification criteria for UE type.

Table I shows an example of a fingerprint database in one cell. In the case of T-UE, p_b $(b = 1, 2, \dots, B, B+1, \dots, B+T)$ represents the position of the T-UE, and b_b^{opt} $(b = 1, 2, \dots, B, B+1, \dots, B+T)$ represents the optimal beam ID at the T-UE's position. In the case highly affected by interference, as will be discussed in detail in the next section, information about interference is exchanged using the intra-joint transmission method. Accordingly, $\tilde{c}_b^{I\_1}$ $(b = 1, 2, \dots, B, B+1, \dots, B+T)$ and $\tilde{b}_b^{I\_1}$ $(b = 1, 2, \dots, B, B+1, \dots, B+T)$ represent the strongest interference cell ID and the corresponding interference beam ID. $\tilde{c}_b^{I\_2}$ $(b = 1, 2, \dots, B, B+1, \dots, B+T)$ and $\tilde{b}_b^{I\_2}$ $(b = 1, 2, \dots, B, B+1, \dots, B+T)$ represent the ID of the second strongest interference cell ID and the corresponding interference beam ID. The fingerprint of the UAV-UE is also constructed by the same rule, but it differs only in that it is capitalized for distinction.

B. Coordinated beam selection algorithm according to user types

The following is a process of selecting the optimal beam in cooperation to alleviate interference between cells based on the constructed database. In the case of UE, position information can be easily utilized due to the built-in high accuracy of Global Positioning System (GPS). Then, the T-BS matches the received position information of the UE against the position information measured in the fingerprint database.

When the matching process is completed, a fingerprint database corresponding to the position is determined, and the serving cell ID and the optimal beam ID stored in the database can be utilized. In addition, in the case of cell-edge UEs that are greatly affected by interference, the joint transmission method of exchanging interference-related information is used to improve performance, which is referred to as the 'Coop. method' in this paper. The SINR when the Coop. method is applied is as shown in Eq. (1), and the SINR without the Coop. method is as shown in Eq. (2).

$$SINR_{Coop.} = \frac{\sum_{t\in T} 10^{\frac{\xi_t}{10}}}{\left(\sum_{i\in S} 10^{\frac{\xi_i}{10}}\right) - \sum_{t\in T} 10^{\frac{\xi_t}{10}} + N_0} \quad (1)$$

$$SINR_{non-Coop.} = \frac{10^{\frac{\xi_t}{10}}}{\left(\sum_{i\in S} 10^{\frac{\xi_i}{10}}\right) - 10^{\frac{\xi_t}{10}} + N_0} \quad (2)$$

IV. SIMULATION RESULTS

A. Simulation setup

We considered the NR downlink system in which one T-BS located within each cell supports multiple UEs, including UAV-UEs and T-UEs by using system-level simulation. The detailed simulation environment was designed by referring to [2].

B. *Performance analysis*

Fig. 3 shows the simulation results conducted to determine the degree to which interference is affected by the ratio of cell-center UE and cell-edge UE before applying the proposed algorithm. Table II shows the number of UEs for each sector used according to each Graph. It shows that the number of UEs located in the cell-edge region decreases from Graph 1 to Graph 3. As the cell-edge region is more affected by interference than the cell-center region, it was confirmed that Graph 1 showed worse performance than Graph 3.

TABLE II. THE NUMBER OF UES PER SECTOR USED IN FIG. 3.

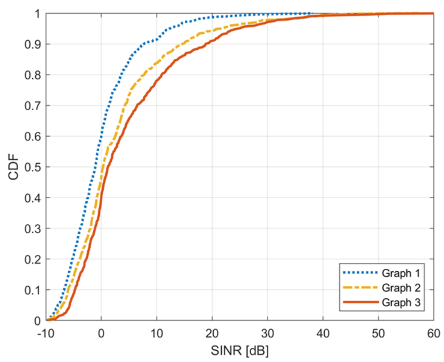

Fig. 3. SINR CDF according to the ratio of center UE and edge UE.

	T-UE		UAV-UE	
	cell-center	cell-edge	cell-center	cell-edge
Graph 1	4	12	4	12
Graph 2	8	8	8	8
Graph 3	12	4	12	4

Fig. 4 shows the simulation results conducted to determine the degree to which interference is affected by the number of UAV-UE before applying the proposed algorithm. The number of UEs for each sector used according to each Graph is shown in Table III. Looking at the Table III, it can be seen that the number of UAV-UEs decreases from Graph 1 to Graph 3. It was confirmed that Graph 1 showed worse performance than Graph 3 because UAV-UE has a higher LOS probability as the altitude increases and is greatly affected by interference.

TABLE III. THE NUMBER OF UES PER SECTOR USED IN FIG. 4.

	T-UE		UAV-UE	
	cell-center	cell-edge	cell-center	cell-edge
Graph 1	8	8	8	8
Graph 2	12	12	4	4
Graph 3	16	16	0	0

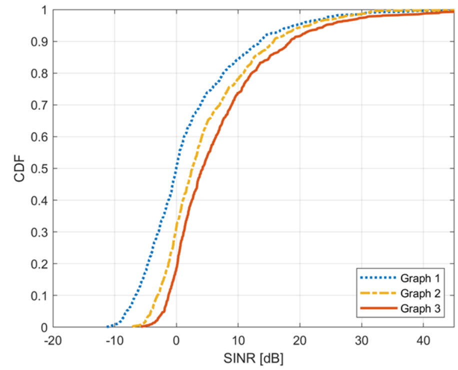

Fig. 4. SINR CDF by number of UAV-UEs.

V. CONCLUSIONS

This paper proposes a cooperative beam selection algorithm method using a position-based fingerprint database in a UAV-enabled cellular cooperative system. In practice, system-level simulations were used to confirm the effect of interference on UAV-UE and cell-edge UE before applying the proposed algorithm. In future studies, we plan to check the performance improvement when applying the proposed algorithm in various scenarios.

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