

Optimization of Feasible Discrete Positions for Circular-Track 6DMA Systems

Jachyeok Kim^a, Seungseok Sin^a, Insik Cho^a, Taehong Kim^a, Huaping Liu^b, Sangmi Moon^c, and Intae Hwang^d

^aDept. of Intelligent Electronics and Computer Engineering, Chonnam National University, Gwangju, South Korea

^bOregon State University, United States of America

^cDept. of IT and Communication Convergence Engineering, Kunsan National University, Kunsan, South Korea

^dSchool of Electronics and Computer Engineering and Department of Intelligent Electronics and Computer Engineering, Chonnam National University, Gwangju, South Korea

kjhyeok5369@naver.com, ssskit7@naver.com, dr-cho@jnu.ac.kr, cute0571@jnu.ac.kr, huaping.liu@oregonstate.edu, moonsm@kunsan.ac.kr, and hit@jnu.ac.kr

Abstract— This study proposes a method for discrete position and rotation optimization applicable to a circular-track-based flexible-sector six-dimensional movable antenna (6DMA) system to improve system performance in environments with non-uniform user distributions. Conventional base stations employing fixed-position antennas, with fixed orientations, possess limited capability to adapt to changes in user distribution. To address this issue, candidate positions satisfying placement constraints are generated in advance on the circular track, and an optimization method is proposed to determine the optimal combination of discrete position and rotation candidates. The proposed method reduces computational complexity while effectively reflecting sector coverage flexibility and antenna orientation adaptability according to user distribution by transforming the continuous search space into a discrete optimization problem. Simulation results obtained demonstrate that the proposed method outperforms conventional fixed-sector schemes and existing flexible-sector schemes.

Keywords– Circular track, Discrete position and rotation optimization, Feasible discrete position generation, Flexible sector, Six-dimensional movable antenna.

I. INTRODUCTION

In next-generation wireless communication systems, the importance of communication technologies capable of flexibly adapting to non-uniform user distributions and complex channel environments is increasing, as requirements such as massive connectivity, ultra-reliability, and low latency are being increasingly emphasized. Accordingly, various technologies, including multiple-input multiple-output (MIMO) [1], [2], reconfigurable intelligent surfaces (RIS) [3], [4], and integrated sensing and communication (ISAC) [5]–[7], are being actively investigated. However, conventional base stations (BSs) that employ fixed-position antennas (FPAs), with fixed orientations, have limitations in proactively adapting to dynamic user distributions and channel conditions [8].

In this study, we propose a discrete position and rotation optimization problem for a circular-track-based flexible-sector 6DMA systems. Its structure allows multiple antenna surfaces to be placed on and rotated along a circular track, thereby enabling sector boundaries and antenna resources to be easily adjusted according to user distributions [10], [11].

II. SYSTEM AND CHANNEL MODEL

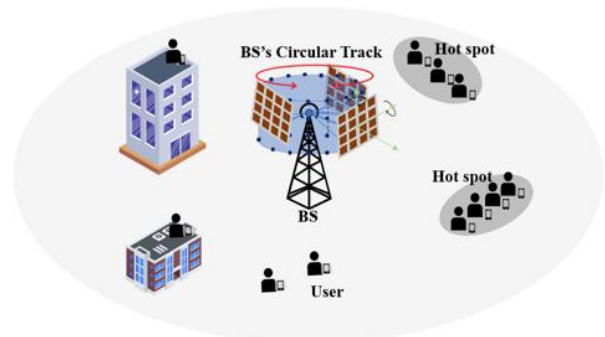


Fig. 1. System model combining the proposed 6DMA BS architecture.

In this study, we adopt the circular-track-based flexible-sector 6DMA BS structure and user distribution reported in [12] and extend the conventional top-view two-dimensional model to a three-dimensional space. Figure 1 depicts that the system consists of one BS and multiple users.

We assume a geometric line-of-sight (LoS) channel that varies based on the variation in the circular-track rotation and the discrete position and rotation of the antenna surfaces according to the structure of the sectorized downlink system reported in [12] and the approach for 6DMA channel modeling reported in [13]. To this end, we define the position and rotation vectors of all the antenna surfaces as

$$\mathbf{q} = [\mathbf{q}_1^T, \mathbf{q}_2^T, \dots, \mathbf{q}_S^T]^T \in \mathbb{R}^{3S \times 1}, \quad (1)$$

$$\mathbf{u} = [\mathbf{u}_1^T, \mathbf{u}_2^T, \dots, \mathbf{u}_S^T]^T \in \mathbb{R}^{3S \times 1}. \quad (2)$$

Moreover, orthogonal multiple access (OMA) is assumed for downlink transmission. The corresponding performance metric is defined as the sum rate [bps/Hz]. To this end, let $\mathcal{K}_s(r)$ denote the set of users belonging to the s -th sector at rotation state r . In addition, let $p_{s,k}$ denote the average transmit power allocated by the s -th sector to user k and σ^2 denote the noise power. Then, achievable rate for user k , and system sum rate are given by

$$R_{s,k}(r, \mathbf{q}_s, \mathbf{u}_s) = \frac{1}{|\mathcal{K}_s(r)|} \log_2 \left(1 + \frac{p_{s,k} G_{s,k}(r, \mathbf{q}_s, \mathbf{u}_s) |\mathcal{K}_s(r)|}{\sigma^2} \right), \quad (3)$$

¹This work was supported by the Institute of Information & Communications Technology Planning & Evaluation (IITP)-Innovative Human Resource Development for Local Intellectualization program grant funded by the Korea government (MSIT: Ministry of Science and ICT) (IITP-2026-RS-2022-00156287). "This research was supported by the Ministry of Science and ICT (MSIT), Korea, under the ICT Challenge and Advanced Network of HRD (ICAN) support program supervised by the Institute for Information & Communications Technology Planning & Evaluation (IITP) (IITP-2026-RS-2022-00156385). "This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT: Ministry of Science and ICT) (RS-2024-00333826). "This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (RS-2026-25476685). "This work was supported by the Institute of Information & Communications Technology Planning & Evaluation (IITP)-ICT Challenge and Advanced Network of HRD (ICAN) grant funded by the Korea government (Ministry of Science and ICT) (IITP-2026-RS-2024-00436837)."

$$R_{sys}(r, \mathbf{q}, \mathbf{u}) = \sum_{s=1}^S \sum_{k=1}^{|\mathcal{K}_s(r)|} R_{s,k}(r, \mathbf{q}_s, \mathbf{u}_s). \quad (4)$$

III. PROPOSED ALGORITHM

A. Circular-track-based rotation optimization

In this section, we determine the optimal value of the discrete rotation index of the circular track that maximizes the system sum rate. The set of bins covered by each sector varies with variations in the rotation index, and the user distribution across sectors also varies accordingly. Let the circular-track rotation index be $r = 0, 1, \dots, N_{CT} - 1$. For a given rotation state, r , bin set $\mathcal{C}_s(r)$ covered by sector s and the corresponding number of users $|\mathcal{K}_s(r)|$ are determined. At the optimization stage of the circular-track rotation, we assume that the discrete position and discrete rotation of the antenna surface of each sector have not been thoroughly optimized thus far. That is, the s -th antenna surface is assumed to be placed at reference position $\mathbf{q}_s^c(r)$ corresponding to the center of the sector under rotation state r and to have reference rotation state $\mathbf{u}_s^c(r)$ aligned toward the sector-center direction. Accordingly, the power gain of the reference channel for user k at rotation state r is defined as

$$G_{s,k}^c(r) = \|\mathbf{h}_{s,k}(\mathbf{q}_s^c(r), \mathbf{u}_s^c(r))\|_2^2. \quad (5)$$

Subsequently, the reference achievable rate of the k -th user in the s -th sector at rotation state r is expressed as

$$R_{s,k}^c(r) = \frac{1}{|\mathcal{K}_s(r)|} \log_2 \left(1 + \frac{p_{s,k} G_{s,k}^c(r) |\mathcal{K}_s(r)|}{\sigma^2} \right), \quad k = 1, 2, \dots, |\mathcal{K}_s(r)|. \quad (6)$$

Therefore, the sum rate at rotation state r is defined as

$$R_{CT}(r) = \sum_{s=1}^S \sum_{k=1}^{|\mathcal{K}_s(r)|} R_{s,k}(r). \quad (7)$$

Accordingly, the optimization problem for circular-track rotation is formulated as

$$(P1) \max_r R_{CT}(r), \quad (8a)$$

$$\text{s. t.} \quad r \in 0, 1, \dots, N_{CT} - 1, \quad (8b)$$

B. Generating feasible discrete positions, discrete position and rotation optimization

In this section, we propose a method to generate discrete position candidates that can be selected by the antenna surface within each sector. The main objective of the proposed candidate generation is to construct a feasible set of discrete positions, in which all candidate positions satisfy the minimum spacing constraint, $d_{\min}$. To this end, we first generate discrete position candidates over a cylindrical search region for each sector and subsequently reflect the circular-track rotation by rigidly rotating the entire candidate set. Let M_{cand} denote the number of discrete position candidates in each sector, and let N_ϕ and N_z denote the number of position candidates along the azimuth and vertical directions, respectively. Then, the following is obtained:

$$M_{cand} = N_\phi N_z. \quad (9)$$

Accordingly, the numbers of azimuth and vertical candidates can be set as equal, which provides similar spatial resolution in the horizontal and vertical directions and prevents the search from being excessively biased toward a specific direction. Therefore, N_ϕ and N_z are expressed as

$$N_\phi = N_z = 2^\kappa = \sqrt{M_{cand}}, \quad \kappa \in \mathbb{Z}_+. \quad (10)$$

The proposed method of candidate generation enables unbiased position exploration over the cylindrical search region by maintaining uniform candidate density in both the horizontal and vertical directions. Let $\tilde{\phi}_{st}$ denote the start angle after applying the circular-track rotation. Then, the start angle of sector s is defined as

$$\phi_s^{st} = \tilde{\phi}_{st} + (s-1)\Phi, \quad s = 1, 2, \dots, S \quad (11)$$

The azimuth interval is defined as $\Delta_\phi = \Phi/N_\phi$. Accordingly, the center angle of the n_ϕ -th azimuth candidate in sector s is expressed as

$$\phi_{s,n_\phi} = \phi_s^{st} + \left(n_\phi - \frac{1}{2}\right)\Delta_\phi. \quad (12)$$

Let the BS center coordinate be $\mathbf{p}_{BS} = [x_{BS}, y_{BS}, z_{BS}]^T \in \mathbb{R}^{3 \times 1}$, radius of the cylindrical search region is ξ_{CT} , and the vertical search range, determined by the number of vertical candidates and the horizontal candidate spacing is denoted as H_{cyl} . Moreover, the key condition that determines whether the proposed candidate set is a feasible set of discrete positions is that the distances between adjacent candidate positions are no smaller than minimum spacing $d_{\min}$. Using $N_\phi = \sqrt{M_{cand}}$ and $\Delta_\phi = \Phi/N_\phi = 2\pi/(SN_\phi)$, the distance between adjacent candidates in the azimuth direction is given by the chord distance on the cylindrical surface, expressed as

$$d_\phi = 2\xi_{CT} \sin\left(\frac{\Delta_\phi}{2}\right) = 2\xi_{CT} \sin\left(\frac{\pi}{S\sqrt{M_{cand}}}\right). \quad (13)$$

In this study, the horizontal adjacent-candidate distance, d_ϕ , is used as the reference length, and H_{cyl} is adaptively set such that the vertical search range increases with the increase in the number of position candidates. Specifically, H_{cyl} is defined as

$$H_{cyl} = d_\phi (\log_2 M_{cand} - 1). \quad (14)$$

Accordingly, the vertical position candidates are defined as

$$z_{n_z} = \begin{cases} z_{BS}, & N_z = 1 \\ z_{BS} - \frac{H_{cyl}}{2} + \frac{n_z-1}{N_z-1} H_{cyl}, & n_z = 1, 2, \dots, N_z \end{cases}. \quad (15)$$

Accordingly, the set of discrete position candidates of sector s is defined as follows:

$$\mathcal{Q}_s = \{\mathbf{q}_{s,n_\phi,n_z} \mid n_\phi = 1, 2, \dots, N_\phi, n_z = 1, 2, \dots, N_z\}. \quad (16)$$

As $N_\phi N_z = M_{cand}$, double index (n_ϕ, n_z) can be re-indexed by a single index, m , as

$$m = (n_\phi - 1)N_z + n_z, \quad m = 1, 2, \dots, M_{cand}. \quad (17)$$

we generated a feasible set of discrete positions, $\mathcal{Q}_s$, for each sector s . To reduce computational complexity, this study applies an AO algorithm that performs position search first and subsequently rotation search. First, at the position optimization stage, the antenna surface in each sector is assumed to maintain a reference rotation state, and the optimal position is selected by comparing the sum rates of different position candidates. Specifically, at each candidate position, $\mathbf{q}_{s,m}$, the reference rotation state of the antenna surface is set such that the surface is aligned with the outward normal direction of the cylindrical sector surface. Let this reference rotation be denoted as $\mathbf{u}_s^{\text{ref}}$. Subsequently, the optimal position and rotation indices of sector s is expressed as

$$i_s^* = \arg \max_{1 \leq m \leq M_{cand}} R_s(r^*, \mathbf{q}_{s,m}, \mathbf{u}_s^{\text{ref}}). \quad (18)$$

$$j_s^* = \arg \max_{1 \leq l \leq L} R_s(r^*, \mathbf{q}_{s,i_s^*}, \mathbf{u}_{s,i_s^*,l}). \quad (19)$$

IV. SIMULATION RESULTS

A. Simulation setup

Herein, Monte Carlo (MC=10⁴) simulations were conducted to verify the performance of the proposed optimization scheme. The BS is located at a height of 20m, and users are assumed to be distributed within a service region with radii ranging between 20–100m. The BS consists of 3 sectors and the system has a total of 30 bins. The carrier frequency is set to 28GHz, and the antenna element spacing is set to $\lambda/2$. The default antenna surface is configured as an 8×8 uniform planar array. The BS antenna surface is assumed to move along a circular track with a radius of 1m, and the number of discrete position candidates for the antenna surface is set to 48. For antenna-surface rotation, the yaw and pitch angles at each candidate position are set to $\{-15^\circ, 0^\circ, 15^\circ\}$. The pathloss exponent is set to $\alpha_0 = 2.5$, and the noise power is set to $\sigma^2 = -114\text{dBm}$. In addition, the antenna radiation pattern follows the data listed in Table 7.3-1 of 3GPP TR 38.901, in which the maximum attenuation is 30 dB and the maximum antenna gain is 8 dBi [14]. To reflect a non-uniform user distribution, Three dense regions of 2, 3, and 2 consecutive bins were randomly generated, with 10 additional users assigned to each region. The user locations were generated according to the distribution model described in [12]. Finally, We examine the sum-rate performances of the proposed and benchmark schemes are compared..

B. Performance evaluation

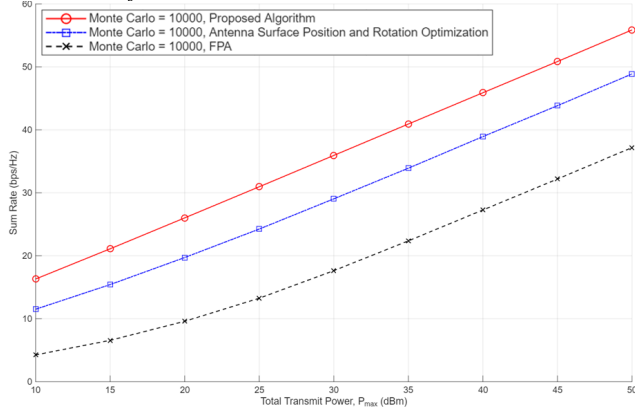


Fig. 2. Comparison of sum rate versus transmit power for the proposed algorithm, antenna surface discrete position and rotation optimization, and fixed-position antenna.

Fig. 2 compares the proposed algorithm, antenna surface position and rotation optimization, and the FPA together. Unlike the previous figures, which individually compare two schemes, Fig. 2 illustrates how the performance improves as the functionalities of the proposed structure are added step by step. Specifically, compared with the FPA, applying antenna-surface position and rotation optimization significantly increases the sum rate, and the highest performance is achieved when BS circular-track rotation is further incorporated. Therefore, Fig. 2 shows that the performance gain of the proposed scheme is not due to a single factor, but is cumulatively obtained

through the sequential combination of antenna-surface position and rotation optimization and BS circular-track rotation

V. CONCLUSION

This paper proposed an algorithm for circular-track rotation and antenna-surface discrete position and rotation optimization to improve system performance under a non-uniform user distribution. Simulation results revealed that the proposed algorithm outperformed the conventional FPA structure and the schemes considering only the circular-track rotation of the BS or only antenna-surface position and rotation optimization. These results confirm that the performance gain originates from the combined effect of BS-level rotational adaptability and antenna-surface-level position and directional adaptability.

REFERENCES

- [1] R. B. Mofidul, A. Imran, M. S. Nazim, and Y. M. Jang, "Hybrid CNN-Swin Transformer denoising network for channel estimation in Optical IRS-assisted indoor MIMO VLC system," *ICT Express*, vol. 11, no. 6, pp. 1047–1053, 2025, doi: 10.1016/j.ict.2025.11.006.
- [2] L. Lu, G. Y. Li, A. L. Swindlehurst, A. Ashikhmin, and R. Zhang, "An overview of massive MIMO: Benefits and challenges," *IEEE J. Sel. Topics Signal Process.*, vol. 8, no. 5, pp. 742–758, Oct. 2014.
- [3] S. Rajak, M. Inbarasan, S. Poongundran, K. V. Babu, S. M. A. Latif, C. Sunil, and D. S. Han, "A novel energy efficient IRS-relay network for ITS with Nakagami-m fading channels," *ICT Express*, vol. 10, no. 3, pp. 507–512, 2024, doi: 10.1016/j.ict.2023.11.005.
- [4] G. Hu, Q. Wu, D. Xu, K. Xu, J. Si, Y. Cai, and N. Al-Dhahir, "Intelligent reflecting surface-aided wireless communication with movable elements," *IEEE Wireless Commun. Lett.*, vol. 13, no. 4, pp. 1173–1177, Apr. 2024.
- [5] H. Qin, W. Chen, Q. Wu, Z. Zhang, Z. Li, and N. Cheng, "Cramer-rao bound minimization for movable antenna-assisted multiuser integrated sensing and communications," *IEEE Wireless Commun. Lett.*, vol. 13, no. 12, pp. 3404–3408, Dec. 2024.
- [6] W. Lyu, S. Yang, Y. Xiu, Z. Zhang, C. Assi, and C. Yuen, "Movable antenna enabled integrated sensing and communication," *IEEE Trans. Wireless Commun.*, vol. 24, no. 4, pp. 2862–2875, Apr. 2025.
- [7] Y. Ma, K. Liu, Y. Liu, L. Zhu, and Z. Xiao, "Movable-antenna aided secure transmission for RIS-ISAC systems," *IEEE Trans. Wireless Commun.*, early access, Jun. 2025.
- [8] K.-K. Wong and K.-F. Tong, "Fluid antenna multiple access," *IEEE Trans. Wireless Commun.*, vol. 21, no. 7, pp. 4801–4815, Jul. 2022.
- [9] X. Shao, Q. Jiang, and R. Zhang, "6D movable antenna based on user distribution: Modeling and optimization," *IEEE Trans. Wireless Commun.*, vol. 24, no. 1, pp. 355–370, Jan. 2025.
- [10] X. Shi, X. Shao, and R. Zhang, "Capacity maximization for base station with hybrid fixed and movable antennas," *IEEE Wireless Commun. Lett.*, vol. 13, no. 10, pp. 2877–2881, Oct. 2024.
- [11] X. Shi, X. Shao, B. Zheng, and R. Zhang, "6DMA-aided cell-free massive MIMO communication," *IEEE Wireless Commun. Lett.*, vol. 14, no. 5, pp. 1361–1365, May 2025.
- [12] X. Shi, Y. Li, X. Shao, J. Xu, and R. Zhang, "Throughput maximization for multiuser communications with flexible-sector 6DMA," *arXiv preprint arXiv:2510.10944*, pp. 1–4, Oct. 2025.
- [13] X. Shao, R. Zhang, Q. Jiang, and R. Schober, "6D movable antenna enhanced wireless network via discrete position and rotation optimization," *IEEE J. Sel. Areas Commun.*, vol. 43, no. 3, pp. 674–687, Mar. 2025.
- [14] Document TR 38.901, 3GPP, V19.1.0, pp. 29, Sept. 2025.