Secrecy Rate Improvement Algorithm for Multiple UAV-RISs enabled Systems

Yuna Sim
Deptartment of ICT Convergences System Engineering
Chonnam National University
Gwangju, Republic of Korea
sya8325@naver.com

Seungseok Sin
Deptartment of ICT Convergences System Engineering
Chonnam National University
Gwangju, Republic of Korea
ssskit7@naver.com

Jina Ma
Deptartment of ICT Convergences System Engineering
Chonnam National University
Gwangju, Republic of Korea
jama@kari.re.kr

Kyunam Kim
Alps Electric Korea Co., Ltd.
Gwangju, Republic of Korea
kyunam.kim@kr.alps.com

Huaping Liu
Oregon State University
United States of America
huaping.liu@oregonstate.edu

Jihyung Kim
Spatial Wireless Transmission Research Section
Electronics and Telecommunications Research Institute
Daejeon, Republic of Korea
savant21@etri.re.kr

Sangmi Moon
Department of IT Artificial Intelligence
Korea Nazarene University
Cheonan, Republic of Korea
moonsm@kornu.ac.kr

Intae Hwang
Department of Electronic Engineering and Department of ICT Convergence System Engineering
Chonnam National University
Gwangju, Republic of Korea

***Abstract*—Recently, as data demand has increased due to the rapidly increasing demand for wireless devices and the influence of data traffic, various technologies are being developed to support it. Among them, in the case of millimeter wave (mmWave) frequencies with rich spectra and high data transmission rates, there is a problem of large path loss. As a result, there is a growing interest in unmanned aerial vehicle (UAV) and reconfigurable intelligent surfaces (RIS) that can be reconstructed advantageously to communicate wireless communication environments. Therefore, this paper introduces a UAV-RIS deployment and beamforming vector optimization algorithm considering system efficiency and security performance in a large system consisting of multiple users, eavesdroppers, and a number of UAV-RISs combining UAV and RIS.**

Keywords*—*reconfigurable intelligent surfaces, optimization, secrecy rate, unmanned aerial vehicle.

I. Introduction

With the recent increase in data demand, various technologies are being developed to support it. Among them, millimeter wave (mmWave) frequencies with rich spectra and high data transmission rates are attracting attention, but there is a problem that signals are easily blocked by obstacles due to large path losses [1-2]. To compensate for this, interest in UAV and RIS is growing as a technology that can advantageously reconstruct the wireless communication environment [3-4]. Most RIS studies are being studied focusing on small-scale systems consisting of a single fixed RIS, but this is not suitable for recent large-scale systems with increasing data demand due to low utilization. Therefore, this paper introduces a UAV-RIS deployment and beamforming vector optimization algorithm that considers security performance in a large system consisting of a large number of users and eavesdroppers.

II. System Model

In this paper, we consider a system in which one BS supports multiple ground users, eavesdroppers, and multiple UAV-RISs are deployed, as shown in **Fig. 1**. In the case of UAV-RIS, it is assumed that the path between each object is an LOS path because the higher the altitude, the higher the LOS probability.

In order to cover a large number of users with a small number of UAV-RISs, the user must be properly clustered. In this paper, a number of UAV-RISs, users, and eavesdroppers are represented by a set, $\boldsymbol{L}$, $\boldsymbol{K}$, and $\boldsymbol{E}$ respectively. In this case, the users supported by the $l-th$ UAV-RIS are represented as a set $\boldsymbol{K_l}$. In this case, for the efficiency of the system, the number of users that can be covered in the cluster is limited, K_l^{max}. When the transmission rate for the $k-th$ user in each $l-th$ cluster and the $e-th$ EVE in the $l-th$ cluster is calculated by $R_{l,k}$ and $R_{l,e}$, the secrecy rate is calculated by subtracting $R_{l,e}$ from $R_{l,k}$. For more information, see the reference [4]. At this time, the average security rate, which is a performance indicator, is calculated as the average of these values after obtaining the sum

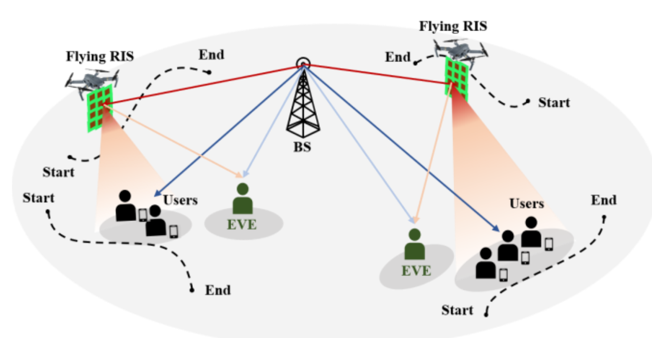

Fig. 1. System model.

of the security rates for all users in the cluster based on each cluster.

III. DNN-BASED ALGORITHM FOR UAV-RISS DEPLOYMENT

The main purpose of the proposed algorithm is to support as many users as possible with a small number of UAV-RISs for high system efficiency, which can be problematic as Equation (1). In this case, $d_{l,k}$ represents the Euclidean distance between the $l-th$ UAV-RIS and the $k-th$ user, and γ_l represents an arbitrary value that can maximize the support range of the second UAV-RIS, which specifies 165 m. q_l shows the location of the $l-th$ UAV-RIS, which should be within the limit of the maximum q_l^{max} and minimum q_l^{min}. $D_{l,cov}^{max}$ represents the radius for determining the clustering range of the UAV-RIS, and is determined according to the altitude of the UAV-RIS.

$$(\mathbf{P1})\ \max_{q,x} \sum_{l=1}^{L} \sum_{k=1}^{K_l} x_{l,k}$$

$$\text{s.t. } d_{l,k}^2 \leq \left(D_{l,cov}^{max}\right)^2 + \gamma_l\left(1 - x_{l,k}\right),$$

$$q_l \in \left[q_l^{min}, q_l^{max}\right],$$

$$x_{l,k} = \{0, 1\},$$

$$K_l \in Z^+, K_l \leq K_l^{max},$$

$$l \in L$$

Since Equation (1) is in the form of Convex, it can be easily solved with CVXPY. However, this method is complex and takes a long time, and is not suitable for large-scale systems that consider multiple users. Accordingly, a DNN-based algorithm is applied [5]. First, it is a step to optimize the problem, create data for training and testing, and then use the data to learn and evaluate the DNN model. To obtain the learning data, we repeatedly solved the problem of Equation (1) using CVXPY for 200 scenarios, and obtained the optimal location of UAV-RISs as a solution. Accordingly, a DNN model with the user position as input and the optimal UAV-RISs position as output was learned. The fully-connected type of DNN model consists of a total of three hidden layers, each of which consists of 200, 80 and 80 neurons. The "sigmoid" function was applied to the hidden layer and the "linear" function was applied to the output layer. For the compilation of the model, the stochastic gradient (SGD) method considering mean square error (MSE) was used.

IV. BEAMFORMING VECTOR OPTIMIZATION ALGORITHM FOR IMPROVING SECURITY RATE PERFORMANCE

In order to maximize the security rate, it is necessary to optimize the transmission beamforming vector and the RIS beamforming vector, which uses an alternative optimization algorithm (AO) that divides it into two incidental problems. First, the successive convex approximation (SCA) algorithm is applied to optimize the transmission beamforming vector, and the minorization-maximization (MM) algorithm is applied to optimize. In addition, in both cases, semi-definite relaxation (SDR) is applied to change the non-convex shape to a convex shape, and in this process, a penalty-based optimization algorithm is applied together to find the optimal solution with a rank of 1. Detailed algorithms are summarized in **Fig. 2** and **Fig. 3**.

Algorithm 1: SCA & Penalty-based algorithm for optimizing transmit beamforming vector

Input: $\varepsilon_1 > 0$, *pen*, Initial Tx beamforming vector (ω^0), Initial flying RIS's amplitude and phase shift matrix ($\boldsymbol{Q}_l^{(0)}$)

(Initial)

Compute $\mathbf{W}^0 = \omega^0(\omega^0)^H$ and q^0.

Optimize $\widetilde{\boldsymbol{W}}_k^0$ by solving problem (*Prob 2*).

(Repeat)

1. If $\left|tr(\widetilde{\boldsymbol{W}}_k^t) - \lambda_{max}(\widetilde{\boldsymbol{W}}_k^t)\right| \leq \varepsilon_1$, algorithm stop and go to step 4. Otherwise, go to step 2.

2. Optimize $\widetilde{\boldsymbol{W}}_k^{t\_2}$ by solving (*Prob 2*) applying penalty based method using $\widetilde{\boldsymbol{W}}_k^t$.

3. If $|\widetilde{\mathrm{W}}_\mathrm{k}^{t_2} - \widetilde{\mathrm{W}}_\mathrm{k}^\mathrm{t}|_F < \varepsilon_1$, set pen = 1 / 2 * pen and go to step 2. Otherwise, set $\widetilde{\mathrm{W}}_\mathrm{k}^\mathrm{t} = \widetilde{\mathrm{W}}_\mathrm{k}^{t\_2}$ and go to step 1.

(Until) $\left|tr(\widetilde{\boldsymbol{W}}_k^t) - \lambda_{max}(\widetilde{\boldsymbol{W}}_k^t)\right| \leq \varepsilon_1$

(Output) 4. $\omega_k = u_{max}(\widetilde{\boldsymbol{W}}_k^t)\sqrt{\lambda_{max}(\widetilde{\boldsymbol{W}}_k^t)}$

(Stable point which satisfies the KKT conditions.)

Fig. 2. BS transmit beamforming vector optimization algorithm.

Algorithm 2: MM & Penalty-based algorithm for flying RIS's amplitude and phase shift matrix

Input: $\varepsilon_2 > 0$, *pen*, Initial flying RIS's amplitude and phase shift matrix ($\boldsymbol{Q}_l^{(0)}$)

(Initial)

Compute $\boldsymbol{V}_l^{(0)}$ using initial $\boldsymbol{Q}_l^{(0)}$.

(Repeat)

1. Calculate $C(\boldsymbol{V}_l^{(t)})$.

2. Optimize $\widetilde{\boldsymbol{V}}_l^{(t)}$by solving (*Prob 3*) using $\boldsymbol{V}_l^{(t)}$.

3. If rank($\widetilde{\boldsymbol{V}}_l^{(t)}$) > 1, recover the rank-1 solution by solving (*Prob 3*) applying penalty based method.

4. Obtain $\widetilde{\boldsymbol{V}}_l^{(t)}$ and compute $C(\widetilde{\boldsymbol{V}}_l^{(t)})$.

5. If $|\ C^{(t+1)}(\boldsymbol{V}_l) - C^{(t)}(\boldsymbol{V}_l)| \leq \varepsilon_3$, algorithm stop. Otherwise, set $\boldsymbol{V}_l^{(t)} = \widetilde{\boldsymbol{V}}_l^{(t)}$ and go to step 1.

(Until) $|\mathrm{tr}(H_{A,l,k}\widetilde{\boldsymbol{V}}_l\ ) - tr(H_{A,l,k}\boldsymbol{V}_l^{(t)})| \leq \varepsilon_2$

(Output) 6. $v_l = \left(u_{max}(\widetilde{\boldsymbol{V}}_l\ )\sqrt{\lambda_{max}(\widetilde{\boldsymbol{V}}_l\ )}[1{:}M]\right)$

(Stable point which satisfies the KKT conditions.)

Fig. 3. RIS beamforming vector optimization algorithm.

V. SIMULATION RESULTS ANALYSIS

Table 1 shows the simulation results comparing the performance of the DNN-based algorithm. In this paper, the case of optimizing the position of RIS using the existing CVXPY was referred to as Conv. OPT. As a result of simulation in three scenarios, it was confirmed that the proposed algorithm deployed RIS faster and with higher accuracy.

TABLE I. DNN-BASED ALGORITHM PERFORMANCE COMPARISON.

Scenarios	Conv. OPT	DNN	Accuracy
$L = 3, K_l = 10$	8.51 s	0.11 s	99.98 %
$L = 3, K_l = 20$	13.98 s	0.11 s	98.89 %
$L = 3, K_l = 30$	14.49 s	0.11 s	95.01%

Fig. 4 is the result of analyzing the security performance of the proposed algorithm when compared according to the RIS type. As a result of comparing performance with the security rate as a performance indicator, it was confirmed that the Active RIS

of the proposed algorithm performs better than the case where passive RIS and RIS were not applied.

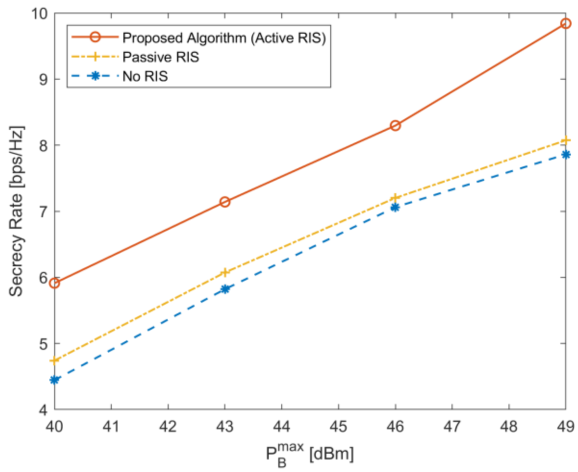

Fig. 4. Secrecy rate performance comparison of proposed algorithm.

VI. CONCLUSION

This paper introduces UAV-RISs deployment and beamforming vector optimization algorithms considering system efficiency and security performance in a large system consisting of multiple users, eavesdroppers, and UAV-RISs combined with UAV and RIS to meet the recently increased demand for wireless devices and data.

Simulation results confirmed that the active RIS of the proposed algorithm performs better than the case using the existing passive RIS and without RIS.

ACKNOWLEDGMENT

"This work was supported by Electronics and Telecommunications Research Institute (ETRI) funded by the Korean government [23ZH1100, Study on 3D Communication Technology for Hyper-Connectivity]." "This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government(MSIT: Ministry of Science and ICT) (2021R1A2C1005058, RS-2023-00220985, and RS-2023-00246381)." "This research was supported by the BK21 Fostering Outstanding Universities for Research (FOUR) Program (5199991714138) funded by the Ministry of Education (MOE, Korea) and National Research Foundation of Korea (NRF). " "This research was supported by the Ministry of Science and ICT (MSIT), Korea, under the Innovative Human Resource Development for Local Intellectualization support program (IITP-2023-RS-2022-00156287) supervised by the Institute for Information & communications Technology Planning & Evaluation (IITP)." "This research was supported by the Ministry of Science and ICT (MSIT), Korea, under the ICT Challenge and Advanced Network of HRD (ICAN) program (IITP-2023-RS-2022-00156385) supervised by the Institute of Information & communications Technology Planning & Evaluation (IITP)."

REFERENCES

[1] S. Moon, H. Kim, Y. You, C. H. Kim and I. Hwang, "Coordinated Millimeter Wave Beam Selection Using Fingerprint for Cellular-Connected Unmanned Aerial Vehicle," KSII Transactions on Internet and Information Systems, vol. 15, no. 5, pp. 1929-1943, 2021.

[2] Z. Qadir, K. N. Le, N. Saeed, and H. S. Munawar, "Towards 6G Internet of Things: Recent advances, use cases, and open challenges, " ICT Express, June 2022, Available online.

[3] F. Nait-Abdesselam, A. Alsharoa, M. Y. Selim, D. Qiao and A. E. Kamal, "Towards enabling unmanned aerial vehicles as a service for heterogeneous applications," in Journal of Communications and Networks, vol. 23, no. 3, pp. 212-221, June 2021.

[4] S. Moon et al., "Multitask learning-based secure transmission for reconfigurable intelligent surface-aided wireless communications, " in ICT Express, vol. 8, no. 3, pp. 334-339, Sep. 2022.

[5] Y. Li, C. Yin, T. Do-Duy, A. Masaracchia and T. Q. Duong, "Aerial Reconfigurable Intelligent Surface-Enabled URLLC UAV Systems," in IEEE Access, vol. 9, pp. 140248-140257, 2021.