Rotator-Aided RIS Beam Stabilization Method in UAV Communications

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Abstract. Unmanned Aerial Vehicle (UAV) air-to-ground communication plays a significant role in the integrated information network. Reconfigurable Intelligent Surface (RIS), a passive antenna array, is particularly well-suited for UAV applications. However, airflow induced UAV wobbling can significantly damage the performance of the RIS enabled beamforming. In this paper, we investigate a robust beamforming method that employs a Rotator-Aided RIS (R-RIS), introducing a novel approach to mitigating disturbances. The design problem is non-convex, prompting the proposal of a heuristic strategy that effectively decouples the original problem. The simulation results validate the effectiveness of the proposed scheme, highlighting its ability to enhance the beam stabilization.

Keywords: UAV communications · RIS · Beamforming

1 Introduction

RIS is a planar metasurface capable of controlling the properties of electromagnetic waves, typically composed of a large array of specially designed passive reflecting elements. Each element can independently modulate the characteristics of the incident signal by applying the required phase shift or tunable amplitude to it [1]. Due to its high energy efficiency and hardware utilization in reshaping the electromagnetic environment, RIS is considered to be one of the most crucial supporting technologies for future 6G networks [2].

UAV, with its high flexibility and low deployment costs, is widely employed in wireless communications [3], such as assisting two-way relaying networks [4].

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Different from terrestrial communications and high altitude platform based communications, systems equipped with low altitude UAVs may benefit from short range Line-of-Sight (LoS) links, potentially resulting in better communication channels. Moreover, such systems generally boast quicker deployment speeds and more flexible reconfigurations [5].

The diversification and complexity of application scenarios in next generation wireless communications presents new challenges for the development of wireless communications. For instance, to meet the demands of mobile communications, both mobility and reliability of the system are forced to adapt to higher standards [6]. Building on the discussions above, the integration of RIS and UAV in wireless communications is a natural progression. Given the numerous uncertainties in the aerial environment, it is worth considering how to address the impacts of UAV jitters. Indeed, a substantial body of research is already based on the combination of RIS and UAV and aimed at tackling the challenges from UAV jittering. Authors in [6] present the UAV's energy consumption model and an algorithm to optimize its trajectory. The work in [4] investigates the effects of jittering UAV on the capacity of UAV assisted communication systems and derives an expression for the system's capacity, taking into account the unique properties of UAV jitters. In [7], an anti-jamming approach is proposed by adjusting the UAV's trajectory. Authors in [8] introduce a strategy designed to reduce energy used in UAV equipped multi-user RIS wireless networks, especially for the challenges posed by UAV jitters and considering the effects of imperfect hardware.

As discussed above, most existing studies focus on adjusting the UAV's position and the RIS's phase shift, potentially increasing system latency. Therefore, inspired by [9], a heuristic approach that installs a mechanical rotator between the UAV and RIS is proposed in this paper, which aims to enhance system performance when the UAV jitters.

Here is the structure of this paper: The first section outlines the background and research significance of RIS and UAV. It reviews existing studies on dealing with UAV jitter based on the integration of the two, identifies their shortcomings and leads into the research content of this paper. In the second section, the system model and signal transmission model are introduced, and the necessary expressions are listed to lay the foundation for the subsequent research. In order to mitigate the effects of UAV jitter on the system and enhance the beam stability, the third section investigates a heuristic method that decouples the problem into two manageable subproblems, determining the optimal azimuth and elevation angles for the R-RIS firstly and configuring the phase shift matrix secondly. The fourth section illustrates the setting parameters and simulation results, which demonstrate the effectiveness of the proposed scheme through comparative performance analyses. The final section provides a conclusion of the entire paper.

Note 1. Lowercase bold letters are used to describe vectors, whereas uppercase bold letters denote matrices. The operation $(x \mod y)$ is defined as the remainder of x divided by y, $\mathbb{E}[\cdot]$ denotes the expectation operation. The superscript

$[\cdot]^{\mathrm{T}}$ signifies the transpose operation and the superscript $[\cdot]^{\mathrm{H}}$ indicates the conjugate transpose operation. The complex normal distribution is represented by $\mathcal{CN}(\mu, \sigma^2)$, where μ and σ^2 stand for the mean and variance, respectively. The floor function is denoted by $\lfloor \cdot \rfloor$ and the absolute value is expressed as $|\cdot|$. Finally, $\|\cdot\|$ symbolizes the l_2 norm and the imaginary unit is defined as $j \triangleq \sqrt{-1}$.

2 System Model

The model of the UAV air-to-ground communication system is introduced in Fig. 1, which includes the process of transmitting and receiving signals. Here considers a down link transmission model in an air disturbance environment where the UAV employs an R-RIS with $M \times N$ reflective elements. The R-RIS, configured as a uniform planar array, is organized on a rectangular grid with gaps of a and b. The center of the R-RIS serves as the origin for the three-dimensional Cartesian coordinate system, and the initial pose of RIS coincides with the $x-y$ plane. Both the Base Station (BS) and the User Equipment (UE) are equipped with a single isotropic antenna. Their positions can be described as $\boldsymbol{p}_{\mathrm{BS}} = [x_{\mathrm{BS}}, y_{\mathrm{BS}}, z_{\mathrm{BS}}]^{\mathrm{T}}$ and $\boldsymbol{p}_{\mathrm{UE}} = [x_{\mathrm{UE}}, y_{\mathrm{UE}}, z_{\mathrm{UE}}]^{\mathrm{T}}$, respectively. Additionally, it is assumed that partial Channel State Information (CSI) is available in advance.

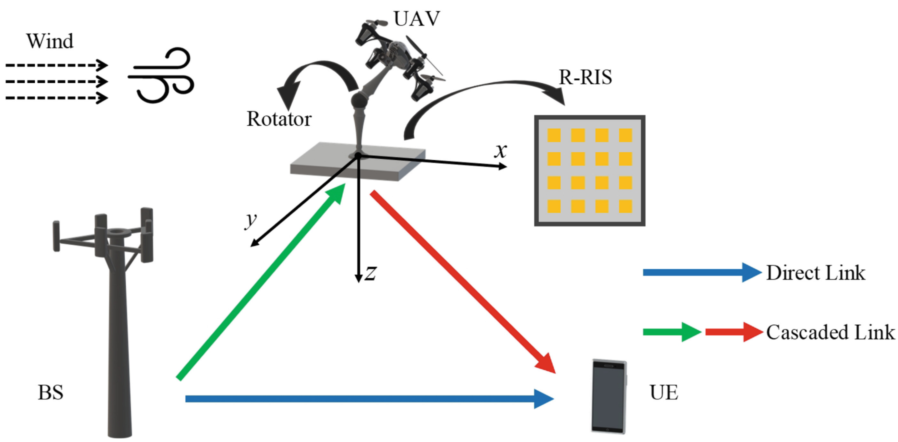

Fig. 1. Transmission model.

The element R-RIS(m, n) denotes the (m, n)-th unit of the R-RIS, the position of which on the $x - y$ plane is

$$\hat{\boldsymbol{p}}_{m,n} = [\omega(m, \alpha, M), \omega(n, b, N), 0]^{\mathrm{T}}, \tag{1}$$

where $\omega(m, \alpha, M) = a(m - 0.5((M + 1) \bmod 2))$, $m \in \omega(M)$ with $\omega(M) = \left\{((M + 1) \bmod 2)) - \left\lfloor \frac{M}{2} \right\rfloor, \ldots, \left\lfloor \frac{M}{2} \right\rfloor \right\}$ [10]. Similarly, we can obtain $\omega(n, b, N)$.

In this paper, the rotator is assumed as a mechanical structure for connecting the UAV and the RIS, allowing the R-RIS to freely rotate beneath the UAV. It is similar to the axis structure of a camera gimbal, which would enable the R-RIS to adjust its orientation in the air. In the environment where the UAV is subject to disturbances from air flow, since the attitude changes of which follow a stochastic process, it is more practical to model and analyze the changes with discrete data block i rather than continuous time. Consequently, the actual position vector of R-RIS(m,n) can be described as

$$\boldsymbol{p}_{m,n}(i) = \boldsymbol{\Gamma}^{\mathrm{T}}(i)\hat{\boldsymbol{p}}_{m,n}, \tag{2}$$

where $\boldsymbol{\Gamma}(i)$ is

$$\boldsymbol{\Gamma}(i) = \begin{bmatrix} \cos(\theta_i^{\mathrm{RIS}}+\theta_i) & -\sin(\theta_i^{\mathrm{RIS}}+\theta_i)\cos(\varphi_i^{\mathrm{RIS}}+\varphi_i) & \sin(\theta_i^{\mathrm{RIS}}+\theta_i)\sin(\varphi_i^{\mathrm{RIS}}+\varphi_i) \\ \sin(\theta_i^{\mathrm{RIS}}+\theta_i) & \cos(\theta_i^{\mathrm{RIS}}+\theta_i)\cos(\varphi_i^{\mathrm{RIS}}+\varphi_i) & -\cos(\theta_i^{\mathrm{RIS}}+\theta_i)\sin(\varphi_i^{\mathrm{RIS}}+\varphi_i) \\ 0 & \sin(\varphi_i^{\mathrm{RIS}}+\varphi_i) & \cos(\varphi_i^{\mathrm{RIS}}+\varphi_i) \end{bmatrix}. \tag{3}$$

As the jitter of the R-RIS is modeled as $\mathcal{CN}(0,{\sigma_1}^2)$ ($\theta_i \sim \mathcal{CN}(0,{\sigma_1}^2)$ and $\varphi_i \sim \mathcal{CN}(0,{\sigma_1}^2)$), $\boldsymbol{p}_{m,n}(i)$ may change at each different data block i. In other words, the azimuth angle θ_i^{RIS} and elevation angle φ_i^{RIS} for the R-RIS vary at different block i. In addition, small-scale fading is negligible [9] and the channels are supposed to be exclusively LoS. Therefore, for data block i, the instantaneous gain of the direct link between the BS and the UE can be expressed as

$$A_d = \frac{\lambda_c}{4\pi d_{\mathrm{BS}}^{\mathrm{UE}}}, \tag{4}$$

where λ_c represents the wavelength of the carrier signal, and ($d_{\mathrm{BS}}^{\mathrm{UE}} = \|\boldsymbol{p}_{\mathrm{UE}} - \boldsymbol{p}_{\mathrm{BS}}\|$) denotes the Euclidean distance between the BS and the UE. Since the relative position between the BS and the UE does not change, Eq. (4) can be considered a constant for the sake of simplifying calculations.

Similarly, the instantaneous gain of the cascaded link for block i is regarded as

$$A_{m,n}(i) = \frac{\lambda_c^2\sqrt{G_{m,n}^{\mathrm{BS}}(i)G_{m,n}^{\mathrm{UE}}(i)}}{16\pi^2 d_{\mathrm{BS}}^{m,n}(i)d_{m,n}^{\mathrm{UE}}(i)}, \tag{5}$$

where $d_{\mathrm{BS}}^{m,n}(i) = \|\boldsymbol{p}_{m,n}(i) - \boldsymbol{p}_{\mathrm{BS}}\|$ represents the distance from R-RIS(m,n) to the BS, and $d_{m,n}^{\mathrm{UE}}(i) = \|\boldsymbol{p}_{\mathrm{UE}} - \boldsymbol{p}_{m,n}(i)\|$ denotes the distance from the UE to R-RIS(m,n). In addition, $G_{m,n}^{\mathrm{BS}}(i)$ is the gain of R-RIS(m,n) with the BS as the observation point, and $G_{m,n}^{\mathrm{UE}}(i)$ indicates the gain of R-RIS(m,n) with the UE as the observation point. Since the initial conditions are undisturbed, it is assumed that the initial localization points of the BS, the center of the R-RIS, and the UE are aligned on the same plane, namely $x-z$ plane. Thus, $G_{m,n}^{\mathrm{BS}}(i) \approx \frac{4\pi}{\lambda_c^2}ab\cos(\theta_i^{\mathrm{BS}})\cos(\varphi_i^{\mathrm{BS}})$ and $G_{m,n}^{\mathrm{UE}}(i) \approx \frac{4\pi}{\lambda_c^2}ab\cos(\theta_i^{\mathrm{UE}})\cos(\varphi_i^{\mathrm{UE}})$, where

θ_i^{BS} and φ_i^{BS} are the azimuth and elevation angles of the BS, respectively, and they can be written as

$$\theta_i^{\mathrm{BS}} = \arccos(\frac{x_{\mathrm{BS}}}{\|\boldsymbol{p}_{\mathrm{BS}}\|}) \in [0, \theta_{max}^{\mathrm{BS}}], \varphi_i^{\mathrm{BS}} = \arccos(\frac{z_{\mathrm{BS}}}{\|\boldsymbol{p}_{\mathrm{BS}}\|}) \in [0, \varphi_{max}^{\mathrm{BS}}]. \quad (6)$$

Similarly, for the UE, the azimuth angle θ_i^{UE} and elevation angle φ_i^{UE} are described as

$$\theta_i^{\mathrm{UE}} = \arccos(\frac{x_{\mathrm{UE}}}{\|\boldsymbol{p}_{\mathrm{UE}}\|}) \in [0, \theta_{max}^{\mathrm{UE}}], \varphi_i^{\mathrm{UE}} = \arccos(\frac{z_{\mathrm{UE}}}{\|\boldsymbol{p}_{\mathrm{UE}}\|}) \in [0, \varphi_{max}^{\mathrm{UE}}], \quad (7)$$

where $\theta_{max}^{\mathrm{BS}}$, $\varphi_{max}^{\mathrm{BS}}$, $\theta_{max}^{\mathrm{UE}}$ and $\varphi_{max}^{\mathrm{UE}}$ are the maximum angle limits. It is important to note that this setup incorporates a specific transformation relationship between the azimuth and elevation angles of the BS, the R-RIS and the UE, which can be expressed as

$$k^{\mathrm{BS}}\theta_i^{\mathrm{BS}} + k^{\mathrm{UE}}\theta_i^{\mathrm{UE}} = \theta_i^{\mathrm{RIS}} \quad (8)$$

and

$$l^{\mathrm{BS}}\varphi_i^{\mathrm{BS}} + l^{\mathrm{UE}}\varphi_i^{\mathrm{UE}} = \varphi_i^{\mathrm{RIS}}, \quad (9)$$

where k and l are adjustment coefficients. Due to the presence of disturbances, $d_{\mathrm{BS}}^{m,n}(i)$ and $d_{m,n}^{\mathrm{UE}}(i)$ may change. Therefore, Eq. (5) can be reformulated as

$$A_{m,n}(i) \approx \frac{ab}{4\pi d_{\mathrm{BS}}^{m,n}(i) d_{m,n}^{\mathrm{UE}}(i)} \sqrt{\cos(\theta_i^{\mathrm{BS}})\cos(\varphi_i^{\mathrm{BS}})\cos(\theta_i^{\mathrm{UE}})\cos(\varphi_i^{\mathrm{UE}})}. \quad (10)$$

Assume that the change of $d_{\mathrm{BS}}^{m,n}(i)d_{m,n}^{\mathrm{UE}}(i)$ induced by the rotator adjustments is very limited, that is to say, $d_{\mathrm{BS}}^{m,n}(i)d_{m,n}^{\mathrm{UE}}(i) \approx d_1 d_2$, where d_1 and d_2 are the distances from the BS to the R-RIS center and from the R-RIS center to the UE, respectively.

Different from the normal fixed RIS, the proposed R-RIS can be controlled by operating the mechanical structure between it and the UAV, which means it is possible to find the certain azimuth and elevation angles to maximize $A_{m,n}(t)$. However, it should be mentioned that the optimal azimuth and elevation angles are impossible to be obtained, since the R-RIS can only be rotated once at each data block i, while the R-RIS is equipped with $M \times N$ elements and each of them has its own optimal azimuth and elevation angles. Therefore, the design considers the R-RIS center as the reference point for calculating the azimuth and elevation angles, with small expected losses.

The latency for the direct link is

$$\tau_d = \frac{d_{\mathrm{BS}}^{\mathrm{UE}}}{c}, \quad (11)$$

where c represents the speed of light. Similarly, the time delay for the cascaded link at data block i is

$$\tau_{m,n}(i) = \frac{d_{\mathrm{BS}}^{m,n}(i) + d_{m,n}^{\mathrm{UE}}(i)}{c}, \quad (12)$$

If $\Phi_{i,mn} \in (0, 2\pi]$ represents the continuous phase adjustment of R-RIS(m, n), $\Phi_d \triangleq e^{-j2\pi f_c \tau_d}$ is the direct link phase part and $\Phi_{m,n}(i) \triangleq e^{-j2\pi f_c \tau_{m,n}(i) - j\Phi_{i,mn}}$ denotes the cascaded link phase part. Therefore, the received complex base band signal is given by

$$y(i) = S_d(i)\Phi_d + \sum_{m=1,n=1}^{M,N} S_{m,n}(i)\Phi_{m,n}(i) + w(i), \tag{13}$$

where

$$S_d(i) = A_d \left\{ \sqrt{P_t} x(i - \tau_d) \right\}, \tag{14}$$

and

$$S_{m,n}(i) = A_{m,n}(i) \left\{ \sqrt{P_t} x(i - \tau_{m,n}(i) - \frac{\Phi_{i,mn}}{2\pi f_c}) \right\}. \tag{15}$$

$x(i)$ denotes the modulated signal with $\mathbb{E}\{|x(i)|^2\} = 1$, and P_t is the transmission power budget. $w(i)$ and f_c are white Gaussian noise at data block i and the carrier frequency, respectively. It is assumed that all devices in this paper are free from hardware impairments.

To evaluate the performance of the UAV air-to-ground communication system, a complex normal distribution $\mathcal{CN}(0, {\sigma_2}^2)$ is introduced to describe the noise affecting the system. Accordingly, the Signal-to-Noise Ratio (SNR) of the UE at data block i is derived as

$$\gamma_i = \frac{P_t \left| A_d + \sum_{m=1,n=1}^{M,N} A_{m,n}(i) \right|^2}{{\sigma_2}^2}, \tag{16}$$

3 Design of Anti-Jitter Scheme

In order to mitigate the effects of UAV jitter caused by air shakes and enhance the stability of communication, it is necessary to design a robust beamforming scheme based on the UAV equipped with the R-RIS. The rotatable feature of the R-RIS can be utilized to improve the performance. Ideally, the R-RIS would dynamically adjust in response to UAV vibrations immediately, in which case the normal beamforming works well. However, considering that the R-RIS is operated by the mechanical rotator that requires reaction time , the ideal situation may not always be satisfied. Therefore, it becomes critically important to explore a joint suppression method of beamforming and rotation, which is detailed in the following.

Considering that the Minimum Mean Square Error (MMSE) criterion effectively balances Bit Error Ratio (BER) and Spectral Efficiency (SE), it is employed as the design criteria in this section. To begin with, the sum of Mean Square Error (MSE) over the entire service period is required to be calculated, which, based on the signal received by the UE in the UAV air-to-ground communication system, can be described as

$$\epsilon = \mathbb{E}\left[\sum_{i=1}^{I} ||y(i) - x(i)||^2\right] = \sum_{i=1}^{I} \mathbf{H}_2(i)\Phi(i)\mathbf{H}_1(i) + IA_d^2P_t + I{\sigma_2}^2, \tag{17}$$

$\mathbf{H}_1(i)$ and $\mathbf{H}_2(i)$ denote the channel matrices for the two hops in the communication link, from the BS to the R-RIS and from the R-RIS to the UE, respectively. $\Phi(i)$ represents the phase shift matrix applied by the R-RIS for the i-th data block.

With the MSE defined, it is able to formulate the design problem, which is

$$\begin{aligned} (\theta_i^{\mathrm{RIS}})^*, (\varphi_i^{\mathrm{RIS}})^*, \Phi(i)^* &= \min_{\theta_i^{\mathrm{RIS}}, \varphi_i^{\mathrm{RIS}}, \Phi(i)} \epsilon \\ \mathrm{s.}t.C1 &: \mathbb{E}\{|x(i)|^2\} = 1 \\ C2 &: \gamma_i \geq \gamma_0 \\ C3 &: \Phi(i) = \mathrm{d}iag\{\Phi_{1,1}(i), \Phi_{1,2}(i), \cdots, \Phi_{M,N}(i)\} \\ C4 &: 0 \leq \theta_i^{\mathrm{RIS}} \leq \theta_{max}, 0 \leq \varphi_i^{\mathrm{RIS}} \leq \varphi_{max} \end{aligned} \tag{18}$$

In this formulation, constraint $C1$ imposes a power limit on transmitted data. $C2$ states that the received SNR should surpass a predefined threshold to assure communication quality. $C3$ confines adjustments to phase shifts alone within the R-RIS. And constraint $C4$ means that the range of the angles is limited.

Obviously, the problem outlined in (18) is non-convex, making it intractable to achieve an optimal solution. Consequently, a heuristic scheme is researched, which decouples the design of rotary angles and hybrid beamforming.

*Step*1: Suppose that the R-RIS's diagonal phase shift matrix is given, the task then revolves around the azimuth and elevation angles, described as:

$$\begin{aligned} (\theta_i^{\mathrm{RIS}})^*, (\varphi_i^{\mathrm{RIS}})^* &= \min_{\theta_i^{\mathrm{RIS}}, \varphi_i^{\mathrm{RIS}}} \epsilon \\ C4 : 0 \leq \theta_i^{\mathrm{RIS}} &\leq \theta_{max}, 0 \leq \varphi_i^{\mathrm{RIS}} \leq \varphi_{max} \end{aligned} \tag{19}$$

While the vibration condition of UAV can be detected by tools such as Inertial Measurement Unit (IMU) [11], formulating a precise design for rotation angles remains a challenge. As mentioned above, the mechanized nature of R-RIS rotation introduces a notable delay relative to communication time.

Therefore, we turn to explore the block rotation angle, which remains constant for a set period. According to the ergodic MSE, the rotation angles are designed as

$$(\theta_i^{\mathrm{RIS}})^*, (\varphi_i^{\mathrm{RIS}})^* = \min_{\theta_i^{\mathrm{RIS}}, \varphi_i^{\mathrm{RIS}}} (1/I)\mathbb{E}\left[\left(\sum_{i=1}^{I} \mathbf{H}_2(i)\right) \Phi \left(\sum_{i=1}^{I} \mathbf{H}_1(i)\right)\right]. \tag{20}$$

Considering that probability distribution of vibration is of significance and the Gaussian random distribution works well, the vibration condition of UAV is assumed to follow $\mathcal{CN}(0, {\sigma_3}^2)$, where ${\sigma_3}^2$ is the variance achieved by experience. Unfortunately, acquiring a closed-form solution is found to be challenging, a numerical solution is taken instead.

*Step*2: Once the rotation angles are given, we proceed to design the R-RIS's diagonal phase shift matrix according to the detected instantaneous vibration condition of the UAV. The design problem can be written as

$$\begin{aligned} &\Phi(i)^* = \min_{\Phi_i(i)} \epsilon_i \\ &\mathrm{s}.t.C1 : \mathbb{E}\{|x(i)|^2\} = 1 \\ &\quad C2 : \gamma_i \geq \gamma_0 \\ &\quad C3 : \Phi(i) = \mathrm{d}iag\{\Phi_{1,1}(i), \Phi_{1,2}(i), \cdots, \Phi_{M,N}(i)\} \end{aligned} \tag{21}$$

Based on MMSE rule, the design matrix can be formulated as

$$\mathbf{W}(i) = \mathbf{H}_1(i)^{\mathrm{H}}\left(\mathbf{H}_1(i)\mathbf{H}_1(i)^{\mathrm{H}} + {\sigma_2}^2\mathbf{I}\right)^{-1}\left(\mathbf{H}_2(i)^{\mathrm{H}}\mathbf{H}_2(i)\right)^{-1}\mathbf{H}_2(i)^{\mathrm{H}} \tag{22}$$

Subsequently, the R-RIS's diagonal phase shift matrix is derived by extracting the angle of $\mathbf{W}(i)$, that is to say, $\Phi(i) = e^{-j\arg(\mathbf{W}(i))}$.

4 Simulation Results

In this section, the impact of UAV jitter on the SE is examined. To begin with, some parameters of the simulation environment are presented in Table 1. For the number of elements on the R-RIS, $M = N = 64$ is set. Assume that the BS and the UE are both positioned at the ground level, and the length of the mechanical structure connecting the UAV to the R-RIS is considered negligible, the altitude of the UAV can be regarded as the absolute values $|z_{\mathrm{BS}}|$ or $|z_{\mathrm{UE}}|$. Furthermore, the values of the carrier frequency f_c and the transmit power P_t are also specified.

Table 1. Simulation Parameters.

Parameters	Values
Number of elements on R-RIS	$M \times N = 64 \times 64$
Altitude of UAV	$\|z_{\mathrm{UE}}\| = 20$ meters
Carrier frequency	$f_c = 2.4$ GHz
Transmit power	$P_t = 20$ dBm

The simulation results are shown in Fig. 2. To verify the effectiveness of the proposed scheme, a comparative scheme, termed 'without anti-jitter scheme', is considered. Additionally, the proposed scheme is assessed under two typical conditions.

As the variance of disturbance increases, the SE of all three schemes deteriorates due to the mismatch of the R-RIS phase matrix when the UAV jitters. The comparative scheme suffers the most significant degradation in performance. In contrast, as a result of considering anti-jitter, the proposed schemes with both tested conditions consistently perform better than the comparative one. Among the conditions, the scenario where $\sigma_1 = \sigma_3$ achieves superior performance. This is attributed to the fact that $\sigma_1 \neq \sigma_3$ represents a non-ideal situation, implying errors existing in the empirical variance values used to design the block rotation angle. This situation is inevitable given the reliance on numerical solutions, which highlights the necessity for a reliable mathematical derivation of the variance to optimize the performance.

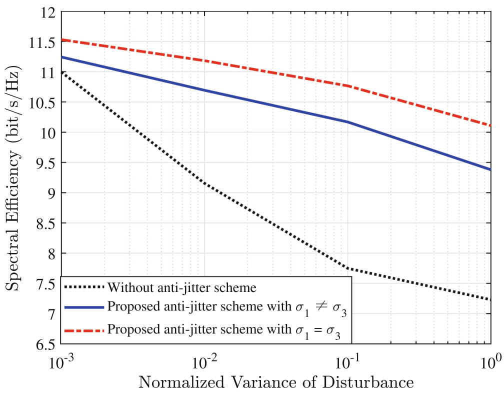

Fig. 2. Effect of UAV jitter on SE with different disturbance variances.

5 Conclusion

In this paper, a novel R-RIS approach for stabilizing the beamforming in UAV air-to-ground communications is presented, which aims to address the challenge of airflow induced UAV wobbling. The proposed method integrates the operation of the mechanical rotator with the phase shift of the R-RIS, enabling dynamic orientation adjustments to optimize beam direction when the UAV jitters.

Firstly, we formulate the system model incorporating the rotator's mechanical properties and derive the signal model considering the UAV's jittering effects as a stochastic process. Secondly, we propose a heuristic strategy that decouples the complex problem into subproblems including the rotation angle adjustments and the R-RIS's phase shift configurations.

Simulation results show that the proposed method effectively improves the system performance under UAV jitter conditions, demonstrating the effectiveness of the proposed scheme in enhancing beam stability.

Future work could explore more advanced dynamic control algorithms that further minimize the response time of the rotator and refine the phase adjustment process of the RIS. Moreover, the system model in this paper is simple, a mobile UE and the UAV with a wide range of movement could be introduced in the future.

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