Performance of Reconfigurable Intelligent Surfaces vs. Relaying for UAV-Assisted Communications

Mohammad Abualhayja'a*±, Anthony Centeno*, Lina Mohjazi*, M. Majid Butt†, Philippe Sehier†, Qammer H Abbasi*, and Muhammad A. Imran*
* James Watt School of Engineering, University of Glasgow, Glasgow, UK
† Nokia Bell Labs, Paris, France
* 2611044a@student.gla.ac.uk, {anthony.centeno, lina.mohjazi, qammer.abbasi, muhammad.imran}@glasgow.ac.uk
† {majid.butt, philippe.sehier}@nokia-bell-labs.com

***Abstract*— Reconfigurable intelligent surfaces (RIS) have been recently proposed as an emerging technology to enhance wireless coverage. In this paper, we examine the performance of RIS-enabled unmanned aerial vehicle (UAV)-assisted communications in comparison with decode-and-forward (DF) relaying. Our results quantify the number of RIS elements required to outperform DF relaying in terms of the achievable rate. Additionally, we demonstrate effect of the UAV height on the total transmit power.**

Keywords*— Reconfigurable intelligent surfaces, decode-and-forward relaying, UAV communication.

I. Introduction

Reconfigurable intelligent surfaces (RIS) have been recently discussed as an inexpensive and energy-efficient technology for improving the spectrum efficiency and coverage of wireless networks [1]. The RIS is a massive array of low-cost reflecting or scattering passive elements, which can be configured to change the incident wave phase, amplitude, frequency, or polarization. The RIS can be easily integrated into wireless communication networks to smartly control the random radio environment, so as to improve the coverage, throughput, and energy efficiency [1]. Relays are also widely recognized as a promising solution for wireless network coverage extension. Similar to the RIS, relay-supported links experience better channel propagation conditions compared to the direct transmission links in case of weak or blocked direct paths. Relays can be classified depending on the relaying protocol into amplify-and-forward (AF) and decode-and-forward (DF) relaying. Although the AF relays are less complex, they also amplify the signal noise [2], whereas the DF relays show better performance in terms of signal-to-noise ratio (SNR) and achievable rate.

The development of unmanned aerial vehicles (UAVs) has recently accelerated, especially in civilian applications, such as traffic monitoring, drones' photography, and delivery services. The unique features of the UAVs and their channel characteristics introduce several challenges to UAV communications [3]. RIS has been recently proposed as an emerging technology to enhance the UAV communications. The authors in [2] proposed a comparison between RIS and DF relaying-supported transmissions. Their results show that RIS should be equipped with a large number of elements to outperform the relay. In this paper, we compare the performance of RIS and relay assisted UAV communications, using channel gains modelled by 3GPP for aerial vehicles, in terms of achievable rate and power requirements. In addition, this paper also investigates the effect of varying the UAV height on the system performance.

II. System model

In this paper, we consider a downlink transmission system consisting of a single antenna terrestrial base station (BS) and

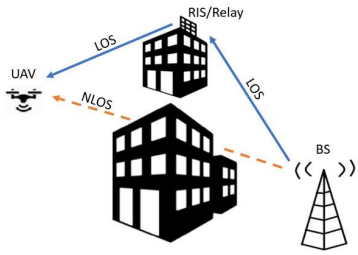

Fig.1: RIS/relay-assisted UAV communication system.

a UAV that acts as an aerial user equipment (UE). The transmission is either supported by a DF relay or an RIS, as shown in Fig. 1. We assume that the relay and the UAV are equipped with a single omni-directional antenna. The RIS is equipped with a uniform linear array (ULA) of M reflecting elements. The links from the BS to the RIS, and from the RIS to the UAV are assumed to be line-of-sight (LOS) channels. We assume a non-line-of-sight (NLOS) channel model for the link from the BS to the UAV. Three different modes of data transmission are considered: (i) direct or single-input single-output (SISO) transmission, (ii) RIS-supported transmission, (iii) relay-supported transmission.

A. Direct transmission

Let x be the transmitted signal and $h_{SU} \in \mathbb{C}$ represents the channel gain between the BS and UAV, accordingly, the received signal at the UAV can be written as:

$$y = h_{SU}x + n\,, \tag{1}$$

where $n \sim \mathcal{CN}(0,\sigma)$ is the additive white Gaussian noise (AWGN) with zero mean and σ variance.

Using (1), the rate at the UAV is given by:

$$R_{SISO} = \log_2\left(1 + \frac{p|h_{SU}|^2}{\sigma^2}\right), \tag{3}$$

where p is the power of the transmitted signal.

B. RIS-supported transmission

In this setup, the RIS reflects the incident signal in the direction of the UAV. Let $\Theta = \left\{e^{j\theta_1}, e^{j\theta_2}, \dots, e^{j\theta_M}\right\}$ be the diagonal phase-shift matrix for the RIS, where $\theta_i \in [0,2\pi)$, $i \in \{1,\dots,M\}$ is the phase shift of the ith reflecting element, and $\alpha \in [0,1)$ is the RIS reflection coefficient. Then the received signal at the UAV is:

$$y = (h_{SU} + \alpha h_{SR}^T \Theta h_{RU})x + n\,, \tag{4}$$

where h_{SR} and $h_{RU} \in \mathbb{C}$ are the channel gains from the BS to the RIS and from the RIS to the UAV, respectively.

Based on (4), the SNR at the UAV can be written as:

$$\gamma = \frac{p\left|h_{SU} + \alpha h_{SR}^T \Theta h_{RU}\right|^2}{\sigma^2}. \tag{5}$$

To minimize the transmit power, the RIS elements phase shifts are selected to coherently combine the signals from

different paths. Hence, the maximum instantaneous SNR at the UAV is written as:

$$\gamma = \frac{p\left|h_{SU}+h_{SR}^{T}h_{RU}\right|^{2}}{\sigma^{2}}. \quad (6)$$

Using (4) and (6), the maximum rate at the UAV can be written as:

$$R_{RIS} = \log_2\left(1+\frac{p\left|h_{SU}+h_{SR}^{T}h_{RU}\right|^{2}}{\sigma^{2}}\right). \quad (7)$$

C. Relay-supported transmission

The relaying system transmission is divided into two stages; in the first stage the BS sends the signal to the relay, and the signal received by the relay can be written as:

$$y_1 = h_{SR}x_1 + n_1\,, \quad (8)$$

where $h_{SR} \in \mathbb{C}$ is the channel gain from the BS to the relay, x_1 is the transmitted signal from the BS, and $n_1 \sim \mathcal{CN}(0,\sigma)$ is the AWGN at the relay. In the second stage the relay decodes the received signal and forwards it to the UAV. Therefore, the signal received by the UAV can be written as:

$$y_2 = h_{RU}x_2 + n_2\,, \quad (9)$$

where $h_{RU} \in \mathbb{C}$ is the channel gain from the relay to the UAV, x_2 is the transmitted signal from the relay, and $n_2 \sim \mathcal{CN}(0,\sigma)$ is the AWGN of the second stage.

The UAV receiver performs selection combining to obtain the desired signal. Utilizing (8) and (9), the SNR of the DF relay-supported transmission can be expressed as [2]:

$$\gamma = \min\left(\frac{p_1|h_{SR}|^2}{\sigma^2}, \frac{p_1|h_{SU}|^2}{\sigma^2}+\frac{p_2|h_{RU}|^2}{\sigma^2}\right), \quad (10)$$

where p_1 and p_2 are the powers of the transmitted signals from the BS and the relay, respectively.

Using (10), the rate at the UAV is:

$$R_{RIS} = \frac{1}{2}\log_2\left(1+\min\left(\frac{p_1|h_{SR}|^2}{\sigma^2}, \frac{p_1|h_{SU}|^2}{\sigma^2}+\frac{p_2|h_{RU}|^2}{\sigma^2}\right)\right). \quad (11)$$

The values p_1 and p_2 are optimised to maximize the rate using [4, proposition.1], while maintaining the same power as the RIS case.

III. NUMERICAL RESULTS AND DISCUSSION

In this section, simulation results are represented to evaluate each transmission mode. The channel gains are modelled using the 3GPP Urban Micro (UMi) for aerial vehicles "from [4], Table B-1" with a carrier frequency of 3 GHz. We extended the setup in [2] to a three-dimensional setup to fit the used channel models as illustrated in Fig. 2.

Fig. 3 shows the achievable rate for SISO, RIS with varying number of elements, and DF relaying. It is observed that RIS needs more than 100 elements to improve upon the DF relay performance. Fig. 4 shows the transmit power that is needed to achieve a rate of R = 6 bit/s/Hz for different transmission modes and different UAV heights with ($M = 150$). The SISO scenario requires the highest power and the DF relay-assisted transmission requires the least power. It can be also noticed that the gap between RIS and DF relaying decreases as the UAV height increases, and RIS achieves better performance than the DF relaying in the case of high altitudes. The reason is that for higher UAV altitudes the channel gain for NLOS link slightly improves. On the other hand, it becomes worse for the LOS link, and the relay-supported links experience better channel gain compared to the direct transmission in case of weak direct links.

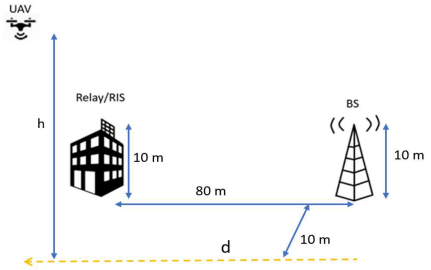

Fig.2: The simulation setup for IRS/relay-assisted UAV communication system.

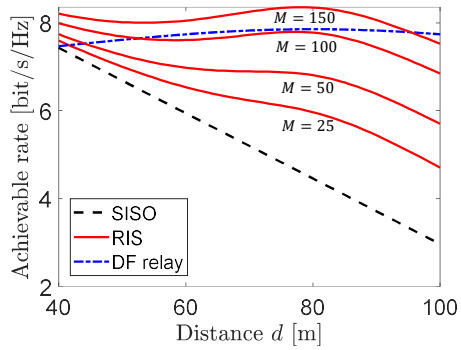

Fig.3: The achievable rate for different transmission modes as a function of distance d, with a fixed UAV height h = 25 m.

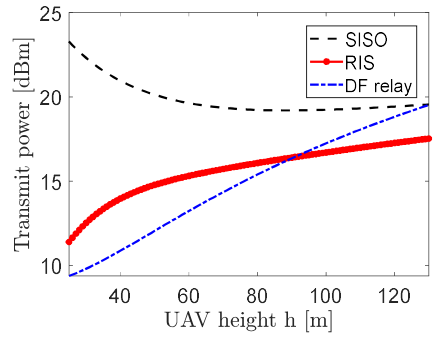

Fig.4: The transmit power needed to achieve a rate of R = 6 bit/s/Hz as a function of UAV height, with d = 70 m.

IV. CONCLUSION

A comparison between the performance of RIS and relay-assisted UAV communications was presented. Results show that the RIS should be equipped with more than one hundred elements to match up to a single DF relay performance in terms of achievable rate. It was also observed that an RIS with sufficiently high number of elements attains a better performance, in terms of power requirements, in the case of high UAV altitudes.

REFERENCES

[1] Y. Liu et al., "Reconfigurable Intelligent Surfaces: Principles and Opportunities," in *IEEE Commun. Surveys Tuts.* (Early access), May. 2021, doi: 10.1109/COMST.2021.3077737.

[2] E. Björnson, Ö. Özdogan and E. G. Larsson, "Intelligent Reflecting Surface Versus Decode-and-Forward: How Large Surfaces are Needed to Beat Relaying?," in *IEEE Wireless Commun. Lett.*, vol. 9, no. 2, pp. 244-248, Feb. 2020, doi: 10.1109/LWC.2019.2950624.

[3] M. Mozaffari, W. Saad, M. Bennis, Y. -H. Nam and M. Debbah, "A Tutorial on UAVs for Wireless Networks: Applications, Challenges, and Open Problems," in *IEEE Commun. Surveys Tuts.*, vol. 21, no. 3, pp. 2334-2360, Mar. 2019.

[4] *Study on Enhanced LTE Support for Aerial Vehicles* ,3GPP TR 36.777 (Version 15.0.0, Release 15), Dec. 2017.