# Sum Rate Optimization for Mixed FSO/RF Downlink Communication with Supporting UAV and Optical RIS-mounted HAP

Binh-Minh Vu
School of Electronic Engineering°
Soongsil University
binhminhvu@soongsil.ac.kr

Oh-Soon Shin*
School of Electronic Engineering°
Soongsil University
osshin@ssu.ac.kr

## ABSTRACT

This paper investigates sum rate optimization in a mixed free space optics (FSO)-radio frequency (RF) downlink communication system, enhanced by an unmanned aerial vehicle (UAV) and an optical reconfigurable intelligent surface (RIS)-mounted high-altitude platform (HAP). We develop an optimization framework to maximize the sum rate, jointly optimizing the UAV location, beamforming, transmitted power at the optical ground station (OGS), and power splitter under QoS constraints. The problem is highly non-linear and non-convex, prompting the proposal of an approximate inner (AI) optimization method. Simulation results demonstrate significant improvements in sum rate compared to random UAV placements, affirming the effectiveness of our approach.

## 1. Introduction

The escalating demand for high-capacity wireless communication, driven by data-intensive applications and the proliferation of the Internet of Things (IoT) devices, has outpaced the capabilities of traditional terrestrial networks. Particularly in challenging environments like disaster-stricken areas, remote regions, and densely populated urban centers, conventional networks often fall short. To address these limitations, hybrid communication systems integrating free space optics (FSO) and radio frequency (RF) technologies have gained traction [1].

Unmanned aerial vehicles (UAVs) serve as dynamic relays, optimizing communication links by adapting their positions, while optical reconfigurable intelligent surface (RIS)-mounted high-altitude platforms (HAPs) dynamically reconfigure the optical propagation environment, enhancing signal strength and minimizing interference [2]. This mixed system synergizes the strengths of FSO and RF technologies to deliver superior communication performance. Motivated by the above, we consider a mixed FSO-RF downlink communication system, enhanced by a UAV and optical RIS-mounted HAP.

Our objective is to develop an optimization framework to maximize the sum rate of the mixed FSO-RF downlink communication system. This involves jointly optimizing parameters including the UAV's location, beamforming, transmitted power at the optical ground station (OGS), and power splitter settings under quality of service (QoS) constraints. The resulting non-linear and non-convex optimization problem poses challenges for conventional methods, prompting the proposal of an approximate inner optimization method tailored for the mixed FSO-RF system.

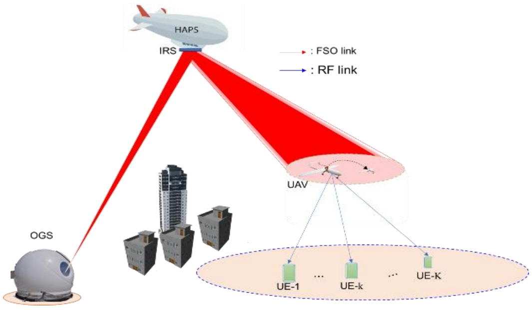

Fig. 1. System model.

## 2. System Model

We consider a mixed FSO/RF downlink network under supporting UAV and IRS-mounted HAP communication, where a UAV is coordinated for receiving the optical reflecting signal via IRS-moused HAP from the OGS and transmitting the RF link to UEs using beamforming, as illustrated in Fig. 1. Specifically, a self-sustainable UAV utilizes the FSO link to simultaneously receive backhaul information and energy from the OGS and leverages the RF links along with the IRS to forward information to UEs. We assume that the set of all UEs, denoted as $K = \{1, \dots, \mathrm{K}\}$ is severed by the set of $N$ antennas, denoted as $N = \{1, \dots, \mathrm{N}\}$, on the UAV. Geometrically, the UAV is located at a 3-D position, $\boldsymbol{U} = \{x_U, y_U, h_U\}$, covering a large area and being away from the OGS, which is located at $\boldsymbol{S} = \{x_S, y_S, h_S\}$. The IRS, mounted in HAP with $\boldsymbol{H} = \{x_h, y_h, h_{HAP}\}$, is used to help communication from OGS to UAV. The proposed system can be divided into two phases. During the first phase, the OGS will transmit the optical signal to the IRS-mounted HAP through the FSO link and reflect the signal to the UAV. At the UAV, a power-splitter is used to split the received signal into two parts for information processing and energy harvesting. Consequently, the received signal corresponding to the information flow can be expressed as

$$y_{uav} = RM_aP_T(1-\rho)G_{Tx}G_{Rx}h_{FSO}x_s + \boldsymbol{n}_u, \tag{1}$$

where $R$ is the responsibility of the photodetector and $M_a$ is the multiplication factor of the avalanche photodiode (APD). $P_T$ and $\rho \in (0,1)$ denote the transmitted power at the OGS and the PS ratio at the UAV, respectively, $x_s$ is the transmission signal vector for the FSO backhaul. $G_{Tx}$ and $G_{Rx}$ are the gains of the telescope of the GSO and the UAV, respectively. $\boldsymbol{n}_u$ is defined as additive white Gaussian noise (AWGN). Consequently, the signal-to-noise ratio (SNR) for the FSO link can be computed as

$$SNR = \frac{\langle I_p \rangle^2}{\sigma_N^2}, \tag{2}$$

where $I_p = RM_aP_T(1-\rho)G_{Tx}G_{Rx}h_{FSO}$ , and $\sigma_N^2 = \sigma_{sh}^2 + \sigma_{th}^2$ is the noise variance. Therefore, the bit rate for the FSO communication at the UAV can be expressed as

$$R_{FSO} = \frac{B_{FSO}}{2} log_2(1 + SNR), \tag{3}$$

where $B_{FSO}$ is the bandwidth of the FSO link. The remaining part of the received signal is used by the UAV to harvest energy, which is given as

$$P_{EH} = \eta M_a P_T \rho G_{Tx}G_{Rx}h_{FSO}, \tag{4}$$

During the second phase, the signal undergoes beamforming before being transmitted to UEs via RF communication. Consequently, the received signal at the $k$-th UE, can be expressed as

$$y_k = \boldsymbol{h}_{U,k}^H \mathbf{w}_k x_k + \sum_{j=1,j\neq k}^{K} \boldsymbol{h}_{U,k}^H \mathbf{w}_j x_j + n_k, \tag{5}$$

where $n_k$ denotes the AWGN with a zero mean and variance of $\boldsymbol{\sigma_k^2}$. As a result, the signal-to interference-plus-noise ratio (SINR) for the $k$-th UE can be expressed as

$$\gamma_k \triangleq \frac{\left|\boldsymbol{h}_{U,k}^H \mathbf{w}_k\right|^2}{\sum_{j=1,j\neq k}^{K} \left|\boldsymbol{h}_{U,k}^H \mathbf{w}_j\right|^2 + \sigma_k^2}, \forall k \in \mathrm{K}, \tag{6}$$

from which the achievable rate for the $k$-th UE can be computed as

$$R_{RF,k} = B_{RF} log_2\left(1 + \gamma_k\right), \forall k \in \mathrm{K}, \tag{7}$$

where $B_{RF}$ is the bandwidth of the RF link.

## 3. Problem Formulation

Our main goal is to maximize the sum rate for the downlink network by jointly optimizing the UAV location, the beamforming, the PS ratio, and the transmitted power. Therefore, the MMR problem can be mathematically formulated as

$$\max_{\mathbf{w},\boldsymbol{U},\rho,P_T} \quad \sum_{k=1}^{K} B_{RF} log_2\left(1 + \gamma_k\right), \tag{8}$$

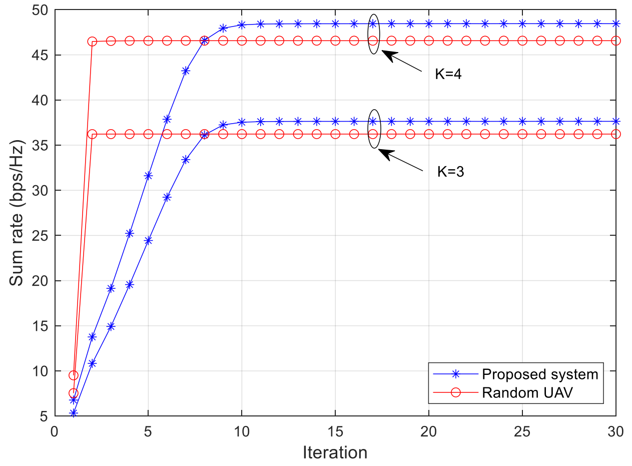

Fig 2. Convergence behavior of the proposed system and random UAV, when $N$=20 and $K$= 3, 4.

$$\text{s.t} \sum_{k=1}^{K} \|\mathbf{w}_k\|^2 \leq P_{\mathrm{B}}^{max};\ 0 < P_T \leq P_{max},$$
$$R_{RF,k} \geq R_{QoS,k}; R_{FSO} \geq \sum_{k=1}^{K} R_{RF,k},$$
$$P_{\mathrm{B}}^{max} + P_{us} \leq P_{max}; 0 < \rho < 1;$$
$$\|\boldsymbol{U} - \boldsymbol{I}\| \leq \mathrm{r}_{max},$$

where $R_{QoS,k}, P_{us}$ are the QoS rate and power level for ensuring UAV's self-sustainability, and $\boldsymbol{I}$ is the center of the FSO beam.

## 4. Simulation Results & Conclusions

We demonstrate the effectiveness of the proposed system, compared to random UAV placement. Numerical results in Fig. 2 show that the proposed system outperforms the random UAV under QoS constraint and PS threshold in both cases of the number of users.

In this paper, an iterative algorithm and approximate inner methods are proposed to address the challenge of non-convex problems for maximizing the sum rate in the mixed FSO-RF system with supporting UAV and optical RIS-mounted HAP. In future work, we will develop this system to serve in multi-cell and apply it in multi-UAV communication.

## Acknowledgment

This work was supported by a National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) under Grant RS-2023-00208995.

## References

[1] L. Qu, G. Xu, Z. Zeng, N. Zhang, and Q. Zhang, "UAV-assisted RF/FSO relay system for space-air-ground integrated network: A performance analysis," *IEEE Trans. Wireless Commun.,* vol. 21, no. 8, pp. 6211-6225, Aug. 2022.

[2] J.-H. Lee, K.-H. Park, Y.-C. Ko, and M.-S. Alouini, "Spectral-efficient network design for high-altitude platform station networks with mixed RF/FSO system," *IEEE Trans. Wireless Commun.,* vol. 21, no. 9, pp. 7072-7087, Sept. 2022.