UAV-Assisted Cooperative Downlink NOMA with Virtual Full-Duplex Operation

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***Abstract*—In this paper, we investigate an unmanned aerial vehicle (UAV)-assisted downlink cellular network where there exist a single base station (BS), two mobile stations (MSs), and multiple UAV relay stations (RSs) between the BS and MSs. We assume that there exist no direct communication links from the BS to the MSs due to unexpected blockages from obstacles or disasters and the BS is assumed to exploit a non-orthogonal multiple access (NOMA) technique for support two MSs. We propose a novel spectrally-efficient *successive* relaying technique, also known as virtual full-duplex operation, which selects a single UAV-RS among randomly deployed UAVs to send a superimposed NOMA signal for two MSs. It is shown that the proposed cooperative NOMA technique with virtual full-duplex operation outperforms the conventional cooperative NOMA technique with half-duplex operation in terms of outage probability.**

***Index Terms*—Unmanned aerial vehicle (UAV), UAV-assisted cooperative communications, outage probability, non-orthogonal multiple access (NOMA).**

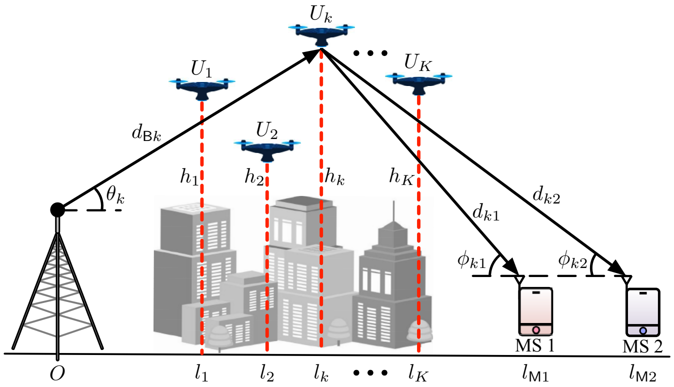

Fig. 1. A system model for UAV relay networks

I. INTRODUCTION

Owing to maneuverability and low cost of unmanned aerial vehicles (UAVs), UAV-assisted terrestrial-aerial integrated communications have become indispensable for coping with emergency relief of terrestrial mobile stations (MSs) in unexpected disasters [1]. In particular, utilizing the UAV as a base station (BS) or as a relay sation (RS) has become more important for supporting MSs in unexpected disconnections caused by disasters. Recently, several techniques on the UAV-assisted cooperative communications were proposed in literature including [2], [3], [4]. In [2], an UAV relay system with cooperative NOMA technique is proposed in order to assist wireless backhaul neworks. In [3], [4], UAV is considered by the relay node in device-to-device network. However, the aforementioned models inherently suffer from multiplexing loss since half-duplex UAVs cannot transmit and receive simultaneously.

To overcome this problem and improve spectral efficiency, we introduce a non-orthogonal multiple access (NOMA)-based UAV-assisted spectrally efficient successive relaying scheme based on the protocol shown in [5]. This scheme can compensate for the multiplexing loss due to the duty cycle loss of half-duplex relaying via successive relaying whereby $N-1$ can be transmitted for N phases as well as superimposed signals in power domain. The introduced schemes will be evaluated and compared in terms of outage probability via numerical simulations. Contrary to [5], the NOMA-based successive relaying scheme is considered in UAV relay networks taking into account for the characteristics of terrestrial-aerial channels. Furthermore, we will show the relationship between the outage probability and the density of fixed UAVs that are randomly deployed.

The rest of this paper is organized as follows. In Section II, we describe the system model and describe a NOMA-based UAV-assisted relaying scheme. The numerical results are shown in Section III and conclusions are presented in Section VI.

II. SYSTEM MODEL AND PROTOCOL DESCRIPTION

We consider an UAV-enabled cooperative network where a BS cannot directly transmit the desired signals of two MSs. More specifically, we consider a single-cell downlink network consisting of a single BS, two MSs, and K decode-and-forward (DF) UAVs as depicted in Fig. 1. We assume that there is no direct link between BS and MSs. The absence of a direct link can be assumed from the aforementioned scenarios due to obstacles, urgent disasters and so forth.

We assume that there are a single BS, K UAVs $(U_k, k = 1, \ldots, K)$ and two MSs, MS 1 and MS 2. Term h_k denotes the height of U_k from each ground, l_k. BS and MSs are located on O, $l_{\mathsf{M}1}$ and $l_{\mathsf{M}2}$, respectively. And, $d_{\mathsf{B}k}$, d_{k1} and d_{k2} denote the distance between BS and U_k, U_k and MS 1, U_k

and MS 2, respectively. UAVs are assumed to be randomly located on a finite region between O and l_{M1}. For UAVs deployment, we define r as the radius of the region where the UAVs are deployed. UAVs are assumed to be randomly distributed a given circular area with radius r and be fixed in a coherence time. We assume that the center of the radius is located in the middle spot between BS and MS 2, i.e., between O and l_{M2}. Thus, if O is the origin point, r is restricted to be subject to $\frac{l_{\mathsf{M2}}}{2} + r \leq l_{\mathsf{M1}}$ for geometrically efficient cooperative communication. Assume each node is equipped with a single antenna. The received SNR in the n-th phase can be formulated as $\rho_{ij}[n] = \frac{GP}{N_0 d_{ij}^{\alpha}}\Omega_{ij}$ where i and j denote the index of the transmitter and the receiver, respectively, α is the path loss exponent, P is the output power of the UAV, G is a constant regarding system parameters such as antenna gain, N_0 is the noise power, and Ω_{ij} denotes a random variable regarding the effects of small-scale fading, and the average of Ω_{ij}, $\bar{\Omega}_{ij}$ is assumed to be 1. Terrestrial-aerial communication links are assumed to be Rician fading. In this paper, G, P, and α for UAVs are assumed to be the same. Perfect channel state information at the receiver (CSIR) is assumed. We assume that signals for two MSs in each transmission phase except for the last transmission phase, i.e., $n = N$, in order to overcome the throughput loss due to the half-duplex operation of UAVs. Meanwhile, a selected UAV among which UAVs successfully decoded the received packet from the BS in the previous transmission phase, i.e., $k \in \mathcal{D}[n-1]$, forwards the packet to the MSs. Hence, $N-1$ packets are sent to two MSs from the BS during N transmission phases. We first investigate the conditions for the successful decoding of the received packet at the UAVs, and then describe how to select an UAV.

Let $\mathcal{D}[n]$ be the index set of the UAVs that successfully decode the signal in the n-th phase from the BS. Then, the cardinality of the decoding set can be defined by $|\mathcal{D}[n]|$. When the decoding set is empty, i.e., $|\mathcal{D}[n]| = 0$, the conditions for the k-th UAV to successfully decode the received signals, $s_1[n]$ and $s_2[n]$, at the n-th transmission phase are represented as $\frac{N-1}{N}\log\left(1+\frac{a_1\rho_{\mathsf{B}k}[n]}{a_2\rho_{\mathsf{B}k}[n]+1}\right) \geq R_1$ and $\frac{N-1}{N}\log\left(1+a_2\rho_{\mathsf{B}k}[n] \geq R_2\right)$.

When the inter-UAV interference exists, i.e., $|\mathcal{D}[n]| \neq 0$, all UAVs except for the selected UAV suffer from the interference signals from the selected UAV at the n-th transmission phase. In this case, the conditions for the successful decoding at the UAV depend on whether it is included in the previous decoding set. If the k-th UAV is not selected to relay signals to MSs and belongs to the previous decoding set, i.e., $k \in \mathcal{D}[n-1]$, then the conditions for successful decoding are the same as the empty decoding set case because it already has the interference signals from the selected UAV and knows the channel coefficient from the selected UAV to itself by the assumption of local CSI. On the other hand, if $k \notin \mathcal{D}[n-1]$, then the k-th UAV tries to perform joint decoding of both the n-th desired signal from the BS and the $(n-1)$-th interference signal from the selected UAV. In this case, a multiple-access channel (MAC) is formed at the UAVs except for the selected UAV, consisting of the BS (superposed desired signals) and the selected UAV (superposed interference signals), e.g., $\sqrt{a_1}s_1[n-1]$, $\sqrt{a_2}s_2[n-1]$, $\sqrt{a_1}s_1[n]$, and $\sqrt{a_2}s_2[n]$.

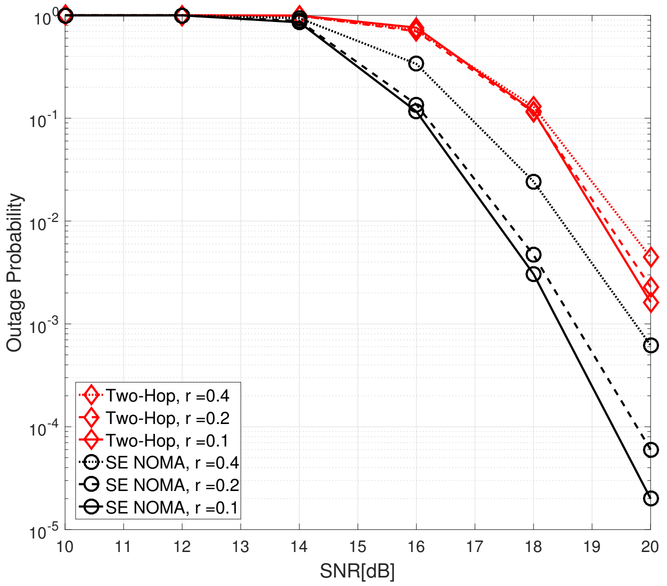

Fig. 2. A system model for UAV relay networks

Based on the decoding set, we explain how to select the UAV for relaying the packet to two MSs at the n-th transmission phase. Obviously, the UAVs that successfully decode the signal in the $(n-1)$-th transmission phase become candidates to be selected for relaying the packet in the n-th transmission phase. Among them, we select the single UAV j reflecting additional conditions as

$$j = \underset{k \in \mathcal{S}[n]}{\arg\max}\ \rho_{k2}[n] \tag{1}$$

where,

$$\mathcal{S}[n] = \left\{ k \in \mathcal{D}[n-1] \,\middle|\, \frac{N-1}{N}\log\left(1+\frac{a_1\rho_{ki}[n]}{a_2\rho_{ki}[n]+1}\right) \geq R_1 \right\}, \tag{2}$$

where $\forall i = 1, 2$. And, a_1 and a_2 are fixed over N transmission phases. Term R_i denotes the target rate of MS i.

III. NUMERICAL RESULTS

In this section, we show the numerical results of the proposed scheme in terms of outage probability according to r. Outage occurs when either of MSs fails to decode. In particular, outage probability of the proposed scheme cannot be directly solved since the status in all the previous phases depends on the performance in the current phase. However, leveraging the stationary distribution from Markov chain regarding the cardinality of decoding set, the dependency can be readily resolved.

We assume the other parameters are set to $a_1 = 0.8$, $\alpha = 2.5$, $G = 1$, $l_{\mathsf{M1}} = 0.9$ and $l_{\mathsf{M2}} = 1$. Note that the distances are a relative metric compared to the unit distance of l_{M2}. The height of each UAV is assumed to be the same, i.e., $h_k = H = 0.75$. Note that 'SE NOMA' and 'Two-hop NOMA' denote the NOMA-based UAV-assisted spectrally efficient successive relaying scheme and the NOMA-based UAV-assisted opportunistic two-hop relaying scheme as a referential scheme [6], respectively. From the benefit of successive relaying, the 'SE NOMA' outperforms the 'Two-hop NOMA'.

Based on the numerical result, we can figure out that outage performance is better as r decreases. That is, when UAVs are more crowded, UAV-assisted opportunistic two-hop relaying schemes can be further improved since the probability that a minimum channel gain of BS-to-UAVs channels and UAVs-to-MSs channel is better. Beside, there is another reason for the aforementioned relationship, which is that the performance of joint decoding in inter-UAV channels can be improved due to more crowded UAVs.

IV. CONCLUSIONS

In this paper, we presented the NOMA-based UAV-assisted spectrally efficient successive relaying scheme. Taking into account randomly deployed UAVs in a given finite region, we evaluated the performance in terms of outage probability. We confirmed that the presented spectrally efficient scheme outperforms the NOMA-based UAV-assisted opportunistic two-hop relaying scheme. In addition, we observed that outage probability performance of each scheme becomes improved as r decreases and the UAVs becomes crowded.

ACKNOWLEDGEMENT

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