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# UAV-assisted cooperative downlink NOMA with virtual full-duplex operation

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**Abstract**

In this paper, we consider an unmanned aerial vehicle (UAV)-assisted downlink cellular network consisting of a single base station (BS), two mobile stations (MSs) with $N$ antennas, and $K$ UAV relay stations (RSs). We assume that there exists no direct link between the BS and the MSs due to unexpected blockages such as obstacles and disasters. We propose a UAV-assisted cooperative downlink non-orthogonal multiple access (NOMA) with virtual full-duplex (VFD) operation for improving spectral efficiency in such an environment. In the proposed VFD technique, a single UAV-RS is selected among multiple UAV-RS. Through computer simulations, we verify that the proposed cooperative NOMA technique with VFD operation significantly outperforms the conventional cooperative NOMA technique with half-duplex operation in terms of outage probability.



*Keywords:* Unmanned aerial vehicle (UAV); UAV-assisted cooperative communications; Outage probability; Non-orthogonal multiple access (NOMA); Relay selection algorithm

## 1. Introduction

Because of advantages of unmanned aerial vehicles (UAVs) in terms of maneuverability and low cost, UAV-assisted terrestrial-aerial integrated communications have been attracted as one of fifth generation services for coping with communication abort caused from unexpected obstacles or disasters [1,2]. In cellular networks, utilizing the UAV station as a base station (BS) or as a relay station (RS) can improve quality of service of mobile stations (MSs) for high connectivity. Recently, several techniques on the UAV-assisted cooperative communications were proposed in many literature [3–7]. In [3], the cooperative NOMA technique which exploits the UAVs as relay stations is proposed in wireless backhaul networks. In device-to-device network, UAV stations are considered in order to expand communication range [4,5]. In [6,7], the isolated user and cell-center user are simultaneously supported by the UAV-RS and NOMA technique in two-hop and multi-hop systems, respectively. However, the system models in these literatures inherently suffer from duty cycle loss and multiplexing loss since half-duplex UAV relays cannot transmit and receive packets simultaneously.

To further improve the spectral efficiency compared to the aforementioned system models, we propose UAV-assisted cooperative downlink NOMA system which is able to relay successively at UAVs. Therefore, we consider the successive relay protocol called as virtual full-duplex (VFD) scheme shown in [8,9]. In [9], authors have mathematically analyzed the outage probability of VFD cooperative downlink NOMA system by using Markov chain. The VFD scheme can compensate the duty cycle loss by utilizing selective transmission of relay station in system models consisting of multiple relay stations. $N-1$ packets can be delivered for $N$ phases. The proposed scheme is compared with conventional scheme, i.e., half-duplex scheme, in terms of outage probability. In this paper, the NOMA-based successive relaying scheme is considered in UAV relay networks taking into account the characteristics of channel between UAV and terrestrial-aerial such as Rician fading. We also consider the MSs with multiple receive antenna and investigate the effect of number of UAVs. This paper is investigated by consider multiple antennas MSs based on [10].

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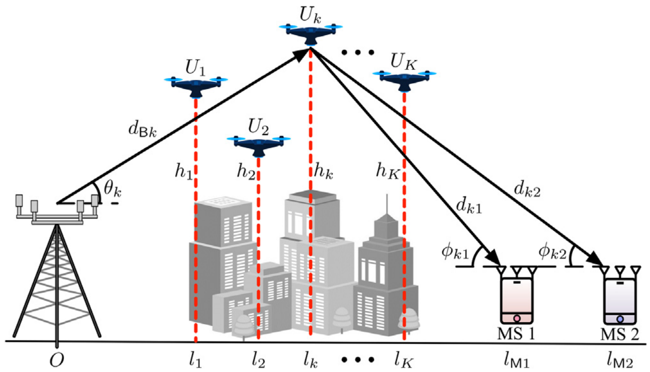


**Fig. 1.** System model of UAV-assisted cooperative downlink NOMA with multiple antenna MSs.

The rest of this paper is organized as follows. In Section 2, we describe the system model and a proposed UAV-assisted cooperative downlink NOMA. In particular, the VFD protocol is explained in detail. Via numerical results, the performance of outage probability is analyzed in Section 4. Finally conclusions are drawn in Section 5.

## 2. System model

We consider a relay-aided cooperative network with NOMA technique where UAVs are utilized as decode-and-forward relay (DF) stations and a BS cannot directly send packets to two MSs. As shown in Fig. 1, we consider a downlink cellular network consisting of a BS and two MSs with $N_r$ multiple receive antennas, and $K$ UAV-RSs. We assume that the direct links between the BS and two MSs are absent. This reason can be caused from obstacles, urgent disasters and so forth.

In this system, notations are denoted as follows: $h_k$ denotes the height (in the same mean as the altitude) of $k$th UAV, $U_k$, from ground and a position of $U_k$ on the ground is located at $l_k$ distance from the BS which exists on $O$. Also, MSs is located on $l_{\mathsf{M1}}$ and $l_{\mathsf{M2}}$. Terms $d_{\mathsf{B}k}$, $d_{k1}$ and $d_{k2}$ denote the distance of direct link between BS and $U_k$, $U_k$ and MS 1, $U_k$ and MS 2, respectively. UAVs are randomly deployed on a finite region between $O$ and $l_{\mathsf{M1}}$. UAV deployment model is assumed to follow uniform distribution and to have finite circle area with radius $r$. We assume that the center point of finite circle area is located in the middle spot between the BS and the MS 2, i.e., $(O + l_{\mathsf{M2}})/2$. From this assumption, the range of radius $r$ is restricted to be subject to $\frac{l_{\mathsf{M2}}}{2} + r \leq l_{\mathsf{M1}}$ for geometrically efficient cooperative communication.

Small-scale fading channel is modeled as Rician fading in links from the BS to $k$th UAV and from $k$th UAV to $m$th MS. Thus, the channel from the BS to $k$th UAV, $h_{\mathsf{B}k}[n]$, is given as follows

$$h_{\mathsf{B}k}[n] = \sqrt{\frac{\kappa_{\mathsf{B}k}}{\kappa_{\mathsf{B}k}+1}} h_{\mathsf{B}k}^{\mathsf{LoS}}[n] + \sqrt{\frac{1}{\kappa_{\mathsf{B}k}+1}} h_{\mathsf{B}k}^{\mathsf{NLoS}}[n], \quad (1)$$

where $\kappa_{\mathsf{B}}$ ($\in [0, 1]$) denotes Rician factor between the BS and $k$th UAV, $h_{\mathsf{B}k}^{\mathsf{LoS}}[n]$ denotes the deterministic value by line of sight (LoS) channel from the BS to $k$th UAV at $n$ transmission phase, and $h_{\mathsf{B}k}^{\mathsf{NLoS}}[n]$ denotes non-line of sight (NLoS) component from the BS to $k$th UAV at $n$ transmission phase and follows complex normal Gaussian distribution with zero mean and unit variance. We assume that $h_{\mathsf{B}k}[n]$ is identically and independently distributed (i.i.d.) RV and averages an unit for all $n$, i.e., $\mathbb{E}[|h_{\mathsf{B}k}[n]|^2] = 1$. The channel vector from $k$th UAV to $m$th MS, $\mathbf{h}_{km} \in \mathbb{C}^{N_r \times 1}[n]$, is modeled the same as above. The i.i.d. elements in this vector are assumed.

Now, we represent the relay-aided cooperative downlink NOMA system with relay selected transmission technique at $n$th phase. At the BS, a superimposed signal for downlink NOMA technique is given as $\sqrt{a}x_1[n] + \sqrt{1-a}x_2[n]$, where $x_m[n]$ ($m \in \{1, 2\}$) denotes the signal of $m$th MS transmitted from the BS at $n$ phase and the parameter $a$ denotes the power allocation parameter for downlink NOMA system. And then, the received signal at $k$th UAV from the BS is represented as

$$y_k[n] = \sqrt{\frac{GP}{d_{\mathsf{B}k}^{\alpha}}} h_{\mathsf{B}k}[n](\sqrt{a}x_1[n] + \sqrt{1-a}x_2[n]) + w_k[n], \quad (2)$$

where $\alpha$ is the path loss exponent, $P$ denotes the transmit power, $G$ denotes a constant regarding physical system parameters such as antenna gain and beam gain, and $w_k[n]$ denotes the additive whit Gaussian noise (AWGN) of $k$th UAV. The distribution of AWGN follows i.i.d. complex normal Gaussian with zero mean and variance of $N_0$. Then, the received SNR for a link from the BS to $k$th UAV in the $n$th phase is formulated as $\rho_k[n] = \frac{GP}{N_0 d_{\mathsf{B}k}^{\alpha}} \mathbb{E}[|h_{\mathsf{B}k}[n]|^2]$. The selected UAV, $U_j$, transmits the superimposed signal to both MSs with multiple antenna. And then, each MS at $n$th phase receives a signal vector represented by

$$\mathbf{y}_{\mathsf{M}m}[n] = \sqrt{\frac{GP}{d_{jm}^{\alpha}}} \mathbf{h}_{jm}[n](\sqrt{a}x_1[n-1] + \sqrt{1-a}x_2[n-1]) + \mathbf{w}_{\mathsf{M}m}[n], \quad (3)$$

where $\mathbf{w}_{\mathsf{M}m}[n]$ denotes the AWGN vector at $m$th MS which follows i.i.d. complex normal Gaussian with zero mean and variance of $N_0$. The received SNR of a link from $k$th UAV to $m$th MS is the same as $\rho_{km} = \frac{GP}{N_0 d_{km}^{\alpha}} \mathbb{E}\left[\|\mathbf{h}_{km}[n]\|^2\right]$.

## 3. Protocol description of UAV-assisted cooperative downlink NOMA schemes

In this section, we describe two different schemes of UAV-assisted cooperative downlink NOMA. First, the existing UAV-assisted cooperative downlink NOMA with two-hop relaying scheme is presented and then the proposed UAV-assisted cooperative downlink NOMA with VFD operation scheme is explained in detail.

### *3.1. UAV-assisted cooperative downlink NOMA with two-hop relaying scheme*

This scheme is independently operated among other signals due to a non-successive communication. Therefore, we represent the two-hop operation for phase 1 and phase 2. In each phase, received stations (UAVs or MSs) operate the successive interference cancellation decoding technique which is the traditional decoding technique dealing with the interference as the noise. When the received SNR is given as $\rho$ in any link, the successful decoding conditions in NOMA based two-hop relay system are represented as follows:

$$\left\{\begin{array}{l}\frac{1}{2}\log\left(1+\frac{a\rho}{(1-a)\rho+1}\right) > R_1 \bigcap \\ \frac{1}{2}\log\left(1+(1-a)\rho\right) > R_2\end{array}\right\}, \quad (4)$$

where $R_m$ ($m \in \{1,2\}$) is a target rate of $m$th MS.

Based on this decoding technique, a transmission UAV is selected by two-step, a pre-filtering UAV and the max-min selection criterion according to channel gain. In summary, the UAV $j$ is selected by

$$j = \arg\max_{k\in\mathcal{S}[2]} \min(\rho_k[1], \rho_{k2}[2]), \quad (5)$$

where

$$\mathcal{S}[2] = \left\{k \mid \frac{1}{2}\log\left(1+\frac{a\rho_{\mathsf{B}k}[1]}{(1-a)\rho_{\mathsf{B}k}[1]+1}\right) \geq R_1, \right.$$
$$\left. \frac{1}{2}\log\left(1+\frac{a\rho_{km}[2]}{(1-a)\rho_{km}[2]+1}\right) \geq R_1, \forall k, i = 1,2\right\}. \quad (6)$$

This selection scheme achieves the best outage probability performance and full-diversity gain in the two-hop relaying systems with NOMA technique in the absence of a direct link between a source and destinations. Because pre-filtering (6) can eliminate the UAVs, which cannot decode $s_1$ by dealing with the interference signal $s_2$ as noise, from candidate of the transmission UAV, diversity gain loss does not occur.

### 3.2. UAV-assisted cooperative downlink NOMA with VFD operation scheme

In order to reduce the throughput loss due to the half-duplex operation of UAVs, the BS transmits the superimposed NOMA signal to MSs for $N-1$ phase of entire $N$ phase by successive relaying scheme in this system. From the first phase to $N-1$ phase, the BS transmits the signal, $s[n]$, to all UAVs except for the UAV which is selected among a set of successfully decoding UAV index in the previous phase, i.e., $\mathcal{D}[n-1]$. At the same time, the selected UAV also sends the signal decoded in the previous phase, $s[n-1]$, over same sub-carrier.

Now we investigate the decoding conditions according to whether to decode in UAVs and then explain the relay selection algorithm for successive relaying scheme. As mentioned before, let $\mathcal{D}[n]$ be index set of the UAVs which successfully decode both $x_1[n]$ and $x_2[n]$ from the BS at $n$th phase. The decoding success condition of the UAV is differently given depending on whether the decoding set is empty. First, when the decoding set is empty at $n$th phase, i.e., $|\mathcal{D}[n]| = 0$, the conditions to successfully decode the $x_1[n]$ and $x_2[n]$ transmitted from the BS for $k$-UAV are given as follows, similar to (4).

$$\left\{\begin{array}{l}\frac{N-1}{N}\log\left(1+\frac{a\rho_{\mathsf{B}k}[n]}{(1-a)\rho_{\mathsf{B}k}[n]+1}\right) > R_1 \bigcap \\ \frac{N-1}{N}\log\left(1+(1-a)\rho_{\mathsf{B}k}[n]\right) > R_2\end{array}\right\}. \quad (7)$$

Next, if there is inter-UAV interference, i.e., $|\mathcal{D}[n-1]| \neq 0$, all UAVs except for the selected UAV receive the desired signal as well as the interference signal from the selected UAV at the $n$th phase. In this case, the successful decoding condition of the UAV depends on whether it is included in the previous decoding set. If $k$th UAV is included a previous decoding set, i.e., $k \in \mathcal{D}[n-1]$, but is not selected as a transmission UAV. Then, the successful decoding condition of $k$th UAV is the same as the condition with the empty decoding set because the previous signals stored in a buffer, $s_1[n-1]$ and $s_2[n-1]$, can be exploited as the cancellation signals to mitigate the interference. In this paper, the perfect interference cancellation is assumed by perfect CIS at receiver.

On the other hand, the decoding fail UAVs, $k \notin \mathcal{D}[n-1]$, are completely subject to interference at $n$th phase. Therefore, in order to improve the performance of outage probability, we exploit the joint decoding scheme known as the optimal decoding scheme in multiple access channel (MAC) at $k$th UAV. This UAV decodes all the signals received at $n$th phase, $x_1[n-1]$, $x_2[n-1]$, $x_1[n]$, and $x_2[n]$. Joint decoding conditions for $k$th UAV ($k \notin \mathcal{D}[n-1]$) are represented by

$$\left\{\sum_{i\in\mathcal{P}} R_i \leq I\left(\mathcal{P}; y_k[n] \mid \mathcal{P}^c, h_{\mathsf{B}k}[n]\right),\right.$$
$$\left.\forall\mathcal{P} \subseteq \{x_1[n-1], x_2[n-1], x_1[n], x_2[n]\}\right\}, \quad (8)$$

where $R_i \in \{R_1, R_2\}$ denotes the rate related to the signal $i \in \{x_1[n-1], x_2[n-1], x_1[n], x_2[n]\}$ and $\{\cdot\}^c$ denotes a complement set of a set $\{\cdot\}$.

Now, we explain how to select the transmission UAV in order to relay the superimposed signal, which is transmitted from the BS at $(n-1)$-th phase, to two MSs at the $n$ phase. The UAVs which are included in a set $\mathcal{D}[n-1]$ are candidates for a selected UAV at the $n$ phase. Among them, a transmission UAV $j$ is selected by considering channel gain as follows

$$j = \arg\max_{k\in\mathcal{S}[n]} \rho_{k2}[n], \quad (9)$$

where

$$\mathcal{S}[n] = \left\{k \mid \frac{N-1}{N}\log\left(1+\frac{a\rho_{km}[n]}{(1-a)\rho_{km}[n]+1}\right) \geq R_1, \right.$$
$$\left. k \in \mathcal{D}[n-1],\ m = 1,2\right\}, \quad (10)$$

where $a$ are fixed value over $N$ phase and $R_i$ denotes the target rate of $i$th MS. This selection scheme means that a transmit UAV is selected as the UAV with maximum channel gain to MS 2 among the UAVs ($\in \mathcal{S}[n]$) with link that can decode MS 1's signal in both MSs.

## 4. Simulation results

In this section, we numerically analyze the performance of the proposed UAV-assisted cooperative downlink NOMA with VFD operation scheme in terms of outage probability and compare it with the traditional two-hop scheme. For computer simulation, we assume the following parameters related to the

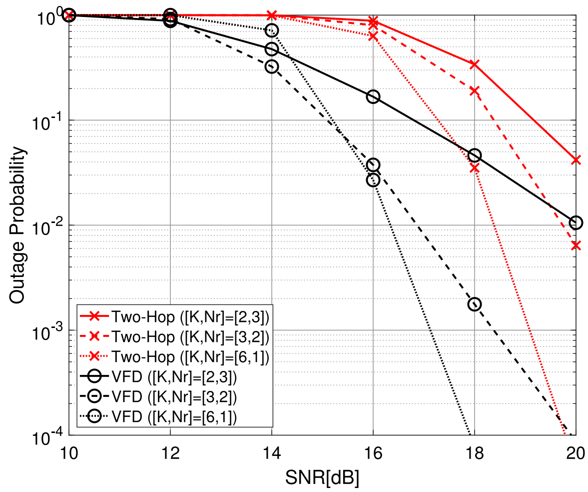


**Fig. 2.** Outage probability of two-hop scheme and VFD scheme according to the change in the number of relay and the number of receive antenna of MSs when $r = 0.1$.

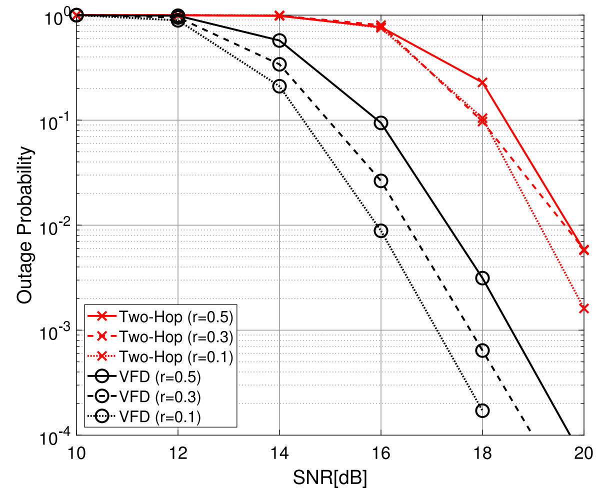


**Fig. 3.** Outage probability of two-hop scheme and VFD scheme according to the range of radius when $K = 4$ and $N_r = 2$.

system model configuration: height of all UAVs is same as $H$, i.e., $h_k = H$ $(k \in \{1, 2, \ldots, K\})$, the Rician factor of each link, $\kappa$ is determined by the ratio between a LoS component to NLoS component. We characterize the Rician factor by using the formula derived in [11]. Therefore, an exponential dependency between the Rician factor and the elevation angle is expressed as follows

$$\Psi(\theta) = ae^{b\theta}, \tag{11}$$

where $a = \Psi(0)$ and $b = \frac{2}{\pi} \ln \frac{\Psi(\pi/2)}{\Psi(0)}$. By numerical evaluations, authors in [11] provide an appropriate value of $\Psi(0)$ and $\Psi(\pi/2)$ as 3dB and 30dB, respectively. We assume that other parameters are set to the power allocation parameter $a = 0.8$, path loss exponent $\alpha = 2.5$, height of UAVs $H = 0.8$, and the distance of MS 1 and MS 2 from the BS $l_{\mathrm{M1}} = 0.9$ and $l_{\mathrm{M2}} = 1$. Value of all distance is expressed as distance relative to $l_{\mathrm{M2}}$.

Fig. 2 shows the outage probability results according to the change in the number of UAVs and the number of receive antennas of the MS when $r = 0.1$. In order to verify the effect between antenna gain and selection gain, we set to $K \times N_r = 6$ in all simulations. In results of both VFD scheme and two-hop scheme, the diversity order increases as the number of UAV-relay, $K$, increases since the diversity order is related to the maximum candidates of transmission UAV, i.e., max $|\mathcal{S}[n]|$. By comparing the two schemes, we can find that the VFD scheme outperforms the two-hop scheme in terms of outage probability. However, the gap between performance of two scheme gets narrower as SNR increases due to different diversity gain. In the case of two-hop scheme, max $|\mathcal{S}[n]|$ is equal to $K$. On the other hand, in the case of VFD scheme, max $|\mathcal{S}[n]|$ is equal to $K - 1$ since the transmission UAV does not participate as the receiving UAV. Nevertheless, the performance of VFD scheme is superior to that of two-hop scheme in the practical SNR regime.

In Fig. 3, we compare the outage probability according to $r$, the range of radius for UAV when $K = 4$ and $N_r = 2$. we can confirm that outage performance is improved as $r$ decreases. This tendency appears by the improvement of the minimum channel gain between BS-to-UAV link and UAV-to-MS link for both protocols and the improvement of decoding success probability of inter-relay interference for VFD scheme.

## 5. Conclusions

In this paper, we considered the UAV-assisted cooperative downlink NOMA system without a direct link between the BS and the MSs. In this system model, we described two different protocols in detail: UAV-assisted cooperative downlink NOMA with two-hop relaying scheme and that with virtual full-duplex (VFD) operation scheme. From the numerical results, we verified that the VFD scheme outperformed the two-hop scheme in the practical SNR regime in terms of outage probability. Also, the more dense UAV-relay group shows better performance. In further work, we will mathematically analyze this system and propose a data transmission method in order to improve the performance.

## Declaration of competing interest

The authors declare that there is no conflict of interest in this paper.

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