Research Article

On the Power-Splitting Relaying Protocol for SWIPT with Multiple UAVs in Downlink NOMA-IoT Networks

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Unmanned aerial vehicle (UAV) communication and non-orthogonal multiple access (NOMA) are two promising technologies for wireless 5G networks and beyond. The UAVs can be used as flying base stations to form line-of-sight communication links to the Internet of things devices (IDs) and to enhance the performance of usual terrestrial cellular networks. Moreover, the UAVs can also be deployed as flying relay nodes for forwarding data from a base station (BS) to the IDs. On the other hand, non-orthogonal resource sharing for many concurrent users is exploited in NOMA, thus improving spectrum efficiency (SE) and supporting massive connections. The NOMA combined with energy harvesting (EH) in an amplify-and-forward (AF) with cooperative UAV systems is researched. Specifically, the UAVs act as rotary-wing relays to forward data from the BSs to two IDs. This paper focuses on the analysis of outage probabilities (OPs), system throughput, and energy efficiency (EE) for two IDs. Besides, we also do the asymptotic analysis of OPs at high signal-to-noise ratios (SNRs). Furthermore, this paper also inspects the impacts of the UAV-based relaying on the OP, system throughput, and EE of the proposed NOMA scheme. The derived asymptotic expansions show that the suggested model can enhance user fairness and the analytical results match the simulation results.

1. Introduction

Unmanned aerial vehicle (UAV) communication and non-orthogonal multiple access (NOMA) are envisioned as two key technologies for unlocking the potential of the fifth-generation (5G) and future networks[1, 2]. In particular, the use of UAVs for 5G and beyond-5G networks has received much attention over the past few years [3]. Owning to distinctive characteristics, UAVs have been adopted for a variety of wireless networks and communication applications, for example, UAV-carried flying base stations (BSs) for capacity and coverage improvement, public safety scenarios, information dissemination, UAV-based wireless backhaul, and cellular connected UAVs as mobile users [4]. The NOMA technique exhibits benefits such as increased user data rate, massive connectivity, reduced end-to-end latency, improved fairness among users, high spectral efficiency (SE), and more energy efficiency (EE) than that of traditional orthogonal multiple access (OMA) [5–11]. The NOMA exploited two mechanisms including superposition coding (SC) and successive interference cancellation (SIC) [12, 13]. Some recent studies have showed that the integration of NOMA into UAV networks can enhance the network performance in terms of max-min rate [14], sum rate [15], and mission completion time [16], over conventional OMA schemes. Two protocols are exploited for energy harvesting (EH) at relays including power splitting relay and time switching relay in the decode-and-forward (DF) cooperative communication network [17, 18]. NOMA in UAV-enabled cooperative amplify-and-forward (AF) with the outdated relay selection algorithm is investigated [19].
1.1. Related Works. In this section, we review the novel study works on NOMA and UAV networks. UAV-assisted communication has become a potential application in industry and academic fields. NOMA is one of the important candidates to integrate UAV into 5G and future networks due to its overwhelming characteristics, such as superior spectral efficiency, low latency, and massive connectivity [2]. UAVs have also been recently studied as a promising solution to prove their potential in civil applications such as aerial photography, enhanced freight distribution, and wildfire management and disasters [4, 20]. A resource allocation scheme was proposed in NOMA UAV communication to enhance the user transmission rate with worse channel state information (CSI) [21]. UAVs can act as moving BSs or relays to facilitate reliable and efficient communication with multiple users [22, 23]. In [24], the authors discussed NOMA-based UAV-aided communications such as UAV-BS-enabled NOMA and NOMA-assisted cellular-connected UAVs. In [25], the authors conducted the complete performance analysis of a NOMA-aided UAV communication system, including selection combining double diversity receivers on UAVs, communicating over bivariate Rician shadowed fading channels. The work in [26] investigated the impact of residual hardware impairments on the performance of UAV-aided NOMA multiway relay networks by deriving the approximate analytical expressions for the achievable sum rate. Specifically, the asymptotic analysis in the high signal-to-noise-ratio (SNR) regions is carried out by invoking a high SNR slope and high SNR power offset. In [27], the authors investigated the impact of residual hardware impairments on the performance of UAV-aided NOMA multiway relay networks by deriving the approximate analytical expressions for the achievable sum rate. Specifically, the asymptotic analysis in the high signal-to-noise-ratio (SNR) regions is carried out by invoking a high SNR slope and high SNR power offset. In [28], the authors studied a 5G-based IoT to access the 5G spectrum to transfer 5G and IoT information simultaneously. The 5G network can be used at the IoT nodes to transmit voice and video information while using the IoT network for forwarding sensing data.

The work presented in [29] investigated a novel UAV relay-assisted IoT model with the emergency communication system that takes into account the latency requirement of Internet of Things (IoT) devices and the limited storage capacity of the UAV. A novel joint content caching and EH scheme is studied to improve UAV communications in the IoT NOMA network wherein a UAV acts like an aerial relay for serving users on demand [30]. In [31], the authors studied the throughput maximization problem with a focus on UAV-assisted wireless communication, considering a communication system with one couple of source and destination, where a UAV serves like an aerial relay based on an AF scheme and EH using a PS protocol. Performance of the IoT system with an EH UAV-enabled relay with downlink NOMA under Nakagami-m fading using the DF and AF schemes is investigated, where the time switching and adaptive power splitting protocols are utilized for the UAV [32].

Based on the above review, in this paper, we focus on power-switching relaying (PSR) for an RF EH and AF-based multiple-UAV NOMA in a SWIPT IoT system.

1.2. Motivation and Contribution. This paper researched the engagement of EH and AF-based multiple-UAV NOMA in a SWIPT IoT system wherein a UAV serves as a rotary-wing relay to communicate with two IoT devices (IDs). We also look at the UAV option (UAVO) scheme because it requires CSI knowledge of one-hop links. Hence, the use of rotary-wing relay AF in the UAVO model is greatly desirable in practice when complicated problems occur as the main anxiety. According to the depicted system model, the outage probabilities (OPs), the system throughput, and EE of the NOMA schemes in AF transition systems with UAVO were studied. The major contributions of this paper are outlined as follows:

(i) We exploit NOMA access technology in a dual-hop network to improve the SE of the network
(ii) A system model is studied in this work that consists of a BS and n types of UAVs and two IDs
(iii) The use of one SWIPT based EH and information processing (IP) protocol, specifically BS-based PSR, is exploited at a UAV that serves as a rotary-wing relay in this model
(iv) We derive closed-form expressions of OPs, system throughput, and EE at two IDs to assess the performance of the PRS scheme in SWIPT based on multiple-UAV cooperative NOMA systems

1.3. Organization. The remainder of the paper is arranged as below: Section 2 shows the proposed system model and assumptions. Section 3 analyzes the performance parameters with OP, throughput, and EE of the system. Section 4 discusses the simulation results. Ultimately, Section 5 is the main conclusion.

2. System Model

We investigate a downlink cooperative two-hop rotary-wing relay system in which a base station (BS) aims to send the signal to two IDs, i.e., $D_1$ and $D_2$ with the support of one out of $N$ AF UAVs ($UAV_1, UAV_2, \ldots, UAV_N$) with $N > 1$, as shown in Figure 1. It is assumed that there is no communication between the UAVs. We mainly focus our attention on a homogeneous network topology in which all wireless links show non-selective Rayleigh block fading and additive white Gaussian noise (AWGN).

As shown in Figure 1, without loss of generality, we assume that the channels of two IDs have been ordered as $h_{SD_1} \leq h_{SD_2}$. We also investigate that $D_1$ and $D_2$ are coupled together to implement NOMA downlink cooperative system. Hence, two successive phases are implicated for completing the information transmission that can be combined by selection combining. Selection combining (SC): Out of the $N$ signal received, the strongest signal is selected. When
signal $N$ is independent and distributes Rayleigh, the increase is shown in the power ratio as follows $\sum_{n=1}^{N}(1/n)$.

Table 1 below lists the parameters used throughout the paper, unless otherwise stated.

2.1. BS-Based PSR Protocol of EH at UAV$_n$.

At the UAV$_n$, we consider the EH mechanism BS-based PSR protocol.

Figure 2 depicts a diagram illustration of BS-based PSR scheme for EH at UAV$_n$ in the block time of $T$.

For direct link: In the whole time, $T$, BS transmits information directly to two IDs $D_1$ and $D_2$, with transmission powers $P_1 = P_r = P_s$.

For indirect link: The collected signal power at UAV$_n$ is indicated by $P$. Assuming that the BS transmits the information to UAV$_n$ in the half-block of $T$, while the information is sent from UAV$_n$ to two IDs $D_1$ and $D_2$ in the remaining time of $T$ (i.e., $T/2$). BS concurrently sends the superposed coding signal to $R_n$. Therefore, the sent signal at BS can be given by

$$x_{BS} = \sqrt{a_1P_s}x_1 + \sqrt{a_2P_s}x_2,$$  

Based on the employment of superposition of the sent signals at BS like in the NOMA scheme, the surveillance at UAV$_n$ can be given by

$$y_{UAV_n} = h_{SUAV_n}x_{BS} + n_{UAV_n},$$

$$= h_{SUAV_n}\left(\sqrt{a_1P_s}x_1 + \sqrt{a_2P_s}x_2\right) + n_{UAV_n}. \quad (2)$$

The signals received at two IDs $D_1$ and $D_2$, respectively, are given by

$$y_{D_1} = h_{SD_1}\left(\sqrt{a_1P_s}x_1 + \sqrt{a_2P_s}x_2\right) + n_{D_1}, \quad (3)$$

$$y_{D_2} = h_{SD_2}\left(\sqrt{a_1P_s}x_1 + \sqrt{a_2P_s}x_2\right) + n_{D_2}. \quad (4)$$

Since $D_1$ is further to UAV$_n$ than $D_2$, the power is allocated for $D_1$ more than that for $D_2$ to ensure the user fairness.

With no generality losses, $0 < a_2 < a_1$ satisfies $a_1 + a_2 = 1$. Based on PSR protocol, UAV$_n$ divides the collected power into two portions consisting of collected energy and IP energy. The energy harvested at UAV$_n$ is obtained by

$$EH = P_s|h_{SR_n}|^2\eta\beta\left(\frac{T}{2}\right), \quad (5)$$

where $\eta$ relies on the rectifier and the EH circuitry at UAV$_n$. The total energy harvested in the EH phase is consumed at UAV$_n$ while forwarding the decoded signal to $D_i$, $i \in \{1, 2\}$. The transmission power at UAV$_n$ depends on $EH$ and is determined by

$$P_{rn} = \frac{EH}{T/2} = P_s|h_{SR_n}|^2\eta\beta = P_sG_E, \quad (6)$$

where $G_E = |h_{SR_n}|^2\eta\beta$ indicates the EH coefficient in the PSR protocol.

2.2. Information Processing at UAV$_n$ and $D_i$.

In the first phase, BS transmits signals $x_1$ and $x_2$ for all UAVs and two IDs as in Equation (1).

During the second phase, UAV$_n$ transmits the signal $x = G_ny_{R_n}$ to two IDs $D_1$ and $D_2$, where $G_n$ denotes the amplifying gain at UAV$_n$, i.e.,

$$G_n^2 = \frac{P_{UAV_n}}{P_s|h_{SUAV_n}|^2 + N_0} = \frac{\rho G_E}{Y_n + 1}, \quad (7)$$

where $\rho\Delta = P_s/N_0$ depicts the sent SNR and the random variables (RVs) $A_i = \rho|h_{SD_i}|^2$, $B_n = \rho|h_{SUAV_n}|^2$, and $C_{im} = \rho|h_{UAV,D_i}|^2$ describe the instantaneous SNRs of the links BS $\rightarrow$ $D_i$, BS $\rightarrow$ $R_n$, $R_n$ $\rightarrow$ $D_i$, respectively. Thus, the signals at $D_1$ and $D_2$ are forwarded by UAV$_n$ and can be given by as follows:

$$y_{UAV_n,D_1} = h_{UAV_n,D_1}x_{UAV_n} + n_{UAV_n,D_1} = G_nh_{UAV_n,D_1}h_{SUAV_n}\sqrt{a_1P_s}x_1$$

$$+ G_nh_{UAV_n,D_1}h_{SUAV_n}\sqrt{a_2P_s}x_2 + n_{UAV_n,D_1}, \quad (8)$$

$$y_{UAV_n,D_2} = h_{UAV_n,D_2}x_{UAV_n} + n_{UAV_n,D_2} = G_nh_{UAV_n,D_2}h_{SUAV_n}\sqrt{a_1P_s}x_1$$

$$+ G_nh_{UAV_n,D_2}h_{SUAV_n}\sqrt{a_2P_s}x_2 + n_{UAV_n,D_2}.$$  

During the first phase, consider $x_2$ like interference in $y_{D_1}$. The immediate SINR at $D_1$ is provided by

$$y_{1,D_1} = \frac{a_1G_n|h_{SD_1}|^2}{a_2G_n|h_{SD_1}|^2 + 1} = \frac{a_1A_1}{a_2A_1 + 1}. \quad (10)$$
Table 1: Notation description.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( h_{SUAV} \sim \mathcal{CN}(0, \Omega_{SUAV}) )</td>
<td>The complex flat coefficient between BS and ( UAV_n )</td>
</tr>
<tr>
<td>( n_{UAV} \sim \mathcal{CN}(0, N_0) )</td>
<td>Additive white Gaussian noise (AWGN) at ( UAV_n )</td>
</tr>
<tr>
<td>( h_{UAV,D} \sim \mathcal{CN}(0, \Omega_{UAV,D}) )</td>
<td>The complex flat coefficient between ( UAV_n ) and ( D_i, i \in {0, 1} )</td>
</tr>
<tr>
<td>( n_{UAV,D} \sim \mathcal{CN}(0, N_0) )</td>
<td>Additive white Gaussian noise (AWGN) at ( D_i ), indirect link between BS and ( D_i )</td>
</tr>
<tr>
<td>( h_{SD} \sim \mathcal{CN}(0, \Omega_{SD}) )</td>
<td>The complex flat coefficient with direct link between BS and ( D_i )</td>
</tr>
<tr>
<td>( n_{D} \sim \mathcal{CN}(0, N_0) )</td>
<td>Additive white Gaussian noise (AWGN) at ( D_i ) with direct link between BS and ( D_i )</td>
</tr>
<tr>
<td>( P_S )</td>
<td>Transmission power at the BS</td>
</tr>
<tr>
<td>( \beta(0 &lt; \beta &lt; 1) )</td>
<td>The power splitting ratio at the ( UAV_n )</td>
</tr>
<tr>
<td>( E[\cdot] )</td>
<td>Expectation operation</td>
</tr>
<tr>
<td>( E[</td>
<td>h_{UAV,D}</td>
</tr>
<tr>
<td>( m )</td>
<td>The path-loss of channel model</td>
</tr>
<tr>
<td>( x_i (i \in {0, 1}) )</td>
<td>The transmitted signals from the forward link and the direct link are associated by selection combining (SC). The instantaneous SNR at ( D_i ) relative to the link is expressed as ( \gamma_D = \max \gamma_{D_i,n} / C_{16}/C_{17} = 1 )</td>
</tr>
<tr>
<td>( E[x_i</td>
<td>^2] = 1 )</td>
</tr>
<tr>
<td>( T )</td>
<td>The total time block</td>
</tr>
<tr>
<td>( a_1 )</td>
<td>Power allocation coefficient for signal ( x_1 )</td>
</tr>
<tr>
<td>( a_2 )</td>
<td>Power allocation coefficient for signal ( x_2 )</td>
</tr>
<tr>
<td>( \eta(0 &lt; \eta \leq 1) )</td>
<td>The energy conversion efficiency at the ( UAV_n )</td>
</tr>
</tbody>
</table>

Figure 2: Diagram illustration of PSR-based \( UAV_n \).

In the same way, the instantaneous SNR at \( D_2 \) is provided by

\[
\gamma_{1,D_2} = \frac{a_1 \rho |h_{SD}|^2}{a_2 \rho |h_{SD}|^2 + 1} = \frac{a_1 A_2}{a_2 A_2 + 1}.
\]

By following the NOMA scheme, \( D_2 \) decrypts the message specified for \( D_1 \) first and deletes it with SIC; then, it decrypts itself without interfering. Hence, the immediate SNR at \( D_2 \) is provided by

\[
\gamma_{2,D_2} = a_2 A_2.
\]

During the second phase, the instantaneous SINR calculation is same as the first phase. Therefore, the immediate SNR at \( D_1 \) relative to the link is expressed as

\[
\gamma_{UAV,D_2} = \frac{a_1 G_{E,n} B_n C_{1n}}{a_2 G_{E,n} B_n C_{2n} + G_{E} C_{2n} + B_n + 1}.
\]

Finally, by using (10)-(15), it is assumed that the signals from the forward link and the direct link are associated by selection combining (SC). The instantaneous SINR per ID can be written as

\[
\gamma_D = \max \gamma_{D_i,n} / C_{16}/C_{17} = 1.
\]

In the next, we will compute the OPs of two IDs assuming a UAVO method [33]. Therefore, the transition index is chosen and its corresponding SNR is given by

\[
n^* = \arg \max_{n=1, \ldots, N} \gamma_{BSUAV,n} B_n = \max_{n=1, \ldots, N} B_n.
\]
in which the instantaneous SNR at \(UAV_n\) is denoted by \(\gamma_{BSUAV_n} = B_n\).

### 3. Performance Analysis

#### 3.1. Outage Performance

The target SNR of two IDs is determined by the ID’s request for the quality of service (QoS). Hence, each ID has a target SNR, \(\gamma_{th_i} = 2^{2\theta_i}, \text{ } i \in \{1, 2\}\) [3, 5].

##### 3.1.1. Outage Probability at \(D_1\)

Based on [4], the RVs’ cumulative distribution functions (CDF) and, correspondingly, can be expressed by

\[
F_A(y_{thi}) = 1 - \exp\left(-\frac{y_{thi}}{\Omega_A}\right),
\]

\[
F_{B_n}(y_{th}) = \left(1 - \exp\left(-\frac{y_{th}}{\Omega_{B_n}}\right)\right)^N = 1 - \sum_{n=0}^{N} \binom{N}{n}(-1)^{N-n} \exp\left(-\frac{y_{th}}{\Omega_{B_n}}\right),
\]

\[
F_{C_n}(y_{th}) = 1 - \exp\left(-\frac{y_{th}}{\Omega_{C_n}}\right),
\]

where \(\Omega_A = \rho \Omega_{L,D_1}\), \(\Omega_{B_n} = \rho \Omega_{BSUAV_{n}},\), \(\Omega_{C_n} = \rho \Omega_{UAV_{n},D_1}\) represent the average SNR of the links, respectively. According to the NOMA principle, one outage event happens if there is indirect transmission or no successful forward sending. Hence, the OP at \(D_1\) is given by

\[
P_{D_1} = \Pr\{y_{D_1} < y_{th1}\} = \Pr\{\max\left[y_{1,D_1}, y_{UAV_{D_1}}\right] < y_{th1}\}
= \Pr\{y_{1,D_1} < y_{th1}, y_{UAV_{D_1}} < y_{th1}\}
= F_{Y_{1,D_1}}(y_{th1}) F_{Y_{UAV_{D_1}}}(y_{th1}).
\]

**Theorem 1** The OP at \(D_1\) can be derived as (see (23)).

\[
P_{D_1} = \left(1 - \exp\left(-\frac{y_{th1}}{\Omega_{A_1}}\right)\right)^2 \left(1 - \sum_{n=0}^{N} \binom{N}{n}(-1)^{N-n} \exp\left(-\frac{y_{th1}}{\Omega_{B_n}}\right)\right)^2 \exp\left(-\sigma \frac{nG_E}{\Omega_{B_n}} + \frac{1}{\Omega_{C_n}}\right).
\]

where \(K_1(.)\) denotes the first-order modified Bessel function of the second kind ([34], Eq.(3.324.1)), \(\alpha = ((n\sigma(1 + \sigma G_E))/((\Omega_{B_n} \Omega_{C_n})), \sigma = ((y_{th1})/(a_2 G_E - a_2 G_E y_{th1})),\) and \(\sigma = ((y_{th1})/(a_1 G_E - a_2 G_E y_{th1}))) with \(a_1 > a_2 y_{th1}\).

**Proof.** See Appendix A.

##### 3.1.2. Outage Probability at \(D_2\)

Because \(D_2\) needs to decode the signal of the first \(D_1\), \(D_2\) will be outage if both the first and the second stage are outages. Therefore, OP at \(D_2\) can be formatted as

\[
P_{D_2} = F_{Y_{1,D_1}}(y_{th1}) F_{Y_{UAV_{D_2}}}(y_{th1}).
\]

**Theorem 2** The OP at \(D_2\) can be derived as (see (25)).

\[
P_{D_2} = \left(1 - \exp\left(-\frac{y_{th1}}{\Omega_{A_1}}\right)\right)^2 \left(1 - \sum_{n=1}^{N} \binom{N}{n}(-1)^{N-n} \exp\left(-\sigma \frac{nG_E}{\Omega_{B_n}} + \frac{1}{\Omega_{C_n}}\right)\right)^2 \exp\left(-\sigma \frac{nG_E}{\Omega_{B_n}} + \frac{1}{\Omega_{C_n}}\right).
\]

An expression for the asymptotic OP for \(P_{D_1}\), whose exact analysis is presented in (23), is simplified as follows:

\[
1 - \exp\left(-\frac{y_{th1}}{(a_1 - a_2 y_{th1}) \Omega_A}\right) = \frac{y_{th1}}{\Omega_A},
\]

\[
\exp\left[-\sigma \left(\frac{nG_E}{\Omega_{B_n}} + \frac{1}{\Omega_{C_n}}\right)\right] = 1 - \sigma \left(\frac{k_G}{\Omega_{B_n}} + \frac{1}{\Omega_{C_n}}\right).
\]

Hence, we can obtain a fraction of the asymptotic approximation for \(P_{D_1}\) in (24) as follows:

\[
M_1 = 1 - \sum_{n=1}^{N} \binom{N}{n}(-1)^{N-n} \left[1 - \sigma \left(\frac{k_G}{\Omega_{B_n}} + \frac{1}{\Omega_{C_n}}\right)\right] = 1 - \sum_{n=1}^{N} \binom{N}{n}(-1)^{N-n} + \sum_{n=1}^{N} \binom{N}{n}(-1)^{N-n} \times \sigma \left(\frac{nG_E}{\Omega_{B_n}} + \frac{1}{\Omega_{C_n}}\right).
\]

\[
\text{With } \sum_{n=1}^{N} \binom{N}{n}(-1)^{N-n} = 1.
\]

We have

\[
M_1 = \left[\frac{N}{\Omega_B} + 1\right]^{N-n} \left(\frac{N}{\Omega_B} + 1\right)^{-N-n} \times \sigma \left(\frac{nG_E}{\Omega_{B_n}} + \frac{1}{\Omega_{C_n}}\right).
\]
Ultimately, from (31) and (34), an asymptotic OP expression for $P_{D_1}$ in (25), we obtain

$$P_{D_1}^{\text{as}} = \frac{\gamma_{th_1}}{\Omega_{A_1}}M_1, \tag{31}$$

3.1.4. Asymptotic Outage Probability at $D_2$. The asymptotic OP for $P_{D_2}$ is expressed the same as $P_{D_1}$, whose exact analysis is portrayed in (27); we have

$$1 - \exp \left( -\frac{\gamma_{th_2}}{a_1 - a_2\gamma_{th_2}}\frac{1}{\Omega_{A_2}} \right) = \frac{\gamma_{th_2}}{\Omega_{A_2}}, \tag{32}$$

$$\exp \left[ -\omega \left( \frac{nG_E}{\Omega_{B_N}} + \frac{1}{\Omega_{C_{2N}}} \right) \right] = 1 - \omega \left( \frac{nG_E}{\Omega_{B_N}} + \frac{1}{\Omega_{C_{2N}}} \right). \tag{33}$$

Thus, we can obtain a portion of the asymptotic approximation for $P_{D_2}$ in (28) as follows:

$$M_2 = 1 - \sum_{n=1}^{N} \left( \frac{N}{n} \right) (-1)^{n-1} \left[ 1 - \omega \left( \frac{nG_E}{\Omega_{B_N}} + \frac{1}{\Omega_{C_{2N}}} \right) \right] = 1 - \sum_{n=1}^{N} \left( \frac{N}{n} \right) (-1)^{n-1} + \sum_{n=1}^{N} \left( \frac{N}{n} \right) (-1)^{n-1} \times \omega \left( \frac{nG_E}{\Omega_{B_N}} + \frac{1}{\Omega_{C_{2N}}} \right). \tag{34}$$

### Table 2: Simulation parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>The standardized distance between the BS and UAV $n$</td>
<td>$d = 0.3$</td>
</tr>
<tr>
<td>The path-loss factor</td>
<td>$m = 2$</td>
</tr>
<tr>
<td>The target rate</td>
<td>$R_1 = 0.5, R_2 = 0.25$</td>
</tr>
<tr>
<td>Energy harvesting efficiency</td>
<td>$\eta = 0.8$</td>
</tr>
<tr>
<td>Power splitting ratio</td>
<td>$\beta = 0.7$</td>
</tr>
<tr>
<td>Power allocation coefficient for signal</td>
<td>$a_1 = 0.8, a_2 = 0.2$</td>
</tr>
</tbody>
</table>

**Figure 3:** Outage probability at $D_1$ of PSR versus $N = \{1, 2, 10\}$ without a direct link.
Figure 4: Outage probability at $D_1$ of PSR versus $N = 1$ with direct link.

Figure 5: Outage probability at $D_2$ of PSR versus $N = \{1, 2, 10\}$ without a direct link.
Figure 6: Outage probability at $D_2$ of PSR versus $N = 1$ with direct link.

Figure 7: Outage probability at two IDs $D_1$ and $D_2$ of PSR versus $N = 3$ without direct link.
Figure 8: Outage probability at two IDs $D_1$ and $D_2$ of PSR versus $N = 3$ with direct link.

Figure 9: Throughput of two IDs $D_1$ and $D_2$ versus $N = 3$ with direct link.
With \( \sum_{n=1}^{N} \left( \frac{N}{n} \right) (-1)^{n-1} = 1 \), we have,

\[
M_2 = \left[ \sum_{n=1}^{N} \left( \frac{N}{n} \right) (-1)^{n-1} \omega \left( \frac{nG_E}{\Omega_{B_1}} + \frac{1}{\Omega_{C_2}} \right) \right]. \tag{35}
\]

Ultimately, from (36) and (39), an asymptotic OP expression for \( P_{D_2} \) in (29), we have

\[
P_{D_2}^{\text{as}} = \frac{\theta}{\Omega_{A_2}} M_2. \tag{36}
\]

3.2. System Throughput. In this case, the BS sends information at a constant target rate, rely on the performance of the OP because of the wireless fading channel. The system throughput of the NOMA indirect link is shown by as follows.

3.3. The System Throughput at \( D_1 \).

\[
\tau_{D_1} = (1 - P_{D_1}) R_1, \tag{37}
\]

where \( P_{D_1} \) is given in (23).

3.4. The System Throughput at \( D_2 \).

\[
\tau_{D_2} = (1 - P_{D_2}) R_2, \tag{38}
\]

where \( P_{D_2} \) is given in (25).

3.5. Energy Efficiency. EE is known as the ratio of sum throughput to total power consumed in the whole network system.

3.5.1. Energy Efficiency at \( D_1 \).

\[
EE_{D_1} = \frac{2\tau_{D_1}}{\rho(1 + G_E \Omega_{Y_x})}, \tag{39}
\]

where \( \tau_{D_1} \) is calculated by using (37).

3.5.2. Energy Efficiency at \( D_2 \).

\[
EE_{D_2} = \frac{2\tau_{D_2}}{\rho(1 + G_E \Omega_{Y_x})}, \tag{40}
\]

where \( \tau_{D_2} \) is calculated by using (38).

4. Simulation Results

This section confirms the derived analytical results shown by the previous sections. The distance between BS and IDs is standardized to unity, i.e., \( \Omega_{BS-D_1} = 1 \), \( \Omega_{BS-R_n} \approx d^{-m} \), and \( \Omega_{R_n-D_1} = (1 - d)^{-m} \). Table 2 lists the simulation parameters.

![Figure 10: Energy efficiency of two IDs \( D_1 \) and \( D_2 \) versus \( N = 3 \) with direct link.](https://example.com/figure10.png)
for assessment circumstances of the SWIPT based on multi-UAV cooperative NOMA systems.

Figure 3 describes the OP at $D_1$ with PSR protocol versus SNR without a direct link. Theoretically correct curves for the OP at $D_1$ for NOMA are plotted according to the corresponding points (3.24) and (3.27). Exact probability curves are consistent with Monte-Carlo simulation results. The value $ID_1$ is assumed to be $N = \{1, 2, 10\}$, and $\Omega_{SD_1} = 0$.

Figure 4 shows the OP at $D_1$ with PSR protocol versus SNR with direct link. Theoretically correct curves for the OP at $D_1$ for NOMA are plotted according to the corresponding points (3.24) and (3.27). Exact probability curves are consistent with Monte-Carlo simulation results. The value $ID_1$ is assumed to be $N = \{1, 2, 10\}$, and $\Omega_{SD_1} = 0$.

Figure 5 describes the OP at $D_2$ with PSR protocol versus SNR indirect link. Theoretically correct curves for the OP of $D_2$ for NOMA are plotted according to the corresponding points (3.24) and (3.27). Exact probability curves are consistent with Monte-Carlo simulation results. The value $ID_2$ is assumed to be $N = \{1, 2, 10\}$, and $\Omega_{SD_2} = 0$.

Figure 6 shows the OP at $D_2$ with PSR protocol versus SNR with direct link. Theoretically correct curves for the OP at $D_2$ for NOMA are plotted according to the corresponding Equations (3.24), (3.27), and (3.37). Assume that the value $ID_2$ is $N = 1$ and $\Omega_{SD_2} = 1$.

Figure 7 shows the OP at $D_1$ and $D_2$ with PSR protocol versus SNR indirect link. Theoretically correct curves for the OPs at $D_1$ and $D_2$ for NOMA are plotted according to the Equations (3.24), (3.27), (3.28), and (3.30), respectively. The values at $D_1$ and $D_2$ are assumed $N = 3$, and $\Omega_1 = \Omega_1 = 0$.

Figure 8 depicts the OP at $D_1$ and $D_2$ of PSR protocol versus SNR indirect link. Assume that the values at $D_1$ and $D_2$ are $N = 3$ and $\Omega_{SD_1} = \Omega_{SD_2} = 1$.

Figure 9 shows the throughput at $D_1$ and $D_2$ of PSR protocol versus SNR with direct link. Theoretically correct curves for the throughput at $D_1$ and $D_2$ for NOMA are plotted according to the Equations (3.43) and (3.44). Throughput curves are consistent with the results of the Monte-Carlo simulation. The values at $D_1$ and $D_2$ are assumed $N = 3$, and $\Omega_{SD_1} = \Omega_{SD_2} = 1$.

Figure 10 shows the energy efficiency at $D_1$ and $D_2$ of PSR protocol versus SNR with direct link. The theoretically correct curves for the energy efficiency at $D_1$ and $D_2$ for NOMA are plotted according to the points (3.45) and (3.46). Energy efficiency curves consistent with Monte-Carlo simulation results. Assume that the values at $D_1$ and $D_2$ are $N = 3$ and $\Omega_{SD_1} = \Omega_{SD_2} = 1$.

### 5. Conclusion

This paper has investigated the BS-based PSR protocol for the NOMA system. We used an AF rotary-wing relay network with cooperative UAV systems with UAV options. Closed-form expressions of OP for the two IDs were derived. Based on a simulation of the OP, throughput, EE, the results indicated that NOMA with the UAV option improves the efficiency increase by increasing the number of UAVs, but hardly any outage performance when the number of UAVs increases from 2 to 10 in the high SNR region. The indicates that the NOMA protocol with the UAV option will not need to use more than two UAVs. Numerical results confirm that our derived analytical results matched precisely with the Monte-Carlo simulation results in connection with all possible system parameters. Furthermore, we also can deploy the multiple antennas system at two IDs along with the investigation of Rayleigh Rician fading channel for enhancing the system performance that would be in our future works.

### Appendix

#### A. Proof of Theorem 1

According to (22), the OP of $D_1$ for NOMA can be calculated as follows:

$$I_1 = F_{y_{th_1}}(y_{th_1}) = \Pr \left( \frac{a_1 A_1}{a_2 A_1 + 1} < y_{th_1} \right) = \Pr \left( A_1 < \frac{y_{th_1}}{a_1 - a_2 y_{th_1}} \right) = 1 - \exp \left( -\frac{y_{th_1}}{\Omega_1} \right).$$

(A.1)

Put $y_1 = y_{th_1}/a_1 - a_2 y_{th_1}$.

Similar to prove $I_1$, the calculation process of $I_2$ is presented as (see (A.2)):

$$I_2 = F_{y_{th_2}}(y_{th_2}) = \Pr \left( \frac{a_1 B_{n_2} C_{1_{n_2}} + B_{n_2} + C_{1_{n_2}} + 1}{a_2 B_{n_2} C_{1_{n_2}} + B_{n_2} + C_{1_{n_2}} + 1} < y_{th_2} \right) = F_{C_{1_{n_2}}}(\sigma) + \int_0^\infty \left[ 1 - \sum_{n=1}^{N} \left( \frac{N}{n} \right) (-1)^{n-1} \exp \left( -\frac{n}{\Omega_{C_{1_{n_2}}}} \left( \frac{\sigma(c+1)}{c-\sigma} \right) \right) \right] dc \exp \left( -\frac{n}{\Omega_{C_{1_{n_2}}}} \left( \frac{\sigma(c+1)}{c-\sigma} \right) \right) \exp \left( -\frac{c}{\Omega_{C_{1_{n_2}}}} \right) dc = 1 - \sum_{n=1}^{N} \left( \frac{N}{n} \right) (-1)^{n-1} \exp \left( -\frac{n}{\Omega_{C_{1_{n_2}}}} \left( \frac{\sigma(c+1)}{c-\sigma} \right) \right) \exp \left( -\frac{c}{\Omega_{C_{1_{n_2}}}} \right) dc = \left( \frac{ngC_{1_{n_2}}}{\Omega_{C_{1_{n_2}}}} + \frac{1}{\Omega_{C_{1_{n_2}}}} \right) 2\sqrt{\alpha}K_1(2\sqrt{\alpha}) = F_{C_{1_{n_2}}}(\sigma) + \int_0^\infty \left[ 1 - \sum_{n=1}^{N} \left( \frac{N}{n} \right) (-1)^{n-1} \exp \left( -\frac{n}{\Omega_{C_{1_{n_2}}}} \left( \frac{\sigma(c+1)}{c-\sigma} \right) \right) \right] dc \exp \left( -\frac{n}{\Omega_{C_{1_{n_2}}}} \left( \frac{\sigma(c+1)}{c-\sigma} \right) \right) \exp \left( -\frac{c}{\Omega_{C_{1_{n_2}}}} \right) dc = \left( \frac{ngC_{1_{n_2}}}{\Omega_{C_{1_{n_2}}}} + \frac{1}{\Omega_{C_{1_{n_2}}}} \right) 2\sqrt{\alpha}K_1(2\sqrt{\alpha}). \right)$$

(A.2)

Put $\sigma = (\frac{ng(1 + \sigma G_E)}{\Omega_{C_{1_{n_2}}}})^2$,

$$\sigma = (y_{th_1})/(a_1 G_E - a_2 G_{EY_{th_1}})$$

and $\sigma = (y_{th_1})/(a_1 G_E - a_2 G_{EY_{th_1}})$ with $a_1 > a_1.$
\( y_{th1} \) and \( K_1(.) \) denotes the first-order modified Bessel function of the second kind \([38, Eq.(3.324.1)]\). By substituting (A.1) and (A.1) into (22), the theorem is proved.

**B. Proof of Theorem 2**

According to (26), the OP at \( D_2 \) for NOMA is calculated as follows:

\[
F_{\gamma_{th_2}} (\gamma_{th_1}) = \Pr \left( \frac{a_1 A_2}{a_1 A_2 + 1} < \gamma_{th_1}, \frac{a_2 A_2}{a_2 A_2 + 1} < \gamma_{th_1} \right) = \Pr \left( A_2 < \gamma_{th_1}, A_2 < \gamma_{th_1} \right) = \Pr \left( A_2 < \max \left( \gamma_{th_2}, \gamma_{th_1} \right) \right) \tag{B.1}
\]

\[
= 1 - \exp \left( -\frac{\theta}{\Omega_2} \right).
\]

Put \( \theta = \max \left( (\gamma_{th_2} - \gamma_{th_1}), (\gamma_{th_2} - \gamma_{th_1}) \right) \), \( \gamma_{th_1} = a_2 Y_{th_1} \), and \( \gamma_{th_2} = (a_1 - a_2 Y_{th_1}) \).

Similarly, we have (see (B.2))

\[
F_{\gamma_{th_2}} (\gamma_{th_2}) = \Pr \left( \frac{a_1 B_2}{a_1 B_2 + 1} < \gamma_{th_2}, \frac{a_2 B_2}{a_2 B_2 + 1} < \gamma_{th_2} \right) = \Pr \left( B_2 < \gamma_{th_2}, B_2 < \gamma_{th_2} \right) = \Pr \left( B_2 < \frac{C_{th_2}}{a_1 A_2 - 1} \right)
\]

\[
= \frac{W_{th_2} + C_{th_2}/A_2 + 1}{1 - \gamma_{th_2} - C_{th_2}/A_2 - 1} = \Pr \left( Y_{th_2} < \gamma_{th_2} \right) = \frac{C_{th_2} + 1}{C_{th_2}/A_2 - 1} = F_{\gamma_{th_2}} (\gamma_{th_2}) \tag{B.2}
\]

Put \( \delta = \left( (\mu_1 (1 + \omega GE))/\left( \Omega_{B_2} \Omega_{C_{th_2}} \right) \right) \), \( \lambda_1 = \left( (\gamma_{th_1})/(a_1 GE) - a_2 GE Y_{th_1} \right) \), and \( \lambda_2 = \left( (\gamma_{th_1})/(a_2 GE) \right) \), \( \omega = \max \left( \lambda_1, \lambda_2 \right) \).

By replacing (B.1) and (B.2) into (26), the expression of (26) is obtained. This completes the proof.

**Data Availability**

The data used to support the findings of this study are included in the paper.

**Conflicts of Interest**

Authors declare there is no conflict of interest in this manuscript.

**References**


