Interference Impact on Decode-and-Forward Relay Networks with RIS-Assisted Source and Relays

Anas M. Salhab, Senior Member, IEEE

Abstract—In this letter, we consider the scenario of decode-and-forward relay network with reconfigurable intelligent surface (RIS)-assisted source and relays in the presence of interference. We derive approximate closed-form expression for the system outage probability assuming Rayleigh fading channels and opportunistic relaying scheme. In addition, we study the system behavior at the high signal-to-noise ratio (SNR) regime, where the diversity order and coding gain are obtained and analyzed. The results show that the system can achieve a diversity order of \( G_d = \min(N_1, N_2)K \), where \( N_1 \) and \( N_2 \) are the numbers of reflecting elements at the source and relays, respectively, and \( K \) is the number of relays. In addition, findings illustrate that for the same diversity order, utilizing one relay with multiple reflecting elements gives better performance than utilizing multiple relays with a single reflecting element. Furthermore, findings illustrate that the interference at the destination is more severe on the system performance than the interference at the relays. Therefore, under the same interference powers and for a fixed number of relays \( K \), results show that the case where the first hop is dominating the performance \( N_1 < N_2 \) gives better results in terms of coding gain than the case where \( N_2 < N_1 \).

Index Terms—Reconfigurable intelligent surface, decode-and-forward relay, Rayleigh fading, co-channel interference.

I. INTRODUCTION

Owing to their excellent features, the reconfigurable intelligent surfaces (RISs) have recently attracted a noticeable attention as a promising technique for future wireless communication networks. An RIS is an artificial surface, made of electromagnetic material, that is capable of customizing the propagation of the radio waves impinging upon it [1]. It has been proposed as a new low-cost and less complicated solution to realize wireless communication with high energy and spectrum efficiencies [2].

In [3], it has been shown that RIS has better performance than conventional massive multiple-input multiple-output (MIMO) systems as well as better performance than multi-antenna amplify-and-forward (AF) relaying networks with smaller number of antennas, while reducing the system complexity and cost. The performances of relay-assisted and RIS-assisted wireless networks from coverage, probability of signal-to-noise ratio (SNR) gain, and delay outage rate aspects have been compared in [4]. In [5], the authors utilized RIS to improve the quality of a source signal that is sent to destination through an unmanned aerial vehicle.

The authors in [6] and [7] have derived accurate approximations for the channel distributions and performance metrics of RIS-assisted networks assuming Raleigh fading channels. Recently, some works on RIS-assisted networks over Nakagami-\( m \) fading channels started to appear in literature [8], [9]. Most recently, limited number of papers have considered the interference phenomenon in a RIS context [10], [11]. All these works on interference considered the scenario, where an RIS is used as a replacement for relays. There exists another important scenario where the RIS could be used as a part of the source node itself to help it in sending its message to destination [6].

Motivated by this, we consider in this letter a new scenario, where the source and relays are internally utilizing RISs to enhance the quality of their transmitted signals in a decode-and-forward (DF) relaying network with interference. We derive accurate closed-form approximation for the system outage probability assuming Rayleigh fading channels for both intended users and interferers. The derived results are valid for arbitrary number of reflecting elements. In addition, in order to get more insights into the system performance, we derive closed-form expression for the asymptotic outage probability at high SNR values, where the system diversity order and coding gain are provided and analyzed. To the best of authors’ knowledge, the derived expressions are new and the achieved key findings on the impact of interference on the performance of relay networks where nodes are internally RIS-assisted are being reported for the first time here.

II. SYSTEM AND CHANNEL MODEL

Consider a dual-hop relay system with RIS-assisted source of \( N_1 \) reflecting elements, \( K \) RIS-assisted DF relay nodes each of \( N_2 \) reflecting elements, one destination, and arbitrary number of interferers at both the relays and destination with opportunistic relay selection scheme. The entire communication takes place in two phases. In the first phase, the source \( S \) transmits its signal to \( K \) relays. In the second phase, only the best relay among all other relays who succeeded in decoding the source signal in the first phase is selected to forward it to destination \( D \). We assume that the signal at the \( k^{th} \) relay is corrupted by interfering signals from \( I_k \) co-channel interferers \( \{x_i\}_{i=1}^{I_k} \).

The received signal at the \( k^{th} \) relay can be expressed as

\[
y_{rk} = \sum_{i=1}^{N_1} h_{s,k,i} x_0 + \sum_{i_k=1}^{I_k} h_{i_k,k}^I x_{i_k,k}^I + n_{s,k},
\]

where \( h_{s,k,i} \) is the channel coefficient between the \( i^{th} \) reflecting element at \( S \) and the \( k^{th} \) relay, \( x_0 \) is the transmitted symbol with \( E\{|x_0|^2\} = P_0 \), \( h_{i_k,k}^I \) is the channel coefficient between the \( i_k^{th} \) interferer and \( k^{th} \) relay, \( x_{i_k,k}^I \) is the transmitted symbol from the \( i_k^{th} \) interferer with \( E\{|x_{i_k,k}^I|^2\} = P_{i_k,k}^I \).
distributed with mean $\lambda = \frac{P}{2}$ and variance $(\lambda - 1)^2$. That is, their mean powers $E\{h_{x,k,i}^2\} = E\{|h_{x,k,i}|^2\} = 1$. In addition, the interferers channel coefficients are assumed to follow Rayleigh distribution. That is, the channels powers denoted by $|h_{i,k,i}^2|$ and $|h_{i,d,i}^2|$ are exponential distributed random variables (RVs) with parameters $\sigma_{2,i,i,k}$ and $\sigma_{2,i,i,d}$, respectively. Using (1), the signal-to-interference-plus-noise ratio (SINR) at the $k$th relay can be written as

$$\gamma_{s,k} = \frac{P_i}{N_0}\left(\frac{N_0}{N_0}\sum_{i=1}^{N_0} |h_{x,k,i}|^2\right)^2 \left(\sum_{i=1}^{N_0} \frac{P_{x,k} I(I_{x,k}^2 + 1)}{N_0} \right). \quad \text{(2)}$$

Let $B_L$ denote a decoding set defined by the set of relays who successfully decoded the source message at the first phase. It is defined as

$$B_L \triangleq \left\{ k \in S_r : \gamma_{s,k} \geq 2^{2R} - 1 \right\}, \quad \text{(3)}$$

where $S_r$ is the set of all relays and $R$ denotes a fixed spectral efficiency threshold.

In the second phase and after decoding the received signal, only the best relay in $B_L$ forwards the re-encoded signal to the destination. The best relay is the relay with the maximum $\gamma_{l,d}$, where $\gamma_{l,d}$ is the SINR at the destination resulting from the $l$th relay being the relay, which forwarded the source information. It can be written as

$$\gamma_{l,d} = \frac{P_i}{N_0}\left(\frac{N_0}{N_0}\sum_{i=1}^{N_0} |h_{l,d,k}|^2\right)^2 \left(\sum_{i=1}^{N_0} \frac{P_{x,k} I(I_{x,k}^2 + 1)}{N_0} \right). \quad \text{(4)}$$

where $P_i, P_{x,k}$, and $N_0$ are the transmit power of the $i$th active relay, the transmit power of the $i$th interferer, and the AWGN power at the destination, respectively, and $I_d$ is the number of interferers at the destination node. Since the denominator is common to the SINRs from all relays belonging to $B_L$, the best relay is the relay with the maximum $\gamma_{l,d}$. The end-to-end (e2e) SINR at D can be written as

$$\gamma_d = \frac{P_i}{N_0}\left(\frac{N_0}{N_0}\sum_{i=1}^{N_0} |h_{b,d,k}|^2\right)^2 \left(\sum_{i=1}^{N_0} \frac{P_{x,k} I(I_{x,k}^2 + 1)}{N_0} \right). \quad \text{(5)}$$

where the subscript $b$ is used to denote the best selected relay.

### III. OUTAGE PERFORMANCE ANALYSIS

#### A. Preliminary Study

The probability of the decoding set defined in (3) can be written as

$$P_r[B_L] = \prod_{l \in B_L} P_r[\gamma_{s,l} \geq u] \prod_{m \notin B_L} P_r[\gamma_{s,m} < u], \quad \text{(6)}$$

where $u = (2^{2R} - 1)$ is the outage SNR threshold. The outage probability of the system can be achieved by averaging over all the possible decoding sets as follows

$$P_{out} \triangleq P_r\left[ \frac{1}{2} \log_2 (1 + \gamma_d) < R \right] = \sum_{L=0}^{K} \sum_{B_L} P_r[\gamma_d < u|B_L] P_r[B_L], \quad \text{(7)}$$

where the internal summation is taken over all of $\binom{K}{L}$ possible subsets of size $L$ from the set with $K$ relays. In order to evaluate (7), we need first to derive $P_r[\gamma_d < u|B_L]$ and $P_r[B_L]$, which are presented in the following section.

#### B. Outage Probability

The approximate outage probability of the considered system is summarized in the following key result.

**Theorem 1:** The outage probability of RIS-assisted source and relays DF relaying network with independent identically distributed (i.i.d.) second hop cumulative distribution functions (CDFs) $(\lambda_{1,d} = \lambda_{2,d} = \ldots = \lambda_{r,d})$ and i.i.d. interferers’ powers at D $(\lambda_{1,d} = \lambda_{2,d} = \ldots = \lambda_{r,d})$ and at relays $(\lambda_{1,k} = \lambda_{2,k} = \ldots = \lambda_{r,k}, k = 1, \ldots, K)$ can be obtained in a closed-form expression by using (7), after evaluating the terms $P_r[\gamma_d < u|B_L]$ and $P_r[\gamma_{s,l} < u]$ as follows

$$P_r[\gamma_d < u|B_L] = \frac{\lambda_d}{I_d} \sum_{g=0}^{I_d - 1} \frac{I_d - 1}{g} \sum_{k=0}^{L} \binom{L}{k} (-1)^k \sum_{j=0}^{N_j} \frac{1}{C/\lambda_d, \lambda_{dx}} \sum_{j=0}^{N_j-1} \prod_{n=1}^{N_j} J_n \Gamma \left( g + \sum_{n=1}^{N_j} J_n + 1, \lambda_d + \frac{u\lambda_{dx}}{C} \right), \quad \text{(8)}$$

where $\Gamma(\cdot, \cdot)$ denotes the upper incomplete gamma function [13 Eq. (8.352.2)].

**Proof:** See Appendix [A].
IV. ASYMPTOTIC OUTAGE BEHAVIOR

In this section, we evaluate the system performance at high SNR values in which the outage probability can be expressed as $P_{\text{out}} \approx (G_e \rho)^{-G_d}$, where $G_e$ is the coding gain of the system and $G_d$ is the diversity order \[15\].

Theorem 2: The asymptotic outage probability for RIS-assisted source and relays DF relaying network with i.i.d. second hop CDFs and i.i.d. interferers at both the relays and destination can be obtained in a closed-form expression by using \[7\], after evaluating the terms $P_r[\gamma_d < u | B_L]$ and $P_r[\gamma_{s,k} < u]$ as follows

$$P_r[\gamma_d < u | B_L] \approx -\frac{\lambda_d^{I_d} e^{\lambda_d(I_d-1)}}{(I_d - 1)!CN_2^{N_2L}(N_2^2)^L} \sum_{g=0}^{I_d-1} \binom{I_d - 1}{g} (-1)^g$$

$$\times (\lambda_d)^{I_d} e^{\lambda_d^{I_d}} (\lambda_d^{I_d-1})^{I_d} \sum_{g=0}^{I_d-1} \binom{I_d - 1}{g} (-1)^g$$

$$\times (\lambda_d^{I_d}) e^{\lambda_d^{I_d}} (\lambda_d^{I_d-1})^{I_d} \sum_{g=0}^{I_d-1} \binom{I_d - 1}{g} (-1)^g$$

$$\times \frac{1}{N_2!} \left( \frac{I_d - 1}{g} \right) (-1)^g$$

$$\times u^{N_2L} \left( \frac{1}{g} \right) (-1)^g$$

$$\times \frac{1}{N_2!} \left( \frac{I_d - 1}{g} \right) (-1)^g$$

$$\times \frac{1}{N_2!} \left( \frac{I_d - 1}{g} \right) (-1)^g$$

$$\times \frac{1}{N_2!} \left( \frac{I_d - 1}{g} \right) (-1)^g$$

$$\times \frac{1}{N_2!} \left( \frac{I_d - 1}{g} \right) (-1)^g$$

$$\times \frac{1}{N_2!} \left( \frac{I_d - 1}{g} \right) (-1)^g$$

$$\times \frac{1}{N_2!} \left( \frac{I_d - 1}{g} \right) (-1)^g$$

$$\times \frac{1}{N_2!} \left( \frac{I_d - 1}{g} \right) (-1)^g$$

$$\times \frac{1}{N_2!} \left( \frac{I_d - 1}{g} \right) (-1)^g$$

$$\times \frac{1}{N_2!} \left( \frac{I_d - 1}{g} \right) (-1)^g$$

$$\times \frac{1}{N_2!} \left( \frac{I_d - 1}{g} \right) (-1)^g$$

$$\times \frac{1}{N_2!} \left( \frac{I_d - 1}{g} \right) (-1)^g$$

$$\times \frac{1}{N_2!} \left( \frac{I_d - 1}{g} \right) (-1)^g$$

Therefore, the diversity order of the system when $N_1$ is not equal to $N_2$ is $G_d = \min(N_1, N_2) K$. On the other hand, when $N_1 = N_2 = N$, the interference value at the relays and destination specifies which hop dominates the system performance. The hop that suffers from higher interference dominates the system performance by determining its coding gain. When the interference at both hops is equal, we noticed that the second hop dominates the system performance through determining its coding gain as in Case 2 above. For the last two cases, the diversity order is $G_d = NK$.

V. NUMERICAL RESULTS

For simplicity, we assume here that the parameters $\sigma_e^2$, $\sigma_i^2$, $\lambda_d$, and $\sigma_d^2$ are all equal to 1. In addition, we call the outage SNR threshold as $\gamma_{\text{out}} = u$.

We can see from Fig. 1 that there is a good matching between the analytical and asymptotic results with the simulation ones. In addition, we can see that the diversity order of the system $G_d$ is increasing when both $N_1$ and $K$ increase. As the system performance is dominated by the first hop, $G_d = N_1 K$, which coincides with Case 1 in the asymptotic analysis section.

![Fig. 1: $P_{\text{out}}$ vs SNR for different values of $N_1$ and $K$.](image1)

Same insights can be drawn from Fig. 2 but here $G_d = N_2 K$ as the system performance is dominated by the second hop in this figure. In addition, results here coincide with Case 2 in the asymptotic analysis section.

![Fig. 2: $P_{\text{out}}$ vs SNR for different values of $N_2$ and $K$.](image2)

In Fig. 3 as $N_2$ is smaller than $N_1$, the diversity order is fixed at $G_d = 3$. This figure informs us that the system with one relay node and multiple reflecting elements ($K = 1$, $N_2 = 3$), gives better performance than the system with multiple relays each of one reflecting element ($K = 3$, $N_2 = 1$).

Fig. 4 shows two main cases, (solid line: $N_1 = 4$, $N_2 = 1$) where the system performance is dominated by the second
hop and (dash line: $N_1 = 1, N_2 = 4$) where the system performance is dominated by the first hop. For all curves on figure, the diversity order is constant at $G_d = 2$. For each main case, decreasing the interference power enhances the coding gain, and hence, the system performance. In addition, this figure informs us that the interference at destination is more impactful/severe on the system performance than the interference at relays. This is clear as the case where ($\bar{\gamma}_r^f = 10 \text{ dB}, \bar{\gamma}_d^f = 20 \text{ dB}$) gives worse results than the case where ($\bar{\gamma}_r^f = 20 \text{ dB}, \bar{\gamma}_d^f = 10 \text{ dB}$). Other cases tell the same insights.

Two main cases are shown in Fig. 5 first hop dominating the system performance ($N_1 < N_2$) and second hop dominating the system performance ($N_2 < N_1$). For each one of these two cases, increasing the number of reflecting elements $N_1$ or $N_2$ increases the diversity order and enhances the system performance. For the first case, $G_d = N_1K$ and for the second case, $G_d = N_2K$. The figure also informs us that having more reflecting elements at the relays than the source gives better performance. This is because when the first hop is dominating the performance, the interference power at the relays determines the coding gain, which is better than that when the second hop is dominating, where the interference at the destination is more severe on the system behavior.

Fig. 6 studies the case when $N_1 = N_2$, where the interference power is determining which hop dominates the system performance. We can see that when $N_1 = N_2 = 2, G_d = 4$, whereas when $N_1 = N_2 = 3, G_d = 6$. Clearly, when the interference power is reduced either at the relays or destination, the coding gain of the system $G_c$ increases and better the achieved performance. In addition, we can see that when the second hop is dominating the performance ($\bar{\gamma}_r^f = 5 \text{ dB}, \bar{\gamma}_d^f = 15 \text{ dB}$), decreasing the number of interferers at the destination from 3 to 1 noticeably enhances $G_c$, whereas when the first hop is dominating the performance ($\bar{\gamma}_r^f = 15 \text{ dB}, \bar{\gamma}_d^f = 5 \text{ dB}$), decreasing the number of interferers at the relays from 3 to 1 does not have a noticeable impact on $G_c$. This is because the interference effect at relays is not severe on the system performance like that at the destination.

**Fig. 6: $P_{\text{out}}$ vs SNR for different values of $N_1$ and $N_2$ and various interference parameters.**

**VI. CONCLUSION**

This letter considered the scenario of DF relay network with RIS-assisted source and relays in the presence of interference. It derived approximate closed-form expression for the outage probability assuming Rayleigh fading channels. In addition, it provided expressions for the system diversity order and coding gain. The results showed that the system can achieve a diversity order of $G_d = \min(N_1, N_2)K$. Furthermore, findings illustrated that for the same diversity order, utilizing one relay with multiple reflecting elements gives better performance than utilizing multiple relays with a single reflecting element. In addition, results showed that the interference at the destination is more severe on the system performance than the interference at the relays. Therefore, under the same interference powers and for a fixed number of relays $K$, the case where the first hop dominates the performance $N_1 < N_2$ gives better results in terms of coding gain than the case where $N_2 < N_1$.

**APPENDIX A**

**Proof of Theorem 1**

In this Appendix, we evaluate the first term in (7) $P_r[\gamma_d < u|B_L]$. First, the e2e SINR can be written as $\gamma_d = Y/Z$. The CDF of $\gamma_d$ given a decoding set $B_L$ is given by $P_r[\gamma_d < u|B_L] = \int_0^\infty f_Z(z) \int_0^z f_Y(y)dydz = \int_0^\infty f_Z(z) \int_0^z f_Y(y)dydz = $
\[ \int_{\infty}^{\infty} f_Z(z) F_Y(uz)dz. \] With RIS-assisted relays of \( N_2 \) reflecting elements, the CDF of the second hop SNR assuming i.i.d. case is given by [6]

\[ F_{\gamma_{sd}}(\gamma) = 1 - e^{-\gamma_{sd}/\gamma} \sum_{k=0}^{N_2-1} \frac{(\lambda_{sd}\gamma)^k}{C^k k!}, \]

(14)

where \( C = 1 + (N_2 - 1)\Gamma^2 \left( \frac{\chi}{2} \right) \). Upon utilizing the Binomial rule, the CDF of the best selected relay can be rewritten as

\[ F_Y(u) = (F_{\gamma_{sd}}(uz))^L = \left( 1 - e^{-\lambda_{sd}uz/\gamma} \sum_{k=0}^{N_2-1} \frac{(\lambda_{sd}\gamma)^k}{C^k k!} \right)^L \]

\[ = \sum_{k=0}^{L} \left( \frac{L}{k} \right) (-1)^k \exp \left( -\lambda_{sd}uz/k \right) \left( \sum_{j=0}^{N_2-1} \frac{u^j}{j!} \right) \times \frac{1}{(C/\lambda_{sd})^{\sum_{n=1}^{k} j_n}} \prod_{n=1}^{k} j_n. \]

Assuming the interferers channels follow i.i.d. Rayleigh distribution, the interference-to-noise ratio (INR) CDFs at D will be following exponential distribution as \( F_{I_d}(\gamma) = 1 - e^{-\lambda_d/\gamma} \). Hence, the RV \( Z \), which equal to \( Z = X+1 \), where \( X = Z \) is the interference at the destination has the following PDF [14]

\[ f_X(x) = -\frac{(\lambda_d)^l}{(l-1)!} x^{l-1} e^{-\lambda_d x}. \]

(15)

Using transformation of RVs and then the Binomial rule, the PDF of \( Z \) can be obtained as

\[ f_Z(z) = -\frac{(\lambda_d)^l}{(l-1)!} e^{\lambda_d} (-1)^{l-1} g \sum_{g=0}^{l-1} \left( I_d - 1 \right)^g z^g e^{-\lambda_d z}. \]

(16)

Now, using the integral \( \int_{\infty}^{\infty} f_Z(z) F_Y(uz)dz \) and with the help of [13] Eq. (8.351.2), the first term in \( P_r \) \( \gamma_d < u \mid B_L \) can be obtained as in [8].

To obtain the second term in \( P_r \) \( \gamma_{sk} < u \), the first hop SNR can be written as \( Y' / Z' \), where \( Y' \) is the first hop SNR with RIS-aided transmitter and \( Z' = X' + 1 \), where \( X' \) is the interference at the relays. Again, the CDFs of the interferers at the relays follow exponential distribution as \( F_{I_k}(\gamma) = 1 - e^{-\lambda_k/\gamma} \), \( k = 1...K \). With RIS-assisted source of \( N_1 \) reflecting elements, the CDF of first hop SNR is given by [6]

\[ F_{Y'}(uz) = 1 - e^{-\lambda_{sk}uz/\gamma} \sum_{i=0}^{N_1-1} \frac{(\lambda_{sk}uz)^i}{B^i i!}, \]

(17)

where \( B = 1 + (N_1 - 1)\Gamma^2 \left( \frac{\chi}{2} \right) \). The PDF of \( Z' \) is similar to that of \( Z \), but with replacing \( \lambda_d \) with \( \lambda_k \) and \( I_d \) with \( I_k \). Again, upon using the integral \( \int_{\infty}^{\infty} f_Z(z) F_Y(uz)dz \) and with the help of [13] Eq. (8.351.2), the second term in \( P_r \) \( \gamma_{sk} < u \) can be obtained as in [9].

**APPENDIX B**

**PROOF OF THEOREM 2**

To find the asymptotic outage probability, we first need to obtain \( P_r \) \( \gamma_d < u \mid B_L \). As \( \rho \to \infty \) and with constant values of \( \rho_1, I_k, \) and \( I_d \), the CDF of the second hop channels with opportunistic relaying can be approximated as

\[ F_{\gamma_{sd}}(\gamma) \approx \frac{\gamma_{N_2}}{(C/\lambda_{sd})^{N_2} (N_2)!}. \]

(18)

Now, the CDF of best selected relay can be written as

\[ F_Y(u) \approx \frac{(uz)^{LN_2}}{(C/\lambda_{sd})^{LN_2} (N_2)!}. \]

(19)

With no change in the PDF of \( Z \) and upon following the same procedure as in Appendix A the term \( P_r \) \( \gamma_d < u \mid B_L \) in [7] can be evaluated at high SNR values as in [10].

Now, the second term in [7] \( P_r \) \( B_L \) can be obtained after evaluating the CDF of \( \gamma_{sk,k} \), which can be approximated at high SNR values as

\[ F_{\gamma_{sk,k}}(uz) \approx \frac{(uz)^{N_1}}{(B/\lambda_{sk})^{N_1} (N_1)!}. \]

(20)

Again, with no change in the PDF of \( Z' \) and upon following the same procedure as in Appendix A the term \( P_r \) \( B_L \) in [7] can be evaluated at high SNR values as in [11].

**References**

[1] M. D. Renzo et al., “Reconfigurable intelligent surfaces vs. relaying: Differences, similarities, and performance comparison,” IEEE Access, vol. 1, pp. 798–807, 2020.

[2] E. Basar, M. D. Renzo, J. D. Rosny, M. Debbah, M.-S. Alouini, and R. Zhang, “Wireless communications through reconfigurable intelligent surfaces,” IEEE Access, vol. 7, pp. 116753–116773, June 2019.

[3] Q. Wu and R. Zhang, “Intelligent reflecting surface enhanced wireless network via joint active and passive beamforming,” IEEE Trans. Wireless Commun., vol. 18, no. 11, pp. 5394–5409, Nov. 2019.

[4] L. Yang, Y. Yang, M. O. Hasna, and M.-S. Alouini, “Coverage probability of SNR gain, and DOR analysis of RIS-aided communication systems,” IEEE Wireless Commun. Lett., vol. 9, no. 8, pp. 1268–1272, Aug. 2020.

[5] L. Yang, F. Meng, J. Zhang, M. O. Hasna, and M. D. Renzo, “On the performance of RIS-assisted dual-hop UAV communication systems,” IEEE Trans. Veh. Technol., Early Access, DOI 10.1109/TVT.2020.3004598.

[6] L. Yang, F. Meng, Q. Wu, D. B. Costa, and M.-S. Alouini, “Accurate close-form approximations to channel distributions of RIS-aided wireless systems,” IEEE Commun. Lett., Early Access, DOI 10.1109/LCOMM.2020.3010512.

[7] A.-A. A. Boulogeorgos and A. Alexiou, “Performance analysis of reconfigurable intelligent surface-assisted wireless systems and comparison with relaying,” IEEE Access, vol. 8, pp. 94463–94483, 2020.

[8] R. C. Ferreira, M. S. P. Facina, F. A. P. D. Figueiredo, G. Fraidenraich, and E. R. D. Lima, “Bit error probability for large intelligent surfaces under coible-Nakagami fading channels,” IEEE Open J. Commun. Soc., vol. 1, pp. 750–759, June 2020.

[9] Monjed H. Samuh and Anas M. Salhab, “Performance analysis of reconfigurable intelligent surfaces over Nakagami-\(m \) fading channels,” arXiv preprint, available online: https://arxiv.org/abs/2010.07841, 2020.

[10] A. Li, L. Song, B. Vucetic, and Y. Li, “Interference exploitation preceding for reconfigurable intelligent surface aided multi-user communications with direct links,” IEEE Commun. Lett., Early Access, DOI 10.1109/LCOMM.2020.3008910.

[11] T. Hou, Y. Liu, Z. Song, X. Sun, and Y. Chen, “MIMO-NOMA networks relying on reconfigurable intelligent surface: A signal cancellation based design,” IEEE Trans. Wireless Commun., Early Access, DOI 10.1109/TWC.2020.3018179.

[12] J. Kim and D. Kim, “Exact and closed-form outage probability of opportunistic decode-and-forward relaying with unequal-power interferers,” IEEE Trans. Wireless Commun., vol. 9, no. 12, pp. 3601–3606, Dec. 2010.

[13] I. S. Gradshteyn and I. M. Ryzhik, Tables of Integrals, series and Products, 6th ed., San Diego: Academic Press, 2000.

[14] A. M. Salhab and S. A. Zummo, “Spectrum-sharing DF generalized order relay selection with interference and multiple primary users using orthogonal spectrums,” Physical Commun., vol. 21, pp. 49–59, Nov. 2016.

[15] M. K. Simon and M.-S. Alouini, Digital communication over fading channels, 2nd Edition, Wiley, 2005.