Hybrid Satellite Terrestrial Relay Networks with Cooperative Non-Orthogonal Multiple Access

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***Abstract*—In this letter, we investigate the outage probability (OP) and ergodic capacity of downlink hybrid satellite terrestrial relay networks (HSTRNs) with a cooperative non-orthogonal multiple access (C–NOMA) scheme, in which a user with better channel condition acts as a relay node and forwards information to other users, thus alleviating the masking effect of users with poor channel conditions in heavy shadowing. Specifically, the exact analytical expression for the OP of the considered system is derived. Furthermore, the ergodic capacity expression is also developed to facilitate the performance evaluation of the proposed framework. Finally, simulations are provided to show the impact of key parameters on the considered system and the superiority of introducing the C–NOMA scheme to the HSTRNs.**

***Index Terms*—Hybrid satellite terrestrial relay networks, cooperative non-orthogonal multiple access, outage probability, ergodic capacity.**

I. Introduction

INCORPORATING the benefits of relaying techniques into satellite systems, hybrid satellite terrestrial relay networks (HSTRNs) can significantly improve the performance of the user whose direct link is unavailable or deteriorated. Until now, several works have been done on the HSTRNs from various key performance measures, such as the outage probability (OP) and ergodic capacity [1]–[4]. Despite of the advantage of the HSTRNs, the time division multiple access (TDMA) scheme adopted in those aforementioned works cannot meet the increasing requirement for high resource efficiency because two time slots are needed to serve a user with a deteriorated link quality. Moreover, the TDMA scheme prefers to serve user with better link qualities to achieve an optimal throughput. Thus, the quality of service for users with deteriorated links may be sacrificed when the number of users is large, which is a common scenario in future satellite communications [3]. Under this condition, other multiple access scheme should be taken into consideration to achieve performance enhancement.

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Recently, a novel multiple access scheme, referred to as cooperative non-orthogonal multiple access (C-NOMA) scheme, has been proposed and studied in a number of works such as [5]–[8]. The key merit of C-NOMA is to transmit multiple signals simultaneously by using the NOMA scheme [9] in the transmission phase, then a user with a better channel condition acts as a relay node and forwards information to other users during the cooperation phase [5]. In this way, more users can gain access than the TDMA scheme to achieve a higher resource utilization efficiency and an improved performance for users with deteriorated link condition. Obviously, this key advantage is quite beneficial for HSTRNs due to the following reasons: 1) The deployment of an extra terrestrial relay node is unnecessary, which is economically and operationally preferred. 2) The cooperation within the group of adjacent users greatly alleviate the poor link gains of users in spot beam edge or in masking effect due to heavy shadowing. However, to the best of our knowledge, existing works on the combination of C–NOMA scheme and HSTRNs have not yet been reported. To fill this gap, this letter studies the performance of C–NOMA based downlink HSTRNs. Specifically, the OP and ergodic capacity expressions for the proposed system are derived. Simulations are provided to show the impact of key parameters on the system performance and the superiority of introducing the C–NOMA scheme to the HSTRNs.

II. System Model

Consider a land mobile satellite communicate system with two pre-paired terrestrial users[1], User p and User q, via the C–NOMA scheme. Each node in the considered system is equipped with a single antenna. We further assume that Users p and q are located in the same spot beam but with different locations. The overall communication takes place in two orthogonal time slots. During the first phase, the satellite broadcasts a superposed signal x ($x = \sqrt{\alpha P_{\mathrm{s}}} x_p + \sqrt{(1-\alpha) P_{\mathrm{s}}} x_q$) to satellite users, the received signal at User j ($j = p, q$) is

$$y_j = \sqrt{L_j G_s G_j(\varphi_j)} h_j x + n_j, \tag{1}$$

where α ($0 \leq \alpha \leq 1$) is a fraction of the transmit power P_{s} allocated to User p, x_j ($\mathrm{E}\left[|x_j|^2\right] = 1$) and n_j ($\mathrm{E}\left[|n_j|^2\right] = N_0$) are the transmit signal and the additive white Gaussian noise (AWGN) at User j, respectively. L_j denotes the free space loss (FSL) of the link from the satellite to Users j.

[1]Only two users are considered here since a NOMA group with two users has been included in the Third Generation Partnership Project (3GPP) [10] and an important conclusion drawn from [11] is that a lower sum rate can be obtained when more than two users are admitted into a cluster.

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Here, we consider $L_p{=}L_q$ since users within a beam present similar FSL towards the satellite [9]. G_s is the antenna gain at the satellite. $G_j(\varphi_j) = G_j\left(\frac{J_1(u_j)}{2u_j} + 36\frac{J_3(u_j)}{u_j^3}\right)^2$ [12] is the beam gain depending on both satellite beam pattern and the position of User j with $J(\cdot)$ denoting the Bessel function and $u_j = 2.07123\frac{\sin\varphi_j}{\sin\varphi_{j3\text{dB}}}$. G_j denotes the antenna gain at User j, φ_j is the angle between User j and the beam center with respect to the satellite, and $\varphi_{j3\text{dB}}$ denotes the 3-dB angle. As for the fading model, a widely-adopted Shadowed Rician (SR) fading model is adopted and the probability density function (PDF) of $|h_j|^2$ is given by [2] as

$$f_{|h_j|^2}(x) = \alpha_j e^{-\beta_j x}{}_1F_1(m_j;1;\delta_j x), \tag{2}$$

where $\alpha_j = 0.5(2b_j m_j/(2b_j m_j + \Omega_j))^{m_j}/b_j$, $\beta_j = 0.5/b_j$, $\delta_j = 0.5\Omega_j/b_j/(2b_j m_j + \Omega_j)$, $2b_j$ and Ω_j are the average power of the multipath component and line-of-sight (LoS) component, respectively, m_j $(m_j > 0)$ denotes the Nakagami-m parameter, and ${}_1F_1(a;b;c)$ represents the confluent hypergeometric function [13, Eq (9.100)]. Moreover, we assume User p has a better channel condition than that of User q, i.e., $G_q(\varphi_q)|h_q|^2 < G_p(\varphi_p)|h_p|^2$ in this letter.

At the receiver side, the user with worse channel condition can decode its own information directly. Thus, the signal-to-interference-plus-noise ratio (SINR) for User q is

$$\gamma_q^1 {=} \frac{(1{-}\alpha)P_s Q_q|h_q|^2}{\alpha P_s Q_q|h_q|^2 + N_0}, \tag{3}$$

where $Q_q{=}L_q G_s G_q(\varphi_q)$. At the same time, the user with better channel condition first decodes the information of User q according to the principle of successive interference cancellation (SIC). So, the decoding SINR can be derived as

$$\gamma_{p\to q} {=} \frac{(1{-}\alpha)P_s Q_p|h_p|^2}{\alpha P_s Q_p|h_p|^2 + N_0}, \tag{4}$$

where $Q_p = L_p G_s G_p(\varphi_p)$. One can obtain that $\gamma_q^1 < \gamma_{p\to q}$ since $G_q(\varphi_q)|h_q|^2 < G_p(\varphi_p)|h_p|^2$. Then, User p decodes its own information, and the received SINR at User p is

$$\gamma_p = \alpha P_s Q_p|h_p|^2/N_0. \tag{5}$$

During the second time phase, User p forwards the decoded information to User q, and the received SINR at User q is

$$\gamma_q^2 {=} P_p Q_{pq}|h_{pq}|^2/\delta^2, \tag{6}$$

where $Q_{pq} = G_p G_q/d_{pq}^u$, P_p is the transmit power at User p, d_{pq}, h_{pq}, and δ^2 are the distance, the channel coefficient, and the variance of AWGN of User $p \to$ User q, and u is the path loss exponent. In this letter, we model the terrestrial link, h_{pq}, as a Nakagami-m fading channel, the PDF of $|h_{pq}|^2$ can be written as

$$f_{|h_{pq}|^2}(x) = \frac{\xi^m x^{m-1}}{\Gamma(m)}e^{-\xi x}, \tag{7}$$

where $\Gamma(\cdot)$ is the Gamma function, $\xi = m/\Omega$ with m being the fading severity parameter and Ω being the average power.

III. PERFORMANCE ANALYSIS

In this section, key performance merits, including OP and ergodic capacity, are derived in the following subsections.

A. Outage probability

1) OP of User p: Based on the downlink NOMA protocol, an outage of User p can occur when either the decoding SINR $\gamma_{p\to q}$ falls below a predefined threshold $\gamma_{\text{th}q}$, or the received SINR γ_p below a threshold $\gamma_{\text{th}p}$ [6], [7], namely,

$$\begin{aligned} P_{\text{out}p}(\gamma_{\text{th}p}) &{=} \Pr(\gamma_{p\to q} {\le} \gamma_{\text{th}q}) + \Pr(\gamma_p {\le} \gamma_{\text{th}p}, \gamma_{p\to q} {>} \gamma_{\text{th}q}) \\ &= F_{\gamma_{p\to q}}(\gamma_{\text{th}q}) {+} F_{\gamma_p}(\gamma_{\text{th}p})\left[1{-}F_{\gamma_{p\to q}}(\gamma_{\text{th}q})\right]. \end{aligned} \tag{8}$$

From (4) and (5), the cumulative distribution functions (CDFs) of $F_{\gamma_{p\to q}}(\gamma_{\text{th}q})$ and $F_{\gamma_p}(\gamma_{\text{th}p})$ can be respectively written as $F_{\gamma_{p\to q}}(\gamma_{\text{th}q}) {=} \Pr\left(P_s Q_p|h_p|^2(1{-}\alpha - \alpha\gamma_{\text{th}q})/N_0 \le \gamma_{\text{th}q}\right)$ and $F_{\gamma_p}(\gamma_{\text{th}p}) {=} \Pr\left(\alpha P_s Q_p|h_p|^2/N_0 \le \gamma_{\text{th}p}\right)$. Applying the technique in [13, Eqs. (9.14.1), (3.381.1)], we get

$$F_{\gamma_{p\to q}}(\gamma_{\text{th}q}) {=} \begin{cases} \sum\limits_{k=0}^{\infty} \Xi_p \gamma\left(k{+}1, \frac{\gamma_{\text{th}q}\beta_p N_0/Q_p}{P_s(1-\alpha-\alpha\gamma_{\text{th}q})}\right), & \frac{1-\alpha}{\alpha} {>} \gamma_{\text{th}q} \\ 1, & \frac{1-\alpha}{\alpha} {\le} \gamma_{\text{th}q} \end{cases}, \tag{9}$$

$$F_{\gamma_p}(\gamma_{\text{th}p}) = \sum_{k=0}^{\infty} \Xi_p \gamma\left(k+1, \frac{\gamma_{\text{th}p}\beta_p N_0}{\alpha P_s Q_p}\right), \tag{10}$$

where $\Xi_p {=} \frac{\alpha_p (m_p)_k \delta_p^k}{(k!)^2 \beta_p^{k+1}}$ with $(a)_k {=} \frac{\Gamma(a+k)}{\Gamma(a)}$ [13] and $\gamma(a,x) = \int_0^x e^{-t}t^{a-1}dt$ represents the incomplete Gamma function [13, Eq. (8.350.1)]. Substituting (9) and (10) into (8), we can get the OP of User p.

2) OP of User q: According to the principle of the decode-and-forward (DF) relaying strategy and the maximal ratio combining (MRC) scheme, the output SINR at User q can be expressed as $\gamma_q {=} \min\left\{\gamma_{p\to q}, \gamma_q^1 + \gamma_q^2\right\}$. Thus, the OP of User q can be expressed as

$$P_{\text{out}q}(\gamma_{\text{th}q}) {=} 1 {-} \left[1 {-} F_{\gamma_q^1+\gamma_q^2}(\gamma_{\text{th}q})\right]\left[1 {-} F_{\gamma_{p\to q}}(\gamma_{\text{th}q})\right]. \tag{11}$$

Due to the fact that $F_{\gamma_{p\to q}}(\gamma_{\text{th}q})$ in (11) has been obtained by (9), the remaining task is to compute $F_{\gamma_q^1+\gamma_q^2}(\gamma_{thq})$, which can be re-expressed as

$$\begin{aligned} F_{\gamma_q^1+\gamma_q^2}(\gamma_{\text{th}q}) &= \Pr\left(\gamma_q^1 \le \gamma_{\text{th}q} - \gamma_q^2, \gamma_q^2 \le \gamma_{\text{th}q}\right) \\ &= \begin{cases} \underbrace{\int_0^{\Delta} F_{|h_q|^2}[g(z)] f_{|h_{pq}|^2}(z)\,dz}_{I_1}, & \frac{1-\alpha}{\alpha} {\ge} \gamma_{\text{th}q} \\ \underbrace{\int_{\Delta(1-\frac{1-\alpha}{\alpha\gamma_{\text{th}q}})}^{\Delta} F_{|h_q|^2}[g(z)] f_{|h_{pq}|^2}(z)\,dz}_{I_2} \\ + \underbrace{\int_0^{\Delta(1-\frac{1-\alpha}{\alpha\gamma_{\text{th}q}})} f_{|h_{pq}|^2}(z)\,dz}_{I_3}, & \frac{1-\alpha}{\alpha} {<} \gamma_{\text{th}q} \end{cases}, \end{aligned} \tag{12}$$

where $g(z) {=} \frac{\gamma_{\text{th}q}N_0(1-z/\Delta)}{P_s Q_q(1-\alpha-\alpha\gamma_{\text{th}q}(1-z/\Delta))}$ with $\Delta {=} \frac{\gamma_{\text{th}q}\delta^2}{P_p Q_{pq}}$. Since PDFs of $|h_q|^2$ and $|h_p|^2$ have the same form, following similar steps as those in the derivation of $F_{\gamma_p}(\gamma_{\text{th}p})$, we get

$$F_{|h_q|^2}[g(z)] = \sum_{k=0}^{\infty} \Xi_q \gamma(k+1, g(z)\beta_q), \tag{13}$$

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$$I_1 = \sum_{k=0}^{\infty} \Xi_q \sum_{n=0}^{\infty} \frac{(-1)^{n+r} \beta_q^w N_0^w \gamma_{\text{th}q}^{-l}}{n! w P_{\text{s}}^w Q_q^w \Gamma(m)} \sum_{l=0}^{\infty} \begin{pmatrix} -w \\ l \end{pmatrix} \frac{(1-\alpha)^l}{(-\alpha)^{w+l}} \sum_{r=0}^{\infty} \frac{(\xi\Delta)^{m+r}}{r!(m+r)} {}_2F_1(l, m+r; m+r+1; 1). \quad (14)$$

$$I_2 = \sum_{k=0}^{\infty} \Xi_q \sum_{n=0}^{\infty} \frac{(-1)^{n+r} \beta_q^w N_0^w \gamma_{\text{th}q}^{-l}}{n! w P_{\text{s}}^w Q_q^w \Gamma(m)} \sum_{l=0}^{\infty} \begin{pmatrix} -w \\ l \end{pmatrix} \frac{(1-\alpha)^l}{(-\alpha)^{w+l}} \sum_{r=0}^{\infty} \frac{(\xi\Delta)^{m+r}}{r!(m+r)} {}_2F_1(l, m+r; m+r+1; 1) \left[1 - \left(1 - \frac{1-\alpha}{\alpha\gamma_{\text{th}q}}\right)^{r+m}\right]. \quad (15)$$

where $\Xi_q = \frac{\alpha_q (m_q)_k \delta_q^k}{(k!)^2 \beta_q^{k+1}}$. By substituting (7), (13), and the expression of $g(z)$ into (12), expanding $\gamma(k+1, g(z)\beta_q)$ and $e^{-\xi x}$ into series representations with [13, Eq. (8.354.1)] and [13, Eq. (1.211.1)], respectively, and utilizing [13, Eq. (3.194.1)], I_1 defined in (12) can be derived as (14), in which $w = n + k + 1$ and ${}_2F_1(\cdot)$ represents the hypergeometric functions [13, Eq. (9.100.1)]. Then, based on (14), I_2 can be derived as (15) by applying the Newton-Leibniz formula $\int_a^b f(x)\,dx = F(b) - F(a)$. At last, I_3 can be derived by inserting (7) into (12) and applying [13, Eq. (3.381.1)], as

$$I_3 = \frac{\gamma\left(m, \xi\Delta\left(1 - \frac{1-\alpha}{\alpha\gamma_{\text{th}q}}\right)\right)}{\Gamma(m)}. \quad (16)$$

Substituting (9) and (12)–(16) into (11), we can obtain the OP of User q.

The OP of the considered network is defined as the event that neither User p nor User q can detect information reliably [9], i.e., $P_{\text{out}} = 1 - [1 - P_{\text{out}p}(\gamma_{\text{th}p})][1 - P_{\text{out}q}(\gamma_{\text{th}q})]$. Substituting (8) and (11) into this equation, we can directly obtain the OP of the proposed system.

B. Ergodic capacity

The ergodic capacity is defined as the expected value of the instantaneous end-to-end mutual information [3]. In this letter, it can be written as

$$\text{E}_{erg} = \text{E}[\log(1+\gamma_p)] + \text{E}[\log(1+\gamma_q)]. \quad (17)$$

Substituting (2) and (5) into (17), we have

$$\begin{aligned} &\text{E}[\log(1+\gamma_p)] \\ &\overset{(a)}{=} \frac{1}{\ln 2} \int_0^{\infty} G_{2,2}^{1,2} \left[\alpha P_{\text{s}} Q_p y / N_0 \,\middle|\, \begin{matrix} 1,1 \\ 1,0 \end{matrix} \right] f(y)\,dy \\ &\overset{(b)}{=} \frac{\alpha_p \beta_p^{-1}}{\ln 2\Gamma(m_p)} G_{1,[1:2],0,[2:2]}^{1,1,2,1,1} \left[\begin{matrix} \frac{-\delta_p}{\beta_p} \\ \\ \frac{\alpha P_s Q_p}{\beta_p N_0} \end{matrix} \,\middle|\, \begin{matrix} 1,1 \\ 1-m_p; 1,1 \\ -- \\ 0,0; 1,0 \end{matrix} \right], \end{aligned} \quad (18)$$

where $G[\cdot|\cdot]$ denotes the Meijer-G functions [13, Eq. (9.301)]. Here, (a) is obtained by expanding $\log(1+x)$ into Meijer-G functions with the aid of [14, Eq. (11)], (b) arises by expanding ${}_1F_1(a; b; c)$ in (2) into Meijer-G functions according to [13, Eq. (9.34.8)] and applying [15, Eq. (2.6.2)].

According to the output SINR at User q, we have

$$\text{E}[\log(1+\gamma_q)] = \min\{\text{E}[\log(1+\gamma_{p \to q})], \text{E}[\log(1+\gamma_q^1+\gamma_q^2)]\}. \quad (19)$$

We define Ψ_1 and Ψ_2 to denote the first and second expected values of (19), respectively. Based on (4) and the rules of Logarithm, Ψ_1 can de further derived as

$$\Psi_1 = \text{E}\left[\log\left(1 + \frac{P_s}{N_0} Q_p |h_p|^2\right)\right] - \text{E}\left[\log\left(1 + \frac{\alpha P_s}{N_0} Q_p |h_p|^2\right)\right]. \quad (20)$$

Note that the second expected value of (20) has been obtained by (18), the first term of (20) can also be derived by following similar steps. Since Ψ_2 consists of two different fading distributions and its PDF is mathematically intractable. Here, we seek to consider the approximation expression for Ψ_2, which can be obtained as [3]

$$\Psi_2 \approx \frac{1}{2\ln 2}\left[\ln\left(1 + \text{E}\left[\gamma_q^{\text{mrc}}\right]\right) - \frac{\text{E}\left[\left(\gamma_q^{\text{mrc}}\right)^2\right] - \left(\text{E}\left[\gamma_q^{\text{mrc}}\right]\right)^2}{2\left(1 + \text{E}\left[\gamma_q^{\text{mrc}}\right]\right)^2}\right], \quad (21)$$

where $\gamma_q^{\text{mrc}} = \gamma_q^1 + \gamma_q^2$. Due to the independence of $|h_q|^2$ and $|h_{pq}|^2$, we have $\text{E}[\gamma_q^{\text{mrc}}] = \text{E}[\gamma_q^1] + \text{E}[\gamma_q^2]$ and $\text{E}\left[(\gamma_q^{\text{mrc}})^2\right] = \text{E}\left[(\gamma_q^1)^2\right] + \text{E}\left[(\gamma_q^2)^2\right] + 2\text{E}[\gamma_q^1]\,\text{E}[\gamma_q^2]$. Firstly, we compute the η-order moments ($\eta = 1, 2$) of γ_q^1, as

$$\text{E}\left[(\gamma_q^1)^\eta\right] = \int_0^{\infty} \frac{(1-\alpha)^\eta P_{\text{s}}^\eta Q_q^\eta y^\eta}{(\alpha P_{\text{s}} Q_q y + N_0)^\eta} f(y)\,dy. \quad (22)$$

Expressing ${}_1F_1(m_q, 1, \delta_q y) = \sum_{k=0}^{\infty} \frac{(m_q)_k \delta_q^k}{(k!)^2} y^k$ according to [13, Eq. (9.100.1)] and utilizing [16, Eq. (2.3.6.9)], we can get

$$\begin{aligned} \text{E}\left[(\gamma_q^1)^\eta\right] &= \alpha_q \sum_{k=0}^{\infty} \frac{(1-\alpha)^\eta (m_q)_k \delta_q^k}{(k!)^2 (\alpha P_{\text{s}} Q_q N_0^{-1})^{1+k}} \Gamma(k+\eta+1) \\ &\times \Psi\left(k+\eta+1, k+2; \frac{\beta_q N_0}{\alpha Q_q P_{\text{s}}}\right), \end{aligned} \quad (23)$$

where $\Psi(\cdot)$ is the confluent Hypergeometric function [13, Eq. (9.210.2)]. Then, substituting (7) into (6) along with [13, Eq. (3.381.4)], the η-order moments of γ_q^2 can be derived as

$$\text{E}\left[(\gamma_q^2)^\eta\right] = \frac{P_p^\eta G_{pq}^\eta \Gamma(m+\eta)}{\Gamma(m)\xi^\eta \delta^{2\eta}}. \quad (24)$$

Thus, (21) can be obtained via (23) and (24) with $\eta = 1, 2$.

At last, by substituting (18) and (21) into (17), the ergodic capacity of the considered system can be obtained.

IV. NUMERICAL RESULTS

This section provides numerical results to corroborate our theoretical results and show the superiority of introducing the C–NOMA scheme to the HSTRNs. Here, we set the

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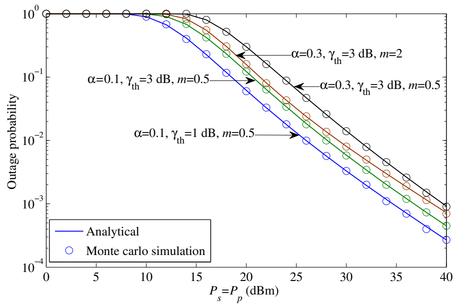
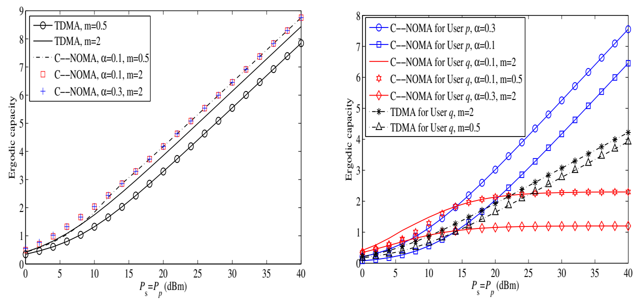


Fig. 1. The OP of the considered system versus $P_{\rm s}=P_p$ with various values of α, $\gamma_{\rm th}$, and m.



(a) (b)

Fig. 2. Ergodic capacity versus $P_{\rm s}=P_p$ with different values of α and m: (a) the sum capacity and (b) each user.

carried frequency to be 2 GHz, $G_s=52.1$ dBi, $\varphi_p=0.1^\circ$, $\varphi_q=0.8^\circ$, $\varphi_{p3{\rm dB}}=\varphi_{q3{\rm dB}}=0.3^\circ$, $u=2$, $d_{pq}=1$ Km, $\gamma_{{\rm th}p}=\gamma_{{\rm th}q}=\gamma_{\rm th}$, Ω=1, and $G_p=G_q=3.5$ dBi. Moreover, we assume that User p undergoes an infrequent light shadowing (ILS) with $(m_p, b_p, \Omega_p)=(19.4, 0.158, 1.29)$, while User q experiences a frequent heavy shadowing (FHS) with $(m_q, b_q, \Omega_q)=\left(0.739, 0.063, 8.97\times10^{-4}\right)$ [2], [12].

We first conduct numerical simulations to show the impact of various parameters on the OP performance of the considered network, as depicted in Fig. 1. It can be seen that the OP performance degrades when either the outage threshold $\gamma_{\rm th}$ increases, or the power allocation factor α increases, or the fading severity parameter m decreases. The reason behind is that an outage of the considered system happens when any user can not achieve a reliable detection, while the OP of User p given in (8) or that of User q given in (11) degrades as α or $\gamma_{\rm th}$ increases. Meanwhile, a more favourable condition is achieved when m is larger. Moreover, we can see that the analytical results agree well with the Monte Carlo simulations.

Then, we analyze ergodic capacity of two schemes. The ergodic sum capacity with different parameters is firstly studied in Fig. 2(a), from which we can see that the capacity curves with the C–NOMA scheme outperform those with the TDMA scheme. That is because in two time slots, multiple users can access in the C–NOMA scheme, while only one user whose direct link is deteriorated and helped by a DF relay node can be served with the TDMA scheme. Moreover, we note that the values of α and m have little effect on the proposed system performance. This phenomenon can be explained by the fact that the γ_q always equals to $\gamma_{p\rightarrow q}$ when $\gamma_{p\rightarrow q}\leq\gamma_q^1+\gamma_q^2$. Thus, the ergodic sum capacity of the proposed system can be derived as ${\rm E}_{erg}={\rm E}[\log(1+P_sQ_p\left|h_p\right|^2/N_0)]$. Furthermore, the ergodic capacities of each user are depicted in Fig. 2(b). As illustrated, capacity curves of User q with the C–NOMA scheme are first superior and then at some point inferior to those with the TDMA scheme. The point occurs at a lower transmit power for a larger α. This implies that with a suitable α, the performance of the user with deteriorated channel quality can be further improved with the C–NOMA scheme when the transmit power is not high. It can also be observed from Fig. 2(b) that the more power allocated to User p, i.e., α gets larger, the better the ergodic capacity of User p is, but the worse the performance of User q is.

V. CONCLUSIONS

In this letter, we have investigated the performance of downlink HSTRNs with the C–NOMA scheme. In particular, we have derived the exact expression for the OP of the considered system. Then, the ergodic capacity has also been analyzed. Simulation results have been provided to show the effect of different channel parameters, the power allocation factor, and the threshold on the system performance. Our findings suggest the superiority of intrducing the C–NOMA scheme in downlink HSTRNs.

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