Outage Performance of Cooperative MISO-NOMA Based Satellite-Terrestrial Networks

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2022 IEEE Wireless Communications and Networking Conference (WCNC) | 978-1-6654-4266-4/22/$31.00 ©2022 IEEE | DOI: 10.1109/WCNC51071.2022.9771787

***Abstract*—This paper studies the outage performance of a cooperative multiple-input single-output satellite-terrestrial network in which the satellite equipped with multiple antennas simultaneously serves two single antenna terrestrial users in a non-orthogonal manner, called MISO-NOMA. Specifically, the satellite utilizes the maximal-ratio transmission technique while the user with strong channel gain (called the strong user) assists to the user with weak channel gain (called the weak user) by acting as a decode-and-forward relay with prior knowledge of weak user. We assume that channels are subjected to Shadowed-Rician and Nakagami-m fading for the satellite and terrestrial links, respectively. In order to characterize the performance behavior of both users, outage probability expressions are derived. Theoretical results validated by simulations demonstrate that user-cooperation has more impact on the performance improvement of the weak user under heavy shadowing condition which is the most crucial channel effect in satellite-terrestrial environment. In addition, with the increasing number of antennas, the weak and strong users receive the best performance improvement in non-cooperation and user-cooperation cases, respectively.**

***Index Terms*—Satellite-terrestrial network, non-orthogonal multiple access, maximal-ratio transmission.**

I. Introduction

Given the explosively growth in the number of new generation smart devices, satellite communications are expected to provide massive connectivity in forthcoming wireless communication systems. Satellites not only provides vast coverage area and high-speed broadcasting but also ensures reliable communication especially in rural areas where the establishment of terrestrial base stations is inconvenient [1], [2]. However, under the consideration of serving multiple internet-of-things devices within a spot beam area, using the existing multiple access schemes (called orthogonal multiple access (OMA)) has caused inevitably degradation on the system performance due to the multiple access interference and also different resources have been allocated to each devices [3], [4]. On the other hand, non-orthogonal multiple access (NOMA), which has been regarded as a promising scheme in the last decade, provides higher spectral efficiency, throughput and low latency thanks to its inherent structure of serving multiple users simultaneously by allocating the same resource [5]. Thereby, exploiting NOMA scheme in satellite-terrestrial networks, which is expected to support many devices, has gained a great deal of interests in the literature to overcome above mentioned issues [6–8]. In [6] and [7] beamforming and power optimization issues have been addressed for downlink NOMA based satellite-terrestrial networks. In [8], the authors have investigated ergodic capacity performance of an uplink NOMA scheme, where users are located randomly, in satellite networks by considering effects of imperfect channel state information (CSI).

In addition, utilizing cooperation (relayed or user-assisted) in NOMA based satellite networks has been widely considered to mitigate possible diverse masking effects on users. In [9], the authors analyze a NOMA based satellite network, where a terrestrial dedicated amplify-and-forward relay is considered to assist multiple users, in terms of outage probability (OP). Also, in order to increase effectiveness of the relay and reliability of users, maximum-ratio combining (MRC) and maximal-ratio transmission (MRT) schemes are also applied at the relay. In [10], the authors consider utilizing a dedicated decode-and-forward (DF) relay to assist weak user in a two-user NOMA based satellite network. By employing MRC and MRT at the relay, the authors provide OP expressions for the system performance measure. On the other hand, the authors of [11] investigate user-assisted cooperation in NOMA based satellite networks, where all nodes are equipped with single antenna, and OP expressions are derived to illustrate performance behavior. However, MRC is used to combine the signals received from direct and relayed links which increases the hardware complexity of the weak user.

Inspired by the above mentioned studies of [10] and [11], in this paper, we investigate the OP performance of cooperative multiple-input single-output (MISO) NOMA based satellite network, where the strong user acts as a DF relay to improve the weak user's reliability. We consider applying MRT scheme at the satellite to exploit benefits of spatial diversity. Also, selection combining (SC) scheme is utilized at the weak user, which has less complexity than MRC scheme. Moreover, we conduct the analyses for the model of Shadowed-Rician fading characterizing satellite-terrestrial links as proposed in [12]. This model not only offers analytical tractability to predict the system performance behavior but also characterize the satellite channel very accurately when compared to other models. In order to illustrate the system performance improvement, exact OP expressions of all users are derived.

II. System Model

We consider a cooperative satellite-terrestrial network as shown in Fig. 1, where the satellite (S) with N_S antennas serves two single antenna terrestrial users (U_1 and U_2) within

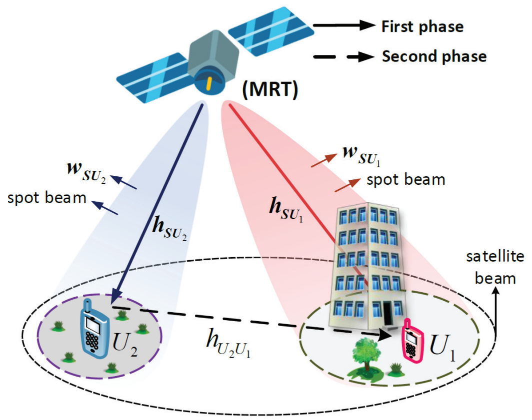


Fig. 1: System model of satellite-terrestrial network.

single beam by applying NOMA scheme[1]. Particularly, in the first phase, the satellite utilizes MRT technique consisting of two spot beams since it is optimum transmit beamforming scheme in case of perfect CSI[2]. On the other hand, in the second phase, the strong user (U_2) assists to the weak user (U_1) by acting as a half-duplex DF relay since we assume that the weak user is corrupted by obstacles blocking the signal sent from the satellite. Then, the received signals come from the satellite and terrestrial links are combined at the U_1 by applying SC scheme[3].

In the first phase, the satellite superimposes symbols corresponding to both users by applying NOMA principle as $\mathbf{s} = \sqrt{a_1 P_S}\mathbf{w}_{SU_1} s_1 + \sqrt{a_2 P_S}\mathbf{w}_{SU_2} s_2$, where s_1 and s_2 are the symbols intended to the U_1 and U_2 with average powers as $E[|s_1|^2] = E[|s_2|^2] = 1$. Here, a_1 and a_2 are power levels allocated to the U_1 and U_2 subjected to $a_1 + a_2 = 1$, respectively, and P_S is the transmit power of the satellite. Also, $\mathbf{w}_k = \{\mathbf{h}_k^H / \|\mathbf{h}_k\|\}_{\{N_S \times 1\}}$ (H: Hermitian transpose and $\|\cdot\|$: Euclidean norm) is the transmit beamforming weight vector of the link $k \in \{SU_1, SU_2\}$ subjected to $\|\mathbf{w}_k\|^2 = 1$, where $\mathbf{h}_k = \{h_k^i\}_{1 \times N_S}$ $(1 \leq i \leq N_S)$ is the channel coefficient vector of the link k. Then the received signal at any user in the first phase can be expressed as

$$y_k = g_k \mathbf{h}_k \mathbf{s} + n_k, \tag{1}$$

where $n_k \sim CN(0, \sigma_k^2)$ is the complex Gaussian noise. Here, $g_k = \sqrt{L_k G_S G_k(\theta_k)}$ is the radio propagation loss in the link k, where $L_k = (L_{FS}/(\kappa_B T W))$ represents the radio propagation path-loss[4]. $L_{FS} = (c/(4\pi f_c d))^2$ is the free-space path loss component, where c and f_c are light speed and carrier frequency, respectively, while d is distance between the satellite and any user. Also, $\kappa_B = 1.38 \times 10^{-23}$ J/K, T and W denote the Boltzman constant, noise temperature at receivers and bandwidth, respectively [15]. G_S denotes the antenna gain of the satellite while $G_k(\theta_k)$ represents the beam gain related to the link k which can be expressed as $G_k(\theta_k) = G_k \left(\frac{J_1(u_k)}{2u_k} + 36\frac{J_3(u_k)}{u_k^3}\right)^2$ [8]. Herein, G_k and $J_n(\cdot)$ denote the antenna gain of the user within link k and the first-kind Bessel function with the nth order [16, eq.(8.402)], respectively. θ_k is the angle between the related user and beam center respectively to the satellite, while $u_k = 2.07123 sin(\theta_k)/sin(\theta_{k-3dB})$ in which θ_{k-3dB} denotes one sided half-power beamwidth.

In the second phase, U_2 transmits the decoded symbol of U_1. During the second phase, we assume the satellite is silent, thus U_1 receives information from only U_2. Therefore, the received signal at U_1 can be written as $y_{U_2U_1} = \sqrt{P_{U_2}} h_{U_2U_1} s_1 + n_{U_2U_1}$. Here, P_{U_2} and $n_{U_2U_1} \sim CN(0, \sigma_{U_2U_1}^2)$ are the transmit power of U_2 and complex Gaussian noise, respectively. Also, $h_{U_2U_1}$ denotes the channel coefficient between the U_2 and U_1.

A. Channel Models

We assumed that all the users are served by single beam of the satellite, however channel gains between each user and the satellite can exhibit significant disparities since the users have different locations and environmental masking effects. In addition, given the ability of the satellite in using very large bandwidth, a considerable amount of data can be transmitted over coherence time under effect of constant channel gain [17]. Therefore, channels in the satellite link are assumed to be independent and identically distributed (i.i.d.) Shadowed-Rician fading. The probability density function (PDF) of the effective channel gain between the ith antenna of the satellite and any user can be given by $f_{|h_k^i|^2}(x) = \alpha_k \exp(-\beta_k x) {}_1F_1(m_k; 1; \delta_k x)$, $x \geq 0$, where $\alpha_k = (2b_k m_k/(2b_k m_k + \Omega_k))^{m_k}/(2b_k)$, $\beta_k = 0.5/b_k$ and $\delta_k = \Omega_k/(2b_k(2b_k m_k + \Omega_k))$ [12][5]. ${}_1F_1(\cdot;\cdot;\cdot)$ represents the confluent hypergeometric function [16, eq.(9.100)]. Throughout the paper, integer values of m_k have been considered to simplify the theoretical analysis. Thus, by using the series expansion, $f_{|h_k^i|^2}(x)$ can be simplified as $f_{|h_k^i|^2}(x) = \alpha_k \sum_{p=0}^{m_k-1} \vartheta(p) x^p \exp(-(\beta_k - \delta_k)x)$ [18], where $\vartheta(p) = ((-1)^p (1-m_k)_p \delta_k^p)/(p!)^2$ and $(\cdot)_p$ is the Pochhammer symbol.

On the other hand, since channels between U_2 and U_1 are assumed to be distributed as i.i.d. Nakagami-m fading, the corresponding cumulative distribution function (CDF) of any effective channel gain can be expressed as $F_{|h_{U_2U_1}|^2}(x) = 1-$

[1]Here, the reason to equip users with single antenna is that we assume users as small devices whose structures may not allow to deploy more antennas. Also, we assume two-user NOMA scheme since it is included Long Term Evolution Advanced Releases for the next generations [13] and deploying more than two users in a cluster has been demonstrated to cause lower sum rate by the conducted works in the literature [14].

[2]It is worth noting that we assume perfect CSIs are available at the satellite, therefore, it is reasonable to apply MRT technique thanks to its optimum benefits. Conversely, in case of imperfect CSIs, novel optimized beamforming approaches are required for the investigated system, which have been considered in the future works.

[3]Note that, MRC can be also applied, however, it will increase the hardware complexity of the weak user that is not beneficial in the scope of the considered system.

[4]Hereafter, we assume that $L_k = L$ since both users are exposed to the similar free space path-loss due to receiving the service within single beam of the satellite [11].

[5]Note that $2b_k$ and Ω_k denote the average powers of multipath and line-of-sight components while $m_k > 0$ is the Nakagami-m fading parameter in the link k.

$exp\left(-x\frac{m_{U_2U_1}}{\Omega_{U_2U_1}}\right)\sum_{r=0}^{m_{U_2U_1}-1}\left(x\frac{m_{U_2U_1}}{\Omega_{U_2U_1}}\right)^r\frac{1}{r!}$. Here, $\Omega_{U_2U_1} = E[|h_{U_2U_1}|^2]$ is the average power and $m_{U_2U_1}$ denote the Nakagami-m parameter which is considered to take integer values in this paper.

III. Outage Performance Analysis

In this section, firstly, end-to-end instantaneous signal-to-interference-plus-noise ratios (SINRs) and signal-to-noise ratio (SNR) corresponding to satellite and terrestrial links are respectively obtained. Then, by using the provided SINRs and SNR, exact OP expressions of U_2 and U_1 are derived individually.

A. End-to-end Instantaneous SINR and SNR Derivations

According to NOMA principle in terms of user ordering based on the effective channel qualities, we assume that $\|\mathbf{h}_{SU_1}\|^2 \leq \|\mathbf{h}_{SU_2}\|^2$ and thus the allocated power levels are determined as $a_1 \geq a_2$ [13]. Here, the strong user (with a better channel condition) needs to apply successive interference cancellation (SIC) method to extract the information of the weak user (with a worse channel condition) from the received signal. The weak user U_1 will decode its own signal by treating information of U_2 as a noise without applying any SIC. Thus, instantaneous SINR at U_1 in the first phase is obtained as

$$\gamma_{SU_{1\to1}} = \frac{LG_SG_{SU_1}(\theta_{SU_1})\|\mathbf{h}_{SU_1}\|^2a_1P_S}{LG_SG_{SU_1}(\theta_{SU_1})\|\mathbf{h}_{SU_1}\|^2a_2P_S+\sigma_{SU_1}^2}. \quad (2)$$

On the other hand, the strong user U_2 will first decode the signal corresponding to U_1. Thus, by considering the perfect SIC method can be carried out, instantaneous SINR that U_2 can detect the signal of U_1 can be expressed as

$$\gamma_{SU_{2\to1}} = \frac{LG_SG_{SU_2}(\theta_{SU_2})\|\mathbf{h}_{SU_2}\|^2a_1P_S}{LG_SG_{SU_2}(\theta_{SU_2})\|\mathbf{h}_{SU_2}\|^2a_2P_S+\sigma_{SU_2}^2}. \quad (3)$$

Afterwards, U_2 can decode its own signal by extracting the information of U_1 from the received signal, so the instantaneous SINR can be obtained as

$$\gamma_{SU_{2\to2}} = \frac{LG_SG_{SU_2}(\theta_{SU_2})\|\mathbf{h}_{SU_2}\|^2a_2P_S}{\sigma_{SU_2}^2}. \quad (4)$$

In the second phase of the transmission, U_2 forwards the decoded signal corresponding to U_1, thus the instantaneous SNR at U_1 can be written as $\gamma_{U_2U_1} = P_{U_2}|h_{U_2U_1}|^2/\sigma_{U_2U_1}^2$.

B. Outage Probability Derivations

In terms of U_2, an outage occurs when the U_2 can not decode the signal of U_1 or its own signal. Thus, we can formulate the OP for U_2 as follows:

$$P_{U_2}^{out} = 1 - Pr(\gamma_{SU_{2\to1}} > \gamma_{th}^{U_1}, \gamma_{SU_{2\to2}} > \gamma_{th}^{U_2}), \quad (5)$$

where $\gamma_{th}^{U_l} = 2^{R_{U_l}} - 1$ is threshold SINR intended for lth user and R_l denotes the bits per channel in use (BPCU). Let $\Theta_k \triangleq LG_SG_k(\theta_k)$ is defined, and $\sigma_k^2 = \sigma_{U_2U_1}^2 = \sigma^2$ and $P_S = P_{U_2} = P$ are assumed for mathematical simplicity, thus the event of $\{\gamma_{SU_{2\to1}} > \gamma_{th}^{U_1}\}$ can be obtained as $\left\{\Theta_{SU_2}\|\mathbf{h}_{SU_2}\|^2 > \frac{\gamma_{th}^{U_1}}{\bar{\gamma}(a_1-a_2\gamma_{th}^{U_1})}\right\}$ subjected to $a_1 - a_2\gamma_{th}^{U_1} > 0$ by using (3). Here, $\bar{\gamma} = P/\sigma^2$ is the average SNR. On the other hand, the event of $\{\gamma_{SU_{2\to2}} > \gamma_{th}^{U_2}\}$ can be found as $\left\{\Theta_{SU_2}\|\mathbf{h}_{SU_2}\|^2 > \gamma_{th}^{U_2}/(a_2\bar{\gamma})\right\}$ by using (4). If we substitute the obtained events into (5), OP of U_1 can be mathematically expressed as

$$\begin{aligned} P_{U_2}^{out} &= 1 - Pr\left(\Theta_{SU_2}\|\mathbf{h}_{SU_2}\|^2 > \varpi^*\right) \\ &= F_{\|\mathbf{h}_{SU_2}\|^2}^{(2)}\left(\frac{\varpi^*}{\Theta_{SU_2}}\right), \end{aligned} \quad (6)$$

where $\varpi^* = \max\left\{\frac{\gamma_{th}^{U_1}}{\bar{\gamma}(a_1-a_2\gamma_{th}^{U_1})}, \frac{\gamma_{th}^{U_2}}{a_2\bar{\gamma}}\right\}$. Also, $F_X^{(l)}(x)$ denotes CDF of the lth order of a random variable X. Since U_2 has the highest channel gain, its order will be 2 over 2. Then, with the help of order statistics property given by [19], we obtain $F_{\|\mathbf{h}_{SU_2}\|^2}^{(2)}\left(\frac{\varpi^*}{\Theta_{SU_2}}\right) = \left[F_{\|\mathbf{h}_{SU_2}\|^2}\left(\frac{\varpi^*}{\Theta_{SU_2}}\right)\right]^2$. To derive the OP of U_2, we need to express statistics of the random variable $\|\mathbf{h}_{SU_2}\|^2$ which comes from MRT beamforming in the first phase. Let $\|\mathbf{h}_k\|^2$ be effective channel gain in link k, thus the CDF can be obtained as [9]

$$F_{\|\mathbf{h}_k\|^2}(x) = 1 - \sum_{p_1^k=0}^{m_k-1}\cdots\sum_{p_{N_S}^k=0}^{m_k-1}\sum_{u=0}^{\Delta_k-1}\frac{\Psi(N_S)\Gamma(\Delta_k)x^u}{u!\zeta_k^{\Delta_k-u}e^{\zeta_k x}}, \quad (7)$$

where $\Delta_k = \sum_{q_1=1}^{N_S}p_{q_1}^k + N_S$, $\zeta_k = \beta_k - \delta_k$ and $\Psi(N_S) = \alpha_k^{N_S}\prod_{q_1=1}^{N_S}\vartheta(p_{q_1}^k)\prod_{q_2=1}^{N_S-1} \quad B\left(\sum_{q_3=1}^{q_2}p_{q_3}^k + q_2, p_{q_2+1}^k + 1\right)$. Here, $B(\cdot,\cdot)$ represents the Beta function given by [16, eq.(8.384.1)]. Finally, if we substitute $F_{\|\mathbf{h}_{SU_2}\|^2}^{(2)}\left(\frac{\varpi^*}{\Theta_{SU_2}}\right)$ into (6) by using the CDF in (7), we obtain the OP of U_2 as given at the bottom of this page (see (8)). In order to get (8), property of binomial expansion given by [16, eq.(1.111)] is used.

In terms of U_1, there are two outage events can occur, one of them is in the direct link and the other one is in the relayed link. Outage event in the direct link can be defined as U_1 can not decode its own signal. Note that U_1 does not apply SIC. The other outage event is that U_2 fails to decode the signal of U_1 or U_1 fails to decode its own signal from the received information in the cooperation link. Thus, based on the SC technique applied at U_1, we can express the OP of U_1 mathematically as

$$P_{U_1}^{out} = P_{U_1}^{dir}P_{U_1}^{relayed}, \quad (9)$$

$$P_{U_2}^{out} = \sum_{b_1=0}^{2}\binom{2}{b_1}(-1)^{2-b_1}\left(\sum_{p_1^{SU_2}=0}^{m_{SU_2}-1}\cdots\sum_{p_{N_S}^{SU_2}=0}^{m_{SU_2}-1}\sum_{u=0}^{\Delta_{SU_2}-1}\frac{\Psi(N_S)\Gamma(\Delta_{SU_2})(\varpi^*/\Theta_{SU_2})^u}{u!\zeta_{SU_2}^{\Delta_{SU_2}-u}e^{\zeta_{SU_2}\frac{\varpi^*}{\Theta_{SU_2}}}}\right)^{2-b_1} \quad (8)$$

$$P_{U_1}^{dir} = 1 - \left(\sum_{p_1^{SU_1}=0}^{m_{SU_1}-1} \cdots \sum_{p_{N_S}^{SU_1}=0}^{m_{SU_1}-1} \sum_{u=0}^{\Delta_{SU_1}-1} \frac{\Psi(N_S)\Gamma(\Delta_{SU_1})(\omega_{U_1}/\Theta_{SU_1})^u}{u!\zeta_{SU_1}^{\Delta_{SU_1}-u} e^{\zeta_{SU_1}\frac{\omega_{U_1}}{\Theta_{SU_1}}}} \right)^2 \tag{13}$$

$$Pr(\gamma_{SU_{2\to1}} > \gamma_{th}^{U_1}) = \sum_{b_2=0}^{2} \binom{2}{b_2} (-1)^{2-b_2} \left(\sum_{p_1^{SU_2}=0}^{m_{SU_2}-1} \cdots \sum_{p_{N_S}^{SU_2}=0}^{m_{SU_2}-1} \sum_{u=0}^{\Delta_{SU_2}-1} \frac{\Psi(N_S)\Gamma(\Delta_{SU_2})(\omega_{U_1}/\Theta_{SU_2})^u}{u!\zeta_{SU_2}^{\Delta_{SU_2}-u} e^{\zeta_{SU_2}\frac{\omega_{U_1}}{\Theta_{SU_2}}}} \right)^{2-b_2} \tag{15}$$

where $P_{U_1}^{dir}$ and $P_{U_1}^{relayed}$ are the OPs occur in the direct and relayed links, respectively, and can be formulated as

$$P_{U_1}^{dir} = 1 - Pr(\gamma_{SU_{1\to1}} > \gamma_{th}^{U_1}), \tag{10}$$

$$P_{U_1}^{relayed} = 1 - Pr(\gamma_{SU_{2\to1}} > \gamma_{th}^{U_1})Pr(\gamma_{U_2U_1} > \gamma_{th}^{U_1}). \tag{11}$$

(11) is obtained by following the outage event and DF relaying protocol given by $P_{U_1}^{relayed} = Pr(\min\{\gamma_{SU_{2\to1}}, \gamma_{U_2U_1}\} \leq \gamma_{th}^{U_1})$. If we substitute (2) into (10), we obtain

$$\begin{aligned} P_{U_1}^{out} &= Pr\left(\|\mathbf{h}_{SU_1}\|^2 \leq \frac{\omega_{U_1}}{\Theta_{SU_1}}\right) \\ &= F^{(1)}_{\|\mathbf{h}_{SU_1}\|^2}\left(\frac{\omega_{U_1}}{\Theta_{SU_1}}\right), \end{aligned} \tag{12}$$

where $\omega_{U_1} = \gamma_{th}^{U_1}/(\bar{\gamma}(a_1 - a_2\gamma_{th}^{U_1}))$ and (12) is valid for $a_1 - a_2\gamma_{th}^{U_1} > 0$. Since U_1 has the lowest channel gain, its order will be 1 over 2. By using the property of order statistics given in [19], we obtain $F^{(1)}_{\|\mathbf{h}_{SU_1}\|^2}(\frac{\omega_{U_1}}{\Theta_{SU_1}}) = 1-(1-F_{\|\mathbf{h}_{SU_1}\|^2}(\frac{\omega_{U_1}}{\Theta_{SU_1}}))^2$. With the help of (7), OP of U_1 in the direct link can be derived as given at the top of this page (see (13)). On the other hand, by substituting (3) into $Pr(\gamma_{SU_{2\to1}} > \gamma_{th}^{U_1})$, we obtain

$$\begin{aligned} Pr(\gamma_{SU_{2\to1}} > \gamma_{th}^{U_1}) &= Pr\left(\|\mathbf{h}_{SU_2}\|^2 > \frac{\omega_{U_1}}{\Theta_{SU_2}}\right) \\ &= 1 - F^{(2)}_{\|\mathbf{h}_{SU_2}\|^2}\left(\frac{\omega_{U_1}}{\Theta_{SU_2}}\right). \end{aligned} \tag{14}$$

By substituting the CDF given in (7) into (14) and by using the property of order statistics [19] and binomial expansion [16, eq.(1.111)], (14) can be re-expressed as given at the top of this page (see (15)). Also, with the help of the CDF $F_{|h_{U_2U_1}|^2}(x)$ provided previously, we can obtain $Pr(\gamma_{U_2U_1} > \gamma_{th}^{U_1}) = 1 - F_{|h_{U_2U_1}|^2}(\gamma_{th}^{U_1}/\bar{\gamma})$. Finally, by substituting (13), (15) and $Pr(\gamma_{U_2U_1} > \gamma_{th}^{U_1})$ together with (11) into (9), the OP of U_1 can be obtained.

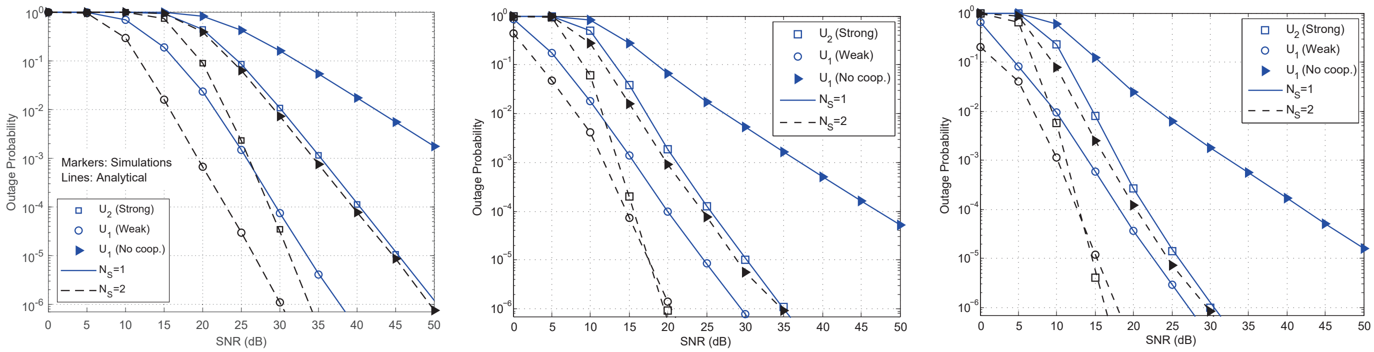
IV. Numerical Results

In this section, analytical results validated by simulations are illustrated. In all Figs., markers and lines indicate simulation and analytical results, respectively. Parameters for both users are set as $a_1 = 3/4$ and $a_2 = 1/4$ for power levels, while $R_{U_1} = 0.2$ and $R_{U_2} = 0.4$ BPCUs for target rates. To be more representative, Strong (user with higher channel gain), Weak (user with lower channel gain) and No coop. (means no cooperation for the weak user) are used. For terrestrial channels, Nakagami-m fading parameters are set as $m_{U_2U_1} = 1$ and $\Omega_{U_2U_1} = 1$. For satellite channel environment, Shadowed-Rician fading parameters are determined as $(m_k = 1; b_k = 0.063; \Omega_k = 8.97\times10^{-4})$ for heavy shadowing (HS), $(m_k = 10; b_k = 0.126; \Omega_k = 0.835)$ for average shadowing (AS) and $(m_k = 20; b_k = 0.158; \Omega_k = 1.29)$ for light shadowing (LS) in terms of both users. Furthermore, we also set $f_c = 2$ GHz, $d = 35786$ km, $W = 15$ MHz, $T = 500°$ K, $G_S = 46$ dBi, $G_{SU_1} = G_{SU_2} = 3.5$ dBi, $\theta_{SU_1} = 0.6°$, $\theta_{SU_2} = 0.1°$, $\theta_{SU_1-3dB} = \theta_{SU_2-3dB} = 0.4°$, respectively, for the geostationary (GEO) satellite [15].

Fig. 2 represents the OP performances of users versus average SNR for (a) HS, (b) AS and (c) LS, respectively, in case of $N_S = 1$ and $N_S = 2$. Also, in order to demonstrate the superiority of the investigated cooperative scheme, curves of non-cooperation (No coop.) scenario are also depicted. As seen in all figures, with the strong user's (U_2) cooperation, the weak user's (U_1) performance can be significantly improved when compared to non-cooperation case. Exemplarily, for an OP value of 10^{-3} and $N_S = 1$, 27 dB SNR gain can be achieved for HS while 22 dB and 18.5 dB SNR gains for AS and LS conditions, respectively. This implies that user cooperation is more effective on the performance improvement under the HS condition which is crucial channel effect when the urban area is considered. On the other hand, as the number of antenna at the satellite increases, U_2 enjoys more performance improvement than U_1 in case of cooperative scenario, such that OP performance of U_2 approaches to that of U_1 at low OP values. Moreover, in case of HS and LS conditions, U_2 exhibits better performance than U_1 at OP values below than 10^{-6}. It is worthy noting that the reason of this observation is that since U_2 has the higher channel gain, it receives better beamforming effect and diversity gain thanks to the benefits of MRT scheme. In addition, for non-cooperation case, U_1 exhibits the best performance improvement when $N_S = 2$ and $N_S = 1$ configurations are compared.

V. Conclusion

In this study, we analyzed the OP performance of a cooperative MISO-NOMA based satellite-terrestrial network, where the strong user assists to the weak user. MRT and SC schemes were considered at the satellite and weak user, respectively, to exploit the benefits of spatial diversity. The exact OP



(a) (b) (c)

Fig. 2: Outage probability performances of users versus average SNR: (a) HS, (b) AS and (c) LS.

expressions were derived for both users. The obtained results demonstrate that user-cooperation brings a significant performance improvement to the weak user in a satellite-terrestrial communication scenario, such that the highest SNR gain can be achieved even under HS environment condition. Moreover, with the increasing number of antennas at the satellite, it is observed that the weak user receives the best performance improvement according to non-cooperation case while the strong user enjoys more performance gain than the weak user in case of cooperative scenario thanks to the benefits of MRT scheme. We also figured out that channel effects in satellite links are quite crucial in a performance perspective. Therefore, in the scope of future works, including the other channel effects can be very interesting by also considering some sub-optimal beamforming approaches.

ACKNOWLEDGMENTS

This work was supported by the Institute of Information & Communications Technology Planning & Evaluation (No. 2021-0-00260) grant, and the Basic Science Research Programs under the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (No. 2021R1A4A1030775).

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