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Outage Performance Analysis of Reconfigurable Intelligent Surfaces-Aided NOMA Under Presence of Hardware Impairment

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ABSTRACT The future of wireless communications looks exciting with the potential new use cases and challenging requirements of future 6th generation (6G) wireless networks. Since the traditional wireless communications, the propagation medium has been perceived as a randomly behaving entity between the transmitter and the receiver, which degrades the quality of the received signal due to the uncontrollable interactions of the transmitted radio waves with the surrounding objects. The recent advent of reconfigurable intelligent surfaces (RIS) in wireless communications enables, on the other hand, network operators to control the radio waves (the scattering, reflection, and refraction characteristics) to eliminate the negative effects of natural wireless propagation. Recent results have revealed that non-orthogonal multiple access (NOMA) benefits from RIS mechanism which can effectively provide effective transmissions. Motivated by the potential of these emerging technologies, we study the impact of hardware impairment in RIS-aided NOMA system in term of performance metrics. We then derive analytical expressions of outage probability and throughput as main performance metrics. Simulations are conducted to validate the analytical expressions. We find that the number of meta-surfaces in RIS, transmit power at the base station, power allocation factors play important role to demonstrate improvement in system performance of RIS relying on NOMA compared with orthogonal multiple access (OMA). Numerical results are presented to validate the effectiveness of the proposed RIS-aided NOMA transmission strategies.

INDEX TERMS Reconfigurable intelligent surfaces, non-orthogonal multiple access, outage probability, throughput.

I. INTRODUCTION

As a promising architecture to improve the energy and spectral efficiency, intelligent reflecting surface (IRS) or so-called as reconfigurable intelligent surface (RIS) are introduced to intergrate to emerging wireless networks [1]–[3]. The most advantage of RIS falls in its artificial planar passive radio array approach which exhibits high efficient in term of cost-effective and energy consumption. In particular, by imposing an independent phase shift to the incident signal, the IRS-adied cellular systems reconfigure each passive element in RIS to vary the channels between the base station (BS) and mobile users constructively or destructively. By jointly optimizing the active beamforming at the BS and the passive beamforming at the IRS, IRS is considered as an driver for improving the spectral and energy Efficiency for IRS-aided wireless systems [4]–[11].

By optimizing the active beamforming at the transmitter and the RIS, the authors in [12] and [13] presented maximal received signal power for a multiple input single output (MISO) strategy. Such technique is performed by adjusting its phase shifters together with enabling active and passive beamforming at the transmittter and RIS respectively. In [14], the authors explored the RIS-aided offshore system to provide high-speed data service and a cost-effective coverage. In particular, to enhance the signal quality at the

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vessels the shipborne RIS is replaced by offshore, and the coastal base station is equipped with low-cost reconfigurable reflect-arrays (RRAs) without using the traditional costly fully digital antenna arrays (FDAAs). In [15], the multi-user RIS system was studied in downlink by employing a multi-antenna base station (BS) which sends information to various users to maximize benefits from the RIS reflecting the incident signals. A wideband RIS-assisted single-input multiple-output (SIMO) scheme is used in [16] to employ orthogonal frequency division multiplexing (OFDM) for communication systems, in which one can divide each transmission frame into multiple sub-frames to execute channel estimation in same time with passive beamforming.

To deal with the growing demand for wireless access, the fixed multiple access techniques satisfying orthogonality in time, code and frequency requirements corresponding to time division multiple access (TDMA), code division multiple access (CDMA), and frequency division multiple access (FDMA). In order to overcome existing challenges in the fifth generation (5G) of wireless systems, the concept of non-orthogonal multiple access (NOMA) is explored as new approach for multiple access which have recently emerged with current wireless systems [17]–[24]. The advantage of cooperative network [25] is included in NOMA such as studies in [20], [21], [23], [24]. In power-domain NOMA, each subcarrier is shared for multiple users and allocating different power levels to the users is recognized as way to achieve the diversity on that subcarrier. Following the principle of NOMA, system can offer the difference in channel gains among users. In the scenario of a two-user NOMA, the user with higher channel gain (the first user) is assigned with the lower power level compared to the user with lower channel gain (the second user). Then, the transmitter sends information of different users by superimposing signals. Despite significant advantages of NOMA reported in [26], [27], several practical difficulties need be tackled before NOMA can be effectively deployed. One such challenge need be considered, i.e. the sensitivity of NOMA to hardware impairments [28]. Another major challenge is resource management in multi-cell multiple-input multiple-output NOMA (MIMO-NOMA) by high computational complexity, flexible clustering, and potential channel correlation [29]. Indeed, a typical NOMA transceiver requires the high cost of MIMO implementation. Moreover, the system performance of NOMA can be substantially limited when there are more than two users served in a cluster. Clearly, these practical issues make it difficult to solely rely on NOMA, particularly, when the massive connections and larger coverage are required in emerging networks. In next section, we will present potentials to integrate with NOMA to improve system performance.

A. RELATED WORK

The integration of RIS to multiple access networks is a cost-effective scheme for enlarging network coverage/connections and boosting spectrum/energy efficiency. In [30], the authors presented theoretical performance comparison between RIS-assisted downlink communications relying on NOMA and orthogonal multiple access (OMA). They also considered the transmit power minimization problems under the discrete unit-modulus reflection constraint on each RIS element. The RIS is deployed to construct a strong combined channel gain at the cell-edge user. Furthermore, while RIS makes a smart radio environment by using surfaces with capable of manipulating the propagation of incident electromagnetic waves in a programmable manner to actively alter the channel realization. By enabling both NOMA and RIS in unique system, wireless channels could be into a controllable system block that can be optimized to enhance overall system performance, especially for system with massive connections. Reference [31] investigated on the usage of RIS ultra reliable and low latency communications (URLLC) system in uplink and proposed a compressive sensing based RIS-based multiple user detection approach to exhibit the sparsity and relativity characteristics of user signal in URLLC system. A combined-channel-strength (CCS) based user ordering scheme is first proposed in [32]. They further provided optimal value of the minimum decoding signal-to-interference-plus-noise-ratio (SNDR) of all users to optimize the rate performance and ensure user fairness. In particular, they jointly optimized both the phase shifts at the RIS and the power allocation at the base station. In [33], they employed conventional spatial division multiple access (SDMA) adopted at the base station to achieve orthogonal beams by enabling the spatial directions of the near users' channels. By aligning the cell-edge users' effective channel vectors with the predetermined spatial directions, RIS-assisted NOMA is implemented to ensure that additional cell-edge users served on these beams. However, a few paper considered how RIS systems integrate with NOMA, and references [30]–[33] motivate us to explore performance of RIS-aided NOMA systems.

The main contributions of this paper are as follows

- Different from [34], [35], this paper presents a RIS-aided NOMA system in downlink to achieve benefits from NOMA to communicate simultaneously with their corresponding destinations via a RIS. It is assumed that the RIS is in the form of a reflect-array comprising N simple and reconfigurable reflector elements, and controlled by a communication oriented software. Unlike other published work dealing with the calculation of symbol error probability (SEP) [36], our work provides outage performance evaluation of the RIS-aided NOMA system in the presence of hardware impairments.
- The closed-form expressions of outage probability for the RIS-aided NOMA system are derived. Since they are formulated in terms of various system parameters, the effect of each system parameter on the outage probability can be numerically evaluated. For instance, the effect of the number of metasurfaces in RIS on the outage probability can be evaluated to how the system can improve its performance in practice. It is demonstrated

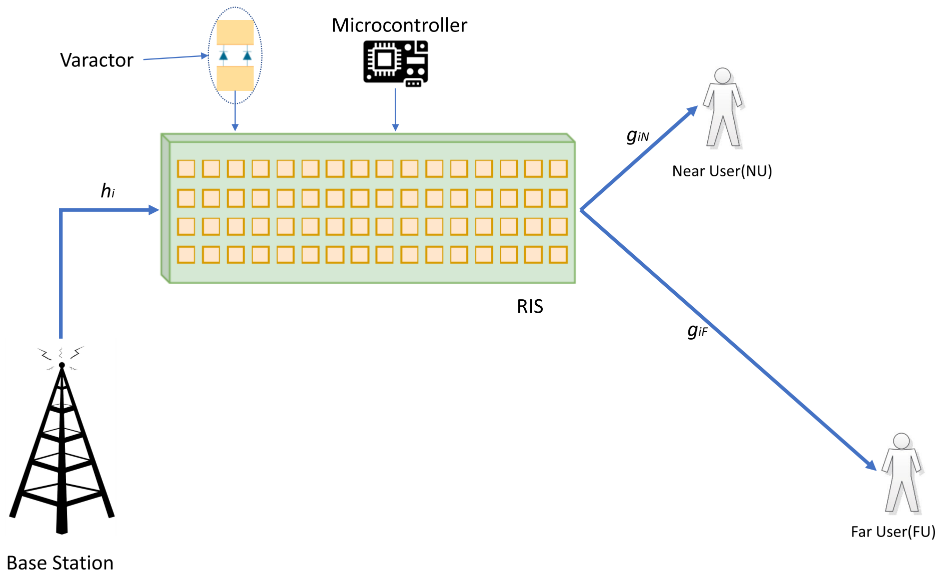

FIGURE 1. System model of RIS-aided NOMA.

in this work that the outage probability of the system mainly relying on the number of metasurfaces in RIS.

- The derivations of asymptotic outage probabilities at high transmit signal to noise ratio (SNR) for two users are also provided as an important evaluation to design such the RIS-aided NOMA system in practice. Furthermore, compared with orthogonal multiple access (OMA)-assisted RIS system, the considered system exhibits more benefits and it becomes prominent candidate to implement for forthcoming networks.

The remainder of this paper is structured as follows. In Section II, the system model of the the RIS-aided NOMA is introduced under the presence of hardware impairment. In Section III, the closed-form expressions of outage probability are derived for such system relying on decoding order scheme in NOMA. Section IV gives simulation results and corresponding performance analysis, followed by conclusions and future directions in Section V.

II. SYSTEM MODEL

We consider the RIS-aided NOMA as depicted in Fig. 1, in which the base station (S) intends to communicate with two destinations. These users are classified as the far user (FU) and near user (NU). To achieve simple design and low cost, we assume that all nodes equipped a single-antenna while a RIS consists of N meta-surfaces. We denote h_i, g_{iN} and g_{iF} as the baseband equivalent fading channels between S and the i-th element in the RIS, channels from the i-th element in the RIS to NU and FU as respectively. These channels are assumed to be independent, identical, slowing varying, flat. In this scenario, we consider their envelop of two links related to FU and NU which follow Rayleigh distributions with different scale parameters. The signal propagates from the source to two kinds of users through the RIS, which aims to enhance the signal quality at these destinations. In ideal case, we assume that the RIS can achieve the channel state information (CSI) of these users [34]. Luckily, the RIS can use such CSI to maximize the received SNR at these destinations.

In the context of NOMA, the base station send superimpose signal containing signals s_1, s_2 which are targeted to user NU and FU, respectively. To provide different quality of service (QoS) for uses, higher power level a_2 is assigned to user FU, such allocation scheme must be satisfied $a_1 + a_2 = 1$. We call P_s is transmit power at the base station. Following principle of RIS, the received signal reflected by the RIS can be formulated by

$$y_{NU} = \sum_{i=1}^{N} h_i e^{j\Phi_i} g_{iN} \left(\sqrt{a_1 P_s} s_1 + \sqrt{a_2 P_s} s_2\right) + w + n, \quad (1)$$

$$y_{FU} = \sum_{i=1}^{N} h_i e^{j\Phi_i} g_{iF} \left(\sqrt{a_1 P_s} s_1 + \sqrt{a_2 P_s} s_2\right) + w + n, \quad (2)$$

where Φ_i stands for the adjustable phase induced by the i-th reflecting metasurface of the RIS, n is the additive white Gaussian noise (AWGN) and variance equal N_0, w is hardware noise term, $w \in \left(0, \left(k_t^2 + k_r^2\right) P_s\right)$. In this case, we call k_t, k_r are the distortion from the transmitter and receiver hardware imperfections, and they can be modeled as a zero-mean complex Gaussian process with variances $|A|^2 k_t^2 P_s$, $|A|^2 k_r^2 P_s$ respectively.[1]

[1] It is noted that this model has been adopted in the literature by providing insights in several analytical and experimental such as [38]. In [39], RIS-aided millimeter-wave (mmWave) systems is studied to address the problems of the phase noise at RIS and the quantization error at base stations. However, such impairments can be applied in other framework of performance analysis.

It is worth noting that w is associated with hardware imperfection situations at transmitters and receivers. We denote $A = \sum_{i=1}^{N} |h_i| |g_{iN}|$, $B = \sum_{i=1}^{N} |h_i| |g_{iF}|$ for ease in further computation.

At user NU, we consider FU's signal as noise, and the maximized signal to noise and distortion ratio (SNDR) to detect signal s_2 is given by [1]

$$\Psi_{NU,s_2} = \frac{|A|^2 a_2 P_s}{|A|^2 \left(k_t^2 + k_r^2\right) P_s + N_0 + |A|^2 a_1 P_s} \tag{3}$$

We can rewrite SNDR at user NU as below

$$\Psi_{NU,s_2} = \frac{|A|^2 a_2 \rho_s}{|A|^2 \left(k_t^2 + k_r^2\right) \rho_s + 1 + |A|^2 a_1 \rho_s}, \tag{4}$$

where $\rho_s = \frac{P_s}{N_0}$ is so-called as signal to noise ratio (SNR) at the base station.

It is noted that, we can rewrite (4) as

$$\Psi_{NU,s_2} = \frac{|A|^2 a_2}{|A|^2 \left(k_t^2 + k_r^2\right) + \frac{1}{\rho_s} + |A|^2 a_1} \tag{5}$$

By performing SIC at user NU, noise signal from user FU is deleted, then we can compute SNDR to detect signal for user NU as

$$\Psi_{NU,s_1} = \frac{|A|^2 a_1 P_s}{|A|^2 \left(k_t^2 + k_r^2\right) P_s + N_0} \tag{6}$$

Then, the SNDR at user NU can be rewritten by

$$\Psi_{NU,s_1} = \frac{|A|^2 a_1 \rho_s}{|A|^2 \left(k_t^2 + k_r^2\right) \rho_s + 1}. \tag{7}$$

Similarly, we obtain SNDR at user NU to detect its own signal as

$$\Psi_{NU,s_1} = \frac{|A|^2 a_1}{|A|^2 \left(k_t^2 + k_r^2\right) + \frac{1}{\rho_s}}. \tag{8}$$

The user FU has different characteristic with NU, it does not rely on SIC, we can obtain SNDR at user FU to detect its own signal as

$$\Psi_{FU,s_2} = \frac{|B|^2 a_2}{|B|^2 \left(k_t^2 + k_r^2\right) + \frac{1}{\rho_s} + |B|^2 a_1} \tag{9}$$

Remark 1: We note that the SNDR in various expressions, for example in (8), (9) imply that these users have the perfect knowledge of channels h_i, g_{iN} and g_{iF}. The channel state information related to RIS, h_i, g_{iN} and g_{iF}, are assumed to be available via the channel estimation methods described in [37]. The information about the predetermined beamforming vectors is expected to be sent to from the RIS using a reliable control channel to the near and far users. Furthermore, we note that the SNDR expressions contain the products of the complex Gaussian distributed random variables, and hence they are more complicated than that of conventional NOMA.

III. PERFORMANCE ANALYSIS

In this section, based on the proposed approximations, we derive new closed-form expressions for the outage probability, and throughput in delay-limited transmission mode for the considered RIS-aided wireless systems.[2]

The considered RIS-aided NOMA system can classify different users with corresponding required quality of service (QoS) which is associated partly with locations of FU and NU. In this case, outage probability is defined as ability of SNDR Ψ_{NU,s_1} less than the predefined SNDR thresholds. We denote $Pr(.)$ as outage probability. It can be formulated by

$$P_{out} = Pr\left(\Psi \le \rho_{th}\right), \tag{10}$$

where Ψ and ρ_{th} are denoted as SNDR and SNDR threshold respectively.

A. OUTAGE PROBABILITY AT USER NU

In this case, outage behavior at user NU occurs once user NU cannot detect FU'signal and NU's signal as well. We can formulate such worse circumstance as below

$$P_{out} = Pr\left(\Psi_{NU,s_1} \le \rho_{th1}, \Psi_{NU,s_2} \le \rho_{th2}\right), \tag{11}$$

where ρ_{th1}, ρ_{th2} correspond to SNDR thresholds of users NU and FU respectively. It is noted that $\rho_{th1} = 2^{2R_1} - 1$, $\rho_{th2} = 2^{2R_2} - 1$ with R_1, R_2 are target rates for NU, FU respectively.

We first compute outage probability for user NU when NU cannot detect FU's signal as below

When NU cannot detect FU's signal, such outage event can be addressed by

$$P_0 = Pr\left(\frac{|A|^2 a_2}{|A|^2 \left(k_t^2 + k_r^2\right) + \frac{1}{\rho_s} + |A|^2 a_1} \le \rho_{th2}\right). \tag{12}$$

Proposition 1: The closed-form expression of outage probability when NU cannot detect FU's signal can be written as (13), shown at the bottom of the next page.

Proof: See in Appendix A.

When NU cannot detect its own signal, such outage event can be addressed by

$$P_1 = Pr\left(\frac{|A|^2 a_1}{|A|^2 \left(k_t^2 + k_r^2\right) + \frac{1}{\rho_s}} \le \rho_{th1}\right) \tag{14}$$

Proposition 2: The closed-form expression of outage probability when NU cannot detect its own signal and such expression can be written as (15), shown at the bottom of the next page.

Proof: See in Appendix B.

Next, we can achieve outage probability at user NU as below

$$P_{out,NU} = P_0 \times P_1. \tag{16}$$

[2] The expressions of average bit error rate (BER), and ergodic capacity are derived in [36] to provide extra performance metrics for the considered RIS-aided wireless systems. Therefore, we do not intend to replicate these metrics in this study

In following computations, the upper and lower incomplete Gamma functions [[40], eq. (8.350/2), (8.350/3)] are respectively represented by $\gamma(.,.)$, while the Gamma function is represented by $\Gamma(.,.)$ [[40], eq. (8.310)].

From (16), when $\Theta = \max(\rho_{th1}, \rho_{th2})$ and $\Theta \leq \frac{1}{k_t^2+k_r^2}$, the closed-form expression of outage probability at user NU is given as (17), shown in the middle of the next page.

Remark 2: From (17), we observe that, for fixed data rates, the outage probability decreases as N increases; thus, the quality of service at user NU can be improved. Similarly, for a given N, as we increase data rates, the outage probability becomes worse.

B. OUTAGE PROBABILITY AT USER FU

The outage probability of user FU can be expressed by

$$P_{out,FU} = Pr\left(\frac{|B|^2 a_2 \rho_s}{|B|^2\left(k_t^2+k_r^2\right)\rho_s + 1 + |B|^2 a_1 \rho_s} \leq \rho_{th2}\right). \tag{18}$$

Proposition 3: The closed-form expression of outage probability when FU cannot its own signal can be formulated as (19), shown at the bottom of the next page.

Proof: Since the method of proof is similar with that of Proposition 2, we do not consider it here.

C. DIVERSITY ORDER FOR NEAR USER

To provide insights of the obtained expression of outage probability, we can compute the diversity order as

$$D_{NU} = -\lim_{\rho_s\to\infty} \frac{\log_2\left(P_{out,NU}\right)}{\log_2\left(\rho_s\right)} \tag{20}$$

Then, we can simplify (20) as (21), shown at the bottom of the next page.

Next, the diversity order of user NU is given by

$$D_{NU} = \frac{\sqrt{a_1 a_2}}{256}\frac{N^2}{4}. \tag{22}$$

D. DIVERSITY ORDER FOR FAR USER

Similarly, we can calculate the diversity order for user FU as

$$D_{FU} = -\lim_{\rho_s\to\infty}\left(\frac{\log_2\left(P_{out,FU}\right)}{\log_2\left(\rho_s\right)}\right). \tag{23}$$

Then, we have diversity order for user FU as

$$D_{FU} = \frac{\sqrt{a_2}\pi^2}{a_1(16-\pi^2}\frac{N}{4}. \tag{24}$$

E. THROUGHPUT

In this scenario, we consider the throughput in delay-limited transmission for RIS-aided NOMA system. As further performance metric, the throughput of the whole system corresponding the fixed bit rate R_1, R_2 for different demands of services for users NU and FU, and such throughput can be computed by

$$T = R_1\left(1-P_{out,NU}\right) + R_2\left(1-P_{out,FU}\right). \tag{25}$$

IV. NUMERICAL RESULT

In this section, we investigate the performance of the RIS-aided NOMA systems. We set level of hardware impairments $k_t^2 = k_r^2 = k = 0.1$ except for specific cases. For NOMA deployment, we set $a_1 = 0.3$, $a_2 = 0.7$. All presented illustrations include average results over 10^6 independent channel realizations for the outage probability. Although different QoS requirements for two users, we just simulate same target rates for them, i.e. $\gamma_{th1} = \gamma_{th2} = \gamma_{th}$.

Fig. 2 shows the outage performance of RIS-aided NOMA by comparing many cases of . In three cases of ρ_{th} at fixed $N = 10$, it is shown that RIS-aided NOMA can improve its performance at higher SNDR threshold ρ_{th}. Furthermore, when we enhance transmit SNR at base station the received signal at destinations can improve as well, as shown in Fig. 2, very low value of outage probability can be achieved as we can see with curves of outage probability. This can be possibly explained by the fact that higher transmit SNR at the base station leads to higher SDNR and hence the corresponding outage probability can be enhanced. More importantly, RIS-aided NOMA shows outage performance in two

$$P_0 = \begin{cases} \dfrac{\gamma\left(\frac{\pi^2}{16-\pi^2}N, \frac{2\pi}{16-\pi^2}\sqrt{\frac{a_2}{a_1+(k_t^2+k_r^2)\rho_{th2}}}\sqrt{\frac{\rho_{th2}}{\rho_s}}\right)}{\Gamma\left(\frac{\pi^2}{16-\pi^2}N\right)}, & \rho_{th2} \leq \frac{1}{k_t^2+k_r^2} \\ 1, & otherwise \end{cases} \tag{13}$$

$$P_0 = \begin{cases} \dfrac{\gamma\left(\frac{\pi^2}{16-\pi^2}N, \frac{2\pi}{16-\pi^2}\frac{\sqrt{a_1}}{\sqrt{1+(k^2{}_t+k^2{}_r)\rho_{th1}}}\sqrt{\frac{\rho_{th1}}{\rho_s}}\right)}{\Gamma\left(\frac{\pi^2}{16-\pi^2}N\right)}, & \rho th1 \leq \frac{1}{k^2{}_t+k^2{}_r} \\ 1, & otherwise \end{cases} \tag{15}$$

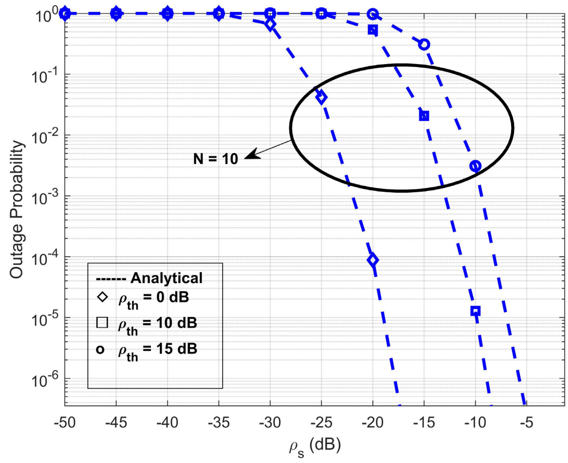

FIGURE 2. Outage probability for case $N = 10$ (For near user).

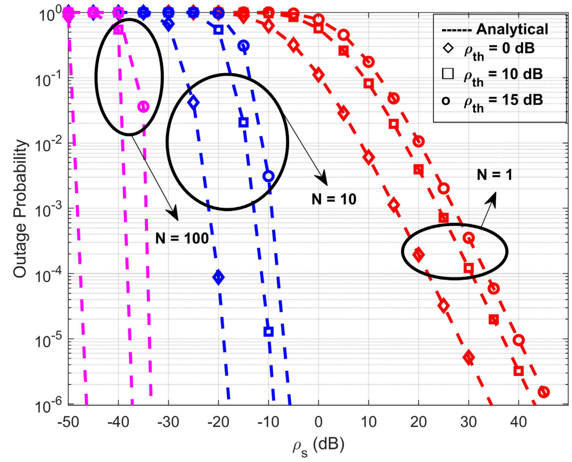

FIGURE 3. Outage probability for different N and ρ_{th} (For near user).

methods of simulations, i.e. curves of outage probability in Monte-Carlo match very tight with analytical results obtained via mathematical derivations in (17). Here, we notice that the outage performance of near user can be improved at higher value of ρ_s although this user has hardware impairment.

Figure 3 demonstrates the outage probability of user NU as a function of the transmission SNR ρ_s if we change values of ρ_s and N. As a benchmark, the outage performance of NOMA dual-hop relaying systems without RIS shows the worst outage performance (case of $N = 1$). It is noted that diversity order found in (20), and (22) which depends on the number of RIS's metasurfaces and not from the level of hardware imperfections. Further more, power allocation factor makes influence on outage performance.

Figure 4 illustrates the outage probability as a function of the transmission SNR at the base station, for different values of ρ_{th} and k, with fixed metasurfaces $N = 5$. We consider perfect hardware impairment $k = 0$ as a benchmark, the best outage performance can be observed for the ideal case in which both the transmitter and receiver does not experience the impact of hardware impairments. Moreover, we observe that independently of ρ_s and k, degraded trends on outage performance can be observed if we increase ρ_{th}. It is worth noting that the importance of accurately modeling the transmitter and receiver's hardware imperfections when evaluating the performance of RIS-assisted NOMA systems. Moreover, we observe that the impact of hardware

$$P_0 = \left\{ \frac{\gamma\left(\frac{\pi^2}{16-\pi^2}N, \frac{2\pi}{16-\pi^2}\frac{\sqrt{a_1}}{\sqrt{1+\left({k^2}_t+{k^2}_r\right)\rho_{th1}}}\sqrt{\frac{\rho_{th1}}{\rho_s}}\right)}{\Gamma\left(\frac{\pi^2}{16-\pi^2}N\right)} \times \frac{\gamma\left(\frac{\pi^2}{16-\pi^2}N, \frac{2\pi}{16-\pi^2}\frac{\sqrt{a_2}}{\sqrt{a_1+\left({k^2}_t+{k^2}_r\right)\rho_{th2}}}\sqrt{\frac{\rho_{th2}}{\rho_s}}\right)}{\Gamma\left(\frac{\pi^2}{16-\pi^2}N\right)} \right\} \tag{17}$$

$$P_0 = \begin{cases} \frac{\gamma\left(\frac{\pi^2}{16-\pi^2}N, \frac{2\pi}{16-\pi^2}\frac{\sqrt{a_2}}{\sqrt{a_1+\left({k^2}_t+{k^2}_r\right)\rho_{th2}}}\sqrt{\frac{\rho_{th2}}{\rho_s}}\right)}{\Gamma\left(\frac{\pi^2}{16-\pi^2}N\right)}, & \rho_{th2} \le \frac{1}{{k^2}_t+{k^2}_r} \\ 1, & otherwise \end{cases} \tag{19}$$

$$D_{NU} = -\lim_{\rho_s \to \infty}\left[\frac{\log_2\left(\frac{\gamma\left(\frac{\pi^2}{16-\pi^2}N, \frac{2\pi}{16-\pi^2}\frac{\sqrt{a_1}}{\sqrt{1+\left({k^2}_t+{k^2}_r\right)\rho_{th1}}}\sqrt{\frac{\rho_{th1}}{\rho_s}}\right)}{\Gamma\left(\frac{\pi^2}{16-\pi^2}N\right)}\right) \times \left(\frac{\gamma\left(\frac{\pi^2}{16-\pi^2}N, \frac{2\pi}{16-\pi^2}\frac{\sqrt{a_2}}{\sqrt{a_1+\left({k^2}_t+{k^2}_r\right)\rho_{th2}}}\sqrt{\frac{\rho_{th2}}{\rho_s}}\right)}{\Gamma\left(\frac{\pi^2}{16-\pi^2}N\right)}\right)}{\log_2\left(\rho_s\right)}\right] \tag{21}$$

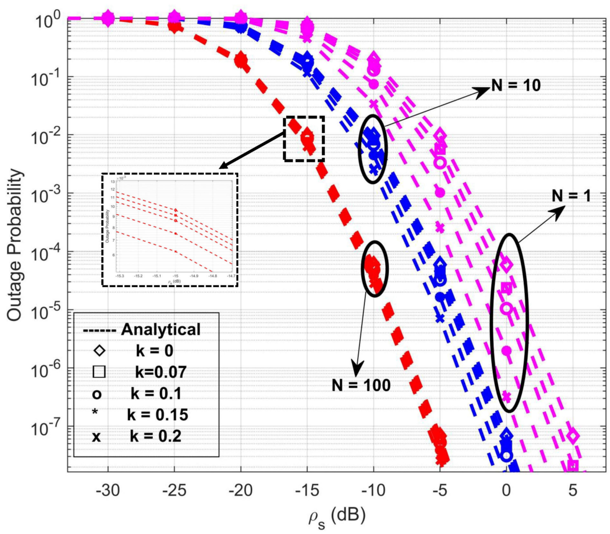

FIGURE 4. Outage probability vs ρ_s, for different values of ρ_{th} and k, assuming $N = 5$ (for near user).

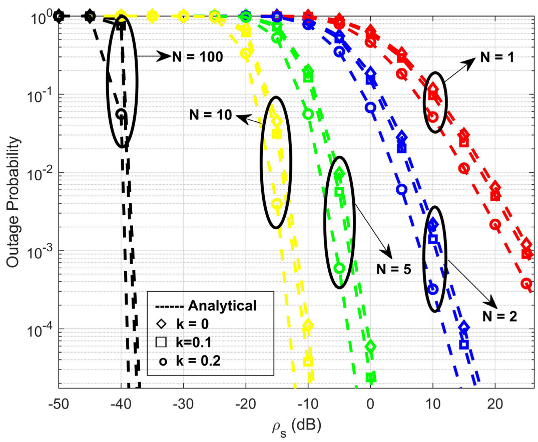

FIGURE 5. Outage probability, for different values of N and K, for ρ_{th} = 10dB (For near user).

imperfections becomes more severe when we increase ρ_{th}. Similar trends of outage performance of user NU can be seen when we change values of N as Fig. 5.

In Fig. 6, we can see variations of outage probability for user FU. Similarly, case of $N = 100$ exhibits significant improvement of outage performance for user FU. It can be seen that big gap of outage probability when we change the number of metasurfaces from $N = 1$ to $N = 10$. The reason is that higher number of metasurfaces contributes to improve SNDR, then the corresponding outage probability can be enhanced. In other words, we observe that the impact of the thresholds ρ_{th} on the RIS-assisted NOMA system would be significant concern at two following scenarios ($N = 10$, $N = 100$.

It can be concluded that outage probability of user FU outperforms than that of user NU, as Fig. 7. The main reason is that higher level of power is assigned to transmit signal s_2 for user FU. The performance gap among two users can be seen clearly at case of $N = 1$, but such gap becomes smaller at

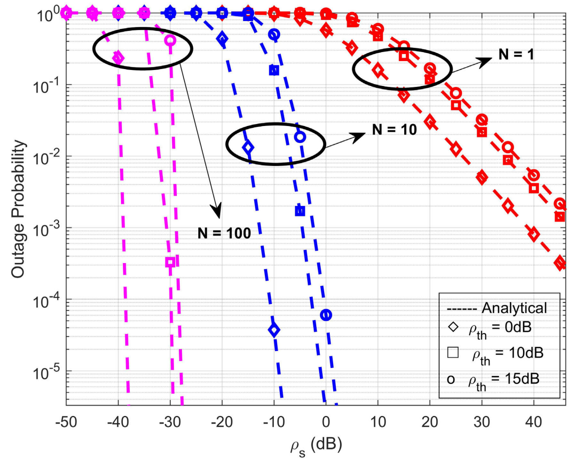

FIGURE 6. Outage probability versus transmit SNR at base station for user FU.

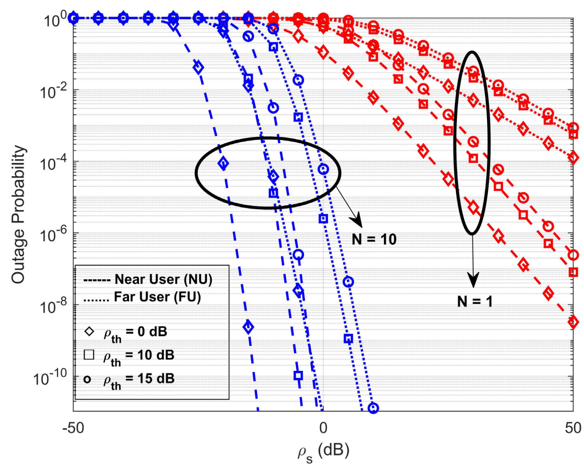

FIGURE 7. Comparison between outage behavior of NU and FU.

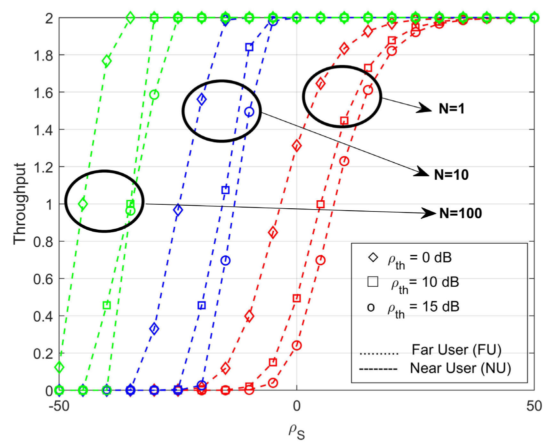

FIGURE 8. Throughput of the entire system.

case of $N = 10$. Other trends of curves of outage probability can be seen similarly as previous figures.

Fig. 8 shows throughput performance of the considered system when we increase ρ_s. In this case, we set

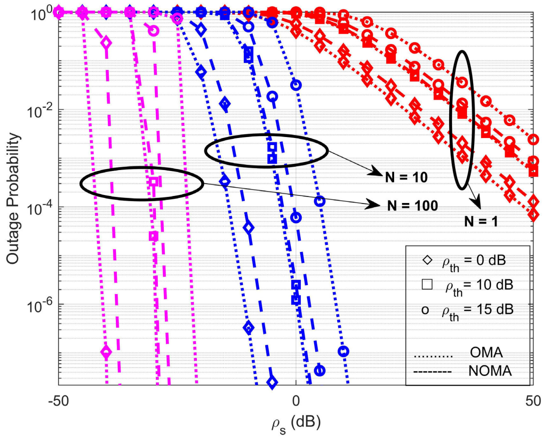

FIGURE 9. Comparison between RIS systems using NOMA and OMA.

$R_1 = R_2 = 1$ bps/Hz. That means our system can approach to 2 at very high value of ρ_s. It can be explained that such throughput depends on achieved outage probabilities in previous steps. It can be confirmed that our RIS system relying on NOMA is better than that using OMA, as Fig. 9. This finding benefits to design RIS in wireless systems to satisfy massive connections.

V. CONCLUSION

In this paper, we have considered a generalized hardware imperfections model in RIS systems at both transmitter and receiver in the context of NOMA, which has been validated in several prior works, in order to assess the impact of hardware impairments on RIS-aided NOMA wireless systems. In particular, we derived simple closed-form expressions to evaluation for outage performance and throughput in delay-limited mode, which takes into account the level of transceivers hardware imperfections. Through out simulations, the number of meta-surfaces at the RIS, as well as the transmit SNR at the base station and the SNDR threshold are determined as main factors make influence on outage probability. Our results manifested the detrimental impact of transceiver hardware imperfections on the outage and throughput performance of these systems. It can be concluded that main results are relying on the importance of accurately modeling the level of hardware impairments when evaluating the performance of our considered systems as reported. In future, we consider RIS systems for case of multiple users under the context of NOMA scheme.

APPENDIX A
PROOF OF PROPOSITION 1

The expression of outage probability when the user NU cannot detect user FU's signal is given by

$$P_0 = Pr\left[|A|^2\left(a_2 - \rho_{th2}\left(k_t^2+k_r^2\right)\rho_s\right)+a_1 \le \rho_{th2}\right] \quad \text{(A.1)}$$

We can rewrite (A.1) as

$$P_0 = Pr\left[|A|^2\left(a_2 - \rho_{th}\left(k_t^2+k_r^2\right)\right)+a_1 \le \frac{\rho_{th2}}{\rho_s}\right] \quad \text{(A.2)}$$

Considering condition of $\rho_{th2} \le \frac{a_2}{k_t^2+k_r^2+a_1}$, we have new expression as

$$P_0 = Pr\left[|A|^2 \le \frac{a_2}{a_1+\left(k_t^2+k_r^2\right)\rho_{th2}}\frac{\rho_{th2}}{\rho_s}\right] \quad \text{(A.3)}$$

It is equivalent to

$$P_0 = Pr\left[A \le \frac{\sqrt{a_2}}{\sqrt{a_1+\left(k_t^2+k_r^2\right)\rho_{th2}}}\sqrt{\frac{\rho_{th2}}{\rho_s}}\right] \quad \text{(A.4)}$$

We call $F(X)$ as the cumulative distribution function (CDF) of variable X, then (A.4) is rewritten by

$$P_0 = F_A\left[A \le \frac{\sqrt{a_2}}{\sqrt{a_1+\left(k_t^2+k_r^2\right)\rho_{th}}}\sqrt{\frac{\rho_{th2}}{\rho_s}}\right] \quad \text{(A.5)}$$

By applying [[41], eq. (8)], we have CDF as

$$F_A(x) = \left(\frac{\gamma\left(a+1,\frac{x}{b}\right)}{\Gamma(1+a)}\right), \quad \text{(A.6)}$$

in which $a = \frac{k^2{}_1}{k_2} - 1$; $b = \frac{k_2}{k_1}$; $k_1 = \frac{N\pi}{2}$; $k_2 = 4N\left(1-\frac{\pi^2}{16}\right)$.

In our situation, we replace $x = \frac{\sqrt{a_2}}{\sqrt{a_1+\left(k_t^2+k_r^2\right)\rho_{th}}}\sqrt{\frac{\rho_{th}}{\rho_s}}$ to (B.3), then such outage probability is given by

$$P_0 = \left(\frac{\gamma\left(1+\frac{k_1^2}{k_2^2}-1,\frac{\frac{\sqrt{a_2}}{\sqrt{a_1+\left(k_t^2+k_r^2\right)\rho_{th}}}\sqrt{\frac{\rho_{th2}}{\rho_s}}}{\frac{k_2}{k_1}}\right)}{\Gamma\left(\frac{k_1^2}{k_2}-1\right)+1}\right) \quad \text{(A.7)}$$

Now, we can achieve such outage probability as

$$P_0 = \left(\frac{\gamma\left(\frac{\left(\frac{N\pi}{2}\right)^2}{\left(4N\left(1-\frac{\pi^2}{16}\right)\right)^2},\frac{\frac{\sqrt{a_2}}{\sqrt{a_1+\left(k_t^2+k_r^2\right)\rho_{th}}}\sqrt{\frac{\rho_{th2}}{\rho_s}}}{\frac{4N\left(1-\frac{\pi^2}{16}\right)}{\frac{N\pi}{2}}}\right)}{\Gamma\left(\frac{\left(\frac{N\pi}{2}\right)^2}{4N\left(1-\frac{\pi^2}{16}\right)}\right)}\right) \quad \text{(A.8)}$$

This completes the proof.

APPENDIX B
PROOF OF PROPOSITION 2

We recall outage probability as below

$$P_1 = Pr\left[|A|^2a_1 - \rho_{th1}\left(|A|^2\left(k_t^2+k_r^2\right)\rho_s+1\right)\right] \le \rho_{th1} \quad \text{(B.1)}$$

It is noted that we can rewrite (B.1) as

$$P_1 = Pr\left[|A|^2\left(a_1 - \rho_{th1}\left(k_t^2+k_r^2\right)\right)+1 \le \frac{\rho_{th1}}{\rho_s}\right] \quad \text{(B.2)}$$

Considering condition of $\rho_{th1} \leq \frac{a_1}{1+(k_t^2+k_r^2)}$, we have new expression as

$$P_1 = Pr\left[|A|^2 \leq \frac{a_1}{1+\left(k_t^2+k_r^2\right)\rho_{th1}}\frac{\rho_{th1}}{\rho_s}\right] \tag{B.3}$$

Similarly, P_1 can be rewritten as

$$P_1 = Pr\left[A \leq \frac{\sqrt{a_1}}{\sqrt{1+\left(k_t^2+k_r^2\right)\rho_{th1}}}\sqrt{\frac{\rho_{th1}}{\rho_s}}\right] \tag{B.4}$$

Similarly, such outage probability is expressed by

$$P_1 = \left(\frac{\gamma\left(\frac{\left(\frac{N\pi}{2}\right)^2}{\left(4N\left(1-\frac{\pi^2}{16}\right)\right)^2}, \frac{\frac{\sqrt{a_1}}{\sqrt{1+\left(k_t^2+k_r^2\right)\rho_{th1}}}\sqrt{\frac{\rho_{th1}}{\rho_s}}}{\frac{4N\left(1-\frac{\pi^2}{16}\right)}{\frac{N\pi}{2}}}\right)}{\Gamma\left(\frac{\left(\frac{N\pi}{2}\right)^2}{4N\left(1-\frac{\pi^2}{16}\right)}\right)}\right) \tag{B.5}$$

This is end of the proof.

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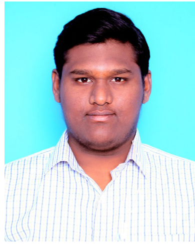

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