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Study on transmission over Nakagami-m fading channel for multiple access scheme without orthogonal signal

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ABSTRACT

In this paper, a downlink performance in non-orthogonal multiple access (NOMA) system is considered. With regard to different priority for two NOMA users, we exploit the closed-form expressions of outage probability over wireless fading channel following Nakagami-m fading. The fixed power allocation factor scheme is examined to reduce the complexity in computation regarding performance analysis. In our analysis, perfect successive interference cancellation (SIC) is applied in order to achieve perfect signal decoding operation. Simulation results show that the considered NOMA downlink scheme is affected by transmit SNR, power allocation factors, fading parameters.

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1. INTRODUCTION

As a encouraging technology in 5G wireless networks with improved the spectral efficiency, non-orthogonal multiple access (NOMA) is widely studied [1]. At the base station (BS), multiple user's signals are superimposed in the power domain while successive interference cancellation (SIC) deploying in receiver to separate multi-user signals [2]. The novel principle of NOMA is related to access division based on the allocated power source to perform multiple access. In some trends, NOMA can be combined with relaying networks with their advantages in term of outage performance [3-5].

Regarding performance analysis, overhead is required in feedback information. Regarding to computation in term of system performance, the channel state information (CSI) is considered as another parameter regarding to the NOMA's performance consideration. It is noted that two great interests are considered such as the CSI is sent to the transmitter and how to reduce information related to overhead. To solve this problem, when only the CSI statistics are known at the base station (BS) the authors of [6] examined the potential performance in NOMA scheme. More specifically, different large-scale fading channels are assumed that to confirm that it is still possible fairness as considering performance of users and NOMA is better that of traditional orthogonal multiple access (OMA). They studied the sum ergodic capacity [6].

To satisfy requirements of fifth-generation (5G) networks, many researchers have believed that NOMA can be implemented effectively to meet both user-experienced and network level data rate [7]. In recent research, possible applications together with point-to-point NOMA has been studied comprehensively in [8-11]. In [8], downlink NOMA with randomly deployed users is examined in terms of the outage performance and ergodic rate by invoking tool of stochastic geometry. To against outside eavesdroppers as performing the secrecy analysis in NOMA [9]. In the scenario of single-antenna and multiple-antenna transmission, the secrecy outage probability of NOMA is exploited in situation of larger scale networks [9]. A unique framework for hybrid satellite/unmanned aerial vehicle terrestrial NOMA networks was studied, in which ground users comunicate with satellite aims be exploiting NOMA protocol and the assistance of a decode-forward (DF) UAV relay [10]. To further achieve higher spectrum efficiency, device-to-device (D2D) applied the secondary network (SN) is designed to assist transmission to NOMA users once the primary network make influence of interference to SN [11]. A back-scatter NOMA system is considered, in which multiple antennas base station support back-scatter device in a downlink NOMA [12]. In addition, to eliminate the multiuser interference at the receiver, the successive interference cancellation (SIC) is applied [13, 14]. The considerable interest regarding NOMA can be proposed in many models in existing and future wireless communications systems. In [15-18], reliability, security capability and outage probability are main metrics to exploit the physical layer security in NOMA. In particular, the optimal secrecy sum rate can be introduced in single-input single-output (SISO) NOMA system [18], in which a predefined quality of service (QoS) requirement is assigned for each user [19].

Moreover, most of the current literature laid main interest for the role of downlink NOMA over Rayleigh fading [20-22], and the impact of Nakagami-m fading in such NOMA has not been well studied. To reduce multiple types of channel, Nakagami-m fading channel is analysed to indicate system performance with the different parameter settings. For example, Rayleigh fading is special case of Nakagami fading as parameter is set $m = 1$. Motivated by aforementioned considerations, in this paper we analyze the outage performance of NOMA to show different performance of two NOMA users and these related expressions of outage behavior are derived with respect to Nakagami-m fading channels.

The contribution of this paper is three-fold:

- We investigate the impact of power allocation factors for two NOMA users on the performance of such NOMA network. More specifically, we focus on the direct link from the base station to mobile users. In such a scenario, a simple closed-form for the outage probability is derived.
- We derive an exact expression for outage probability in the case that the SOS of the channels is known. Since the channels are Nakagami-m fading, other parameters are impacts on the system performance and these results are applied to yield performance comparison on two NOMA users.
- We present a consideration on throughput in delay-limited mode for such NOMA scheme, based on achieved outage probability. The presented analytical and numerical results demonstrate that NOMA always achieves reasonable performance in deployment of NOMA in real applications.

The remaining parts of the paper is summarized as follows. Section 2 illustrates the system model of downlink NOMA. Section 3 studies the outage performance and throughput in delay-limited transmission mode, while section 4 investigates the diversity order analysis of NOMA systems based on derived outage probability. In section 5, to examine the accuracy of the proposed analysis, numerical results are performed and Monte Carlo simulations are deployed. Finally, Section 6 concludes the paper.

2. SYSTEM MODEL

This paper studies Nakagami-m channel model deploying in downlink from the base station (BS) to two NOMA users. In this scenario, pair of NOMA users is considered to highlight different outage performance. In particular, the base station (BS) serves two users including d_n (near user) and d_f (far user) as illustrated in Figure 1. For simple computation, all nodes are equipped with single antenna. We denote direct links BS to two NOMA users d_n, d_f are h_{SD1} and h_{SD2}, respectively. To adapt to NOMA requirement for decoding operation, the arrangement of channel gains are $|h_{SD1}|^2 \leq |h_{SD2}|^2$. The transmitted signal with corresponding energy is normalized to one. Meanwhile, the noise terms are additive white Gaussian noise (AWGN) with zero mean and variance of N_0. To perform system analysis, we provide several denotations. By employing NOMA scheme, the BS transmits the superposed signal $\sqrt{a_n P_S x_n} + \sqrt{a_f P_S x_f}$ to two NOMA users, d_n and d_f, while x_n and x_f are the signal for d_n and d_f, respectively. The power allocation coefficients including a_n and a_f are allocated to d_n and d_f respectively, and it is constrained by $a_n + a_n = 1$. It is further assumed that $a_f > a_n$. It is assumed that d_f is SIC-based user while d_n is higher priority to decode its signal. The received signal at the two NOMA users, d_n and d_f are given by

$$y_{d_n} = h_{SD1}\left(\sqrt{a_n P_S} x_n + \sqrt{a_f P_S} x_f\right) + n_{SD1}, \tag{1}$$

$$y_{d_f} = h_{SD2}\left(\sqrt{a_n P_S}x_n + \sqrt{a_f P_S}x_f\right) + n_{SD2}, \tag{2}$$

in which noise terms at user d_n and d_f are AWGN with their notations, i.e. n_{SD1} and n_{SD2} respectively. Considering on signal detection at d_n, it is required to compute the received signal to interference and noise ratio (SINR). At side of user d_n, to detect its own signal and corresponding SINR can be determined by

$$\gamma_{sd_n} = \frac{|h_{SD1}|^2 a_n \rho}{|h_{SD1}|^2 a_f \rho + 1}, \tag{3}$$

where the transmit signal to noise ratio (SNR) computed at the BS as $\rho = \frac{P_S}{N_0}$. To detect and decode the d_f's information, SIC is required to perform at d_f in first step related to NOMA signal processing. In similar way, such received SINR at d_f can be expressed as

$$\gamma_{sd_{f\to n}} = \frac{|h_{SD2}|^2 a_n \rho}{|h_{SD2}|^2 a_f \rho + 1}. \tag{4}$$

By assistance of SIC, regarding on decoding of the far user's message, d_n can decode its own information and the related SNR is examined by

$$\gamma_{sd_f} = |h_{SD2}|^2 a_f \rho. \tag{5}$$

In the next section, these achieved SINR expressions are deployed in outage metric analysis. We further provide these considered outage computation.

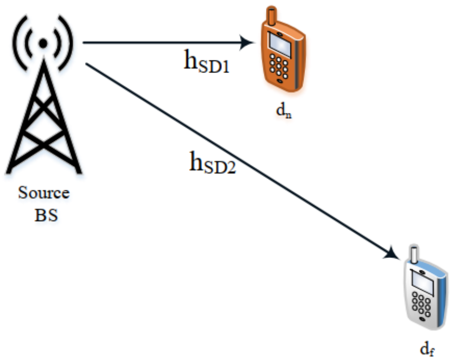

Figure 1. System model of downlink two-user NOMA

3. PERFORMANCE EVALUATION: OUTAGE PROBABILITY AND THROUGHPUT

3.1. Outage Probability

In this observation, main metric related to user quality of service (QoS) is outage probability. Such an outage probability of each NOMA user over Nakagami-m fading channels is analyzed in following section. It is well-known that consideration on the probability density function (PDF) with respect to $x = |h|$ and it is formulated by

$$f(x) = \frac{2\mu^{\mu}}{\Gamma(\mu)\,\omega_0^{\mu}} x^{2\mu-1} e^{-\frac{\mu x^2}{\omega_0}}, \quad x > 0, \tag{6}$$

where $\Gamma(.)$ is is Gamma function, multipath fading parameters are ω_0 and μ. To recall the PDF and cumulative distribution function (CDF) function with respect to $\leftthreetimes = x^2$ as below [23]

$$f\left(\lambda\right)=\frac{\mu^{\mu}\lambda^{\mu-1}}{\Gamma\left(\mu\right)\omega_0^{\mu}}e^{-\frac{\mu\lambda}{\omega_0}},\quad \lambda\geq 0, \tag{7}$$

$$F\left(\lambda\right)=1-e^{-\frac{\mu\lambda}{\omega_0}}\sum_{k=0}^{\mu-1}\frac{1}{k!}\left(\frac{\mu\lambda}{\omega_0}\right)^{k},\quad \lambda\geq 0, \tag{8}$$

where $\omega_0 = \mathrm{E}\left\{\lambda^2\right\}$ is denoted as the average power. In this case, the PDF and CDF of the user channel gain $|h_m|^2$ can be expressed. The PDF and CDF of channel h_m [24] are

$$\begin{aligned}f_{|h_m|^2}\left(x\right)=&\frac{2!}{(m-1)!\,(2-m)!}f_{|h|^2}\left(x\right)\\&\times\left(F_{|h_m|^2}\left(x\right)\right)^{m-1}\left(1-F_{|h_m|^2}\left(x\right)\right)^{M-m},\end{aligned} \tag{9}$$

And

$$\begin{aligned}F_{|h_m|^2}\left(x\right)=&\frac{2!}{(m-1)!\,(2-m)!}\sum_{i=0}^{2-m}\left(\begin{array}{c}2-m\\ i\end{array}\right)\\&\times\frac{(-1)^{i}}{m+i}\left(F_{|h_m|^2}\left(x\right)\right)^{m+i}.\end{aligned} \tag{10}$$

respectively, where $|h_m|$ stands for channel transmitting from the BS to an arbitrary user. It is noted that those channels are unsorted channel gain. In particular, the users can detect their own signal-based priority of different services in this considered NOMA scheme. In fact, SIC operation can be deployed in specific situation. Consequently, an outage behavior of d_f is determined as worse case. To make it clear, the outage probability of d_n is formulated by

$$P_{d_n}=\Pr\left(\gamma_{sd_n}<\gamma_{th_n}\right), \tag{11}$$

where with $\gamma th_n = 2^{2R_n}-1$ with R_n is called as target rate at d_n. The outage probability is explained as following proposition providing performance of d_f.

Proposition 1. The outage probability is investigated at d_n as:

$$\begin{aligned}P_{d_n}=&\sum_{i=0}^{2-f}\sum_{q=0}^{f+i}\left(\begin{array}{c}2-f\\ i\end{array}\right)\frac{\varphi_f}{f+i}\left(\begin{array}{c}f+i\\ q\end{array}\right)(-1)^{q+i}\theta_f\\&\times\sum_{p_0+\cdots+p_{\mu-1}=q}\left(\begin{array}{c}q\\ p_0,\cdots,p_{\mu-1}\end{array}\right)\prod_{k=0}^{\mu-1}\left(\frac{\psi_f^k}{k!}\right)^{p_k},\end{aligned} \tag{12}$$

where $\varpi\triangleq\frac{\gamma_{th_f}}{\rho\left(a_n-a_f\gamma_{th_f}\right)}$ with $a_f>a_n\gamma_{th_f},\varphi_f=\frac{2!}{(f-1)!(2-f)!},\theta_f=e^{-q\psi_f},\psi_f=\frac{\mu\varpi}{\Omega_{SD1}},\left(\begin{array}{c}q\\ p_0,\cdots,p_{\mu-1}\end{array}\right)=\frac{q!}{p0!p1!\cdots p_{\mu-1}}$. It is noted that link between the BS and the d_n user, and link from the BS to d_f user are Ω_{SD1}, Ω_{SD2} as the average power for, respectively.

Proof: It can be shown outage behavior as:

$$\begin{aligned}P_{d_n}=&\Pr\left(\gamma_{sd_n}<\gamma_{th_n}\right)\\=&\Pr\left(\frac{|h_{SD1}|^2a_n\rho}{|h_{SD1}|^2a_f\rho+1}<\gamma_{th_n}\right)\\=&\Pr\left(|h_{SD1}|^2<\frac{\gamma_{th_n}}{\rho\left(a_n-a_f\gamma_{th_n}\right)}\triangleq\varpi\right).\end{aligned} \tag{13}$$

Then it can be re-computed by:

$$\begin{aligned} P_{d_n} =& \frac{2!}{(f-1)!\,(2-f)!} \sum_{i=0}^{2-f} \sum_{q=0}^{f+i} \binom{2-f}{i} \frac{(-1)^i}{f+i} \binom{f+i}{q} (-1)^q \\ & \times e^{-\frac{\mu q \varpi}{\Omega_{SD1}}} \sum_{p_0+\cdots+p_{\mu-1}=q} \binom{q}{p_0,\cdots,p_{\mu-1}} \prod_{k=0}^{\mu-1} \left(\frac{\psi_f^k}{k!}\right)^{p_k}. \end{aligned} \tag{14}$$

Now, we focus performance of d_f. It is worth noting that we require d_f can first detect d_n's information and then extracts its own information in second constraint. Therefore, the outage probability for d_f in this case can be examined by:

$$P_{d_f} = 1 - \Pr\left(\gamma_{sd_{f\to n}} > \gamma_{th_f}, \gamma_{sd_f} > \gamma_{th_f}\right), \tag{15}$$

where target rate at d_n as R_f and then $\gamma th_f = 2^{2R_f} - 1$ with being the target rate at d_n. It is necessary to consider performance of user d_f.

Proposition 2. The outage probability of d_f is computed by:

$$\begin{aligned} P_{d_f} =& \sum_{i=0}^{2-n} \sum_{q=0}^{n+i} \binom{2-n}{i} \frac{\varphi_n}{n+i} \binom{n+i}{q} (-1)^{q+i} \theta_n \\ & \times \sum_{p_0+\cdots+p_{\mu-1}=q} \binom{q}{p_0,\cdots,p_{\mu-1}} \prod_{k=0}^{\mu-1} \left(\frac{\psi_n^k}{k!}\right)^{p_k}, \end{aligned} \tag{16}$$

where $\beta \triangleq \frac{\gamma_{th_n}}{\rho a_n}$, $\xi = \max(\varpi, \beta)$, $\varphi_n = \frac{2!}{(n-1)!(2-n)!}$, $\theta_n = e^{-q\psi_n}$ and $\psi_n = \frac{\mu\xi}{\Omega_{sd_n}}$.

Proof: Substituting (4) and (5) into (15) the outage probability of d_n is expressed below:

$$\begin{aligned} P_{d_f} =& 1 - \Pr\left(\frac{|h_{SD2}|^2 a_n \rho}{|h_{SD2}|^2 a_f \rho + 1} > \gamma_{th_n}, |h_{SD2}|^2 a_f \rho > \gamma_{th_f}\right) \\ =& 1 - \Pr\left(|h_{SD2}|^2 > \max\left(\frac{\gamma_{th_f}}{\rho\left(a_n - a_f \gamma_{th_f}\right)}, \frac{\gamma_{th_n}}{a_f \rho}\right)\right) \\ =& 1 - \Pr\left(|h_{SD2}|^2 > \max(\omega, \beta) \triangleq \xi\right). \end{aligned} \tag{17}$$

Then, it can be re-written as

$$\begin{aligned} P_{d_f} =& \frac{2!}{(n-1)!\,(2-n)!} \sum_{i=0}^{2-n} \sum_{q=0}^{n+i} \binom{2-n}{i} \frac{(-1)^i}{n+i} \binom{n+i}{q} (-1)^q \\ & \times e^{-\frac{\mu \xi q}{\Omega_{SD2}}} \sum_{p_0+\cdots+p_{\mu-1}=q} \binom{q}{p_0,\cdots,p_{\mu-1}} \prod_{k=0}^{\mu-1} \left(\frac{\psi_n^k}{k!}\right)^{p_k}. \end{aligned} \tag{18}$$

3.2. Throughput in delay-limited transmission mode

The outage probability is used to achieve throughput performance. At fixed data rates R_f; R_n, the throughput is calculated as

$$R_{fir} = \left(1 - P_{d_f}\right) R_f + \left(1 - P_{d_n}\right) R_n. \tag{19}$$

4. DIVERSITY ANALYSIS

To provide insights, diversity order is studied. By definition, the diversity order is formulated by

$$d = -\lim_{x\to\infty} \frac{\log\left(P\left(\rho\right)\right)}{\log \rho} \tag{20}$$

Interestingly, the approximate computation of channel h_f in case of $\varpi \to 0$ are given by [25]:

$$F_{|h_f|^2}(\varpi) \approx \frac{M!}{(M-f)!f!}\left(\frac{\mu\varpi}{\Omega_0}\right)^{\mu f}\left(\frac{1}{\mu!}\right)^{f}. \tag{21}$$

Based on (21), the asymptotic outage probability for (12) is given by:

$$P_{d_f}^{\infty} = \frac{2!}{(2-f)!f!}\left(\frac{\mu\varpi}{\Omega_{SD1}}\right)^{\mu f}\left(\frac{1}{\mu!}\right)^{f} \propto \frac{1}{\rho^{\mu f}}. \tag{22}$$

Similar to (22), the asymptotic outage probability for (16) is given by:

$$P_{d_n}^{\infty} = \frac{2!}{(2-n)!n!}\left(\frac{\mu\xi}{\Omega_{SD2}}\right)^{\mu n}\left(\frac{1}{\mu!}\right)^{n}. \tag{23}$$

5. NUMERICAL RESULT

In this section, numerical results and Monte Carlo simulations are provided to validate the analytical results presented in this paper. Particularly, the parameters used in the simulations are set as follow. The Monte Carlo simulation results are averaged over 10^5 independent trials. We call d_f as User f and d_n as User n in this section for simplicity. In Figure 2, the outage probability of two user's performance is illustrated as varying SNR with $\mu = 1$. By matching with the theoretical results derived, the exactness is verified for outage probability curves to highlight performance two NOMA users for NOMA. It is recalled that these channel are Nakagami-m fading channels. The other observation is that, at high SNR, the asymptotic curves well approach with the exact curves. At high SNR regime, it can be seen that NOMA is better than OMA in terms of outage probability.

To consider impact of parameters regarding Nakagami-m fading channel, Figure 3 shows outage probability versus SNR with respect to the theoretical analysis in two cases $\mu = 2$ and $\mu = 3$. It is observed that as the parameter μ increases, our NOMA system has improved outage probability. This is guidelines to design NOMA with Nakagami-m fading in real practice. Figure 4 plots the outage probability of the far users versus $R_f = R_n$ with different transmit SNR at the BS. One can observe that the outage probabilities of two users increase as $R_f = R_n$ increases. The reason is that increasing $R_f = R_n$ will make the threshold of decoding higher, and then more outage is raised. It can also be observed that performance gap between OMA and NOMA is small in term of the outage performance. While Figure 5 indicated that $\mu = 3$ is best performance as comparing such system at different parameter regarding Nakagami-m fading.

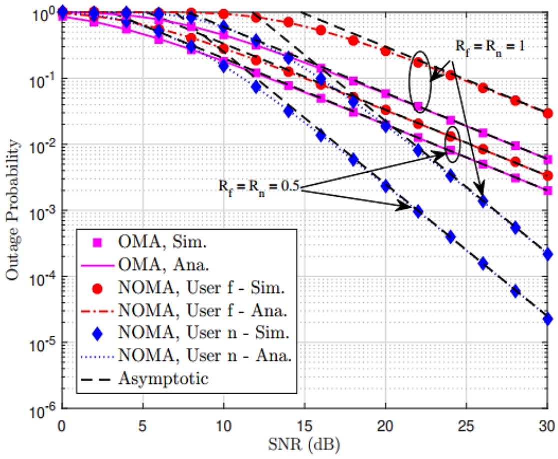

Figure 2. Outage probability versus SNR with $f = 1, n = 2$ and $\mu = 1$

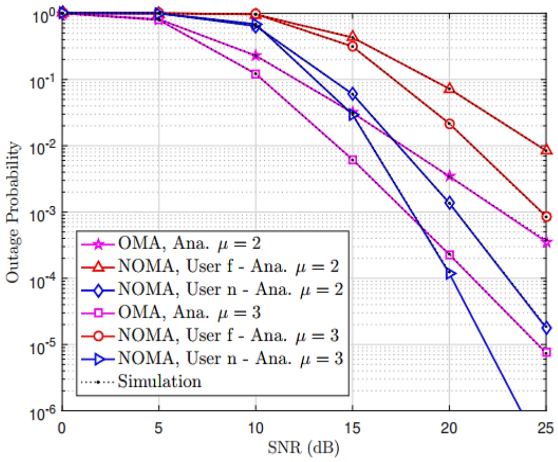

Figure 3. Outage probability versus SNR with $f = 1, n = 2, \mu = 2$ and $\mu = 3$

Moreover, from Figure 6, we can observe that af has a considerable impact on the outage probability of the proposed system at different SNR. It is interesting as finding optimal outage at specific value of a_f. To further evaluation, from Figure 7, there also exist an optimal outage threshold for all Nakagami-m channels as varying m. This is intuitive, since according to (19), the outage behavior is related to throughput. It is noted that the threshold is small, throughput is low. However, throughput will be increase as threshold rate increases to optimal value. When the threshold rate is larger than optimal point, the outage probability increases significantly, which again degrades the throughput. In addition, we find an interesting phenomenon that the optimal outage threshold is found via such simulation.

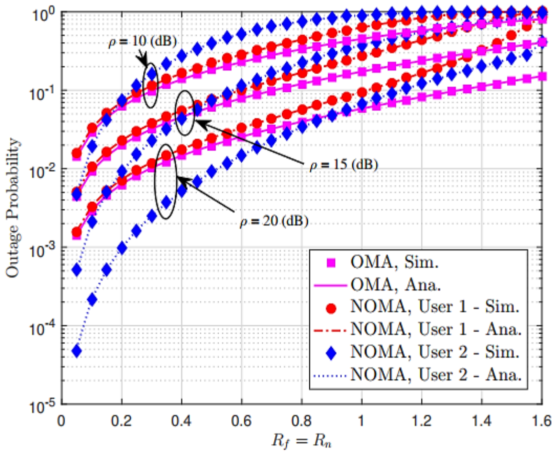

Figure 4. Rayleigh fading $f = 1, n = 2$ and $\mu = 1$

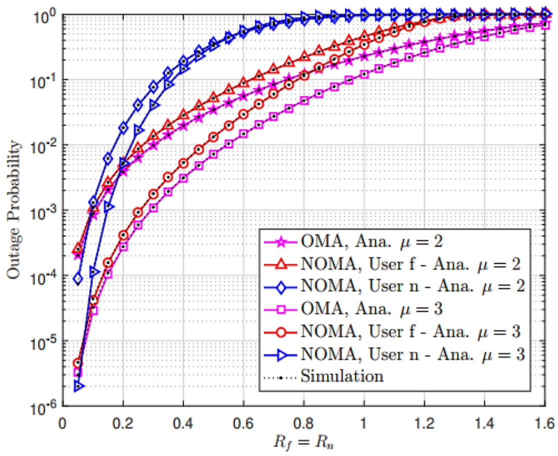

Figure 5. Nakagami-m fading
$f = 1, \rho = 10\ db, n = 2, \mu = 2$ and $\mu = 3$

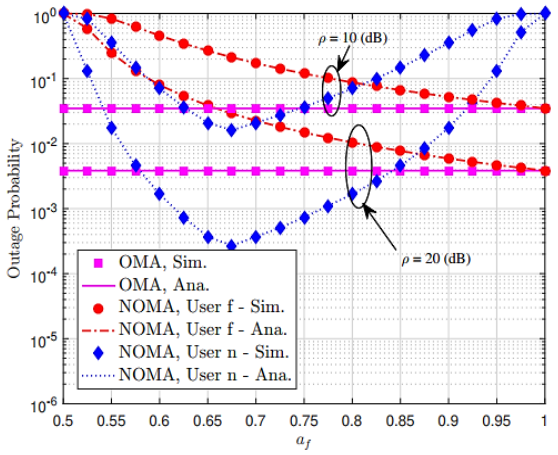

Figure 6. Outage probability comparison with respect to the power allocation coefficient a_f: $f = 1, n = 2$, and $\mu = 2$

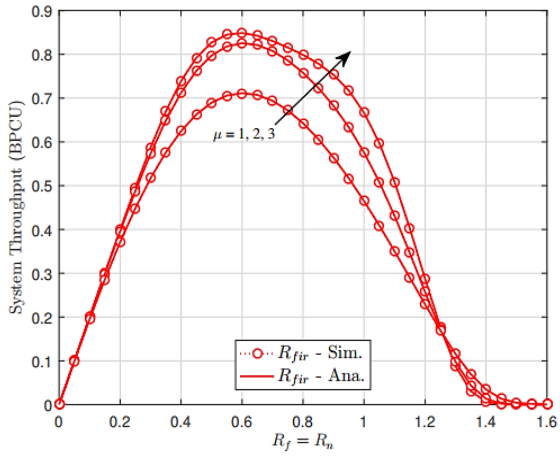

Figure 7. Nakagami-m fading
$f = 1, \rho = 10\ db, n = 2, \mu = 2$ and $\mu = 3$

6. CONCLUSION

The novel NOMA scheme based on Nakagami-m fading for downlink is presented. In the scheme, power allocation factors, transmit SNR at the BS, threshold rates at each user are jointly designed to find optimal performance. Moreover, two NOMA users in different outage performance are distinguished as varying parameter of Nakagami-m fading. A closed-form expression of ouatge is developed to examine system performance under the constraint of individual rate budget. Simulation results show that the exactness of derived expression of the proposed scheme.

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