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A Comparison of BER Performance for Receivers of NOMA in 5G Mobile Communication System

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5G 이동 통신 시스템에서 비직교 다중접속의 수신기들에 대한 BER 성능의 비교

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Abstract In the fifth generation (5G) mobile networks, the mobile services require 100 times faster connections. One of the promising 5G technologies is non-orthogonal multiple access (NOMA). In NOMA, the users share the channel resources, so that the more users can be served simultaneously. There are several advantages offered by NOMA, such as higher spectrum efficiency and low transmission latency, compared to orthogonal multiple access (OMA), which is usually used in the fourth generation (4G) mobile networks, for example, long term evolution (LTE). In this paper, we compare the receivers for NOMA. The standard NOMA receiver, the non-SIC NOMA receiver, and the symmetric superposition coding (SC) NOMA receiver are compared. Specifically, it is shown that the performance of the standard receiver is the best, whereas the performances of the non-SIC receiver and symmetric SC receiver are dependent on the power allocation.

Key Words : NOMA, 5G, Superposition coding, Successive interference cancellation, Power allocation

요 약 5G 이동 통신 시스템에서는, 통신 서비스가 100배 빠른 망 연결을 연구한다. 비직교 다중접속은 선도적인 5G 기술들 중 하나로 주목받고 있다. 비직교 다중접속에서는 사용자들이 채널 자원들을 공유하여, 더 많은 사용자들이 동시에 서비스를 받을 수가 있다. LTE와 같은 4G 이동 통신에서 사용되는 직교 다중접속과 비교하면, 비직교 다중접속은 높은 주파수 효율과 초저 지연과 같은 장점을 가진다. 본 논문에서는 비직교 다중접속의 수신기들을 비교한다. 표준 수신기, SIC를 수행하지 않는 수신기, 그리고 대칭 중첩 코딩 수신기가 비교된다. 구체적으로, 표준 수신기의 성능이 가장 우수하며, SIC를 수행하지 않는 수신기, 그리고 대칭 중첩 코딩 수신기의 성능은 전력 할당에 따라 달라지는 성능 분석을 본 논문에서 고찰한다.

주제어 : 비직교 다중접속, 5G, 중첩 코딩, 연속 간섭 제거, 전력 할당

1. Introduction

Since the fifth generation (5G) mobile communication service was commercialized in Korea, April 3, 2019, one year has passed. However, still the 5G service providers and the international standardization bodies try to further improve the 5G mobile communication. Higher spectral efficiency is one of the main challenges of 5G networks that require the 1000 times higher data rate than current 4G systems

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[1-2]. With several key technologies such as millimeter wave (mmWave), massive multiple-input multiple-output (MIMO), and non-orthogonal multiple access (NOMA) has attracted great attention to achieve higher spectral efficiency with low cost [3]. In particular, NOMA is considered as a promising multiple access candidate of 5G networks. By opening up a power domain in which multiple users' signals are multiplexed using superposition coding (SC), NOMA achieves high spectral efficiency with a help of successive interference cancellation (SIC) at receiving nodes [4]. In NOMA systems, multiple users' signals are superimposed at the transmitter, by SC, while SIC is applied to separate the superimposed signals at the receivers [5]. Recently, the bit-error rate (BER) performance for the NOMA networks was analyzed for M-user in [6]. The impact of local oscillator imperfection for NOMA was studied in [7]. On the other hand, in [8], the BER expression was presented with randomly generated signals. In [9], the exact BER expression was derived for the two and three-user cases. The exact average symbol error rate (SER) expressions for the two-user case were presented in [10].

Recently, it is reported that SIC is a key component of NOMA systems, and is crucial for the performance of NOMA transmission [11]. The performance of a secure NOMA-enabled mobile edge computing network is investigated in [12].

In NOMA, the performances are investigated by the achievable data rate, the outage probability, and the BER. In this paper, the BER performance is evaluated for the various receivers. Specifically, three receivers are considered; first, the ideal perfect SIC NOMA receiver is investigated. Second, the non-SIC NOMA receiver is considered. Third, the symmetric SC NOMA is evaluated. Note that the ideal perfect SIC NOMA receiver achieves the best BER performance, while the non-SIC NOMA receiver and the symmetric SC NOMA show the worse BER performance than the ideal perfect SIC NOMA, because the BER performance of NOMA greatly depends on the performance of SIC.

2. System and Channel Model

We consider a cellular downlink NOMA transmission system, in which two users are paired from a base station within the cell. The Rayleigh fading channel between the mth user and the base station is denoted by $h_m \sim CN(0, \Sigma_m)$, $m = 1,2$. The channels are sorted as $\Sigma_1 > \Sigma_2$. The base station will send the superimposed signal $x = \sqrt{\alpha P} s_1 + \sqrt{(1-\alpha)P} s_2$, where s_m is the message for the mth user with unit power, $E[|s_1|^2] = E[|s_2|^2] = 1$, α is the power allocation factor, with $0 \le \alpha \le 1$, and P is the total transmitted power at the base station. The observation at the mth user is given by

$$r_m = |h_m| x + n_m, \quad (1)$$

where $n_m \sim N(0, N_0/2)$ is additive white Gaussian noise (AWGN). We assume the binary phase shift keying (BPSK) modulation with $s_m \in \{+1, -1\}$.

It should be noted that in contrast to orthogonal multiple access (OMA), the channel resources, such as frequency and time, are shared by both users in NOMA, as in the equation (1). For example, in orthogoanl frequency devision multiple access (OFDMA) of long term evolution-advanced (LTE-A), a single user can use the channel in the equation (1).

3. BER for Various Receivers

In this section, we consider the various receivers for NOMA and compare the BER performances. The various receivers' structures for the users are summarized in Table 1.

Table 1. Various receivers for two users

receiver \ user	stronger channel user	weaker channel user
standard NOMA	SIC receiver	non-SIC receiver
non-SIC NOMA	non-SIC receiver	non-SIC receiver
symmetric SC NOMA	symmetric non-SIC receiver	non-SIC receiver

3.1 Standard Receiver

In NOMA, the standard receiver for the stronger channel user performs SIC. Usually the ideal perfect SIC is assumed. This is validated by the random channel codng, theoretically. Practically, the low-density parity-check (LDPC) codes and turbo codes are used to implement the ideal perfect SIC at the stronger channel user's receiver. Thus, the ideal perfect SIC is assumed, the received signal given by

$$y_1 = |h_1| \sqrt{\alpha P} s_1 + n_1. \tag{2}$$

Then, the BER of the ideal perfect SIC NOMA for stronger channel user is given as

$$P_e^{(1;\, iedal\, perfect\, SIC\, NOMA)} = F\left(\frac{\Sigma_1 P\alpha}{N_0}\right), \tag{3}$$

where

$$F(\gamma_b) = \frac{1}{2}\left(1 - \sqrt{\frac{\gamma_b}{1+\gamma_b}}\right). \tag{4}$$

3.2 Non-SIC Receiver

As opposed to the ideal perfect SIC NOMA, the non-SIC NOMA receiver dose not perform SIC for the stronger channel user [13]. In this case, the maximum likelihood (ML) detection is based on observation itself

$$\begin{aligned} y_2 = r_2 &= |h_2| x + n_1 \\ &= |h_2| \sqrt{\alpha P} s_1 + |h_2| \sqrt{(1-\alpha)P} s_2 + n_2 \end{aligned} \tag{5}$$

Thus, the decision boundary changes according to the power allocation α, as follows

$$\begin{aligned} &\text{for } \alpha < 0.5, \quad y_2 > 0, \\ &\text{for } \alpha > 0.5, \quad \begin{cases} y_2 > |h_2| \sqrt{\alpha P} s_1, \\ 0 > y_2 > -|h_2| \sqrt{\alpha P} s_1. \end{cases} \end{aligned} \tag{6}$$

Then, the BER of the optimal ML receiver for the stronger channel user is given as [13], for $\alpha < 0.5$,

$$\begin{aligned} P_e^{(1;\, non-SIC\, NOMA)} &\simeq F\left(\frac{\Sigma_1 P\alpha}{N_0}\right) \\ &- \frac{1}{2} F\left(\frac{\Sigma_1 P\left(\sqrt{(1-\alpha)} + \sqrt{\alpha}\right)^2}{N_0}\right) \\ &+ \frac{1}{2} F\left(\frac{\Sigma_1 P\left(\sqrt{(1-\alpha)} - \sqrt{\alpha}\right)^2}{N_0}\right) \\ &+ \frac{1}{2} F\left(\frac{\Sigma_1 P\left(2\sqrt{(1-\alpha)} + \sqrt{\alpha}\right)^2}{N_0}\right) \\ &- \frac{1}{2} F\left(\frac{\Sigma_1 P\left(2\sqrt{(1-\alpha)} - \sqrt{\alpha}\right)^2}{N_0}\right), \end{aligned} \tag{7}$$

and for $\alpha > 0.5$,

$$\begin{aligned} P_e^{(1;\, non-SIC\, NOMA)} &\simeq \\ &+ \frac{1}{2} F\left(\frac{\Sigma_1 P\left(\sqrt{\alpha} + \sqrt{(1-\alpha)}\right)^2}{N_0}\right) \\ &+ \frac{1}{2} F\left(\frac{\Sigma_1 P\left(\sqrt{\alpha} - \sqrt{(1-\alpha)}\right)^2}{N_0}\right). \end{aligned} \tag{8}$$

3.3 Symmetric SC Receiver

Now, we consider the symmetric SC receiver, which is basically based on the non-SIC receiver [14]. Assume the information input message bit with $b_m \in \{0,1\}$ In the symmetric SC NOMA, the bit-to-symbol mapping is different from the standard NOMA. Such mapping is given by

$$\begin{cases} s_1(b_1=0 \mid b_2=0)=+1 \\ s_1(b_1=1 \mid b_2=0)=-1 \end{cases}, \begin{cases} s_1(b_1=0 \mid b_2=1)=-1 \\ s_1(b_1=1 \mid b_2=1)=+1 \end{cases}$$

$$\begin{cases} s_2(b_2=0)=+1 \\ s_2(b_2=1)=-1 \end{cases}. \tag{9}$$

Then the BER of the optimal ML receiver for the stronger channel user is given as [14], for $\alpha < 0.5$,

$$P_e^{(1;symmetric\,SC\ NOMA)} \simeq F\left(\frac{\Sigma_1 P\alpha}{N_0}\right) + \frac{1}{2}F\left(\frac{\Sigma_1 P\left(2\sqrt{(1-\alpha)}+\sqrt{\alpha}\right)^2}{N_0}\right) - \frac{1}{2}F\left(\frac{\Sigma_1 P\left(2\sqrt{(1-\alpha)}-\sqrt{\alpha}\right)^2}{N_0}\right), \tag{10}$$

and for $\alpha > 0.5$,

$$P_e^{(1;symmetric\,SC\ NOMA)} \simeq F\left(\frac{\Sigma_1 P(1-\alpha)}{N_0}\right) + \frac{1}{2}F\left(\frac{\Sigma_1 P\left(2\sqrt{\alpha}+\sqrt{(1-\alpha)}\right)^2}{N_0}\right) - \frac{1}{2}F\left(\frac{\Sigma_1 P\left(2\sqrt{\alpha}-\sqrt{(1-\alpha)}\right)^2}{N_0}\right). \tag{11}$$

3.4 Receiver for Weaker Channel User

Up to now we present the receivers of the stronger channel user for the three NOMA schemes. In this subsection, we consider the receiver of the second user with the weaker channel gain. In NOMA, the SIC is not performed on the weakest channel user, who is the second user in our case. Therefore, for the three NOMA schemes, the BER performances are the same, based on the detection rule. If the optimal ML receiver is used, then the BER is given by, for $\alpha < 0.5$,

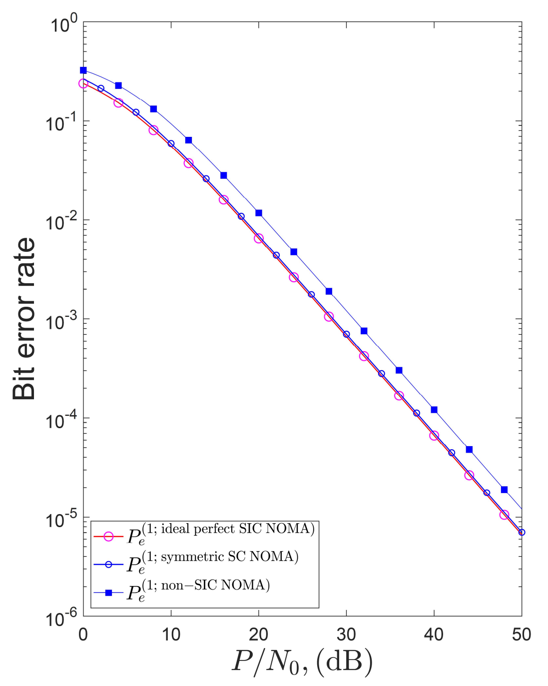

Fig. 1. Comparison of BERs for various receivers with $\alpha=0.25$, for stronger channel user.

$$P_e^{(2;optimal\ ML\ NOMA)} \simeq + \frac{1}{2}F\left(\frac{\Sigma_1 P\left(\sqrt{(1-\alpha)}+\sqrt{\alpha}\right)^2}{N_0}\right) + \frac{1}{2}F\left(\frac{\Sigma_1 P\left(\sqrt{(1-\alpha)}-\sqrt{\alpha}\right)^2}{N_0}\right), \tag{12}$$

and for $\alpha > 0.5$,

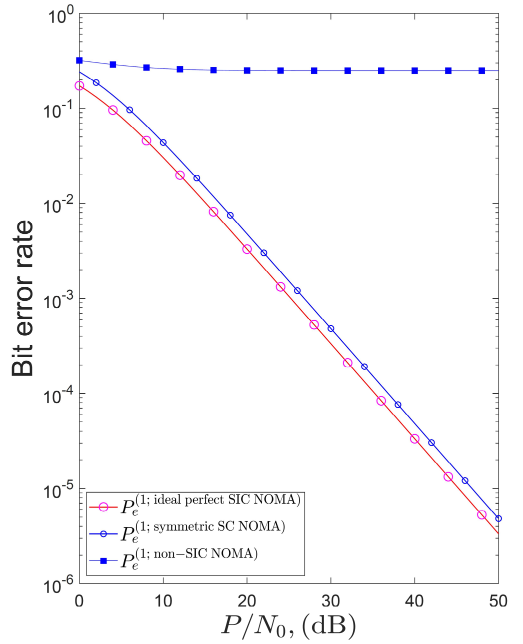

Fig. 2 Comparison of BERs for various receivers with $\alpha=0.5$, for stronger channel user.

$$P_e^{(2;optimal\ ML\ NOMA)} \simeq F\left(\frac{\Sigma_1 P(1-\alpha)}{N_0}\right) - \frac{1}{2}F\left(\frac{\Sigma_1 P\left(\sqrt{\alpha}+\sqrt{(1-\alpha)}\right)^2}{N_0}\right) + \frac{1}{2}F\left(\frac{\Sigma_1 P\left(\sqrt{\alpha}-\sqrt{(1-\alpha)}\right)^2}{N_0}\right) + \frac{1}{2}F\left(\frac{\Sigma_1 P\left(2\sqrt{\alpha}+\sqrt{(1-\alpha)}\right)^2}{N_0}\right) - \frac{1}{2}F\left(\frac{\Sigma_1 P\left(2\sqrt{\alpha}-\sqrt{(1-\alpha)}\right)^2}{N_0}\right). \tag{13}$$

4. Numerical Results and Discussions

It is assumed that $\Sigma_1=1.5$ and $\Sigma_2=0.5$, for the numerical results.

4.1 BER for Stronger Channel User

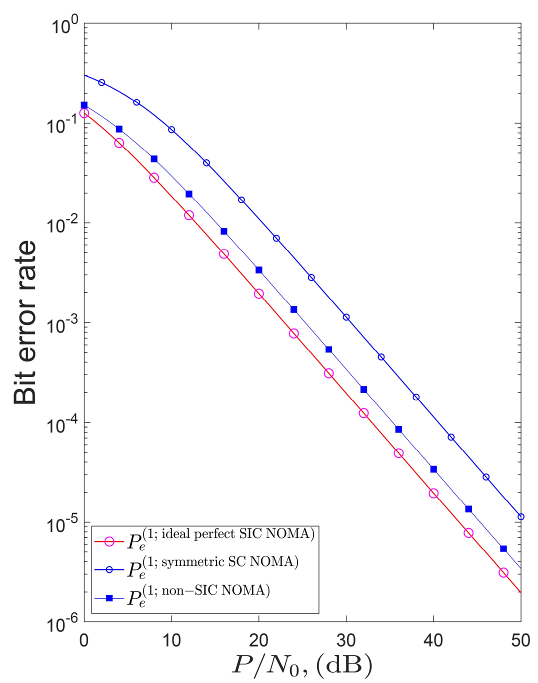

Fig. 3 Comparison of BERs for various receivers with $\alpha=0.8$, for stronger channel user.

First, we compare the BER performance of the three receivers for the first user. As shown in Fig. 1, for $\alpha=0.25$, the BER of the ideal perfect SIC receiver is the best, because the inter-user interference, i.e., the signal of the second user, is removed perfectly. The BER of the symmetric SC receiver is almost the same as that of the ideal perfect SIC receiver. while the non-SIC receiver shows the worst performance, compared to the other two receivers. Then we have the following inequality

$$P_e^{(1;iedal\ perfect\ SIC\ NOMA)} \le P_e^{(1;symmetric\ SC\ NOMA)} \le P_e^{(1;non-SIC\ NOMA)}. \tag{14}$$

At the BER of 10^{-4}, the ideal perfect SIC

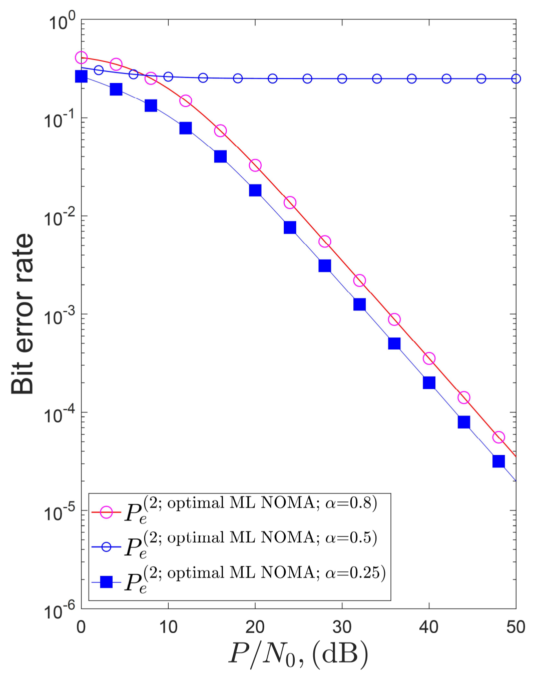

Fig. 4. Comparison of BERs with various power allocation for weaker channel user.

receiver and symmetric SC receiver perform better than the non-SIC receiver by about 3 dB.

In Fig. 2, we depict the BER performances of three receviers for $\alpha = 0.5$, i.e., the equal power allocation for both users. We observe the similar BER performances to those in Fig. 1. One difference is that the BER of the non-SIC receiver shows the error floor. Therefore, the equal power allocation is hard to be used in the non-SIC receiver.

In Fig. 3, the BER performances of the three receivers are presented for $\alpha = 0.8$, the power allocation of which is usually not used for the user fairness, i.e., the less power to the stronger channel user and the more power to the weaker channel user. However, in order to have the broader perspective to the BER performances of the three receivers, we compare such performances. We observe that the receiver of the symmetric SC NOMA shows the worst performance, as opposed to Fig. 1 and Fig. 2. The BER of the non-SIC receiver is better than that of the symmetric SC receiver. The reason is that the symmetric SC is designed especially for the range of the power allocation $\alpha < 0.5$. In this case, we have the following inequality

$$P_e^{(1;\, iedal\, perfect\, SIC\, NOMA)} \leq P_e^{(1;\, non-SIC\ NOMA)} \leq P_e^{(1;\, symmetric\, SC\ NOMA)}. \tag{15}$$

At the BER of 10^{-4}, the ideal perfect SIC receiver performs better than the non-SIC receiver and symmetric SC receiver by about 2 dB and 7 dB, respectively.

Table 2. BER comparison for various receivers

SNR gain of standard NOMA	with respect to symmetric SC NOMA	with respect to non-SIC NOMA
$\alpha = 0.25$	0 dB	3 dB
$\alpha = 0.5$	1 dB	∞ dB
$\alpha = 0.8$	7 dB	2 dB

We also summarize the SNR gains of the ideal perfect SIC receiver over the non-SIC receiver and symmetric SC receiver in Table 2.

4.2 BER for Weaker Channel User

Up to now, we present the BER performances of the stonger channel user. We now consider the BER performances of the weaker channel user. As opposed to the stronger channel user, the BER performances of the weaker channel user are the same for the three receivers. The reason is that in NOMA, the SIC is not performed on the user with the weakest channel gain, i.e., the second user in our case. Furthermore, the symmetric SC does not affect the BER performance of the waeker channel user. Therefore, we depict the BER of the weaker channel user for the three receivers for different values of the power allocation α. As shown in Fig. 4, the best BER performance is achieved when $\alpha=0.25$. However, the worst BER performance occurs when $\alpha=0.5$, not $\alpha=0.8$. The reason is that when $\alpha=0.5$, the inter-user interference, i.e., the stonger channel user's signal, interferes severely with the second user's signal.

An additional comment is that the standard SIC receiver shows the best BER performance, compared two other receivers. However, the complexity of the standard receiver is the largest, owing to SIC.

Lastly, it should be mentioned that the meaning of the comparison in this paper is to have the better understandings and braoder perspectives for the receiver's structure in NOMA.

5. Conclusion

In this paper, we compared the BER performances for the various receivers in NOMA. Specifically, the ideal perfect SIC receiver, the symmetric SC receiver, and the non-SIC receiver were compared, in terms of the BER. We also presented the impact of the power allocation on the BER performance for both the songer channel user and weaker channel user. In result, the receiver for NOMA could be selected, according to the power allocation, given in the system.

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