Journal of Convergence for Information Technology
Vol. 10. No. 9, pp. 22-27, 2020
e-ISSN 2586-4440
DOI : https://doi.org/10.22156/CS4SMB.2020.10.09.022

Impact of Channel Estimation Errors on SIC Performance of NOMA in 5G Systems

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5G 시스템에서 비직교 다중접속의 SIC 성능에 대한 채널 추정 오류의 영향

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Abstract In the fifth generation (5G) networks, the mobile services require much faster connections than in the fourth generation (4G) mobile networks. Recently, as one of the promising 5G technologies, non-orthogonal multiple access (NOMA) has been drawing attention. In NOMA, the users share the frequency and time, so that the more users can be served simultaneously. NOMA has several superiorites over orthogonal multiple access (OMA) of long term evolution (LTE), such as higher system capacity and low transmission latency. In this paper, we investigate impact of channel estimation errors on successive interference cancellation (SIC) performance of NOMA. First, the closed-form expression of the bit-error rate (BER) with channel estimation errors is derived, And then the BER with channel estimation errors is compared to that with the perfect channel estimation. In addition, the signal-to-noise (SNR) loss due to channel estimation errors is analyzed.

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

요 약 5G 시스템에서는, 통신 서비스가 4G 통신보다 더욱 더 빠른 망 연결을 요구한다. 최근, 선도적인 5G 기술들 중 하나로 비직교 다중접속이 주목받고 있다. 비직교 다중접속에서는 사용자들이 주파수와 시간을 공유하여, 더 많은 사용자들이 동시에 서비스를 받을 수가 있다. LTE와 같은 직교 다중접속과 비교하면, 비직교 다중접속은 더 큰 시스템 용량과 초저 지연과 같은 장점을 가진다. 본 논문에서는 비직교 다중접속의 SIC에 채널 추정 오류가 미치는 영향을 고찰한다. 우선, 채널 추정 오류를 가지는 수신기의 폐쇄형 수식을 구한다. 그리고 채널 추정 오류의 BER를 완벽한 채널 추정의 BER과 비교한다, 또한, 채널 추정 오류로 발생하는 SNR 손실을 분석한다.

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

1. Introduction

Non-orthogonal multiple access (NOMA) has recently emerged as a key radio multiple access (MA) technology to meet the tremendous requirements of future mobile fifth generation (5G) networks, owing to its inherent advantages of high spectral efficiency, massive connectivity, and low latency [1-2]. With the state-of-the-art technologies such as millimeter wave (mmWave), massive multiple-input multiple-output (MIMO), NOMA has attracted great attention to achieve higher system capacity [3]. In particular, NOMA is considered as a promising MA of 5G mobile

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Received July 31, 2020
Revised September 6, 2020
Accepted September 20, 2020
Published September 28, 2020

communications. The key idea of NOMA is that when the siginal with using superposition coding (SC) is transmitted at the base station, successive interference cancellation (SIC) is performed for separating the signals in power domain, and after cancellation, the signals with lower power levels will be considered as noise [4]. In the NOMA scheme, many users' signals are superimposed at the base station, while SIC is applied to separate the transmitted signals at each receiver [5]. In addition, the bit-error rate (BER) NOMA performance was analyzed for *M*-user in [6]. The effect of local oscillator imperfection was studied for NOMA [7]. In [8], the BER expression was analyzed with randomly generated signals. In [9], the exact BER expression was presented for the two and three-user cases. The exact average symbol error rate (SER) expressions were presented in [10].

Recently, it was reported that SIC is crucial for the performance of NOMA [11]. The performance of a secure NOMA-enabled mobile network is investigated in [12]. In addition, the state-of-the-art advances in NOMA can be found in [14-17],

NOMA performances are investigated by the achievable rate, the outage probability, and the BER. In this paper, the BER performance is evaluated for the imperfect channel state information (CSI). Specifically, we define the percentage channel estimation, and derive the closed-form expression of the BER for NOMA with imperfect CSI. In addition, we investigate the signal-to-noise (SNR) loss for imperfect CSI.

The remainder of this paper is organized as follows. In Section 2, the system and channel model are described. The analytical expression of the BER for NOMA with imperfect CSI is derived in Section 3. The results are presented and discussed in Section 4. Finally, the conclusions are presented in Section 5.

Our contributions are summarized as follows; 1. An analytical expression for the BER of NOMA with channel estimation errors is derived. 2. The impact of channel estimation errors on the BER is investigated. Especially, we oberve that the BER degradation is severe, for the power allocation range, about $\alpha < 0.2$, and the SNR loss due to imperfect CSI is about 6 dB.

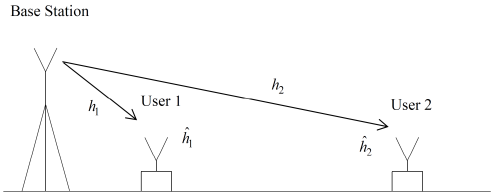

Fig. 1 System and Channel Model.

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. For the number of users more than two, the results can be generalized with more complex derivations. The block diagram for the system and channel model is illustrated in Fig. 1. We investigate the Rayleigh fading channels, because this channel model is mostly used in cellular mobile communications. The Rayleigh fading channel between the mth user and the base station is denoted by $h_m \sim CN(0, \Sigma_m)$, $m = 1,2$, where $CN(\mu, \Sigma)$ represents the distribution of circularly-symmetric complex Gaussian (CSCG) random variable (RV) with mean μ and variance Σ. 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 $0 \le \alpha \le 1$, i.e., the percentage power allocation of the first user, and P is the total transmitted power at the base station. The observation at the mth user is given by

$$r_m = |h_m| x + n_m, \tag{1}$$

where $n_m \sim N(0, N_0/2)$ is additive white Gaussian noise (AWGN). The notation $N(\mu, \Sigma)$ represents the distribution of Gaussian RV with mean μ and variance Σ, and N_0 is one-sided power spectral density. We assume the binary phase shift keying (BPSK) modulation with $s_m \in \{+1, -1\}$. We consider the BPSK modulation, because BPSK is one of the common modulation techniques.

Table 1. Two causes for imperfect SIC

SIC	decoding	channel estimation
perfect SIC	perfect	perfect
imperfect SIC #1 in [13]	imperfect	perfect
imperfect SIC #2 in this paper	perfect	imperfect

3. BER Derivation with Imperfect CSI

We consider the power allocation range, $0 \le \alpha \le 0.5$, to ensure the user fairness. Then, we define the percentage channel estimation error,

$$e_m = \frac{|h_1| - |\widehat{h}_m|}{|h_1|}, \tag{2}$$

where $0 \le e_m \le 1$. Such definition may be viewed as the simplified version of more complex and realistic channel estimation errors, such as minimum mean squared estimation (MMSE) errors and least squares (LS) estimation errors. The causes of the imperfect SIC are mainly two; one thing is the decoding error of the weaker channel user's signal, and the other is the channel estimation error. In this paper, we only consider the impact of the channel estimation error, assuming that the decoding of the weaker channel user's signal is perfect. Such cases are summarized in Table 1.

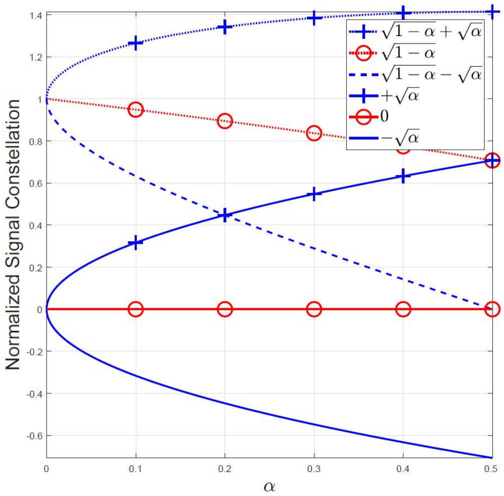

Fig. 2 Normalized signal constellation for perfect SIC.

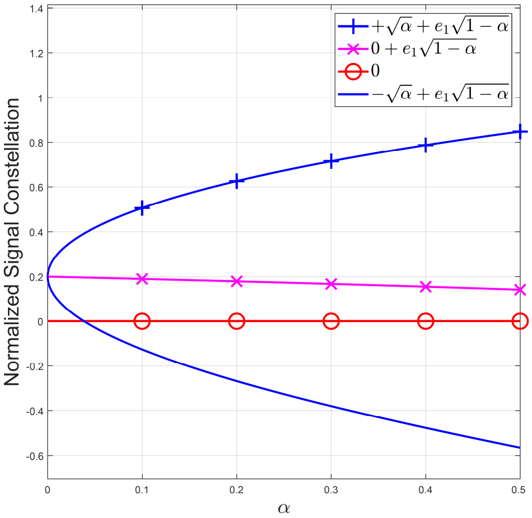

Fig. 3. Normalized signal constellation for imperfect SIC.

Before preceeding, we should mention that the impacts of the imperfect SIC due to imperfect decoding errors with perfect CSI was analyzed in [13].

Then without loss generality, we assume that the perfectly decoded signal of the second user is $s_m = +1$. In this case, for the perfect channel state information (CSI), the decision boundary for the first user is given by

$$r_1 = 0, \tag{3}$$

whereas for the imperfect CSI, the decision boundary of the first user is given by

$$\begin{aligned} r_1 &= |h_1| \sqrt{P(1-\alpha)} - |\hat{h}_m| \sqrt{P(1-\alpha)} \\ &= \left(|h_1| - |\hat{h}_m| \right) \sqrt{P(1-\alpha)} \\ &= |h_1| e_m \sqrt{P(1-\alpha)}. \end{aligned} \tag{4}$$

Then, the BER performance of the first user with imperfect CSI is given by

$$\begin{aligned} P_e^{(1;NOMA;imperfect\ CSI)} &= \\ -\frac{1}{2}F&\left(\frac{\Sigma_1 P \left(\sqrt{\alpha} + e_1 \sqrt{(1-\alpha)} \right)^2}{N_0} \right) \\ +\frac{1}{2}F&\left(\frac{\Sigma_1 P \left(\sqrt{\alpha} - e_1 \sqrt{(1-\alpha)} \right)^2}{N_0} \right), \end{aligned} \tag{5}$$

where

$$F(\gamma_b) = \frac{1}{2}\left(1 - \sqrt{\frac{\gamma_b}{1+\gamma_b}} \right). \tag{6}$$

Table 2. BER loss for varying power allocation

BER loss	compared to perfect SIC
$\alpha = 0.1$	3×10^{-4}
$\alpha = 0.2$	3×10^{-5}
$\alpha = 0.5$	5×10^{-6}

4. Numerical Results and Discussions

It is assumed that $\Sigma_1 = 1.5$ and $\Sigma_2 = 0.5$, for the numerical results. In addition, we assume $e_1 = 0.2$, i.e., 20% channel estimation error.

For comparison, the BER performance of the first user with perfect CSI is given by

$$P_e^{(1;NOMA;perfect\ CSI)} = F\left(\frac{\Sigma_1 P \alpha}{N_0} \right). \tag{7}$$

First, in order to investigate the impact of perfect CSI on the signal, we depict the signal constellation, in Fig. 2. As shown in Fig. 2, when the perfect CSI is available at the receiver of the first user, the interference is perfectly removed. However, when CSI is imperfect, the interference remains at the first user's receiver, as shown in Fig. 3. Therefore, the imperfect CSI degrades the BER performance of the first user. Such degradation is depicted in Fig. 4, with the fixded SNR $P/N_0 = 40$ dB, over the power allocation range $0 \le \alpha \le 0.5$. As shown in Fig. 4, the BER degradation due to imperfect CSI is severe up to the power allocation less than about $\alpha = 0.2$. As the power allocation approaches $\alpha = 0.5$, the BER degradation becomes negligible. Such BER losses are summarized in Table 2. In addition, to analyze the SNR loss owing to the channel estimation, in Fig. 5, we depict the BER performance for the fixed power allocation, $\alpha = 0.1$, with varying SNR $0 \le P/N_0 \le 50$ (dB). As shown Fig. 4, we observe the SNR loss of 6 dB, at the BER of 10^{-4}.

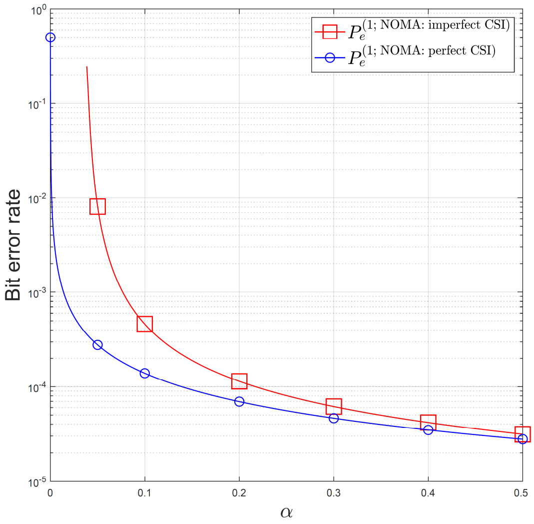

Fig. 4 Comparison of BERs for perfect/imperfect SIC, for varying power allocation.

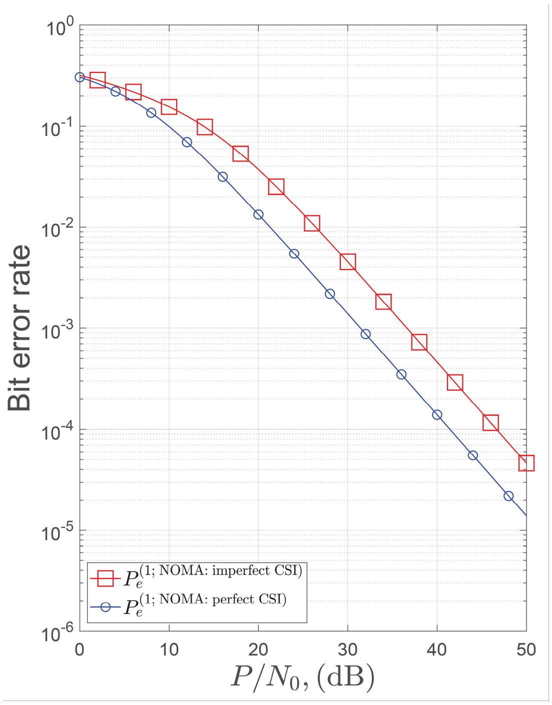

Fig. 5 Comparison of BERs for perfect/imperfect SIC, for fixed power allocation.

5. Conclusion

We derived an analytical expression for the BER of NOMA with channel estimation errors. Then the impact of channel estimation errors on the BER was investigated. It was shown that the BER degradation is severe, less than the power allocation, about $\alpha = 0.2$, and the SNR loss due to imperfect CSI is about 6 dB, at the BER of 10^{-4}. In result, the channel estimation error should be considered in design of NOMA systems, especially for the stronger channel user.

As a direction for future research, it would be significant to optimize the channel estimation errors with algorithm, in more realistic channel models' surroundings,. In addition, it would be interesting to investigate the impacts of MMSE errors and LS estimation errors on the BER performance.

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