IEEE Wireless Telecommunications Symposium (WTS2019), April 9- 12, New York City, USA

Performance of Uplink Non-Orthogonal Multiple Access (NOMA) in the Presence of Channel Estimation Errors

Faeik T. Al Rabee, *Student Member*, *IEEE* and Richard D. Gitlin, *Life Fellow*, *IEEE*
Innovation in Wireless Information Networking Lab (*i*WINLAB)
Department of Electrical Engineering,
University of South Florida
Tampa, Florida 33620, USA

Email: faeiktayseer@mail.usf.edu, richgitlin@usf.edu

***Abstract*— Non-orthogonal multiple access (NOMA) is a promising technique to meet the demands of low latency and massive connectivity in Fifth generation (5G) mobile networks. This paper investigates the performance of a system with power-domain NOMA and Successive Interference Cancellation (SIC) reception. A simulation study is used to determine the bit error rate (BER) performance of two-user uplink NOMA using BPSK, QPSK, and 16- QAM with a SIC receiver in the presence of channel estimation errors. As expected, with perfect channel estimation, the BER of the SIC receiver increases as the modulation order is increased. For example, for BPSK at a signal-to-noise ratio (SNR) of 5 dB, the user that is detected first has a BER of 0.0007 and that is detected with the aid of the SIC receiver has a BER of 0.10, illustrating the performance of SIC receiver. With channel estimation errors, for BPSK with a channel estimation error value of 0.25, the BER of the first signal at a SNR of 15 dB is equal to 0.032 compared to a BER of 0.007 for perfect estimation at the same SNR. Results are also presented for QPSK and 16-QAM modulations with and without channel estimation errors.**

Keywords— Non-orthogonal multiple access (NOMA); 5G; successive interference cancellation (SIC); BER.

I. Introduction

In 5G wireless communication systems, new radio access technologies are explored to satisfy the demanding requirements such as massive connectivity, low latency, and high data rate. Designing a suitable multiple access technique is an important aspect to improve system capacity [1]-[2].

Non-orthogonal multiple access (NOMA) is a promising multiple access technique for 5G cellular systems to improve spectral efficiency, provide low latency, high reliability, and massive connectivity [3]. NOMA techniques are divided into two categories, namely, power-domain and code-domain [4]-[5]. This paper focuses on the power-domain NOMA in the uplink, where different users share the same time, frequency, and (possibly) code, but with different power levels. To detect the desired signals while minimizing the interference, a SIC [6] technique is employed at the base station (BS) receiver. The signals are assigned unique power levels so that the received signals arrive at the BS with an adequate power difference to allow the SIC receiver to decode them correctly. The SIC receiver sequentially detects the signals from the superimposed received signal at the BS. Once a user signal is successfully decoded, it is subtracted from the composite signal. Various modulations schemes (levels) can be used to modulate the transmitted signals such as BPSK, QPSK, and 16-QAM. Here the bit error rate (BER) is investigated for the NOMA receiver with and without channel estimation errors.

Recently, NOMA has been extensively studied in the last few years [7]-[8]. For example, in [7], switching between orthogonal multiple access (OMA) and NOMA scheme has been proposed to improve performance of the far user (FU) while ensuring that near user (NU) does not lose performance due to cooperative NOMA [9]. In [8], a NOMA developed system has been proposed and its performance has been analyzed by proposing a power allocation scheme to guarantee the data rate by minimizing the outage probability.

In this paper, the BER performance of a two-user uplink NOMA system using successive interference cancellation (SIC), has been analyzed via simulation. Also, the BER for a given channel estimation error is investigated for BPSK, QPSK, and 16-QAM modulation schemes. The performance in the presence of different estimation errors is analyzed.

The main contribution of this paper can be summarized as follows:

- A simulation study of the BER performance of a two-user uplink NOMA using BPSK, QPSK and 16-QAM with a SIC receiver is introduced.

- For the above study, two scenarios are studied:
  - Perfect channel estimation.
  - Performance with a channel estimation error as a function of the modulation level.

The rest of this paper is organized as follows: Section II describes the system model of a two-user uplink NOMA system with SIC reception. The simulation results of the BER performance for different modulation schemes with and without channel estimation errors is presented in Section III. Finally, the paper is concluded in Section IV.

II. System Model

This paper considers the uplink NOMA system which consists of two users and a BS receiver. The corresponding system diagram is illustrated in Fig. 1. The first user transmits its signal, X_1 scaled by a power coefficients P_1, to the BS over a channel with (scalar) coefficient h_1. The second user sends its signal, X_2 with its power coefficients P_2, to the BS with channel coefficient h_2. The received signal, y, at the BS is represented as:

$$y = h_1 x_1 + h_2 x_2 + n, \quad (1)$$

where n is the additive white Gaussian noise (AWGN) with zero mean and variance σ^2. The transmitted signals x_1 and x_2 in (1) represent the transmitted signals X_i for each user with its power coefficients P_i.

In [6], the optimum received uplink power levels using a SIC detector for any number of transmitters were determined. The analysis in this paper assumed that there is a constant channel during the estimation and communication process. In this paper, a constant channel estimation error, e, is assumed. Furthermore, the power coefficients are set to the optimum levels as determined in [6]. As in Fig. 1, the SIC receiver detects user 2 signal first from the superimposed signals and noise, then the detector subtracts this signal from the superimposed signal in order to perform the detection of user 1 signal. This is illustrated in Fig. 2.

This paper focuses on studying the BER performance of a two-user uplink NOMA using a SIC detector for different modulation schemes. First, the BER performance, with various modulations schemes, is studied assuming no channel estimation error (perfect channel estimation). Second, the effect of a channel estimation error on each modulation scheme is investigated.

For the perfect scenario, the methodolgy assumes that the two users signals have been generated each 10^6 bits in duration to create the BPSK, PSK and 16-QAM signals. In addition, AWGN noise has been generated and then it is added to the two transmitted signals at the receiver side as shown in (1).

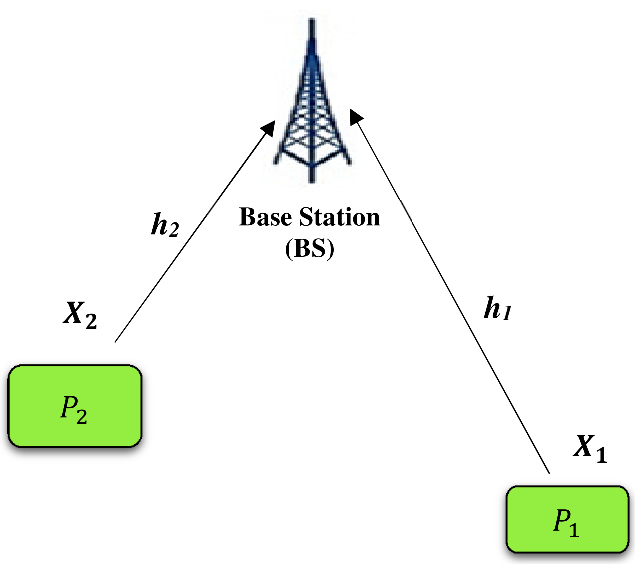

Fig. 1. Uplink NOMA system with two users.

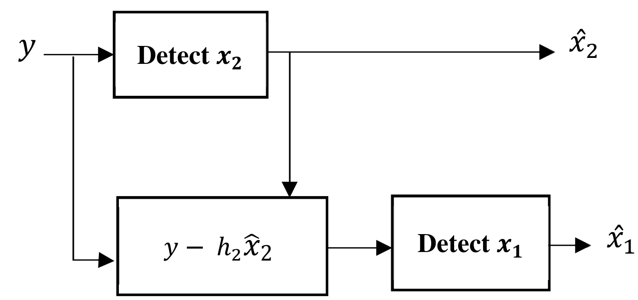

Fig. 2. Illustration of SIC signal detection for a two-user uplink NOMA.

Taking into account the channel attenuation, the power coefficients P_1 and P_2 have been selected so that the received signals are the optimum values as in [6] and are communicated using the Slotted Aloha-NOMA (SAN) protocol as introduced in [10]-[11]. In the present analysis, user 2 is assumed to be detected first by the SIC detector. The simulation results of this scenario are discussed in details in Section III.

For the case with channel estimation errors, the BER performance is investigated for the different modulation schemes. In addition to the same assumptions in the perfect estimation case, there are some additional assumptions. With channel estimation errors, the received signal powers are selected to be the values that would be optimal when there are no channel estimation errors. The estimation error (e) is defined as the absolute value of the difference between the channel coefficient and its estimated value normalized to the magnitude of the channel coefficient. So that, the error value is considered as a percentage value (normalized to the channel coefficient). The results have been simulated for different values of channel estimation error. For simplicity, we show the results for 0.15 and 0.25 estimation errors.

III. SIMULATION RESULTS AND ANALYSIS

Based on the assumptions in Section II, the two scenarios are simulated for the three modulation schemes and the results are analyzed. The simulation results for perfect channel estimation of BPSK uplink NOMA system with two users is shown in Fig. 3. As expected, the figure shows that user 2 has better BER performance than user 1. In this case, the parameter that affects the performance of SIC detection is the ratio of user 2's power to the combination of user one's power plus the noise power. As assumed, the SIC detector will detect user 2 signal first from the superimposed received signal plus noise. The noise power will have a significant effect on the detection of user 1 since the receiver first performs subtraction of the detected user 2's signal in addition to processing the noise. After detecting user 2's signal with the SIC receiver, the remaining signal, assuming correct detection of user 2, is user 1's signal in addition to the noise. So that, the subtraction of user 2's signal makes the detection of user's 1 signal more vulnerable to noise than user 2 and this leads to a larger BER for this user as compared to user 2. As shown in Fig. 3, the BER for user 2 at SNR = 0 dB is equal to 0.0123 compared to 0.15 for user 1 at the same SNR of 0 dB. Furthermore, for SNR = 5 dB, user 2 has a BER of 0.0007 and user 1 has a BER of 0.10.

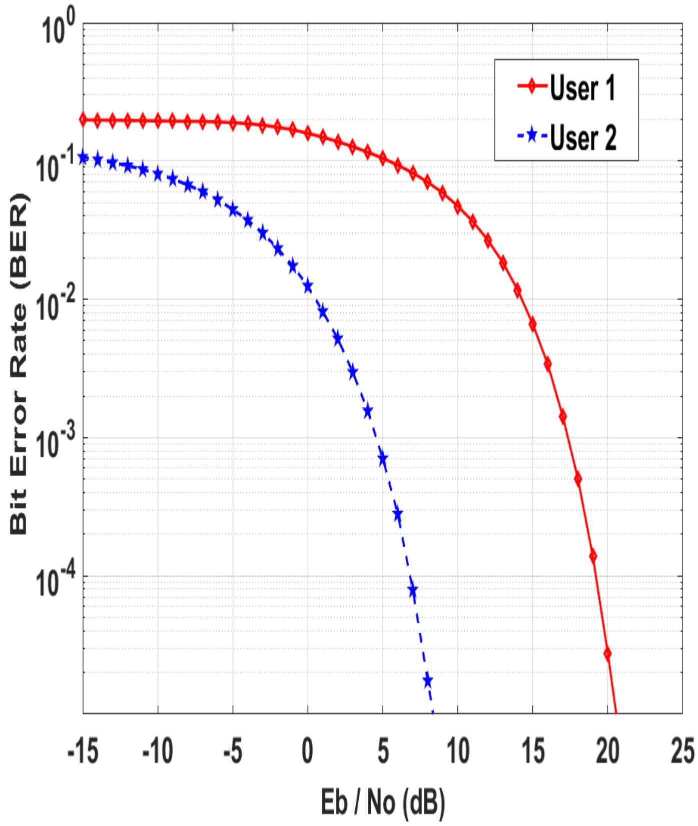

Fig. 3. BER vs. SNR for two BPSK uplink NOMA users with perfect channel estimation.

On the other hand, for the same modulation of BPSK but with channel estimation errors, the simulation results are shown in Fig. 4. In this figure, two channel estimation errors, 0.15 and 0.25, are assumed. In addition to the affecting parameters of the perfect case, adding an estimation error degrades the SIC detection process and the BER performance. Assuming detection of user 2's signal first by the SIC detector, the remaining signal after detection user 2's signal is user 1's signal with an added estimation error in addition to the noise. This degrades signal reception and, as expected, leads to a degraded BER compared to the perfect case. For example, at SNR = 15 dB, the BER for user 1 is equal to 0.01 for 0.15 channel estimation error compared to a BER of 0.007 for perfect estimation at the same SNR value. As the estimation error value increases, the BER is increased. In the same way, as shown in Fig. 4, at SNR = 15 dB, the BER for user 1 is equal to 0.32 for 0.25 channel estimation error which is higher than the BER of 0.007 for perfect estimation and 0.01 for 0.15 channel estimation error at the same SNR value.

Approximately, the same analysis for the two scenarios can be followed for higher modulation schemes, QPSK and 16-QAM, as shown in Fig. 5 and Fig. 6, respectively. In these figures, the results for various channel estimation errors are demonstrated. For the perfect case, at SNR = 5 dB, the BER of user 2 for QPSK modulation is equal to 0.005 compared to 0.14 for user 1 at the same SNR. On the other hand, for 16-QAM, the BER for user 2 at SNR = 5 dB is equal to 0.04 compared to 0.20 for user 1 at the same SNR. As a result, the BER performance of user 1 becomes worse for the same reason discussed in the perfect BPSK case and at the same time increasing the modulation level increases the degradation of the BER.

For the channel estimation error scenario, 16-QAM has a higher BER than QPSK BER which is expected as discussed above. For example, at SNR = 15 dB and 0.15 channel estimation error, Fig. 5 shows that the QPSK BER of user 1 is equal to 0.028 compared to 0.017 for the perfect estimation at the same SNR value. In addition, for the same SNR value of 15 dB, Fig. 6 shows that 16-QAM of user 1 has a BER of 0.17 for 0.15 channel estimation error compared to 0.07 for the perfect estimation at the same SNR value. Furthermore, for a QPSK with 0.25 channel estimation error, the BER of user 1 is equal to 0.058 at SNR = 15 dB compared to 0.017 for perfect estimation and 0.028 for 0.15 channel estimation error at the same SNR. For 16-QAM, the BER at SNR = 15 dB is 0.20 for 0.25 channel estimation error compared to 0.07 for perfect estimation and 0.17 for 0.15 channel estimation error at the same SNR.

As a result, with increased channel estimation error, the BER is also increased and further increases with increased modulation order. An interesting observation is that, at high channel estimation error, the results for the three modulation schemes indicate a very high BER and a flattened performance as compared to the perfect estimation and the given channel estimation errors results. This is due to the degradation in the SIC receiver that results in high BER.

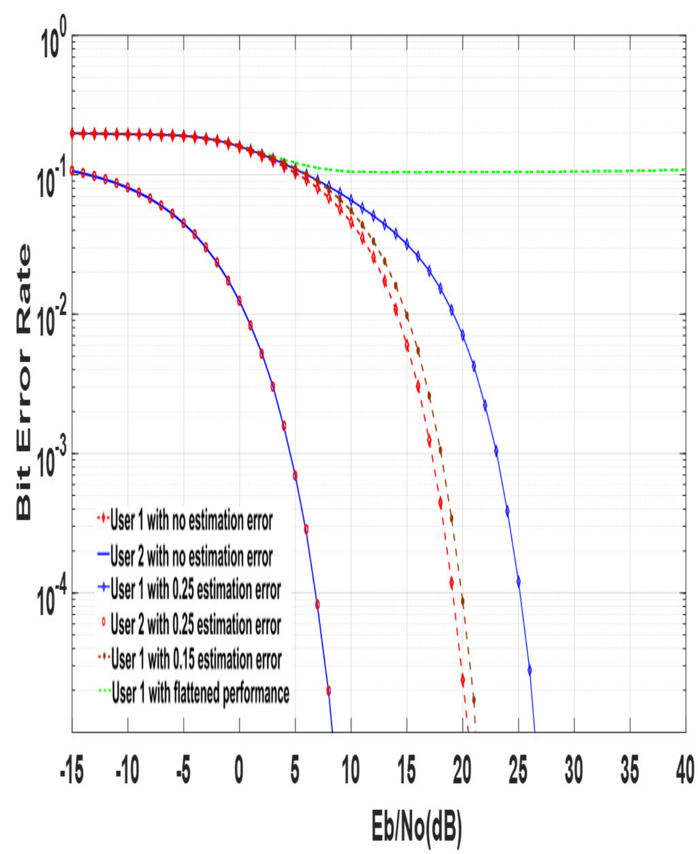

Fig. 4. BER vs. SNR for two BPSK uplink NOMA users with different channel estimation errors.

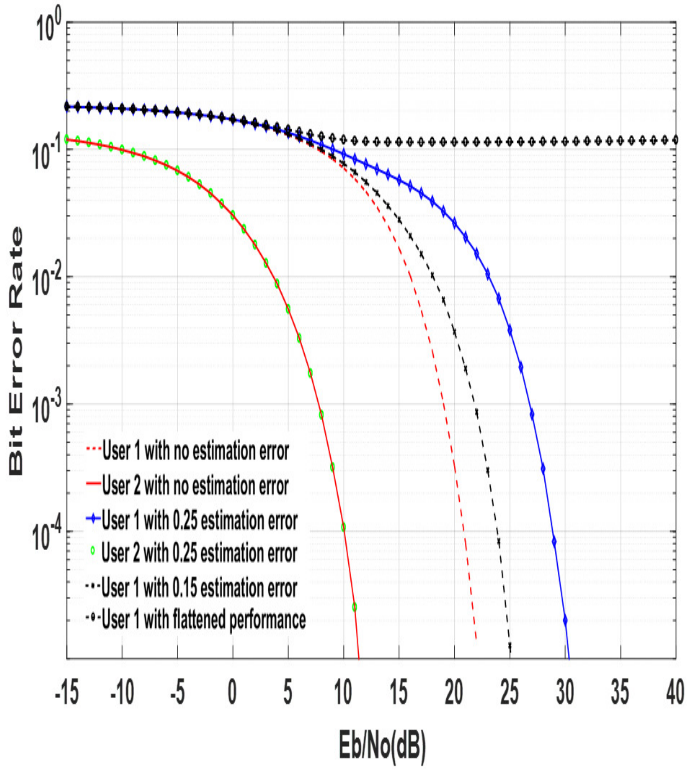

Fig. 5. BER vs. SNR for two QPSK uplink NOMA users with different channel estimation errors.

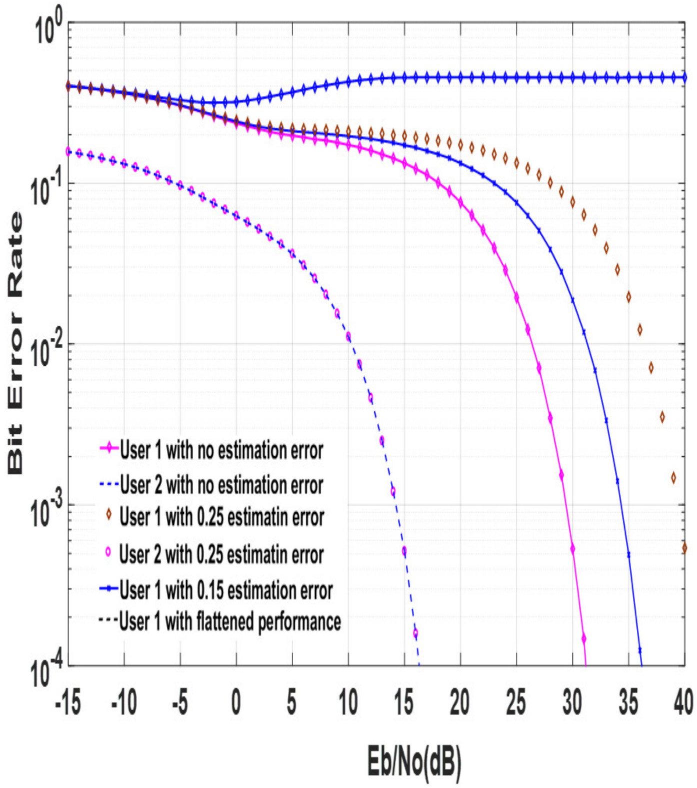

Fig. 6. BER vs. SNR for two 16-QAM uplink NOMA users with different channel estimation errors.

IV. Conclusion

In this paper, a simulation study for the BER performance of a two-user uplink NOMA system for BPSK, QPSK and 16-QAM, using a SIC detector, has been presented. For each modulation level, two scenarios have been considered: perfect channel estimation and a channel with estimation errors. For perfect channel estimation, as expected, the simulation results show that the BER of the SIC receiver increases as the modulation order is increased. Similarly, with channel estimation errors, the BER increases as the estimation error is increased for a given noise level. For example, for perfect case, at SNR = 5 dB, user 2 has a BER of 0.0007 and user 1 has a BER of 0.1. In contrast, 16-QAM results in a BER of 0.04 for user 2 and a BER of 0.20 for user 1 at the same SNR of 5 dB. On the other hand, for channel estimation error, the QPSK BER, for user 1 with 0.25 channel estimation error, is 0.058 at SNR = 15 dB compared to 0.017 for perfect estimation and 0.028 for 0.15 channel estimation error at the same SNR. For 16-QAM, the BER at SNR = 15 dB is 0.20 for 0.25 channel estimation error compared to 0.07 for perfect estimation and 0.17 for 0.15 channel estimation error at the same SNR. As a result of the degradation in the SIC receiver, at a high estimation error value, all the modulation levels results show a very high BER and a flattened performance.

Acknowledgment

Faeik Al Rabee is supported by Al-Balqa' Applied University (BAU), Jordan. The statements made herein are solely the responsibility of the authors.

References

[1] C. Jarray, A. Bouabid and B. Chibani, "Enabling and challenges for 5G Technologies," *2015 World Congress on Information Technology and Computer Applications (WCITCA)*, Hammamet, pp. 1-9, Jan. 2015.

[2] F. Al Rabee, Ashraf Al-Rimawi, and R. D. Gitlin, "Channel Capacity in a Dynamic Random Waypoint Mobility Model," *9th IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON)*, New York City, NY, pp. 1-5, Nov. 2018.

[3] Y. Yuan and Z. Ding, "The application of non-orthogonal multiple access in wireless powered communication networks," *2016 IEEE 17th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, Edinburgh, pp. 1-5, July 2016.

[4] S. M. R. Islam, N. Avazov, O. A. Dobre and K. Kwak, "Power-Domain Non-Orthogonal Multiple Access (NOMA) in 5G Systems: Potentials and Challenges," *in IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, pp. 721-742, Oct. 2016.

[5] Y. Tao, L. Liu, S. Liu and Z. Zhang, "A survey: Several technologies of non-orthogonal transmission for 5G," in *China Communications*, vol. 12, no. 10, pp. 1-15, Oct. 2015.

[6] F. Al Rabee, K. Davaslioglu and R. Gitlin, "The optimum received power levels of uplink non-orthogonal multiple access (NOMA) signals," 2017 IEEE 18th Wireless and Microwave Technology Conference (WAMICON), Cocoa Beach, FL, pp. 1-4, Apr. 2017.

[7] K. Janghel and S. Prakriya, "Performance of Adaptive OMA/Cooperative-NOMA Scheme With User Selection," in IEEE Communications Letters, vol. 22, no. 10, pp. 2092-2095, Oct. 2018.

[8] Z. Ding, M. Peng and H. V. Poor, "Cooperative Non-Orthogonal Multiple Access in 5G Systems," in *IEEE Communications Letters*, vol. 19, no. 8, pp. 1462-1465, Aug. 2015.

[9] X. Liu, X. Wang and Y. Liu, "Power allocation and performance analysis of the collaborative NOMA assisted relaying systems in 5G," *in China Communications*, vol. 14, no. 1, pp. 50-60, Jan. 2017.

[10] E. Balevi, F. T. Al Rabee and R. D. Gitlin, "ALOHA-NOMA for Massive Machine-to-Machine IoT Communication," *2018 IEEE International Conference on Communications (ICC)*, Kansas City, MO, pp. 1-5, May. 2018.

[11] M. Elkourdi, A. Mazin, E. Balevi and R. D. Gitlin, "Enabling slotted Aloha-NOMA for massive M2M communication in IoT networks," *2018 IEEE 19th Wireless and Microwave Technology Conference (WAMICON)*, Sand Key, FL, pp. 1-4, Apr. 2018.